

# Analysis of GIS-Based Disaster Risk and Land Use Changes in The Impacted Area of Mudflow Disaster Lapindo

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**Abstract.** The mudflow disaster Lapindo in Sidoarjo Indonesia, that has occurred since 2006, until now still poses a risk of danger to residential settlements in the impacted areas. This study aims to make disaster risk analysis and land use changes in disaster impacted areas since before the disaster occurred until now. This research is expected to be very useful as a basis for developing spatial policies in the region. The method used is quantitative based on satellite imagery, then GIS-based data is analyzed quantitatively. GIS-based disaster risk analysis can be used as a reference in spatial revisions that can anticipate spatial regional developments, especially for the needs of residential settlements. Observations from satellite imagery show a very significant level of change in residential land which is now 42.1% and the level of disaster risk varies with the medium-high index. With the results of this study, in an effort to improve the resilience index of the region, planning the location of residential land should use land outside the impacted area in order to ensure the safety and security of the community.

**Keyword :** disaster risk; landuse changes; GIS

## 1. Introduction

### 1.1. Background

Sidoarjo, the location of this research (Figure 1), has long been known as the Delta City. Brantas River, Mas River, and Porong River in the vicinity of Sidoarjo form a delta, where Mojokerto is at the top of the delta, while Surabaya and Bangil are at the foot of the delta. In its history, the Delta has been formed for centuries and became the birthplace and development of Medang, Kahuripan, Jenggala, and Majapahit kingdoms. The progress and decline of these kingdoms seems to have been influenced by everything that happened to Delta Brantas (Nash, 1931 in [1]). In the view of Satyana, the similarity of places is in the Delta Brantas between the Jenggala, Majapahit region and the location of the Lapindo mudflow, geological settings, historical records / sources in the Babad Pararaton and Serat Kanda, Jenggala folklore, and geological principles, the background of the suspicion / hypothesis that a mud disaster had also occurred during the Jenggala and Majapahit kingdoms. Disasters play an important role in the decline of these two kingdoms. However, the mud disaster in the past has been forgotten even though there are also several mud volcanoes in the surrounding area [1].



The mudflow disaster Lapindo in Sidoarjo, East Java, is one of the disasters that have been a national issue in Indonesia, even the world. Many expert debates about the causes of disasters, whether caused by human negligence or natural disasters, caused this disaster to be a unique case. The events of the release of hot gas and mud from the ground on May 29, 2006 which inundated and destroyed the lives of thousands of people in 17 villages in 3 sub-districts in Sidoarjo Regency (East Java) became the beginning of a disaster that continues to be a threat to community settlements to the present. While the consequences of the disaster, communities in the affected areas have suffered heavy losses such as loss of land, houses and livelihoods, as well as greater socio-economic losses. In fact, they are forced to move from their homes and old social environments and are deprived of their socio-historical roots.

Actually the phenomenon of the mudflow disaster that occurred in Sidoarjo is nothing extraordinary in the world of geology. But the case of the Sidoarjo mudflow has extraordinary uniqueness, namely the scale of the bursts and its large overflow, also the nature of the hot and thick mud. This phenomenon in geology is known as the mud volcano. The temperature of a very high burst with a surface temperature of 96 °C or close to 100 °C on the surface close to the center of the burst is a unique condition of the mud volcano in Sidoarjo which may not be found on other mud volcanoes in the world. While thick deposits are in the form of mud and water with a ratio of 70% water and 30% solid material [2].

However, the broad impact of the Sidoarjo region due to the disasters of mud volcanoes is precisely due to the movement of land around the center of the burst, both in the form of land subsidence and horizontal movement, which extends to areas outside the center of the bursts [2,3]. The impact of land subsidence and horizontal displacement has provided tremendous obstacles to the handling of bursts and overflow of mudflow [2]. Several times the embankments hold back the mud, which is very detrimental to the people living in the surrounding villages because the area becomes very risky if a disaster returns.



**Figure 1.** Map of research location in Sidoarjo, East Java, Indonesia (Source: [http://www.sman2sidoarjo.sch.id/index.php?id=profil&kode=27&profil=Kon tak%20Sekolah](http://www.sman2sidoarjo.sch.id/index.php?id=profil&kode=27&profil=Kon%20tak%20Sekolah))

### 1.2. The Aim

From the background that has been described above, a problem arises regarding how the level of disaster risk in the impacted areas and changes in settlement land use that existed during the period of 2006 to the present using GIS baseline data. The purpose of this study is to analyze and assess disaster risk in the area impacted by the mudflow disaster Lapindo, Sidoarjo, so that later it can minimize the impact of the disaster that must be borne by the community. The benefits of GIS-based disaster risk analysis research will be greatly needed in disaster mitigation programs, looking at trends in disaster risk development and spatial policy formulation in the region.

