Measuring the damage rate of prehistoric cave images: a case study in the Maros-Pangkep karst area South Sulawesi Province, Indonesia

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Abstract. Damage to prehistoric cave drawings, like other cultural objects, is inevitable. This claim was widely accepted among researchers and observers of prehistoric culture in Indonesia. Even more so for images in karst caves with a medium for painting in the form of limestone surfaces that have dynamic properties. The life cycle of this rock type is influenced by natural processes, mainly by water factors such as dissolution and sedimentation. In addition, the sun, temperature fluctuations, and wind also accelerate the weathering rate, which causes many changes in the structure of the rock both thoroughly and massively, and partially. The belief in damage to prehistoric cave drawings in the Maros-Pangkep Karst Area has long been echoed by researchers and conservationists, but very few of these circles can prove how the damage process occurred, even to prove how fast the damage is. However, the development of image conditions can be measured by a simpler method to determine the speed of damage. This article offers a method that can be applied to cases of prehistoric cave image damage so that changes can be identified, in particular the volume of damage.

1. Introduction
There are many prehistoric cave sites found in Southeast Asia that contain evidence of prehistoric human settlement in the past [1–3], such as stone tools, pottery, and cave paintings. One of the cultural heritages in prehistoric caves is the cave wall paintings that have been damaged and extinct. Prehistoric cave wall pictures (Rock art/rock painting) are archaeological findings that are distinctive and unique because of their shape and nature. In terms of form, the expression of artists shows forms that are directly related to themselves and their environment, for example, body parts such as palms, legs, or their own body profile. In addition, various types of colors are often used to express their expression, such as red, black, purple, yellow, and white. Meanwhile, by its nature, it becomes special because of the level of susceptibility to damage but is proven to last up to 40,000 years after its manufacture. The forms that are found today are the result of natural and cultural processes, like other objects that have perishable properties.

In the Maros-Pangkep Karst Area of South Sulawesi (119°31'111°059'BT and 4°45'-5°10'LS) covering ± 46,200 Ha [4], there are 310 prehistoric cave sites and 242 caves, including prehistoric images. Various forms of images have been identified, including palms, soles, human profiles, deer pigs, Sulawesi pigs, the anoa, fish, birds, and geometric shapes. These images use various types of colors, such as easy red, dark red, purple, black, and yellow. In general, most of the images are damaged. Based on a conservation study conducted by the South Sulawesi Preservation Reserve Office in 2015 in 5 sample caves, it was found that from 340 images identified, 92.7% of them were...
damaged. 12 types of damage were identified, dominated by peeling (89.1%), and algae growth (30.6%).

These conditions are often associated with natural activities, in addition to increasing human activity in the karst and surrounding environment. Global climate change and the earth's temperature, which continue to increase faster than before, are considered to be a trigger for changes in the system in a vulnerable karst environment. The increasing number of people who need land for settlement and agriculture also accelerates changes in environmental conditions. In addition, limestone, as the main landscape of the karst environment, is seen as an economic commodity whose prospects are quite promising for improving people's welfare. Stone quarries for buildings, cement, and marble are warm environmental issues in the last 20 years in the region.

Mining activities are always followed by social changes. The daily activities of the surrounding communities are also affected, industrial activities, improvement of mechanical equipment, and of course, pollution and waste. These facts are identical to the causes of environmental damage. Moreover, the karst environment is known as a fragile environmental system. Instability in one part will trigger damage in another, and this will have a systemic impact on the macro environment. Some people consider that the condition of prehistoric images in caves in the karst environment is greatly influenced by this fragile environmental system. It was clearly concluded that the rate of damage in the image had been very fast since the presence of the mining and limestone industry in the region in the last few decades.

However, it is very difficult to prove the acceleration of damage to these images since mining and industrial activities have penetrated this area. An increase in the rate of damage must be based on definitive measurement results, namely the increase in the volume of damage at any given time. Rough observations of images in large numbers that are not accompanied by good records and measurements cannot be used as evidence of acceleration or damage. Even observations that are accompanied by good recording are not enough, because the results of observation and recording of damage must be measured and carried out routinely, in order to obtain a definite increase in damage to each observation and recording.

