A strategy for the sustainable development of the karst area in Wonogiri

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Abstract. The karst area is a strategic area with economic, scientific, and humanitarian values related to livelihood. The karst area of Wonogiri is part of the Gunung Sewu Area, a Global Geopark established by the UNESCO Global Geopark Network. The local inhabitants have not gained any benefit from the potential natural resources. Meanwhile, they are constrained by the harsh nature and the obligation to preserve the karst area. This leads to the question of how spatial planning could intervene in the socio-economic conditions of the inhabitant by utilizing the natural resources of the karst. The study first describes the characteristics of karst areas from their potentials, problems, opportunities, challenges, and trends. The result of the study is the spatial arrangement of the karst area in Wonogiri based on karst classification and its nature. The karst area can be developed based on its natural resources, such as agriculture, livestock, special tourism attractions utilizing the landscape and natural formations, including the sustainable exploitation of mineral resources. It can also be used as a source of knowledge. The challenge faced is the obligation to protect its uniqueness related to its geology, geomorphology, paleontology, hydrology, flora and fauna, and the development of knowledge repertoire.

1. Introduction

Karst landscape is the result of the dissolution process of carbonate rock resulting in various unique and attractive shapes of terrain. Karst areas consist of porous limestone resulting in the absorption of surface water into the ground since the bare ground lacks vegetation. Although the constituent materials of karst are rocks that are generally impermeable, it cannot store water.

The karst landscape characterizes the Wonogiri Regency in Central Java Province and is connected to karst in Pacitan Regency in East Java, and in Gunung Kidul Regency in the Special Region of Yogyakarta. These regions located in the southern part of the Island of Java, form a single natural entity called Pegunungan Sewu (literally Thousand Mountains) which is a karst landscape. The three administrative regions are territorially interconnected and culturally close related. In 1986, a partnership named Pawonsari an acronym of Pacitan, Wonogiri, and Wonosari was established. The regions are known as disadvantaged areas with barren natural conditions.

The karst landscape has an important role for the environment, i.e., in the ecosystem, it can store and provide resources such as clean water, minerals, biological resources, both above and below the surface, and can also contribute to controlling the impacts of climate change. Karst also often plays an important role in the life of the community because there are people who cultivate the surrounding
area of the karst. Therefore, the karst area not only has hydrological and ecological roles but also socio-economic. Reckless exploitation will cause the karst area to be vulnerable and easily damaged if one of the constituent elements of the ecosystem is polluted or lost.

Thus, the problem is how the Karst area in Wonogiri can be preserved for its environmental roles whilst benefiting the inhabitants. The Indonesian Geologist Association conveys three main factors that must be balanced when developing a karst area, namely management and utilization of natural resources, disaster mitigation, and environmental conservation. As an ecosystem, the karst area of Wonogiri can be seen as a system, in which there are interactions and interdependencies between the physical and non-physical, biological and non-biological environments, as well as bio-geochemistry in both exokarst and endokarst. Though the nature is rich, it can be easily damaged if disturbed. The economic condition of Wonogiri’s inhabitants is at the lower-middle range while the utilization of land is considerably low. Therefore, the research aims to propose sustainable development strategy for the area that conserves the nature of the karst area while alleviating the socio-economic conditions of the local inhabitants.

2. Literature review
Karst is a form of the earth's surface that is generally characterized by closed depression, surface drainage, and caves. This area is formed mainly by dissolving rocks, mostly limestone. Karst, originally Yugoslavian language meaning a dry and cold place, also connotes bare rock surfaces. Karst areas are classified as minor or micro karst areas and major or macro areas. In Micro karst areas, new karstification is developing on the rock surface, so it cannot be identified from the base map. Whereas the macro karst area can already be identified from the base map due to the very intensive karstification. Karst areas have many benefits enlisted below.

2.1. Karst as the best source of water reserves
Although karst areas often appear arid and dry, these areas are good places for storing water. The epikarst layer at the top of the karst area allows a time delay so that it can store and drain water to underground springs and rivers during the dry season.

2.2. Pest control
Pest predators live in the caves in the karst area. Insectivorous bats are touted as one of the natural predators of agricultural pests. Various works of literature stated that each bat can eat no less than 6,000 mosquitoes. Not only serving as a pest predator, but bats also play an important role in fruit pollination. If the bat population shrinks or becomes extinct, then fruits that depend on their pollination will also diminish or even go extinct.

