Karst imaging of Mangkalihat in East Kalimantan; insight from Landsat OLI 8, DEMNAS and field investigation

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Abstract. Karst is one of the typical of landscape which is formed by soluble rock and mineral formation such as limestones, dolomites, gypsum, anhydrites and others types that have the same characteristic. Based on Permen ESDM 17/2012, Karst Landform Area has two main function; conservation and development area. Mangkalihat Karst has some critical issues both on conservation and sustainable utilisation of its resources. We aim to delineate karst landform and other limestones formation in the area. Using DEMNAS-based combined with the multispectral imagery from Landsat OLI 8, we were able to delineate the karst area according to visual interpretation on karst morphology. Mangkalihat Karst presents as half-circular morphology consists of Tendehantu Hills in the west and Mangkalihat Hills in the east. The stratification of limestones formation has been clearly visible on image structured parallel strike with the arc. The slope is very steep (more than 45%) and it is densely vegetated areas. To the north, karst morphology formed undulated karst hills as slope average ranging from very steep to moderate. Scattered conical hills were identified as a result of surface karstification. However, drainage pattern had not clearly formed in karst landscape, they were formed subsurface. Tendehantu Formation (Tmt) is the main rock formation in the Mangkalihat Karst. Field investigation indicated that Tendehantu Formation (Tmt) is composed by coral limestones, white to light yellowish in color, well bedded and deposited during Middle Miocene in shallow marine (neritic zone). Caves and subsurface rivers had been identified in the area as a manifestation of endogenic and exogenic karst. The result can be approach for resource sustainability in Mangkalihat Karst Area.

1. Introduction
Karst is one of the typical of landscape which is generally composed by limestones formed by soluble rock and mineral formation such as limestones, dolomites, gypsum, anhydrites and characterized by subterranean drainage, caves and closed depressions [1]. Karst formation generally has low porosity and temporary low water storage due to its rock characteristics. Thus, water flows through rock cavities and cracks. The existence of soils above the karst has a chance to store water longer. The Mangkalihat Karst Area is located in Berau and East Kutai Region, Eastern Kalimantan Province (Figure 1). Mangkalihat Karst Area (KLA) has critical issues both on conservation and sustainable utilization of its resources. We aim to delineate karst landform and other limestones formation in the area by using digital elevation model (DSM) and optical imagery. Based on Permen ESDM 17/2012 [2], KLA has two main function; conservation and development area. KLA is the area where the exokarst and endokarst are exist as a representative of karstification. Those have a function as scientific development (cultural and geological heritage), groundwater recharge area, natural water storage (aquifer), and permanent springs and lastly it has Subterrain River which flows through caves. If the KLA does not fullfill these function then the KLA are able to be exploited its resource.
2. Regional Geology and Tectonic Setting

According to the Regional Geological Map of Mangkalihat sheet scale 1:250,000 [3], The Mangkalihat Karst Area composes of several limestone formations from old to young (Figure 2): Tabalar Formation (Teot); Limestones, white to pale greyish, massive, deposited in shallow water during Late Eocene to Oligocene. Lembak Formation (Toml); intercalated between marls and limestones. In the upper part, marls is dominant while in the lower part limestones is dominantly occurred. This formation was deposited in shallow water (mainly in neritic zone) during Late Oligocene to Early Miocene. Tendehantu Formation (Tmt); It consists of coral limestones, white to yellowish, well bedded and deosited in shallow water during Middle Miocene. Domaring Formation (Tmpd); It composes of coral and calcareous limestones intercalated with tufaceous marls, shales and crystalline limestones nodules. This formation was deposited in outer sub-litoral during Late Miocene to Pliocene.

