Analysis of landscape changes using high-resolution satellite images at former rice fields after earthquake and liquefaction in Central Sulawesi Province

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Abstract. An earthquake and liquefaction in Palu and Sigi on September 28, 2018, caused serious damage in the rice fields and agricultural infrastructure. The aim of this research was studying and mapping the impact of the disasters by using high-resolution satellite images and field verification. This research uses a visual analysis method to compare images before and after the disasters. The results showed that 6,467 ha of rice fields affected by the disaster. The heavy damaged rice fields were caused by earthquakes, damaged river embankment, and liquefaction. The landscape with undulating slope having height difference of 1 to 5 m, reversed soil surface, crack width > 100 cm, damage on the irrigation system, and sand boiling, were naturally cannot be used again for rice fields. It can be used as tourism spot or historical sites with natural landscape. Whereas rice fields with undulating slope having height difference 20 to 100 cm, crack width up to 100 cm, and sand boiling were classified as moderate. The lightly damaged rice fields could not be planted because the irrigation system was destroyed. It can be used as rice fields after repairing the irrigation system to support water availability.

1. Introduction

Sigi Regency is the fourth rice producer after Parigi Moutong, Banggai and Poso Regencies, with rice fields covering around 17,263 ha, planting area of 30,532 ha, and productivity of 4.65 t ha⁻¹ [1]. Palu City and Sigi Regency are located side by side and are in one stretch of territory. During the earthquake that followed by tsunami and liquefaction that occurred on September 28, 2018, these two cities suffered the heaviest damage and claimed 2,113 lives [2], with material losses of around 184 trillion rupiah [3]. The earthquake and liquefaction disaster had an impact directly or indirectly on agricultural land, especially rice fields in Palu and Sigi. In addition to damage to rice fields, the disaster also caused changes in soil characteristics, landscape changes in rice fields and damage to infrastructure supporting agricultural activities such as irrigation canals and dams. The phenomenon of liquefaction that occurred after the earthquake also occurred in several regions such as Nigata, Japan and the United States since 1964.

Liquefaction can be defined as a change in the properties of granular soil that is solid into a liquid [4]. Liquid in this case the land does not turn into water, but changes become like water. Previous studies have also explained many processes of liquefaction [5-7]. Liquidation can occur when there is a vibration that can be caused by an earthquake and the pressure of water in the ground so that soil particles rub against each other. The soil rubbing against each other then turns into liquid and loses power to...
support it. The phenomenon of liquefaction can cause sand boil, soil cracks, reversed soil surface, and drying of well water in areas affected by liquefaction [8].

Liquefaction is common in regions with characteristics of sandy soil and close to the epicenter of the earthquake [8]. Some previous studies explained that liquefaction is also common near rivers, lakes, or coastal areas. Some examples of liquefaction are in 2008 around Lake Pinions in Greece and the earthquake in Chile in 2010 which resulted the liquefaction close to Lake Calafquen and Panguipulli [9,10]. The latest phenomenon of liquefaction in Indonesia occurred in 2018 in Palu City and Sigi Regency which was triggered by an earthquake mag: 7.7 [11]. To study the landscape and land use changes, visual interpretation on satellite imagery can be used to identify the distribution of the affected areas through differences in hue, texture, pattern, size and shape.

This paper presents an analysis of agricultural landscape changes after an earthquakes and liquefaction in Palu City and Sigi Regency. The aim of this research was to study and mapping the impact of disasters by using high-resolution satellite images and field verification. In addition, it also discusses the characteristics and physical condition of existing affected land both directly and indirectly, which is equipped with a distribution map of heavy, moderate and light damaged, as well as recommendations for future land use.

2. Materials and methods
This research was carried out in existing rice fields before and after the occurrence of earthquakes and liquefaction in Palu and Sigi, Central Sulawesi Province. Palu and Sigi are located side by side, consists of lowlands and highlands, having landform varying from flat to mountainous. Rice fields in Palu before the disaster reached 538 ha or around 14% of the total area of Palu City [12]. The area of rice fields in Sigi Regency before the disaster covering an area of 17,263 ha or 3% of the total area of Sigi Regency [13]. The type of wetland in the study area was dominated by irrigated rice fields planted one to three times a year.

The research begins with data collection on both tabular and spatial data. Spatial data used as research materials includes a map of rice fields, SPOT-6 satellite imagery and LiDAR imagery for period after the disaster. SPOT-6 imagery has spatial resolution of 1.5 m, while the LiDAR imagery has spatial resolution of 15 cm. The LiDAR imagery was chosen to make it easier to map the liquefaction location through visual interpretation. While tabular data was in the form of rice fields from Central Sulawesi Province BPS [3], BPS of Palu City [12], and BPS of Sigi Regency [13].