2.3. Karst as a climate regulator
One of the functions of karst is as a climate regulator by storing carbon. Karst has a role in climate change mitigation through CO$_2$ reduction. The largest carbon reservoirs on earth are stored in the form of carbonate rocks: limestone (CaCO$_3$) and dolomite (MgCO$_3$); on land, the rock forms a karst ecosystem.

2.4. Agricultural activities in the karst area
Agriculture in karst areas is different from other areas, this is due to the dominating characteristics of karst rocks and the limited availability of water resources for irrigation. Development and land use in karst areas require careful planning considering the unique characteristics of karst areas that are very vulnerable to land damage from both soil erosion and loss of water sources.

2.5. Supporting agriculture in karst areas
The karstic drainage system is unique because it is dominated by subsurface drainage. Surface water mostly enters the underground river network through a pit or inlet. Under these conditions in the rainy
season, rainwater that falls into the karst area cannot be held at ground level but will go straight into the underground river network through the pit. The only water sources in the karst area are ponds and water surfacing from underground rivers [1]. Rain storage in the karst area can be found in small ponds that have a waterproof layer at the bottom of the lake so that they are able to prevent the water from entering the underground river network.

2.6. Karst areas as tourist sites

The beauty of the karst area is a great attraction for tourists. Hills and limestone look exotic when viewed from the surface. When entering the cave, in the dark, people might see different beautiful views; the ornaments in the caves sparkle like diamonds if they are tinted by light. Based on the location of the karstification development on the topographic surface, there are two different karst areas, i.e., exokarst and endokarst. The exokarst area is formed above the surface of the topography, exemplified by the formation of a karstic cone, whereas, the endokarst can only be identified if the observer enters the subsurface, such as a karst cave.

In addition to the classification based on the relative level of development, kars areas are classified as mesokarst and holokarst areas. The mesokarst area is characterized by the surface river flow still which leads to significant fluvial processes, karstic cones have not yet developed, and these areas are found in a transitional zone between non-karst and holokarst areas. The holokarst area is the opposite of mesokarst, characterized by almost no surface river flow which then turns into sub-drainage river flow so that exogenic processes that take place effectively are dissolved. The topographic surface is almost adorned by various karstic cones.

Therefore, the karst landscape will show special forms, depending on its location. The formation of karst topography in the tropics is certainly different from the karst formation in the sub-tropics, arid environment, etc. The caves in the karst area are formed by the process of dissolving limestone with acidic water. These caves are the part that remains after the dissolved limestone is transported by water.

3. Research method

This study explores the conditions in the Wonogiri karst area. At the initial stage, preparation is undertaken for both exploring the field and collecting secondary information. In the fieldsurvey, the necessary data were collected through direct observation, trying to comprehend the situation, and conducting interviews with residents and selected parties. Whilst, the secondary data were obtained from documents, archives and relevant previous studies. There are many secondary data about the Wonogiri karst area. The data are compiled according to their topic, for example, grouped by classification of karst types and their uses, conditions, management efforts, and socio-cultural and economic features of the population.

The data were analyzed by elaborating on the data with the intention of obtaining a complete picture of the land utilization of the karst area and its control measures. The land use is assessed in terms of whether it is in line with theoretical and practical norms. The land use control is assessed whether it is effective in conserving the karst area. Besides the analysis, the land use and its control of the potential Wonogiri karst area are discussed.

4. Results and discussion

4.1. The region: Wonogiri Regency

The total area of Wonogiri Regency is 1,822 km², while 10.2% of it is karst formation. Generally, the karst area lies along the southern part of the regency, up to the southern coast bordering the Indian Ocean at the karst beach. In the opposite direction, 30 km inland from the coast at Waduk Gajah Mungkur (reservoir), nature is also dominated by karst.

Most of the inhabitants of the regency are farmers who cultivate the land near their settlements. As a karst area, the soil layer is relatively thin. Carved bulges are often found which appear to be
limestone or coral rocks scattered on the cultivated land between dry crops. The income from farming or raising livestock is low so farmers lead a simple life. In 2016, the population of Wonogiri Regency was 628,914. Whilst in the karst area, the average population density is around 30 people per hectare with the lowest population density of around five people per hectare in Batuwarno District.

Wonogiri is involved in inter-regional cooperation which was established in 2002 with two other neighboring regencies, named Pawonsari. This cooperation is in the field of development and community welfare improvement. In the Pawonsari area, there are centers of activity in the form of towns or urban nodes, such as Pacitan, Ponjong, and Giriwoyo. This karst area can be developed based on its potential natural resources as specific agricultural areas, special tourism areas by utilizing its landscape and natural formations, as well as the sustainable exploitation of mineral resources.