### 1.3. Theoretical Review

Indonesia is a country that has geographical, geological, hydrological and demographic conditions that enable disasters to occur, whether caused by natural factors, non-natural or human factors that cause

human casualties, environmental damage, and other impacts. Disaster is defined as an event or series of events that threaten and disrupt the lives and livelihoods of people caused, either by natural factors and / or non-natural factors and human factors resulting in human casualties, environmental damage, property losses, and psychological impacts. While Mitigation is a series of efforts to reduce disaster risk, both through physical development and awareness and capacity building in the face of disaster threats [4].

The disaster meant here is of course a disaster caused by the activities of the Sidoarjo mud volcano such as mudflow from a holding pond, land movement (both subsidence and horizontal displacement), land cracks, gas abruptions, damage to residential buildings, roads, railroads and other social facilities. The high level of vulnerability and potential disasters in this region has resulted in the need for more adequate evaluation of disaster mitigation programs in order to reduce the impact of disasters that may occur. Some natural events can then turn into natural hazards and natural disasters when related to the location of human populations exposed to vulnerability. The five elements associated with a disaster event for humans according to Wisner [5] are : 1) Disaster; 2) Hazards; 3) Vulnerability; 4) Capacity and resilience; 5) Culture. Vulnerability and Resilience represent two different but related things. Vulnerability is also a concept in the paradigm of Disaster Risk Reduction. In line with Gallopin GC [6]. Frazier suggested that Vulnerability is a function of exposure, sensitivity, and adaptive capacity [7]. Kusumastuti argues that by understanding the level of resilience against natural disasters, recommendations for public policy in disaster management to be able to increase sustainability in areas facing natural disasters can be made, so that the impact of disasters on communities and businesses can be reduced and recovery periods can be shortened [8]. The Resilience Index (RI) is calculated as the ratio of preparedness scores to vulnerability scores, which refers to the Simpson [9] Disaster Resilience Index, namely :

$$\text{Resilience Index} = \text{Preparedness Index (PI)} / \text{Vulnerability Index (VI)} \quad (1)$$

Disaster risk is the potential loss caused by a disaster in a region, and a certain period of time that can be death, injury, illness, life threatening, loss of security, displacement, damage or loss of property, and disruption of community activities, due to a combination of hazards, vulnerability and capacity of the region concerned [10].

Some of the terms related to disaster risk include:

- Hazards is a situation or event that has the potential to cause damage, loss of life, or damage to the environment [11]. Hazards can cause disaster or not and will be considered a disaster if they have caused casualties and losses.
- Risk is the potential loss caused by a disaster in a certain region and period of time that can be in the form of death, injury, illness, life threatening, loss of security, number of people displaced, damage or loss of property and infrastructure, and disruption of community activities socially and economically [11].
- Vulnerability is a condition that is determined by physical, social, economic, and environmental factors or processes that result in decreased ability to deal with hazards [11]. The series of conditions can generally be in the form of physical, social conditions and attitudes that affect the ability of the community to carry out prevention, mitigation, preparation and response to the effects of hazards. P2MB UPI describes the types of vulnerabilities such as the following: 1) Physical Vulnerability (buildings, infrastructure, weak construction); 2) Social Vulnerability (poverty, environment, conflict, high growth rates, children and women, the elderly; 3) Mental Vulnerability (ignorance, unaware, lack of confidence, etc.) [10].
- Capacity is the mastery of resources, technology, methods and strengths owned by the community, which enables them to, prepare themselves, prevent, tame, overcome, defend themselves in the face of disaster threats and quickly recover from the consequences of disasters [11]. This capacity can be in the form of local wisdom which is transmitted from generation to generation.

## 2. Research Method

This disaster risk analysis study uses images produced by Remote Sensing technology. The approach used is a spatial approach using quantitative descriptive analysis. At the initial analysis stage, an interpretation of satellite images was conducted, which aims to identify residential areas in the impacted areas of the Lapindo mudflow disaster, Sidoarjo, which will then be carried out quantitatively on disaster risk analysis of the potential and vulnerability of settlements in the area. Materials and data used in this research for area studies here is satellite imagery and maps.

