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Threat Existence to Limestone Formations Around *Goa Peteng* in South Bali Island, Indonesia

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ABSTRACT

The limestone formations are a unit of geological rock formations that are important for the formation of unique Karst Landscapes but are often threatened by development interests, one of which is in the environment around *Goa Peteng*, whose existence is threatened. This research aims to investigate: 1) the conditions of limestone formations around *Goa Peteng*, 2) identified threats to the existence of limestone formations around *Goa Peteng*, and 3) potential opportunities for protecting the existence of limestone formations around *Goa Peteng*. The methods used in this research include field observation, literature review, and assistance with map digitization. This assistance involves utilizing literature studies, both scientific articles and reports containing maps that also cover the study location. The results of the research show that the limestone formations in the *Goa Peteng* environment exist at of a level of karst development in the *Goa Peteng* environment which is Mesokarst and parts of the surrounding area are Non-Karst apart from that there is Exokarst Potential and Endokarst though not much exists at the study location. The real threat to the existence of the karst landscape in the *Goa Peteng* environment is the development of mass tourism in the form of tourist accommodation such as hotels and villas, which has developed rapidly over the last 14 years, as seen from Satellite Image data. The limestone formations in the *Goa Peteng* environment themselves has the opportunity to be a place for education and further studies need to be carried out on the limestone formations and karst development in South Bali.

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1. Introduction

Geomorphologically, limestone formations are often associated with karst landscapes. However, in certain cases, it can be stated that a limestone formation contains karst features, such when it reaches mesokarst developement stage indicated by underground river stream in the area, while in some areas of the formation, karst features may be absent. Karst is generally defined as a limestone area with porosity, allowing water from the surface to enter and travel underground. The processes that characterize the formations of karst, especially the landscapes, are studied by examining factors in the karst dissolution process, which are caused by the type of rock and geology, the presence of cracks, rainfall, vegetation, the presence of rock gaps or cavities, and the topography of the land. Karst development is divided into three categories: 1) Holokarst, which refers to well-developed karst where all the characteristics features (such as sinkhole, dolin, uvala, karst domes or towers, caves, and underground rivers) are present, 2) Mesokarst, which denotes karst that is not-well developed, with karst features (sinkhole, dolin, uvala, karst domes or towers, caves, and underground rivers) being rarely found; and 3) Non-karst, which referes to carbonate rocks lacking karst characteristics (Diah et al., 2021). Every natural landscape on the Earth's surface has potential ecosystem services that can be utilized and protected to support sustainability, with Karst Landscapes being among them (Mijiarto et.al., 2014; Arany et al., 2018; Golob et al., 2019).

The limestone formations, a geological rock formations unit, are one of the essential conditions for the formation of karst and, ultimately, for the development of a karst landscape (Dong et al., 2019; Woodhead et

al., 2022). Base on The Geomorpological Map of Indonesia at a scale of 1:5.000.000 by Poedjoprajitno in 2012 from The Center for Geological Survey, Geological Agency, Ministry of Energy and Mineral Resources, karst landscapes in Indonesia are widespread across various islands, from the western tip of Sumatra to the eastern tip of Papua. However, these karst landscapes, with their unique characteristics compared to other natural landscapes, are threatened by human activities (Pisano et al., 2022). One location of the Indonesian Karst Landscape that needs attention is on the island of Bali. This is due to Bali being Indonesia's tourism development center and a top foreign tourist destination.

According to the Geological Map of Bali Sheet at a scale of 1:250,000 published by the Center for Geological Research and Development in 1998, the Karst Landscape in Bali is spread over the South Formations, which is a limestone formation covering South Kuta (Suryana & Wijayanti, 2020; Nugraheni et al., 2021) and Nusa Penida Island (Narendra & Setiawan, 2013; Nugraheni et al., 2021) as well as formations in West Bali located within the West Bali National Park. Using a remote sensing imagery approach with Google Earth from various times the South Formations location, especially in the South Kuta area, has experienced rapid tourism development in the last few decades, which has resulted in changes in land use. However, it should be noted that remote sensing research on the South Formations location is still limited, especially concerning its relation to limestone formations and karst in the region.