Figure 1. Karst Gunung Sewu Area as retrieved from http://nationalgeographic.co.id/berita/2015/09/.

4.2. Wonogiri karst area
The Wonogiri karst landscape is formed by dissolving rocks such as limestone, dolomite, and gypsum. It is characterized by an underground drainage system with sinkholes and caves. As a karst area, land cover is dominated by organic sediments of coral reef limestone, marlstone, or dolomite limestone. These rocks are easily weathered and dissolve when exposed to sunlight and rain. In this area, there are also many loose sediments such as white sand from limestone, or calcite, or carbonate. Formed from ancient processes, the structures left standing are calcite hills or bulges, as well as valleys containing dolomites (CaCO₃ or CaMg (CO₃)₂). Dissolved rocks in the soil due to underground flows have created caves and underground rivers in this area. At the upper layer of the land, the created formation has rows of countless small hills (conical hills) that have given the area the name Gunung Sewu or Thousand Mountains. Sinkholes in the Wonogiri karst area can be found in a variety of sizes, and some created large wells with varying diameters and depths. This is a result of rock collapse in the underneath cave due to erosion in the soil or intensive dissolution of limestone. Residents call it luweng (vertical holes).

Limestone-type rocks are not fertile for cultivation. Coupled with low rainfalls in several locations, agricultural productivity in the Wonogiri karst area is uneven. Rainwater cannot be stored easily in the karst area so that agriculture depends on the presence of rain. Rainwater that seeps into the cracks of karst forms underground river flows that have the potential to be exploited in certain ways, such as pumped up to the surface, or stored in underground dams. Most farming is carried on dry fields (dry-land agriculture) and only about 18% of the area is used for paddy fields (rain-fed agriculture). Most of the region is made up of open natural land without cultivation. This open land is partly used for herding goats and cattle. Karst natural wildlife also widely found in the Wonogiri area.
Based on the classification by Purnomo and Sugeng [2] using Landsat TM7 for the Wonosari area, west of Wonogiri, there are three classes of karst conditions. They are the formation of broad valleys, limited size valleys, and the undulating morphology. The type is Kegel Karst which is also divided further into labyrinth cone karst, polygonal karst, and residual cone karst. For its inherent scientific values, the natural formation of Wonogiri becomes a place for studies and researches. It also becomes a tourist attraction, as a sideattraction for tourists visiting the beaches on the south coast or the main attraction for special-interest tourism. In addition, the karst area is also the object of speleologists.

4.3. Potential and utilization of Wonogiri karst area
The Wonogiri karst area has the complete appearance of karst characteristics and natural potential. This well-maintained natural potential needs to be properly conserved. Besides, certain places have a uniqueness that is rarely found somewhere else. In addition, cooperation between the Pawonsari regions can increase the promotion and development of tourism-related products, the provision of infrastructure and proper transportation, and the improvement of social welfare. It is also important to build an educational concept for the context of preservation and development of Pawonsari and Pegunungan Sewu in particular, since this karst area has been established as a global geopark by UNESCO Global Geopark Network on September 19, 2015, following the BATUR Geopark in Bali. In relation to this, there is now a Karst Museum in Pracimantoro Wonogiri.

4.3.1. Mineral resources. Most minerals originating from the karst areare used for building materials as well as for industrial raw materials. While at present the utilization of minerals from the Wonogiri karst area has not been carried out optimally, especially for industrial purposes. Only limestone is traditionally excavated at a limited scale for building materials. The good aspect of small-scale exploitation is that the natural environment in the Wonogiri area will not be degraded too soon. However, the use of minerals, especially for high-value and large-scale industries, is strictly limited.

Foreign investment for the cement industry which would exploit limestone extensively has been rejected recently. Therefore, the utilization of minerals from this karst area would not be able to become a driver for improving the welfare of local communities. Agate from the Wonogiri area is also
well-known but it is not enough to be able to increase the prosperity of the community sustainably since the demand for this particular product is volatile. At the time of the agate boom several years ago there was enough market demand to provide an increase in the income of the agate craftsmen.

4.3.2. Land resources. The use of natural resources by the community in the Wonogiri karst area is still limited even though there are some relatively extensive and fertile lands for agriculture. The limited land in between the karst rocks is planted with seasonal crops such as rice, corn, soybeans, cassava, etc. With limited depth, the soil in the karst area tends to be very dry in the dry season.