Such a systematic observation and recording process has never been done in this area. In general, the statement of an increase in the rate of damage to an image is only based on arbitrary observations, and cannot be proven clearly. In contrast, the measurement of damage volumes on a regular basis against the object image can be authentic evidence of whether or not the acceleration of the damage. Measurements can be made directly on the object, for example, by printing on plastic sheets, but this method is not safe for object preservation. Intense contact with objects can actually be the cause of damage, such as flaking, increased humidity, or increased wear.

A safer method is needed so that the measurement and recording carried out do not cause a destructive effect on the sustainability of the object to prove the damage rate of the image. Methods of measurement without direct touch can be considered proposed in this paper. The principle is measured using optical devices and digital measuring devices. Identifying images based on location can be obtained directly after field measurements, but image volume measurements can be obtained after digital optical images have been processed.

2. Damage rate measurement method

The number of cave sites (242) that contain images is too much to be observed and measured in total, as well as the number of images in each cave, which varies greatly. For that reason, in conducting routine observations, it is necessary to do sampling, choosing caves, and the observed object images. The selection of the cave as a sample is very dependent on the purpose of observation based on the condition of the environment around the site, which shows the factors that are suspected as a factor causing damage. Likewise, with the selection of panels or objects to be observed, the exact position for the purpose of observation must be considered.
2.1. Determining sample
Selection of observational samples is crucial to prove the correlation of factors that are suspected as the cause of damage, and the speed of damage. Certain environmental conditions must be believed to influence the image damage conditions in the sample cave. For example, a dense residential environment is believed to have made a major contribution to the condition of image damage in a particular cave, chosen to prove that settlement density had an impact on the damage and acceleration of the rate of damage in prehistoric cave images. In addition to consideration of the purpose of the evidence, several other important considerations to consider in determining the cave sample are:

- Accessibility, which is an ease in reaching the sample location, related to distance, supporting facilities, and level of difficulty;
- The condition of the cave room is the situation of the cave room that allows the observer team to carry out activities safely, both for the observer, the equipment, as well as for the cave and the images in it;
- The number and intensity of visitors are how much and often visitors come to the cave. This is closely related to the purpose of observation, and factors that are suspected to be the cause of the damage (one of which is a visitor);
- The availability of a control point, a permanent point to obtain the definition of the position of coordinates and altitude, usually used geodetic control net points provided by the Geospatial Information Agency.

After the site is determined, the next step is to determine the object of observation, which can be a panel (which consists of several images), or one object image. As with the requirements for choosing a cave, in choosing an object, it also depends on the factors determining the damage, including:

- Layout, i.e., the position of the image placed in the cave, such as walls, ceilings, niches, stalactites, or other parts of the cave;
- Lighting, i.e., the intensity of natural light that strikes or exposes an image, both direct and indirect light, or even not being exposed to light at all;
- Wind exposure, i.e., the level of wind exposure to the surface of the image, either directly, indirectly, or not at all;
- Water flow/infiltration, i.e., water intensity which influences the picture, whether the water is in the form of flow, infiltration, or permanent or seasonal droplets;
- Affordability, i.e., the position of the image reached by visitors or not;
- The shape of the media surface, i.e., the shape of the rock surface where the image is placed, the flatter the surface the easier it is to record and analyze;
- Some other considerations that are more specific and are determined by the purpose of the observation.

The selected sample object is then marked virtually to avoid direct physical contact or intervention to the object and the surface of the limestone as an inherent image media. The location of these virtual points will be identified by standard measurement tools and can easily be found when objects are needed (stakeout).

2.2. Determining absolute position
The sample image is important to determine its position globally to avoid the disposition of observation points on the object. For this reason, permanent points with horizontal (x, y) and vertical / elevation (z) coordinates are needed as measurement bases. This point is known as Datum Point (DP), which is placed around or within the site area. Its global position can be transferred from the nearest geodetic datum point (National Geodetic Control Network) provided by the Geospatial Information Agency. For the Prehistoric Karst Maros Pangkep area, the JKGN reference used is the TTG.2010.0092 pillar with coordinates 50° 1'42,8898 80" LS and 119° 34" 13,41840 "BT with elevation 8,908 m above sea level. From this JKGN point, the DP stake was measured using GPS Sokkia GCX2 and Leica Viva GS08 Plus. Due to natural conditions that are closed, due to vegetation or cliffs, the datum point is often placed at some distance from the cave so that the Cave Bench Point
is used to serve as a measurement/recording base for observations. Determination of the coordinates of the Point Bench Cave, is done using the Topcon ES Series Total Station, measured from the Site DP. The next measurement starts from the Cave Mark to the sample object observed with a total station, so that the boundary panel or image of the observed object can be identified by its global coordinate values. Thus, every object of observation - even objects in the form of dots - can determine the value of coordinates \((x, y, z)\). Including the points of damage in the image can be monitored for changes, because with good measurements, in fact, every point in the sample frame has horizontal and vertical coordinate values.