Figure 1. The map location of Mangkalihat Karst Area (red box) in East Kalimantan
Figure 2. Regional geological map of Mangkalihat Karst Area and age correlation of its rocks formation (modified from Djamal, B., et.al, 1995)

The structural geology of this area consists of folds, faults and fractures. The former folds are anticlines and synclines where those fold axes are generally trending east – west. The folds are gentle and open. Faults, however, comprise thrust, strike slip and normal. The thrust faults discovered in the Teluk Sumbang may have caused pra-Tertiary rocks to come up to the surface and show northeast-southwest trending faults. The strike slip faults in the western area are northwest-southwest direction and include dextral faults. The normal faults in the northern and eastern areas reveal northwest-southeast and north-south direction. Faults encountered in this area could be younger (Plio-Pleistocene). It is the facts that the Pliocene sediments have been faulted. The older faults, if present are difficult to observe. Tectonic activity may have occurred in the Cretaceous associated with ophiolite. Early Tertiary clastic sediments deposited in this area and covered by thick carbonates. On the middle and late Tertiary, folding and faulting took place.

3. Methodology
In order to interpret and delineate the Karst Landform Area (KLA) in Mangkalihat, we utilize the remotely sensed data from DEMNAS and Landsat OLI 8. Indonesian Digital Elevation Model (DEMNAS) is freely accessible of 5-m and 7-m resolution of DEM throughout Indonesia which organized by Indonesia Geospatial Agency [4] and Landsat OLI 8 is a multispectral imagery produced by NASA which has 8 bands in visible and infrared spectral region [5]. Hill-shaded with 135° sun angle was applied to visualize the DEMNAS in grey scale [6]. False color composite of Red (band 5), Green (band 6) and Blue (band7) was applied to Landsat OLI 8 [7]. Those two images were combined to produce one single image as a basic image for interpretation (Figure 3). Morphometic and visual interpretation criteria such as; slopes, textures, relief, vegetation covers, association, patterns and tones were applied to interpret and classify the Karst Landform in Mangkalihat Karst Complex. Field investigation was done by carried out the description of outcrops such as stratigraphic measurements, megascopic rock descriptions, structural geology description and measurements and geomorphological analysis.
4. Result and Discussion
Mangkalihat Karst Complex presents as half-circular morphology consists of Tendehantu Hills in the west and Mangkalihat Hills in the east. The stratification of limestones formation has been clearly visible on image structured correspond to strike with the arc. The slope is very steep (more than 45%) and it is densely vegetated areas. To the north, karst morphology formed undulated karst hills as slope average ranging from very steep to moderate. Scattered conical hills were identified as a result of surface karstification. However, drainage pattern had not clearly formed in karst landscape, they were formed subsurface. Image characteristics of this karst area have a dark to moderate tones, hard textures along outer rings and smoothen towards its centre.

In terms of structural geology, this area has been intensively fractured and faulted. The older fault presents to have northeast – southwest trending and those were cut by the younger faults which has northwest – southeast trending. Lineament Analysis of Mangkalihat Areas according to visual interpretation on fusion image of Landsat and Demnas. The number of lineament are 705 including faults inferred from imagery. Figure 4 shows that the majority of lineament has NW-SE and N-S directions where only few of lineaments are in NE-SW and E-W direction. The regional structural geology reveals that the first majority direction are correspond to normal faults and strike-slip faults while the NE-SW direction are correlated with thrust faults. The drainage within the area were exist performs as trellis and sub-angular patterns and in some parts are disappeared.

Figure 4. Lineament interpretation (extracted from hill-shaded DEMNAS) (left image) and the rose diagram shows the main direction of faults/lineament trends) (right image)
4.1. Field Investigation

Tendehantu Formation (Tmt) is the main rock formation in the Mangkalihat Karst. Previous researcher stated that this limestone formation are composed by coral limestones, white to yellowish in color, well bedded and deposited in shallow marine (neritic zone) during Middle Miocene [3]. According to our field investigation, this formation has a variation limestone characteristic. Instead of coral limestones, fine to hard clastic limestones were found in the field mainly along Teluk Sulaiman to Teluk Sumbang in the south. Figure 5 shows the field location of limestone formation surveyed by the author.