The threat of land use change poses a risk of damage to the original karst landscape, especially the epicarst (Pisano et al., 2022). Land use changes are related to clearing and destroying rocks. In the South Kuta area, which has karst potential, residents conduct extensive drilling activities (Suryana & Wijayanti, 2020). They explained that that drilling depths reach ± 80 meters with each meter of drilling costing IDR 1,000,000, resulting in a total cost of around IDR 80,000,000 to get groundwater. The South Kuta District is also experiencing rapid tourism development, leading to an increase intourist accommodations such as hotels and villas. This development has the potential to threaten the karst landscape and reduce the carrying capacity of the environment. In particular, the demand for water from drilling is due to the needs ofhotel and villa tourism accommodation compared to other necessities (Cahyani et al., 2018).

Several related studies have been carried out previously on the limestone formations in the South Kuta District, Badung Regency, Bali. (Kurniawan, 2020) mapped the Erosion Hazard Level in the South Kuta District, using several aspect parameter maps related to rainfall, soil type, slope, andlLand use. (Suryana & Wijayanti, 2020) investigated the potential of the Pecatu Hill limestone method to harvest and store rainwater due to the dry South Kuta area. Research conducted by (Nugraheni et al., 2021) focuses on the aesthetics of the Karst Landscape around the location for tourism promotion. The development of tourist attractions, as explained by (Hariyana & Mahagangga, 2013), showedthat the community was very enthusiastic about developing *Goa Peteng* as a tourist attraction. However, despite the numerous research studies conducted, none has addressed the threat to the existence of the limestone formations at this location. Based on research that has been conducted, this study marks the first time anyone has investigated the existing threat to limestone formations in South Bali, with specific case studies in the environment around *Goa Peteng*.

2. Method

2.1. Research Location

Location of the research is conducted in an area around *Goa Peteng*, Jimbaran Village, South Kuta District, Badung Region, Bali Province, Indonesia. The *Goa Peteng* is located in coordinates 8°47'33.89"S - 115° 8'14.51"E. The reason for the research location over other Limestone Formations and Karst areas in Bali is because around *Goa Peteng* and its area have potential mesokarst development landscape compared to other cave and karst areas in Bali Island such as *Goa Lawah* in Klungkung, *Goa Gong* also in South Kuta that already been sacred and the karst development limited inside the cave and access.

2.2. Research Design

This research was conducted as a case study specifically in the environment around *Goa Peteng*, usinga qualitative descriptive research design (Fitriani & Sriartha, 2021; Padmayoni et al., 2021; Dwipa et al., 2021). Fieldwork was carried out twice, on 24th and 27th November 2022. Case study specifically in the environment around *Goa Peteng* provides a focused investigation into a particular geographical area, allowing for an in-depth exploration of the research problem. Qualitative descriptive research was used for better understanding and describing the condition of the area around *Goa Peteng*.

2.3. Data Use and Materials

This research used data and materials from both primary data and secondary data. Primary data includes by field observations, digitization, and map overlay. It should be noted that this research is also limited to groundwater exploration in *Goa Peteng* cave because it was restricted and sacred by the locals so it only covers the surface and utilizes secondary data.