2.3. Visual recording

Recording as a form of perpetuating observations is important as a provider of data and evidence of conditions or damage. In addition to verbal recording such as description (including measurement), the most important thing to do is recording pictorially, namely visual digitization of the sample object image. Digital visualization of the sample is done with a DSLR camera to capture image images to the maximum and stored in a digital format with JPEG extension. The results of the photo recording are required to have a clear unit of measurement in order to be registered in the processing application. For this purpose, the photo shoot is done by three methods, namely:

- Static photographs, i.e., shooting with 2-dimensional projections, wherewith certain requirements the object is photographed normally. In order to obtain the photo results with the lowest distortion, then the position of the camera is placed right in the middle of the 4 corner points of the object's photo frame. Likewise, the shape of the sample object's surface needs to be taken into account in order to obtain the most balanced shooting position. The distance of the camera with the object is set so that in obtaining detailed images, do not rely on the use of zoom.

  Static shooting is done in two models, namely shooting natural object lighting in three moments, morning (7.30-8.30), afternoon (11.30-12.30), and evening (16.00-17.00), and shooting with artificial lighting that can be done at any time all day.

- Photogrammetry is the union of several static photos to obtain photos with a 3-dimensional image. The principle of photographing for this need only requires the position of the camera perpendicular to the object in each frame and the percentage of overlapping frame areas (overlays). This perpendicular position is in an effort to reduce distortion in the dimensions of the image space, and the percentage of frame velocity to determine the level of accuracy of size. The higher the percentage of frames that are overlaid, the higher the level of accuracy. The final result of photogrammetry is the image of a 3-dimensional object with an advantage in realistic projections, more tangible surface shapes.

- Photo Timelapses, is a visual recording with 2-dimensional image images arranged into a live image, like a video. This method is used to record the lighting conditions of objects over a period of time, from time to time, and also to record the development of light exposure touching the cave space.

  A DSLR camera is used to record the visualization of sample objects since it is more applicable, inexpensive, and superior to reality and color quality compared to 3D scanners.

2.4. Routine repetition

Observation and recording procedures must be done repeatedly with a certain period to get periodic data records. The emphasis is on consistent technical procedures and data output models so that all observations and recordings are similar and easy to compare. Periodic repetition is carried out in a disciplined manner to capture moments that have an impact on time, such as season considerations, daily time, and certain conditions.

Since the sample image or panel image is not physically marked, measurements are made using the total station to find the coordinates of the observation frame virtually. Thus the maximum observation and recording can be done without any direct contact with the object. As a consequence,
accuracy and caution in establishing control points and boundaries of the object of observation, installation of measurement equipment, and measurement processes become a necessity.

2.5. Analysis
To measure the damage or weathering experienced by the sample object, the type of damage is identified directly on the object, then the distribution of the frame is then carried out. Each location of the damage is determined by marking the colors and textures that can be recognized in the results of the photo, then determined by coordinates. If the shooting is done correctly, then the types of damage will be mapped by themselves on the resulting photo. Everything will appear with the appearance of differences in color and surface texture of the image in the photo. Therefore direct observation of the sample object is very important, accompanied by notes to explain the character or characteristics of each type of damage. Records become an important means to help in recognizing and differentiating, especially if the type of damage is in large amounts. For this purpose, 2 methods of photo analysis are carried out, namely:

- Static photo analysis to determine the extent of 2-dimensional projections, and for other measurement purposes. The AutoCad application is used to find out the extent of two-dimensional projection
- Photogrammetry analysis to determine the actual surface area with 3-dimensional projections, controlled by several points with coordinates. With this projection, the volume of damage to sample objects can be communicated more realistically. To obtain photogrammetry using the Agisoft Photo Scan / Agisoft Metashape application, to guide the interpretation of images and help measure the extent or volume of damage on the surface of the sample image.