The National Disaster Management Agency [11] calculates the Indonesia Disaster Risk Index based on the following formula :

$$\mathbf{Risk} = \mathbf{Hazard} \times \frac{\mathbf{Vulnerability}}{\mathbf{Capacity}} \quad (2)$$

Hazards in the formula are calculated based on the average level of danger in the form of frequency and magnitude data from natural hazards such as floods, landslides, earthquakes, tsunamis, and others. While vulnerability is observed based on socio-cultural, economic, physical and environmental parameters. In its calculations, BNPB uses parameters of exposure to souls, loss and damage to the environment. Data on capability capacity is carried out using capacity assessment methods based on regulatory capacity, institutional parameters, warning systems, skills training education, mitigation and preparedness systems.

Another method adapted and developed by Agustawijaya and Syamsuddin [2] using disaster risk analysis based on:

- 1) Potential aspects of the disaster are geohazard aspects, in the form of mud flow, soil movement, cracks, and gas boiling
- 2) Aspects of regional vulnerability are the presence of dikes, asphalt / railroad roads, residential houses, and public and social facilities. If these factors are considered, a mud volcano risk analysis in the area can be considered.

In developing his method, Agustawijaya uses a rating analysis technique for modified landslide risks to be simpler so that it is easier to apply in the analysis of the Sidoarjo mud volcano disaster. This is intended as a disaster mitigation effort. In contrast to formula (2) from BNPB which uses Capacity in its calculations, disaster risk according to Agustawijaya [2] is a combination of two things, namely the probability and level of impact of a disaster. Therefore, disaster risk is formulated as a multiplication of Hazard and Vulnerability of the population or region against the threat of disaster:

$$\mathbf{R_h} = \mathbf{H} \times \mathbf{V_h} \quad (3)$$

where: Rh = disaster risk  
H = Hazard  
Vh = Vulnerability to disaster

Whereas Arsjad and Hartini [12] in an analysis of the potential risk of landslides in Ciamis Regency and Banjar City, West Java, used the same as BNPB (formula 2)

$$\mathbf{Risk} = \mathbf{Hazard} \times \mathbf{Vulnerability/Capacity} \quad (4)$$

This study uses equation (2) in assessing the index of disaster risk. To operationalize the calculation, the following scoring tables are created :

**Table 1.**Category and Hazard Scores

Geohazard	Category	Scores
Mudflow	Low/	1/2/3
Soil Movement	Medium/	1/2/3
Soil Cracks	High	1/2/3
Gas Bubble		1/2/3

**Table 2:** Category and Vulnerability Scores

Vulnerability	Category	Scores
Embankment	Low/	1/2/3
Settlement	Medium/	1/2/3
Road / Railway	High	1/2/3
Public Facility		1/2/3

**Table 3:** Category and Population Density Scores

Total score	Category	Color
4 - 10	Low	Green
11 - 20	Medium	Yellow
>21	High	Orange

**Table 5:** Disaster Risk Category

Density	Category	Scores
< 1000 people/km <sup>2</sup>	Low	1
1001 – 2000 people/km <sup>2</sup>	Medium	2
> 2000 people/km <sup>2</sup>	High	3

**Table 4 :** Category and Population Capacity Scores

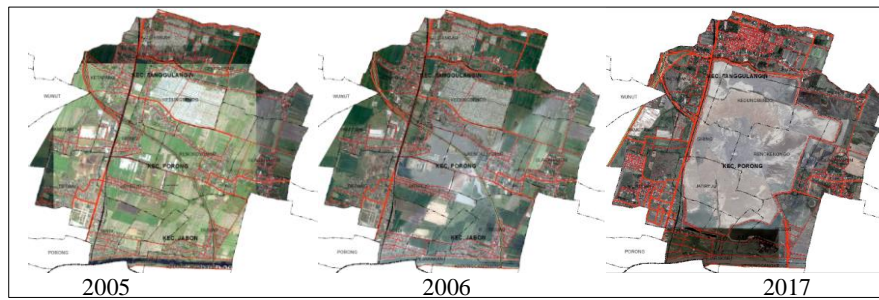
Population Capacity	Category	Scores
1. Disaster Knowledge of community	Yes/No	2/1
2. Community cooperations orgnisazations / institution	Yes/No	2/1
3. Availability of tools for disaster detection	Yes/No	2/1
4. Disaster management System	Yes/No	2/1

The scores for all aspects of Hazard, Vulnerability, population density and Disaster Risk were divided into 3, namely Low, Medium and High with a score of 1-3. In Table 1 there are 4 aspects of Hazard that are assessed namely the presence of mudflows, soil movement, soil cracks and gas bubble which will be given score 1-3. Similarly in table 2 there are 4 aspects of vulnerability namely the distance to the embankment, the location of the settlement, the road / railroad and the public / social facilities. This vulnerability calculation is done by analysis using GIS help to obtain the distribution of the vulnerability aspects represented on the map. It is then calculated by multiplying the residential aspect score using the population density score so that the Vulnerability score is obtained. In this case, the mapping unit used for mapping the vulnerability is the village. However due to the limited data on the population of each village, the density of the villagers in one district is considered uniform. Population density classes are presented as in Table 3. Whereas Table 4 is a score of population capacity that is only assessed from either (score = 2) or not (score = 1).