2.4. Collection Methods

The data collected includes 1) The Condition of the limestone Formations around *Goa Peteng*, including geological conditions, rainfall, soil type, land cover, mesokarst and non-karst, and socio-cultural conditions; 2) Threats to the existence of limestone Formations around *Goa Peteng*, include changes in land use, the presence of rubbish and waste; and 3) Opportunities to protect the existence of limestone Formations around *Goa Peteng*, including the use of existing communities, the potential for educational tourism, and the potential for Karst Landscape Areas (KBAK). Data collection was carried out by field observation (Bharata et al., 2022) literature study (Aja & Arida, 2020), and interviews with collages from Mapala Wanaprastha Dharma to guide and also know the location as well we utilized and conducted map analysis with maps from the results of literature studies, both scientific articles and reports containing maps such as geological map, DEMNAS data, open source multitemporal satellite imagery in Google Earth that also cover the study location to obtain a comprehensive picture of the threat of the existence of karst landscapes in South Bali. It should also be noted the map and spatial data that have been obtained are only analyzed through visual interpretation, overlay, georeferencing, and digitization to help better understand the area and there is no process of generalizing map data to a certain scale. The tool used in this study is an Android Smartphone as Mobile GPS (Tomaštík Jr et al., 2017) using the Alpine Quest application (Bharata et al., 2021a; Yanti et al., 2022), a laptop for processing and presenting data via Microsoft Word, QGIS, and Google Earth Pro software (Bharata et al., 2022). The flowchart of the research can be seen in (Figure 1).