Landscape change analysis of rice fields after an earthquake and liquefaction was carried out by comparing the images before and after the disaster. To find out the distribution of affected rice fields, an interpretation analysis was conducted using SPOT-6 satellite imagery for the period before the disaster and LiDAR imagery for the period after the disaster by using visual analysis method. The interpretation results of the image were used as the basis of the initial calculation of the affected rice field area. Affected rice fields were indicated by differences in the hue, texture, pattern, size, and shape of interpreted image objects [14, 15]. The affected rice fields will be divided into three classes i.e. light damaged, moderate damaged, and heavy damaged, which will then be verified during the observation and data validation. The main output of this stage was the distribution of rice fields prior to the disaster map, distribution of affected rice fields map, and land use change map. The next stage was field verification to validate the results of image interpretation. Field verification include observing changes in existing land use especially rice fields, landscape and observing land characteristics to compare the result of visual image interpretation with the reality.

3. Results and discussion

3.1. Location of earthquake and liquefaction
An earthquake followed by a tsunami and liquefaction that occurred on September 28, 2018 in Central Sulawesi Province was centered in Donggala Regency with mag: 7.7. The disasters hit several regions such as Balaroa and Petobo in the City of Palu, and Lolu, Jono Oge, Sidera, Sidondo, Sibalaya, and
Potoya in Sigi Regency. The results of field observations showed that the rice fields directly or indirectly affected by the disaster were found in all of these locations except Balara, Palu City which was a residential area. Distribution of liquefaction locations in Palu City and Sigi Regency are showed by figure 1.

![Figure 1. Distribution of liquefaction locations in Palu City and Sigi Regency.](image)

The process of liquefaction in various regions in Palu City and Sigi Regency has similarities. Based on the geological maps scale 1: 250,000 Palu sheets [16], Pasangkayu sheets [17] and Poso sheets [18], all liquefaction locations is close to the faults. The liquefaction process that occurs in the area was originally triggered by an earthquake which caused a change in the character of solid soil (saturated loose sand) to resemble water or be liquid that occurred in areas having soil saturated with water. In addition to earthquakes that cause the saturated soil particles to rub against each other, the breakdown of the irrigation canal embankment also triggers liquefaction. It flows for 2 km as happened in Jono Oge, Sigi Biromaru Subdistrict (figure 2).

The breakdown of the Gumbasa irrigation canal on the east of the location of the liquefaction phenomenon at Jono Oge (blue point) is one of the factors that also trigger the phenomenon of liquefaction in that region. Based on topographic data, there is a slope in the region caused gravitational flow towards the slope. In the case of the Jono Oge, the direction of flow liquefaction is towards the Palu River. The same thing happened in Sibalaya, Tanambulava Subdistrict, where liquefaction was triggered also by the breakdown of the irrigation canal from Gumbasa Dam. Liquefaction locations in Sibalaya are showed by figure 3.
3.2. Rice field landscape changes

Based on the visual interpretation results of satellite imagery, it shows that there has been a change in land use from rice fields to open land with varied surface forms, landslides, cracks, high differences with the surface, reversed soils, and others. Landscape changes appearance can be seen clearly in the imagery for after the disaster period. Based on visual interpretation, it can be calculated that the area of liquefaction in Petobo is 181 ha, Jono Oge is 209 ha, Sibalaya is 57 ha, Sidondo is 7 ha, and Lolu is 5 ha. The appearance of rice fields in any subdistrict on SPOT-6 imagery and LiDAR imagery before and after the disasters are showed by figure 4 to 11.
Figure 4. Petobo before liquefaction.

Figure 5. Petobo after liquefaction.

Figure 6. Sibalaya before liquefaction.

Figure 7. Sibalaya after liquefaction.

Figure 8. Sidondo before liquefaction.

Figure 9. Sidondo after liquefaction.

Figure 10. Lolu before liquefaction.

Figure 11. Lolu after liquefaction.
Based on the results of the visual analysis of satellite imagery combined with the results of field verification, the damage level of the rice fields has been determined, both directly and indirectly affected. Light damaged rice fields are rice fields that are not directly affected by disasters, while moderate and heavy damaged rice fields are directly affected by liquefaction. Affected rice fields characteristics were presented in table 1.

| Condition       | Heavy damaged                                                                 | Moderate damaged                                      | Light damaged |
|-----------------|-------------------------------------------------------------------------------|------------------------------------------------------|--------------|
| Land Surface    | Undulating with a height difference of 1 to 5 m, reversed soil surface        | Undulating with a height difference about 20-100 cm   | -            |
| Soil Cracks     | >100 cm                                                                       | 20 to 100 cm                                         | -            |
| Irrigation      | Broken                                                                        | Cracked                                              | Cracked      |
| Soil Material   | a mixture of soil, gravel and sand                                           | sand boil                                            | -            |

Light damaged of rice fields were not physically damaged. It cannot be planted because of the unavailability of water because the irrigation canal was broken. If the soil is still good and the canals are repaired, they should be able to be planted. Moderately and heavily damaged was indicated by changes in the shape of the land surface, cracks, destroyed irrigation canal, and mixed soil material. The field verification data was processed and analyzed as input to improve the distribution map and damaged area rice fields as well as recommendations for further land use. The condition of rice fields after an earthquake and liquefaction are presented in figure 12.