### 3. Analysis and Discussion

#### 3.1. Disaster Impacts on the Land and Infrastructure Environment

Based on the image recording in Figure 2, it can be said that the area impacted by the mudflow and gas continues to expand. The area inundated by mud is also increasingly widespread. If the land prior to the mudflow disaster (in 2005) was dominated by paddy fields, after the 2006 disaster, it could be seen that the mud embankment expanded in all directions, threatening the existence of the Porong arterial and railroad roads in the West and sinking settlements in the villages. surrounding villages. The Surabaya-Gempol toll road that divides the broken area. Even the Tanggulangin Sejahtera Housing in the North is also submerged. This condition indicates the existence of disaster risk that all relevant parties need to be aware of.



**Figure 2.** Aerial photos of impacted areas before disasters (2005) and after disasters (2006 and 2017) mudflow Lapindo, Sidoarjo (Source: Processed from [www.earthexplorer.usgs.gov](http://www.earthexplorer.usgs.gov), 2019)

Villages that have "sunk" in part or in full up to 2017 are Siring, Jatirejo, Renokenongo, Kedungbendo, Ketapang, Gempolsari, Mindi, Pejarakan, Kedungcangkring, Besuki and Glagaharum. The sinking of these villages was due to various reasons, including: uncontrolled mudflow volumes, soil cracks, land subsidence, even due to gas bursts which endanger the safety of residents.

The impact of the disaster in the initial phase can be seen in the recording of figure 3 where it is clearly seen the center of the bursts and the surrounding physical environment which is drowned by mud, both community settlements and industrial environments which are the source of income for local residents. The occurrence of disasters not only causes people to lose land, houses and livelihoods, but they are also forced to leave their homes and move from their old social environment to other places, uprooted from their socio-historical roots (Figure 4).



**Figure 3.** Impact of hot mudflow disaster Lapindo on the environment (Source: <http://pr-sekolahku.blogspot.com/2015/02/artikel-bencana-lumpur-lapindo.html>)

The impact on infrastructure that is felt by the community is the breakdown of toll bridges which have become the economic lifeblood of East Java because it connects Surabaya to the East (Pasuruan, Probolinggo, Jember and Banyuwangi) and South of (Malang) East Java Province. In addition, activities on the Porong artery and railroad roads were also disrupted.



**Figure 4.** Several houses in the area impacted by the mud disaster Lapindo which were damaged and left behind by residents. (Source: Author Documentation, March 19, 2019)

### 3.2. Hazard Analysis

The occurrence of land movement resulted in damage to infrastructure that already exists around the site of the burst. These impacts include: the downgrade of the Porong arterial road, the twisting of the railroad tracks, the rupture of PDAM pipes, the rupture of Pertamina's pipelines, and the breakdown of the toll road bridge. Another impact is the sinking of the mud retaining dike around the center of the



burst, which is called the ring embankment, as well as the outer embankment to resist the mudflow around the impacted area.

In 2009 the direction of the mud flow was more dominant to the east, north and a small part to the west, while the dominant flow could be predicted to the East (Hariyanto and Sulistyono, 2009). But from the 2011 figure of BPLS based on the 2010 CRISP image (appendix 1), it is seen that the flow of mud is more towards North, Northwest, West and Southwest. Fewer mud flows that go East, Southeast and South. Potentially flooded villages include Ketapang, Siring, Pamotan and Gedang villages. In the area in the South to East there is a white image which is an area in the form of soil solids and is predicted to experience an uplift land so that a pump is needed to direct the flow of mud to Porong River in the South of the area.

The Horizontal Displacement in Appendix 2 shows some variations in the affected villages, between 0.011 to 0.035. Soil movement is measured using GPS which is carried out routinely by BPLS every month on the same date for each measurement point. Horizontal Soil Movements are seen in Kedungbendo, Siring, Renokenongo, Jatirejo, Gedang, Mindi, Besuki, Gempolsari and Glagaharum Villages. The occurrence of soil cracks observed in appendix 3 is in Ketapang, Kalitengah, Siring, Jatirejo, Gedang, Mindi, Pejarakan, Kedungcangkring, Besuki, Glagaharum, and Gempolsari villages. The soil cracks measured in the field are found in every cracks. The position of the crack is then plotted on the map as in Appendix 3. Whereas the distribution of gas bubble in 2010 (appendix 4) includes Ketapang, Siring, Jatirejo, Pamotan, Mindi, Pejarakan, Kedungcangkring and Besuki.