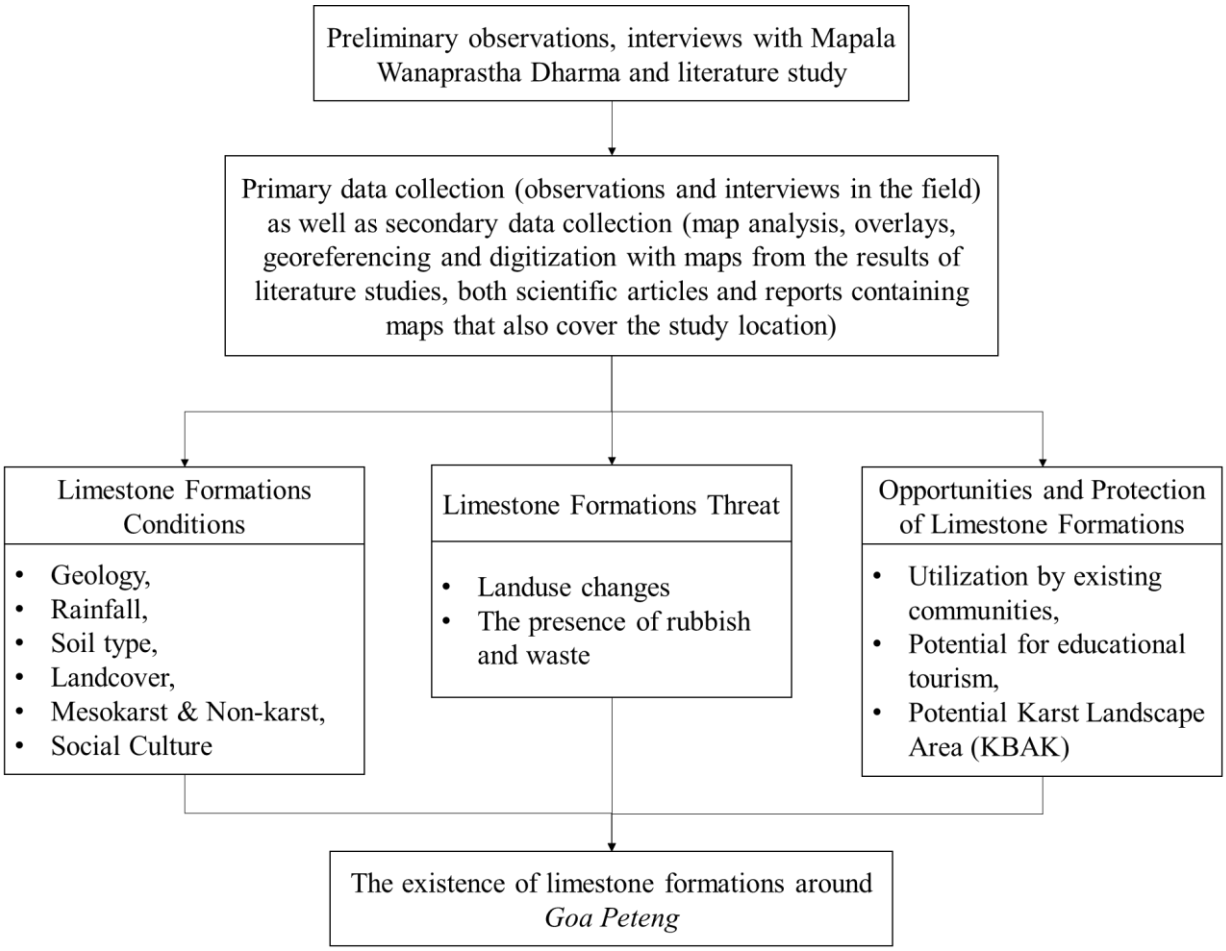

Figure 1. Research Flowchart

2.5. Data Analysis

The analysis will be carried out descriptively based on the results conducted by field observations, literature studies, digitization, and map overlay with a spatial approach by presenting information with maps and an environmental approach, considering conditions, threats, and opportunities for protection.

3. Result and Discussion

3.1. The Existence of the Limestone Formations around *Goa Peteng*

Geologically, based on the Bali Sheet Geological Map 1:250,000 Scale by the Center for Geological Research and Development in 1998, the Limestone Formations in the *Goa Peteng* Environment are in the South Formations and has a reef limestone rock structure, which is a rock that contains calcium carbonate or $CaCO_3$ (Diah et al., 2021). The composition of the reef limestone rocks in the South Formations is similar to the Blambang Formations in southern East Java and the Akas Formations on Lombok Island. There are also many cracks in the *Goa Peteng* environment, even though the outside of the surrounding area is still solid limestone without any cracks. The Southern Formations on the island of Bali are also included in the Tropical area, but this location has relatively low rainfall (Kurniawan, 2020; Supriyati et al., 2018). Through appearance data from Google Earth remote sensing imagery (Bharata & Rahman, 2021b) and field observations from the vegetation cover of the surrounding environment, including non-built lands such as open land, bushes, and mixed plants that indicate low vegetation density. The density of vegetation cover itself will affect the condition of the soil and water in it (Zhong et al., 2022).