The results of the analysis of recorded data from two or more measurement sessions with a certain time span will be calculated the difference in the volume of two or more measurement sessions.

3. The implementation in the Maros-Pangkep karst area
The implementation of the method of observing and recording prehistoric cave sample images has been started by the Conservation Preservation Center of South Sulawesi in order to support conservation efforts against the rate of damage to prehistoric cave sites, especially those containing prehistoric cave pictures in this region since 2018. From 242 cave sites containing prehistoric cave images, 5 caves with different environmental variations were selected, one of which was Leang Jarie in Samanggi Village, Simbang District, Maros Regency, South Sulawesi Province with an astronomical position of 50° 01' 55.53" - 50° 01' 57.44" LS and 119° 41' 12.61" - 119° 41' 13.97" East with an elevation between 195-32.5 meters above sea level (masl).

Leang Jarie was selected to see the effect of population activity and the possibility of traffic effects, both due to emissions and vibrations caused because the object is located 130 meters from the highway with a fairly dense vehicle volume. Another reason was the settlement that although not densely populated, the site area is located in a residential environment with quite intensive agricultural activities. In addition to these considerations, the selection is also related to good accessibility, very suitable for periodic monitoring activities.

The observation began with determining the sample in the form of a panel on the ceiling of the niche on the upper wall east of the main room of the cave, or at an altitude of 5.7 meters above the surface of the cave floor. The sample points were determined by horizontal and vertical coordinates of the cave stakes with a measurement base on the DP stakes Site drawn from JKGN Standing No. TTG.2010.0092 with coordinates 50° 1’ 42,89880” LS and 119° 34’ 13,41840” East longitude with an elevation of 8,908 m above sea level. Measurement and transfer of geodetic control points were done by using Sokkia GCX2 GPS Geodetic with the net method. Point DP Site was then identified by the JRE01 Code (JRE = Jarie, and 01 = Bench Mark / BM identity number), which were then horizontally and vertically transferred to the Cave Mark, namely the point x 797966,890 and y 9443134,339 at altitude (z) 26,307 masl.
The cave mark becomes a measurement base to determine the position of the sample panel identified by 4 camera coverage angle points, 2 damage points, and 2 control points, namely:

| No. | Point              | X          | Y          | Degree Position | Altitude (masl) |
|-----|--------------------|------------|------------|-----------------|-----------------|
| 1   | Standpoint 1       | 797969,49151700 | 9443138,9955900 | 5°1’56,706”          | 32,208          |
| 2   | Standpoint 2       | 797969,30300000 | 9443139,5480000 | 5°1’56,688”          | 32,094          |
| 3   | Standpoint 3       | 797969,70800000 | 9443139,6580000 | 5°1’56,684”          | 32,075          |
| 4   | Standpoint 4       | 797969,70900000 | 9443139,6620000 | 5°1’56,686”          | 32,084          |
| 5   | Control Point 1    | 797969,75500000 | 9443139,2110000 | 5°1’56,698”          | 32,299          |
| 6   | Control Point 2    | 797969,57300000 | 9443139,3940000 | 5°1’56,693”          | 32,308          |
| 7   | Damage point *) 1  | 797969,53200000 | 9443139,2280000 | 5°1’56,698”          | 32,318          |
| 8   | Damage point *) 2  | 797966,53200000 | 9443139,2590000 | 5°1’56,700”          | 32,347          |

Note: *) damage in the form of exfoliation.

The samples were recorded by using Sony α7 for photographing 2-dimensional photo projection samples and Sony Nex 7 cameras for photogrammetric 3-dimensional projection samples. Two-dimensional panel shooting used a modified monopod to ensure the camera's position was stable and permanent, so the shooting process can be done repeatedly and consistently both for the camera's position and the distance to the panel. The position of the camera was at the point x 797969,69400000 (119°41’13,54” BT), and y 9443139,3160000 (5°1’56,695”) at an elevation of 31,416 masl.
Figure 1. Observation sample at Leang Jarie, karst hillside 17 km east of Maros City in Maros Regency, South Sulawesi Province. Astronomically, the location is defined by coordinates X, Y, Z, which are drawn from JKGN TTG.2010.0092 to the cave markers.