### 3.3. Assessment of Disaster Risk

For the analysis of disaster risk in the impacted area, the author only assesses villages outside the mud embankment, meaning only villages that have not been submerged or partially submerged. Thus the villages of Jatirejo, Renokenongo and Kedungbendo were not included.

**Table 6.** Category of population density per subdistrict

No	Subdistrict	Area Size (km <sup>2</sup> )	Number of Population 2010	Density people/km <sup>2</sup>	Density Category
1	Porong (Siring, Pamotan, Glagaharum, Gedang, Mindi)	29.82	65.909	2.210,23	High
2	Tanggulangin (Ketapang, Kalitengah, Gempolsari)	32.29	84.580	2.619,39	High
3	Jabon (Pejarakan, Kedung-cangkring, Besuki)	81.00	49.989	617,15	Low

Source: Author processed data based on Sidoarjo Regency in Figures, BPS in 2013, 2019

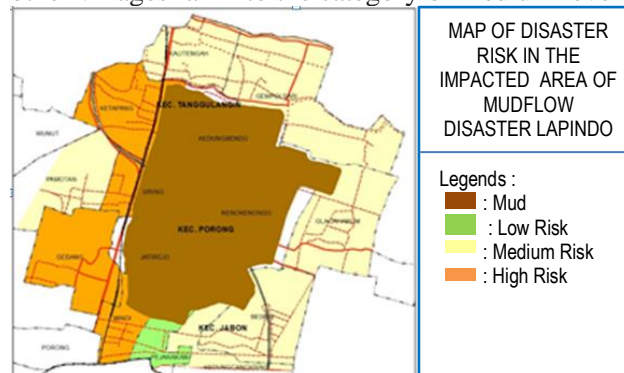
**Table 7.** Disaster risk in mudflow disaster Lapindo Area, Sidoarjo

Villages	Geohazard (H)	Vulnerability (V <sub>h</sub> )	Capacity	Category	$\frac{\sum H \times \sum V_h}{C}$ Total Score R <sub>h</sub>
Kalitengah	8	12	6	Medium	16
Gempolsari	8	10	6	Medium	13,3
Glagaharum	8	11	6	Medium	14.7
Besuki	9	8	6	Medium	12
Pejarakan	6	8	6	Low	8
Mindi	11	12	6	High	22
Kedungcangkring	8	9	6	Medium	12
Gedang	11	12	6	High	22
Siring Barat	12	12	6	High	24
Ketapang	11	12	6	High	22

Villages	Geohazard (H)	Vulnerability (V <sub>h</sub> )	Capacity	Category	$\frac{\sum H \times \sum V_h}{C}$ Total Score R <sub>h</sub>
Pamotan	11	8	6	Medium	14.7

Source : Author Processed from GIS-based data, 2019

From the assesment of disaster risk index in Table 7, the results show that villages that have a high risk of disaster risk are Mindi, Gedang, Siring Barat, and Ketapang. These villages besides having a very high hazard score, also a very high vulnerability aspect, including the distance from the mud embankment and population of settlement in high density (> 2000 people/km<sup>2</sup>). The village that have a low level of disaster risk is Pejarakan. This village has a low density (± 600 people/km<sup>2</sup>) and the hazard score is also low. While other villages fall into the category of medium level disaster risk.



**Figure 5.** Map of disaster risk in the impacted area of mudflow disaster Lapindo (Source : Author analysis, 2019)

Figure 5 is a map of Disaster Risk assessment in the impacted area of the mudflow disaster Lapindo, Sidoarjo, which shows village locations with low to high levels of disaster risk. It shows that village clusters that have a high risk category of disaster are located in the West to the South from arterial, railroad and mud embankments. While villages that are at medium risk are in the North, East and South. The low category of Pejarakan Village is to the south of the embankment, between the two high and medium risk village clusters.