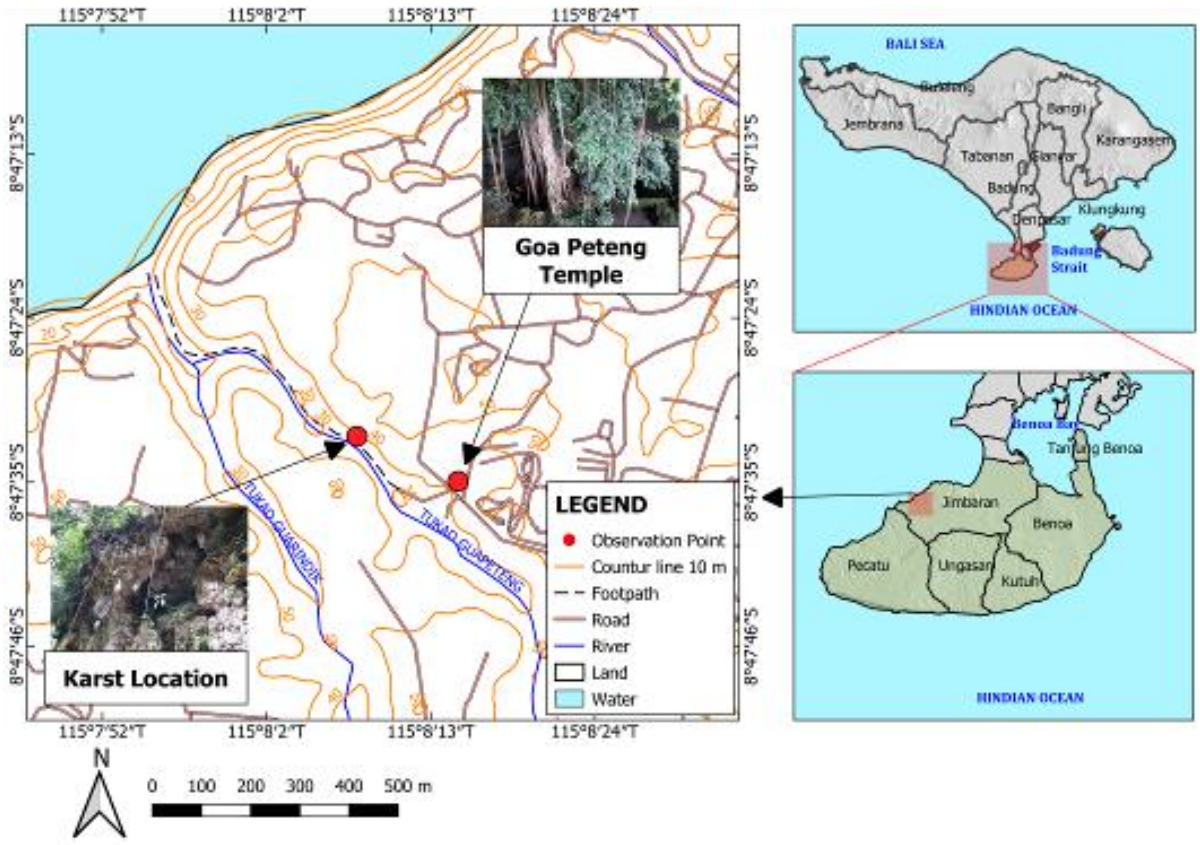

Figure 1. Location map of limestone and karst formations around *Goa Peteng*

The types of soil found in the *Goa Peteng* environment are Regosol soil and some Mediterranean soil (Kurniawan, 2020) which shows that the location is a young area with a neutral to slightly wet pH. The Mediterranean soil that dominates the area can give potential for erosion in the area and can impact the river development in the Valley of *Tukad Guapeteng*. Vegetation with low density makes it difficult to produce humus soil and water content with low or acidic pH (Di et al., 2019). Judging from the rainfall, it ranges from 3.96 – 10.625 mm/month (Kurniawan, 2020) or it could be categorized as very low (Supriyati et al., 2018). The low rainfall condition at this location was also explained by (Suryana & Wijayanti, 2020) where residents have to drill the land and incur high costs. But the interesting thing is that some areas already develop into Mesokarst such as inside the *Goa Peteng* and *Tukad Guapeteng* River Valley. The *Goa Peteng*

environment also has many gaps and cracks or rock cavities which indicate the geomorphological karst process that happened (Margielewski & Urban, 2017). When it rains, in the valley of the *Tukad Guapeteng* River, one of the rivers in the *Goa Peteng* area, a flow of groundwater and surface river water emerges. Because of the limitation of the study, it is hard to determine the implications of these features for groundwater flow dynamics, surface water drainage, and landscape stability, particularly in relation to potential threats and vulnerabilities. However, when it does not rain, the water on the surface disappears into the ground, possibly due to several other karst development factors, such as limestone, which dissolves quickly, and cracks and cracks or rock cavities around river banks. Based on the land's topography, the *Goa Peteng* environment has a sloping but wavy topography and a complex of limestone rocks, valleys, and caves (Figure 1).