![Figure 5. Field location of limestone formation](image)

Figure 6a depicts limestone (classified as floatstone; mud-supported carbonate rock), white to light grey, hard in matricks, very hard clastic fragmental texture, poorly sorted, sub angular to angular grains with direction (up to 80cm with average grain 10cm) with composition of bioclastic, coral and crystalline limestones. The occurrence of joints within these limestones was many in outcrops. This floatstone was outcropped in location of 18SGT014, 18SGT015 and 18SGT016. Figure 6b illustrates the excavation of fossil mollusc identified as Tridacna sp [8]. It was outcropped in the location of 18SGT016. The similar fossil was discovered in Kutai Basin which located in southern part of study area [9]. Another finding of floatstone which developed into rudstone (grain-supported carbonate rock) was exhibited in the location of 18SGT026 (Figure 6c). The limestones has white to very light brownish in color, compact, less hard, poorly bedded, very hard clastic, very poorly sorted, angular to sub angular grains (up to 150cm in size) which comprised by coral-algae-bryozoa, bioclastic, coral and mollusc fragments. Horizontal cave and its subsurface river had been identified in the location of 18SGT009 as a manifestation of endogenic karst with dimension of 3 meter width and 2m of height in dry condition (field survey was conducted during dry season) as seen in Figure 6d.
Figure 6. The rocks (limestone formation) outcrops in Kampung Teluk Sumbang, Biduk-biduk, Berau Region, East Kalimantan Province a). Floatstone of Tendehantu Formation, consists of coral and mollusc fragments. b). Tridacna sp., one of mollusc fossil discovered in floatstone Tendehantu Formation. c). Zoom out of multisource fragments (corals,algae,fossils) of rudstone Tendehantu Formation. d). Horizontal cave, dry condition, formed in layered packstone of Tendehantu Formation.

4.2. Discussion

The utilization of remote sensing imagery for mapping lithology particularly in remote areas is significant. Field survey is very expensive. Instead, using remote sensing support us to map larger areas and validate in key parts of lithological boundaries of rock formation.

The Karst of Mangkalihat Areas particularly composed by several limestones formations. So that, the delineation of lithological boundary that indicate the karst morphology suppose to carry out clearly and carefully. Thus, other limestone which do not indicate the kartsification can be exploited wisely. In the research area, the karstification has been occuring within the Tendehantu Formation and Tabalar Formation. Tabalar Formation deposited earlier performed as rims which had been highly dissected. These rims have a function as barrier of Tendehantu Formation which deposited subsequently (Middle Miocene).

The exploitation of karst area also present for a reason of economic bosting for local government income. The increase of population is parallel with the necessity of raw materials to build infrastructures such as road constructions, residential areas, and city developments. Those raw materials can be extracted from limestone formation.

In contrast of the issues of karst exploitation, in the research area, along the eastern seaside, the concept development of eogeological tourism is potential to be explored [10]. For example, just less than 10 km from the Teluk Sulaeman to the north, the beautiful “open” lake composed of karst formation has been established. Locals say as Labuan Cermin Lake. Along the coastline of the Teluk Sulaeman to the south, there are Teluk Sumbang tourism spots such as Bidadari Waterfall and hidden white coral beach where the private villas established in ecotourism term. This tourism spots present the evidence that karst area has not only benefit for biodiversity and suistainable ecosystem but also contribute to eogeotourism to boost local income and attraction.
The two existing karst development (exploitation and ecogeological tourism) is need to be considered by the local governments where the karst is also have a right to be conserved as stated in PerMen ESDM 17/2012. Finally, the concept of Mangkalihat Karst sustainability is requisited.

5. Summary
Remote sensing imagery and analysis for rocks and lithological boundary applied in karst morphological features are significant to be utilized in order to give the preliminary result of karst sustainability in Mangkalihat Karst Area.

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