### 3.4. Analysis of Regional Land Use Changes

In terms of geography, Sidoarjo Regency is actually not in a disaster-prone area that can naturally threaten the safety of the population. But as a result of the hot mudflow disaster Lapindo, in addition to physical and environmental changes in the impacted areas, this disaster has also resulted in changes in land use and changes in spatial structure stipulated in the East Java Provincial Regulation (Perda Number 2 of 2006 concerning the East Java Provincial Spatial Planning) and Sidoarjo Regency Regional Regulation (Perda on Sidoarjo Regency Spatial Planning). Based on 2008 data, the area directly impacted reached around 740 hectares (Sidoarjo Regency RTRW 2009-2029, in [13]). There is uncertainty about when the cessation of the eruption is certainly difficult in making spatial planning policies, especially in the impacted areas.

Table 8 shows the extent of land use change for rice fields, industries and community settlements that are increasingly shrinking, while water bodies, mud and empty land are becoming increasingly widespread. This was caused by the expansion of dikes in all directions. Table 8 also shows the composition of the percentage of land changes in the impacted area. Changes in land use in these locations which were initially dominated by rice fields, settlements and some industries were water bodies, vacant land and mud reservoirs. The biggest depreciation in land use change is in rice fields and settlements. If originally (in 2005) the allocation of residential land was 6.97 million m<sup>2</sup> then in 2017 only 2.93 million m<sup>2</sup> or 42.1% of the original area, shrinking by 4 million m<sup>2</sup>. While for paddy fields it



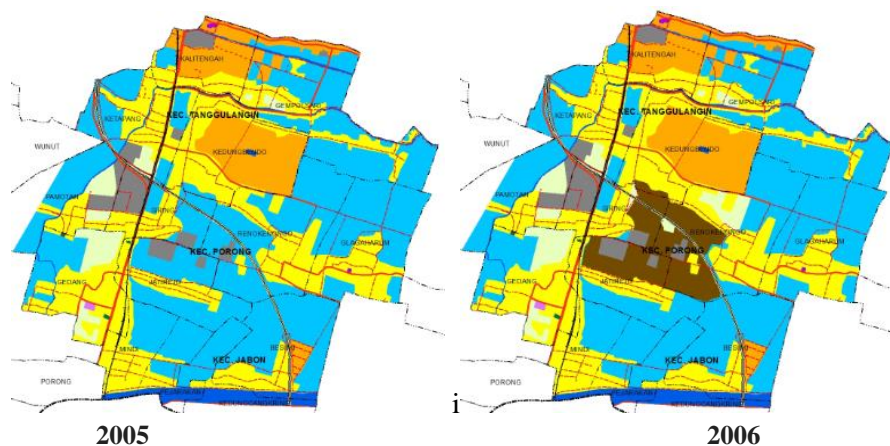
shrank by around 72% from 7.8 million m<sup>2</sup> (in 2005) to 2.4 million m<sup>2</sup> (in 2017). Conversely, water bodies, mud and empty land have experienced a significant increase in the number of large areas. Mudflow from 0 m<sup>2</sup> (in 2005) to 5.65 million m<sup>2</sup> (in 2017). While the water body from 0.6 million m<sup>2</sup> (in 2005) to 1.23 million m<sup>2</sup> (in 2017). The map of land use changes that occur in the area impacted by the mudflow disaster Lapindo can be seen in Figure 6.

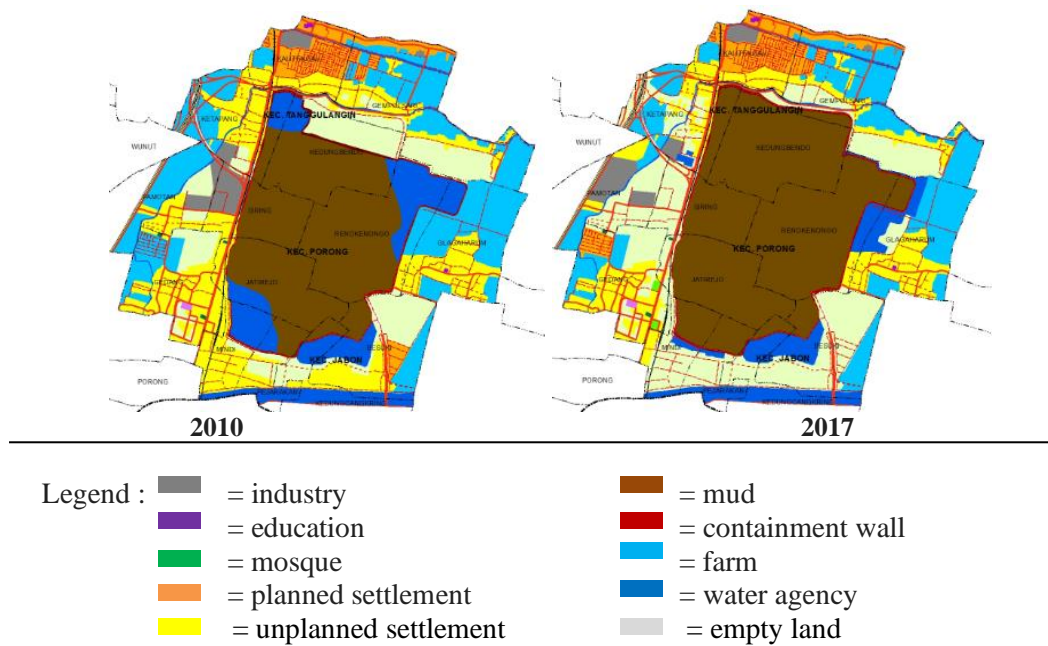
**Table 8.** Changes of land use in impacted areas before disasters (2005) and after disasters (2006, 2010 and 2017) mudflow Lapindo, Sidoarjo