The results found that the karst development level in the *Goa Peteng* environment is Mesokarst indicated by the river valley in *Tukad Guapeteng*, the existence of exokarst and endokarst (Figure 1), but some parts of the landscape in the surrounding area are non-Karst based on field observations and other supporting data. Mesokarst is located around *Goa Peteng* Temple to the *Tukad Guapeteng* River valley. Meanwhile, Non-Karst is found at the entrance to the road to the location and several hundred meters from *Tukad Guapeteng*. Mesokarst itself is identified because there is Exokarst Potential and Endokarst Potential as stated in the Minister of Energy and Mineral Resources Regulation Number 17 of 2012 (Nuraini & Pramono, 2013; Utama et al., 2016) but not so many are found in locations. The exokarst covers the doline of the entrance to the *Goa Peteng* at the *Goa Peteng* Temple. Judging from the endokarst, stalactites are at the edge of the *Tukad Guapeteng* River valley and *Batu Layah* Temple.

There are pillars and stalagmites in *Batu Layah* Temple and cracks and rock cavities in the *Goa Peteng* environment. Non-Karst itself is found mainly on the outskirts of the Mesokarst location of *Goa Peteng* Temple and *Tukad Guapeteng* river valley, where outside the Mesokarst area, such as the access road to the location, there is limestone along with slits resulting from road construction that did not experience the Karst process. *Goa Peteng* is a watery cave with a spring that comes out of rock fractures (Dwipa et al., 2021). However, further explanation is needed to clarify how these areas differ from Mesokarst regions in terms of geological composition, hydrology, and ecological features. Even though the Exokarst and Endokarst potential has taken form in a long time that has relation to karst landscape formation, they are also vulnerable to threats such as erosion and degradation because of the Mediterranean soil that dominated the area and flooding in *Tukad Guapeteng* river valley during the raining season.

One of the exciting things is that the Endokarst appearance in Mesokarst is located on the edge of the *Tukad Guapeteng* River Valley, where the path *Tukad Guapeteng* river valley is a footpath to a beach near the Tourism Beach, namely Kubu Beach. Apart from that, the location of the Southern Formations of the *Goa Peteng* environment area is also adjacent to the beach, so the process of forming a Marine Landscape occurs as a result of sea wave erosion in the Kubu beach area. Judging from the factors influencing the karst development process, why are Mesokarst and Non-Karst Vegetation there? The results of studies in the field and multi-time remote sensing imagery via Google Earth Pro show that the locations of *Goa Peteng* Temple and *Tukad Guapeteng* River Valley have denser vegetation than the surrounding area, even during the dry season. Even though base on the soil and rainfall moderately support the claim and their implications for karst landscape dynamics and ecosystem services.

3.2. Existential threat to the Limestone Formations around *Goa Peteng*

The threat of mass tourism development in southern Bali is real. In several case studies in several similar areas, such as Tulungagung Regency, the use of karst areas that are not well managed has hurt the environment by losing various strategic functions of karst, both aesthetic, scientific, and hydrological functions, especially in So Gentong Cave which is threatened by marble mining activities (Nugroho et al., 2021). Several cases also occurred in several areas, such as KBAK Gunungkidul and the Kendeng area in Central Java, due to the limestone mining of PT Semen Indonesia and PT Sahabat Mulia Sakti Limited (Asrawijaya & Hudayana, 2021). Not only karst areas in general, the Karst Landscape Area (KBAK) in Gunungkidul is also threatened by tourism development, as in the recent case, artist Raffi Ahmad will build a Beach Club in this Geologically Protected area (Aulia & Samadi, 2023).

The case in Lowo Cave in Kendeng, Central Java, also triggered a problem where intervention from Development, in this case Cement Mining, had an impact on water availability and the livelihoods of local communities (Zarkasi & Rahardian, 2022). The result of the research reveals that in Bali especially in the case study of *Goa Peteng* based on satellite imagery from Google Earth Pro shows that on October 15, 2009, tourism accommodation facilities such as Hotel and Villas began to appear around the *Goa Peteng* Karst Landscape Area. However, they are increasing in number, as seen in the satellite image recorded on June 20,

2023, over 14 years. One of the hotels with a pool is attached to the eastern part of the *Goa Peteng* Temple, located at the underground entrance to *Goa Peteng* itself (Figure 2). These hotels can impact groundwater availability inside the cave of *Goa Peteng* inside the Temple in the future because of how close the hotels are to the site. More large tourist accommodation facilities such as these hotels and villas could damage the site's natural and cultural heritage values.