Based on the results of a conservation study conducted by BPCB of South Sulawesi in 5 sample caves in Pangkep Regency in 2015, 12 types of damage and weathering were experienced by prehistoric cave drawings. The damage and weathering include; worn, cracked rock, algae, lichen, moss, uneven surface, popcorn, faded, insect/termite nest, chipped, vandalism, and travertine. The most dominant type of damage encountered is peeling, so this type of damage is considered the most urgent to know the speed of damage. For this purpose, this observation and recording were carried out to monitor the rate of damage and its speed. However, to facilitate or overcome resource limitations, the object of observation was narrowed to a small area in the sample panel. The observation area of 21.71 cm² from this position is x 797969.549208-797969.553390 and y 9443139.217383-9443139.222576 at an altitude of 32.45-32.46 masl.
Observations over three periods, September, October 2018, and March 2019 produced 9 photos with natural lighting conditions and 3 photo panels with artificial lighting. To identify the occurrence of added damage - especially flaking - 3 photos of artificial lighting are overlapped. The data used was a 2-dimensional static projection photo by registering the photo in the AutoCad application in the form of a raster.

As for the results of recording 3-dimensional projection photos used to compare the distribution of damage in realistic visualization with 2-dimensional photos in the AutoCad application, this is important to avoid image distortion due to shooting angles in the inclined plane that are not perpendicular to the position of the camera lens. The corner points of the frame and the control points in the determination of coordinates help in interpreting images that are thought to be inaccurate (Figure 2).
Figure 3. Damage monitoring and damage volume measurement with the AutoCad application.

Based on the results of two-dimensional projection analysis with AutoCad on three photos, obtained damage conditions in the observation area in the form of:
- Photo 1 of the period October 2018, the volume of damaged area 4,038 cm$^2$;
- Photo 2 of the period November 2018, the volume of damaged area 4,038 cm$^2$;
- Photo 3 of the period March 2019, the volume of damaged area 5,407 cm$^2$.

From the analysis of the photo data, it was found that there was no increase in damage within 1 month after the first observation, but 4 months after the second observation, it was found that there was an increase of 1,372 cm$^2$ peeling. However, the damage volume cannot be categorized as the actual volume because the 2-dimensional projection removes the unreadable curved surface volume in this projection method. The peeling volume from the 3-dimensional projection analysis is believed to produce a larger volume. In the context of monitoring image damage, the 2-dimensional projection method can still be used to determine the speed of damage. This is because the photo and the size of the damage are only instruments to determine the increase, provided that the shooting methods and specifications are carried out consistently.

4. Conclusion
The recording method to identify and measure the rate of damage in the prehistoric cave drawings can actually be done more accurately by using a 3D scan tool, but it is still constrained by the availability of tools or a high cost. Besides, the difficult karst environment conditions in the mobilization of scan equipment become one of its own obstacles. This method is one of the solutions offered, although it is not yet perfect, and development and improvement are still being carried out. Some weaknesses are still a problem in terms of accuracy and consistency, both 2-dimensional and 3-dimensional projections, which are the neglect of the image's surface curvature and being forced into a flat surface projection on 2D photos. In 3-dimensional projection, weaknesses in the measurement system with the photogrammetric method with a digital camera, need to be corrected to the accuracy of the mosaic results or incorporation through digital processing of tens to hundreds of photo frames. This is caused by the inconsistency of the distance of the photo-taking from the corrugated surface to the camera's optical lens in a static position.

For the measurement of other types of damage, it is necessary to develop better methods, especially related to damage with certain characters, such as color and wear. This is because it really
depends on the camera settings, the ability of the lens, the level of water/humidity content, and lighting. A belief that by continuing to reform and develop this method can be an applicable solution in monitoring the development of the condition of the preservation of prehistoric cave images, especially in the karst area of Maros-Pangkep today.

A well accurate analysis and measurement system can recognize damage/weathering, measure the volume, change, and finally, the speed of damage is identified. In more intensive observations, repeated with a certain time span, it can be predicted the maximum ability to survive an image can exist. Likewise, if the observation is equipped with a recording of environmental conditions around the object or cave, both micro and macro, then the cause of damage from external correlations can be identified. Furthermore, coping strategies can be arranged for conservation. Finally, these efforts are expected to be able to extend the life of prehistoric cave drawings with all their uniqueness, in terms of form, value, and nature.

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