No	Land Use	Area Size (m <sup>2</sup> )							
		2005	%	2006	%	2010	%	2017	%
1	Water agency	588.521,49	3.54	588.521,49	3.54	1.902.312,79	11.44	1.230.358,52	7.40
2	Industry	595.194,90	3.58	595.194,90	3.58	430.065,01	2.59	404.696,71	2.43
3	Road	130.917,88	0.79	130.917,88	0.79	58.051,43	0.35	55.225,49	0.33
4	Empty land	519.520,22	3.12	698.561,53	4.20	2.139.994,39	12.87	3.665.999,70	22.05
5	Mud	-	0	1.091.090,12	11.49	4.101.077,09	24.67	5.650.174,09	33.99
6	Mosques	8.529,64	0.05	8.529,64	0.05	8.529,64	0.05	8.723,65	0.05
7	Planned Settlement	1.654.632,82	9.95	1.654.632,82	9,95	816.096,76	4.90	864.573,83	5.20
8	Unplanned Settlement	5.312.141,10	31.95	5.312.141,10	31.95	3.593.680,89	21.62	2.068.439,49	12.44
9	Farm	7.794.778,59	46.89	6.524.649,19	39,25	3.327.658,12	20.02	2.401.614,63	14.45
10	Elementary school	8.964,24	0.05	8.964,24	0.05	8.964,87	0.05	8.964,24	0.05
11	Junior High School	10.929,60	0.07	10.929,60	0.07	10.929,60	0.07	10.929,60	0.07
12	Parks	-	0	-	0	-	0	25.428,01	0.15
13	Containment wall	-	0	-	0	226.776,59	1.36	229.016,71	1.38
Total		16.624.130,48	100	16.624.130,48	100	16.624.130,48	100	16.624.130,48	100

Source: Processed from Google Earth Satellite Image Data, 2019

By observing the land use changes in impacted areas from time to time as seen in table 8 and visualization in Figure 6, it is absolutely necessary to revise spatial planning that can anticipate spatial development of the region, especially for the needs of residents. The disaster risk analysis carried out in the previous section can be a reference in planning the location of new community settlements by taking into account the carrying capacity of the environment and its capacity, as well as anticipation of the geological conditions of the region in the next decades. However, the location of community settlement land must be free from all threat of disasters such as flood (mudflow), movement and cracks of land, as well as dangerous gas bursts. The next action of the disaster risk assessment is to make efforts to reduce the risk of disasters to reduce its vulnerability and increase the capacity of the population in the impacted area.





**Figure 6.** The map of land use changes in impacted areas before disaster (2005) and after disasters (2006, 2010 and 2017) mudflow Lapindo, Sidoarjo (Source: Processed from [www.earthexplorer.usgs.gov](http://www.earthexplorer.usgs.gov), 2019)

#### 4. Conclusions

As a conclusion of the study on disaster risk and land use changes in the impacted areas of the mudflow disaster Lapindo above, a conclusion can be drawn that GIS-based disaster risk analysis can be used as a reference in spatial revisions that can anticipate spatial regional development, especially for the needs of residential settlements. With a very significant change in residential land which is now 42.1% and the level of disaster risk varies in the villages in the impacted area with a medium-high index, then planning the location of residential land should use land outside the impacted area.

Efforts that can be made to reduce disaster risk and improve the resilience index of the region are to reduce the level of vulnerability and increase community capacity in dealing with disasters such as periodic disaster mitigation and disaster response housing training by the local government in collaboration with academics, planning construction of houses in safer locations and the construction of social facilities in disaster response efforts, as well as re-cultivating local wisdom which is often able to prevent environmental damage. In addition, the government also needs to ensure the security and safety of community settlements in areas impacted by disasters.