Plants that grow in the wild are also seen growing planted with fodder grass and lamtoro gung for animal feed. Cattle farming is still limited to cows and goats but the communities also have chickens and ducks. The land use does not interfere with the process of water infiltration into the earth. As such, underground hydrology is still good.

4.3.3. Flora resources. With the influence of unique landscapes, the plants that grow in the karst area can also vary. These are grasses, shrubs, and bush, as well as trees. Grass and shrubs are usually used for fodder. This area is also rich with various herbs that are used for medicinal purposes by residents. The use of local plants as raw materials for the herbal and beauty industry was once quite high. However, changes in demand have affected its use. Perennial plants that grow a lot in Wonogiri are Teak, Mahogany, Acacia and Sengon. They are mostly used as building materials.

4.3.4. Fauna resources. Animals that live in the karst area include several types of monkeys, many species of birds, bats, and reptiles. In places where there is plenty of water, there are various types of fish, snails, as well as freshwater crabs and frogs. Numerous types of insects are found here, some such as stinky bugs and grasshoppers serve as a local complementary food. Honey as a product of beekeeping can also be found in several places. The natural presence of fauna in the karst area has been stable for years and has not changed significantly. The current land use has not disturbed the ecosystem.

4.3.5. Water resources. In general, the karst area cannot store water at the ground surface. However, there are several lakes and reservoirs in this area. Moreover, some places are known to have underground rivers. The lakes have become a habitat for various flora and fauna. In permanent lakes, there are many types of plants that can be consumed such as clover (semanggi) or as visually enjoyed for its beauty such as lotus (padmawijaya). In these lakes, a variety of local birds live such as herons.

There are also rivers in the area. The famous Bengawan Solo originate from several springs in this area. This ancient river formerly headed south to the Indian Ocean. When geological forces lifted up of the southern part of Java Island, the river flow turned to the north and east before flowing into the Java Sea. A great reservoir Waduk Gajahmungkur has been built in the middle of the Wonogiri karst area, forming an 88km² water-bodies. There are also underground rivers here. The entry points of the stream into the ground or the exit of the underground river are attractive tourist locations. For instance,
there is a waterfall to the ocean from an underground river as well as an offshore underground river outlet into the ocean.

4.3.6. Landscape resources. The Wonogiri karst area has unique terrain and features. Valleys, hills, numerous small mountains, coral cliffs, and wells are stunning views to be enjoyed, they are especially interspersed with the presence or absence of plants. Below the surface, there are many caves with various lengths and branching patterns. The long caves were formed due to scouring in underground rocks which then shaped underground rivers, which eventually dry up. Therefore, this karst area can be very vulnerable to erosion or by a lack of rainfall which causes the karst rocks to dissolve easily or be destroyed.

On the southern coast, many beaches are very worthy to be enjoyed for their waves, sand, cliff, or their landscape. However, the Wonogiri beaches have not been well-developed as tourist destinations as in Pacitan and Gunung Kidul. The beaches in Wonogiri are already well known, e.g., Pantai Nampu and Pantai Sembukan. Another usage of Pawonsari coast is for transportation purposes. There are several ports that function for the transportation of goods, passengers, as well as fisheries, military, etc. These ports are Tamperan and Gelon in Pacitan and Sadeng in Gunung Kidul.

![Figure 5. South Coast in the Karst Wonogiri Region as retrieved from https://www.brobali.com/2016/09/beach-cable-beach-beautiful-in-wonogiri.html.](image)

4.3.7. Cultural resources. The lifestyle of the people who live in the karst area might be unique in accordance with their harsh nature. There are also various cultural traditions in the form of rituals and ceremonies that can be found in the karst area of Wonogiri, e.g., Malem Selikuran and Adat Ruwatan. While in the Pacitan region, there are ceremonies of Mantu Kucing, Ceprotan in Donorojo District. In Gunungkidul there are Melasti at Ngobaran Beach, Rasulan, Cing-cing Goling in Karangmojo District, Kembang Lampir Hermitage in Panggang District, Babad Dalan Sodo in Paliyan District, and Sea Alms on Kukup Beach in Tanjungsari District. In Kebonagung District there are traditional ceremonies of the Gunung Limo Tataken, Eretan, and Baritan traditional ceremonies. There is active community involvement in these cultural ceremonies.