Figure 2. Land changes that occurred in the *Goa Peteng* environment based on the appearance of Satellite Images (a) on October 15, 2009 and (b) on June 20, 2023

Studies conducted in several countries have also highlighted the threat to limestone Formations and the karst within them, which has even been in the spotlight for quite some time. Research conducted (Alexander & Milske, 1986) in the Minnesota karst area found that human activities threatened the springs' condition with contamination. Research conducted by (Tomaškinová & Tomaškin, 2014) stated that conditions such as the existence of illegal or random rubbish dumps, rubbish (plastic, cans, and glass bottles), buildings, hazardous waste (red, white, and green chemicals in paper and plastic bags), dead animal bodies should be a concern because shows the degradation of the karst landscape. In the environment around *Goa Peteng*, especially in the *Tukad Guapeteng* valley itself, there is already some rubbish, including plastic, cans, and glass bottles, scattered there, apart from hotels and villas, which are buildings that are increasingly surrounding the area *Goa Peteng*. It is possible that the rubbish comes from the erosion that is carried out by water flow from the top of the river valley and tourists that come to Kubu Beach downstream northwest of the *Tukad Guapeteng* River. So this needs to be a concern for efforts to protect it, as one of the Limestone Formations has karst on the island of Bali.

3.3. Utilization by Existing Communities and Opportunities in the Limestone Formations around *Goa Peteng*

Generally, the existing community in *Goa Peteng* is used for prayer and ceremonies (Rahayu *et al.*, 2023). Based on research conducted by (Hariyana & Mahagangga, 2013) The community has a good perception of developing tourist attractions in *Goa Peteng*. Apart from the community sanctifying *Goa Peteng* as a water source and holy place, the environment around *Goa Peteng* and having the perspective of developing a tourist attraction, *Goa Peteng* has the opportunity to become one of the educational locations regarding Karst Landscapes in Bali. In contrast to several cave locations in other karst landscapes in Bali, such as *Goa Lawah* in Klungkung and *Goa Giri Putri* on Nusa Penida Island, which have limited access, the *Goa Peteng* environment is not entirely a cave. The exokarst and endokarst objects outside the cave are mainly located in the *Tukad Guapeteng* river valley, as in Figure 1 and Figure 3 (a) during a visit with the Mapala Loka Samgraha Student Activity Unit at Universitas Pendidikan Ganesha during activities to study caves and karst landscapes. Another potential that can be explored is the downstream location of *Tukad Guapeteng*, which is directly located on a white sand beach, namely Kubu Beach in Figure 3 (b). On Kubu Beach itself, more potential marine landforms are found, such as marine deposition coasts and wave erosion coasts for secondary coasts as a result of the dynamic processes of sea waves and primary coastal cliffs (structurally shaped coasts) (Marfai et al., 2013; Safitri et al., 2021; Wibowo et al., 2022; Bharata et al., 2024) on the right and left downstream of *Tukad Guapeteng* river.