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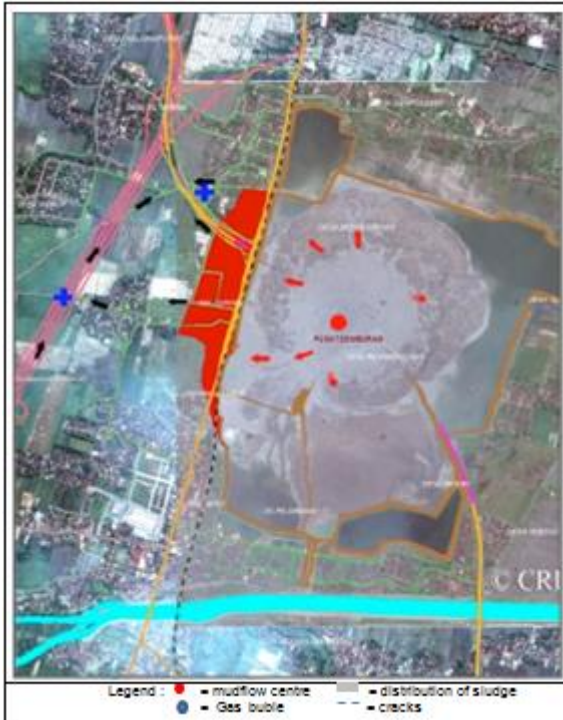
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**APPENDIX 1**



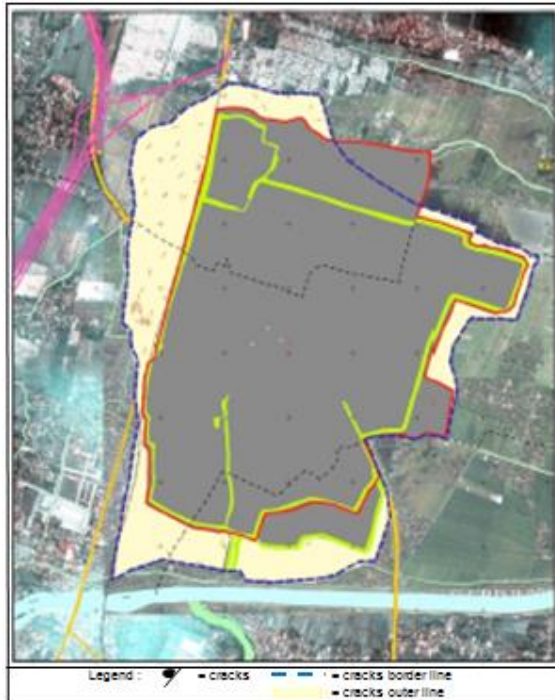
Map of Mudflow Directions  
(Source : BPLS in Agustawijaya, 2017)

**APPENDIX 2**



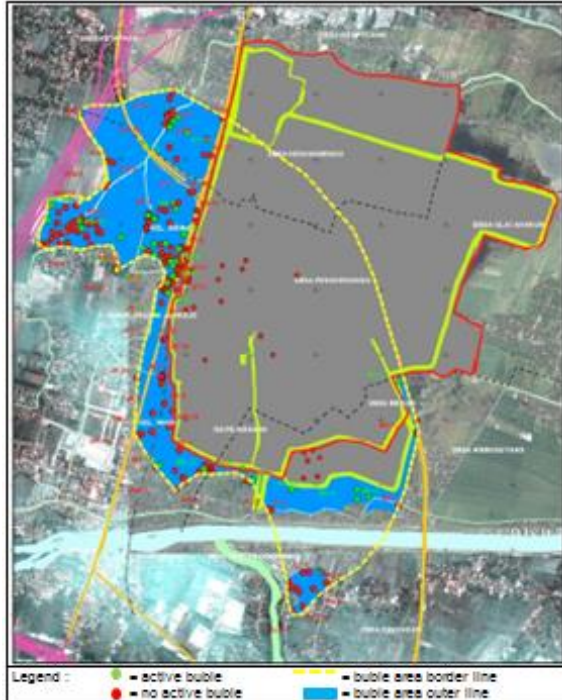
Map of Horizontal Displacement  
(Source : BPLS in Agustawijaya, 2017)

**APPENDIX 3**



Map of Land Cracks Lapindo  
(Source : BPLS in Agustawijaya, 2017)

**APPENDIX 4**



Map of Distribution Area of Hydrocarbon Gas on the Mudflow disaster Lapindo  
(Source : BPLS in Agustawijaya, 2017)