![Figure 12. Condition of rice fields after earthquake and liquefaction.](image-url)
Heavy damaged rice fields are in the liquefaction area. The liquefaction causes sand boil, soil cracks, and reversed soil surface, so that rice fields become heavily damaged and difficult to restore. Affected rice fields are in the vicinity of the liquefaction area which also has a serious impact on the physical condition of rice fields. The surface of this rice field is bumpy and there are soil cracks. Meanwhile, the affected rice fields are lightly physically not seriously damaged. These locations are quite far from the area of liquefaction.

3.3. Performance of existing rice field in Palu City and Sigi Regency

Rice fields in Palu City and Sigi Regency are dominated by irrigated rice fields. The area of rice fields in Palu City is 538 ha and all of them are irrigated [12]. Whereas Sigi Regency based on BPS Sigi Regency data in 2018 has rice fields with a total area of 17,263 ha. Area and type of rice field in the affected area in Palu City dan Sigi Regency were presented in table 2.

### Table 2. Area and type of affected rice fields area in Palu City dan Sigi Regency (in ha).

| Subdistrict                  | Irrigation | Non Irrigation | Total |
|------------------------------|------------|----------------|-------|
| Palu Selatan (Petobo)        | 122        | -              | 122   |
| Sigi Biromaru (Jono Oge, Sidera, Sidondo, Lolu) | 5,131      | -              | 5,131 |
| Dolo (Potoya)               | 1,700      | -              | 1,700 |
| Tanambulava (Sibalaya)      | 1,155      | -              | 1,155 |
| **TOTAL**                   | **8,108**  | -              | **8,108** |

Sigi Biromaru subdistrict has the largest rice fields among the four sub-districts affected by the earthquake and liquefaction disasters with a total area of 5,131 ha before the disaster occurred. The four sub-districts contributed rice production to Central Sulawesi Province on average 3.9% or around 39,500 t annually. Rice fields damaged by earthquakes and liquefaction are presented in table 3.

### Table 3. Rice fields damaged by earthquakes and liquefaction (in ha).

| Subdistrict                  | Light Damaged | Moderate Damaged | Heavy Damaged | Total |
|------------------------------|---------------|------------------|---------------|-------|
| Palu Selatan (Petobo)        | 48            | 5                | 29            | 82    |
| Sigi Biromaru (Jono Oge, Sidera, Sidondo, Lolu) | 3,950        | 375              | 241           | 4,566 |
| Dolo (Potoya)               | 835           | 402              | 53            | 1,290 |
| Tanambulava (Sibalaya)      | 485           | 10               | 35            | 530   |
| **TOTAL**                   | **5,318**     | **792**          | **357**       | **6,467** |

Table 3 showed that rice fields damaged by direct or indirect impacts by earthquakes and liquefaction in Palu City and Sigi Regency were 6,457 ha. The damaging rice fields is dominated by mildly affected classes with an area of 5,318 ha or 82% of the total area of the affected rice fields. Mildly affected rice fields cannot be planted due to the unavailability of water because the irrigation canal is broken. The impact of 6,467 ha of rice fields due to disasters in Palu City and Sigi Regency resulted in 3.1% decrease in rice production in Central Sulawesi Province.
The reduction in rice fields due to land use changes after the disaster caused a change in farmer's household labor activities. The number of farmer household workers in the agricultural sector in the affected areas in Palu City decreased from 85% to 69% from total population 96 people. Whereas in the affected areas in Sigi Regency the number of farmer household workers in the agricultural sector decreased from 98% to 11% of the data population 882 people.

4. Conclusions
The occurrence of earthquakes followed by liquefaction resulted in direct and indirect damage to agricultural land, especially rice fields in Palu City and Sigi Regency with an area of 6,467 ha consist of 5,317 ha being lightly damaged, 792 ha being moderately damaged, and 358 ha being heavily damaged. The light damaged rice fields have no physical damage in landscape, but there is no water source to irrigate the rice field. The moderately and heavily damaged rice fields were indicated by changes in the shape of the land surface, cracks, destroyed irrigation canal, and mixed soil material. Rice fields that are affected lightly and moderately can be restored by repairing irrigation canal or finding other water sources. Heavily damaged rice fields are recommended to be used as tourism spot or historical sites with annual crops and natural landscapes. There is a need of coordination and synergy among the relevant parties to rehabilitate and plan the future use of rice fields.

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