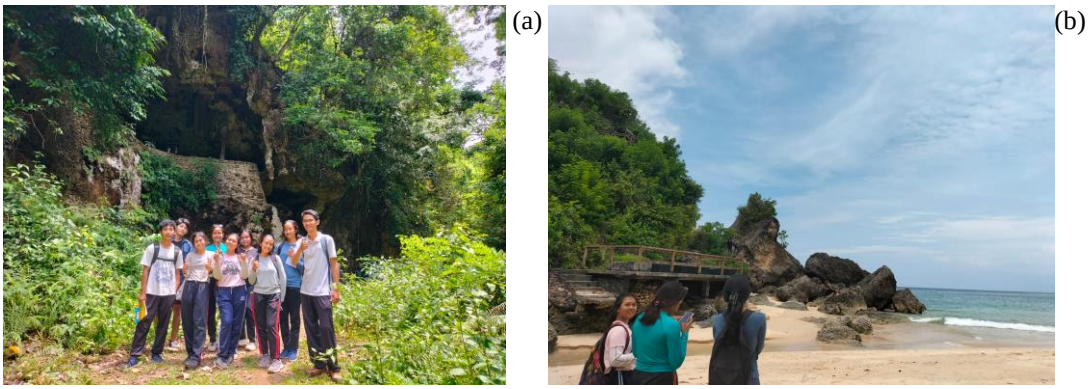

Figure 3. Tourism opportunities for educational purposes as a form of protection for the existence of limestone formations around *Goa Peteng* (a) in front of *Batu Layah* Temple near the Endokarst location in the *Tukad Guapeteng* valley, (b) Kubu Beach downstream of *Tukad Guapeteng*.

In Serbia itself, there are also cases similar to those in Bali according to research conducted by (Antić, 2020) presented the case of the sacred snchorite save, where there was a debate about whether the cave should be used as a pilgrimage site or for religious tourism. However, the results of his research show that the site's management is complicated because many visitors and other caves visit some caves, but some caves do not. Of course, the more tourists who visit, the more they will impact the site because tourists often do not care about the sacredness of an object as conveyed by it. However, planning the location of *Goa Peteng* needs to be carefully considered because the area around *Goa Peteng* is already surrounded by mass tourism development, the community is also sanctifying *Goa Peteng*, and the condition of the surrounding environment is a karst landscape, which is correlated with dry areas.

The existence of a cave with water and people with a spiritual connection is a sign that *Goa Peteng* needs to be conserved. Looking at the various cases that have occurred, further study is needed regarding the karst landscape around *Goa Peteng*, which has the potential to become a karst landscape area (KBAK) and is currently threatened by tourism development. Because of the potential, the educational initiatives and programs that could be implemented based on this opportunity such as geographical field study and fieldwork from nearby schools in Badung Regency and Denpasar City and also the university. Due to this, both the community and government at the village, sub-district, district, and provincial levels need to play an active role in protecting *Goa Peteng* and its surrounding environment, considering its use for the spiritual/prayer interests of the community, especially the Balinese people, from land conversion and property development permits and other mass tourism accommodation that will privatize the land around this site. Also, further social and cultural research needs to be conducted especially because this research is limited to personal sources or key informants that should be included such as the *Goa Peteng* Temple *Jero Mangku* (Balinese Hinduism Saint), *Kelian Adat* (Chief local custom), *Jero Bendesa* (Chief of village local custom), and *Perbekel* (Head of Village) that can help better insight and updated knowledge of the location.

4. Conclusion

The limestone formations in the *Goa Peteng* environment have a level of karst development. The level of karst development in the *Goa Peteng* environment is Mesokarst, and parts of the surrounding area are non-Karst. There are Exokarst and Endokarst potentials, but they are only found a little at the location. The real threat to the existence of the karst landscape in the *Goa Peteng* environment is the development of mass tourism in the form of tourist accommodations such as hotels and villas, which have developed rapidly over the last 14 years, as seen from Satellite Image data. The limestone Formations in the *Goa Peteng* environment can serve as an educational forum as campuses or schools can visit to see the limestone Formations and karst more closely on the island of Bali. Moreover, further studies need to be carried out on the Limestone Formations and the development of karst in South Bali itself and in-depth cultural and ethnography studies. Amidst the ongoing threat of tourism development in Bali.

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location of *Goa Peteng*. This research was carried out independently and sourced from personal concerns regarding the natural conditions and sites in Bali, which continue to be threatened by tourism development.

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