With all its resources, the Wonogiri karst area can be developed based on its potential of exokarst and endokarst natural resources. The possible developments are as a specificagricultural area, a limited tourism area by utilizing natural landscapes and formations, exploitation of natural resources, minerals and clean water sources in a sustainable manner. For tourism development, there is the potential to implement geotourism. Meanwhile, spatial planning must protect the uniqueness of the area in relation to the geology, geomorphology, paleontology, hydrology, as well as flora and fauna, and then use them for science development. Therefore, the principle of place integrity is used in utilizing all resources, strengthening the character of the karst area while maintaining local wisdom, to develop geotourism attractions.
4.4. Utilization control

Departing from the study of the potentials of the Wonogiri karst area and its utilization and development, this study proposes three measures, namely inventory, spatial planning, and rehabilitation.

4.4.1. Inventory. An inventory of the potentials and problems of the Wonogiri karst area is necessary which includes all the available resources, i.e., minerals, land, flora, fauna, water, landscape, and culture. The specific values of an ecosystem in one site must be identified. However, in this area, there is also the potential for conflict between the preservation of natural resources and its utilization for the purpose of the welfare of its inhabitants, development of tourism industry, even with education and science, when conducted in an unwise manner. The diversity of the karst area potentials can stimulate a wide variety of activities and development. For example, the region could be developed as a place for living, an attraction for geotourism, and a means for learning and study, or merely as a conserved object. The capacity of the community also must be identified to intensify their participation in managing the karst area.

4.4.2. Spatial planning. Spatial planning within the framework of the karst area utilization must open opportunities to utilize all existing potentials as well as regulate the development efforts to be in accordance with the capabilities and problems of the land. The karst area is complex, in terms of its physical nature, microclimate, socio-economic and culture of its inhabitants, as well as the availability of facilities and infrastructure. One important thing to note is that in the karst area, there are specific values that are strongly related to geology, geomorphology, paleontology, hydrology, as well as the flora and fauna. On the other side, the karst area is also relatively vulnerable with a limited carrying capacity, and any damage occurring on it would not be easily restored.

Considering the growing market demand, developing a well-controlled tourism industry is a good way to utilize the land so as to improve people's welfare. As such, the development of the tourism industry could let local inhabitants improve their lives and benefit from their land. However, restrictions on utilization must be strictly applied without neglecting the needs of ordinary tourists or special-interest visitors’ experts. Tourism control can be by controlling the number of tourists visiting an attraction object. This means to distribute tourists into various sites of attraction, while at the same time channeling them to only visit relevant objects first (market selectivity). Overall, the goal is to gain the best benefit and optimum utilization of the karst area considering the potentials and limitations of the karst area.
4.4.3. Rehabilitation. The karst area which has already been damaged due to over-exploitation, especially for lime extraction, needs to be restored to achieve a balanced ecosystem. As stated in the discussion, rehabilitation in the Wonogiri karst area is carried out so that the natural cycle of the karst area can take place again. Utilization of the natural resources needs to be done wisely, by using the scarce resources carefully and exploiting them according to its natural capabilities by orienting at sustainability and prioritizing renewable resources. The public and visitors are urged to realize and interpret the developments. Therefore, the control and evaluation of the conditions in the Wonogiri karst area must be carried out continuously. As a geotourism object, there must be the principle of protection and enhancement of destination appeal.

5. Conclusion
The karst area in Wonogiri has great potentials but at the same time high vulnerability. It is inhabited by residents who have a middle-low economic level from the cultivation of land. Therefore, their economic welfare needs to be improved by allowing them to benefit from the potential of the land. While utilizing its potentials, conservation in the Wonogiri karst area should also be carried out by preserving its vulnerable characteristics. Any environmental damage and degradation due to over-exploitation is to be rehabilitated so that environmental balance is maintained.

Natural or geotourism should adhere to certain principles. First, it has to consider the capacity of the natural resources in the karst area to be exploited. These resources must be employed with care using the concept of environmental responsibility. Second, the local community with its socio-economic-cultural aspects and its uniqueness must be valued as local cultural potential. Local wisdom should be incorporated in the management of the karst area to improve the social and economic welfare. This ensures tourism is culturally responsible. Third, development should maximize the added value (synergy) between the uses of karst natural resources with the cultural resources in a place. This synergy is expected to develop the tourism sector in the area so it could provide comprehensive benefits for recreation, education, science while continuing conservation efforts to ensure the sustainability of the region. These principles could increase the dignity of the local community as they are involved in maintaining and utilizing the Wonogiri karst area.

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