OPTIMAL BENCH MARK DISTRIBUTION TO MONITOR SOUTHERN SEGMENT OF SUMATRAN FAULT

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ABSTRACT

The southern segment of a Sumatran fault zone was one of the sources of earthquakes in Lampung Province. The source of hazard came from stress accumulation of crust, which can be derived from movement of bench mark in surface. Lack of research in southern segment was caused by small numbers of monitoring bench mark. This research shown optimal monitoring bench mark distribution by considering existing bench mark and location which is decent and representative to monitor Sumatran Fault Zone movement by considering on its position relative to Sumatran Fault Zone, earthquake history, Digital Elevation Model and land use. Decent location was determined by overlaying land use and slope processed from Digital Elevation Model. Representative location was determined by taking into account the distance to Sumatran Fault Zone and earthquake history. Very decent location was around 10.5 percent of the total area. Very representative location was around 44.5 percent of the total area. There were total 15 planned bench marks, located on three parts of the fault, to make southern Segment of Sumatran Fault Zone monitoring bench mark more optimal based on segments which lack monitoring bench marks as well as decent and representative location resulted from Geographic Information System analysis.

Keywords*: Bench Mark, Geographic Information System, Land Use, Sumatran Fault Zone*

A. INTRODUCTION

Many great earthquakes is occurring on the Sumatran Fault Zone in the past shown in Figure 1 (Sieh & Natawidjaja, 2000). Sixteen great earthquakes with magnitude more than 5 were occurred in southern segment of Sumatran Fault Zone in last three years (USGS, 2019). Research on Sumatran Fault Zone to understand its behavior is focused on northern segment of Sumatran Fault Zone especially after the occurrence of the 2004 Aceh earthquake which triggers activity of Sumatran Fault Zone. Southern Segment of Sumatran Fault Zone research is rarely conducted compared to northern segment since slip rate of northern segment is higher (Bradley et al., 2017). Fault monitoring bench marks is measured using the geodetic technique to get coordinate values difference over time that generate fault parameters such as slip rate, locking depth, and segmentation (Lindsey et al., 2013).

Lack of research on the southern segment of Sumatran Fault Zone is also caused by small numbers of monitoring bench marks around southern segment, especially in Lampung Province, which in only 14 periodic bench marks owned by Geospatial Agency of Indonesia and Ministry of Public Works and Housing (Alif et al, 2016; Alif et al., 2019). Movement of monitoring bench marks is used to update earthquake hazard maps by calculating stress accumulation of the crust which is source of hazard. Density of monitoring bench marks with proper position relative to the fault makes hazard map generated from more detail fault parameter is more precise. Hazard map is used as consideration in developing region. The study of points or monitoring bench mark to accommodate more precise fault movement or slip and stress accumulation is important for sustainable development in Lampung Province. This research will show optimal monitoring bench mark distribution by considering existing bench mark and location which is decent and representative to monitor Sumatran Fault Zone movement by considering on its position relative to Sumatran Fault Zone, earthquake history, Digital Elevation Model and land use.

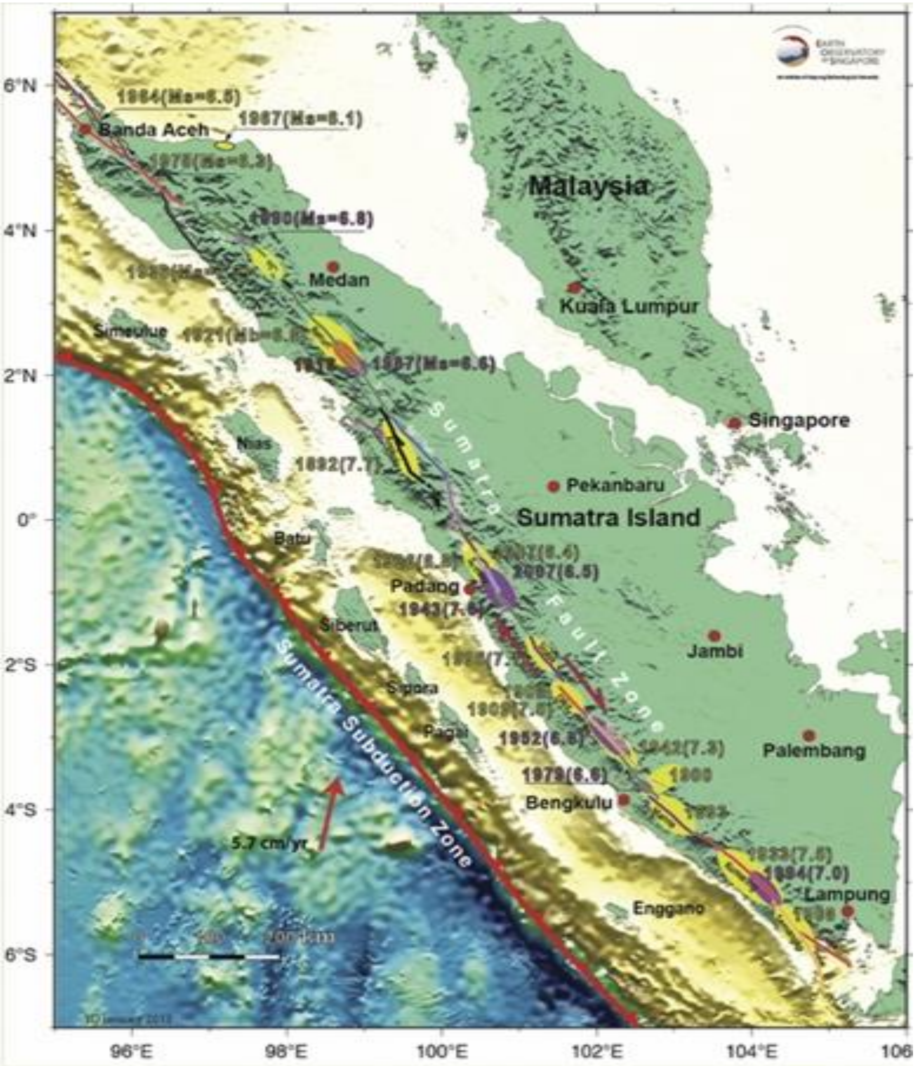

Figure 1. Sumatran Fault Zone (Sieh & Natawidjaja, 2000)

B. MATERIALS AND METHODS

Study area of this research is southern segment of Sumatran Fault Zone in Lampung Province in three regencies: Tanggamus, West Lampung, and West Pesisir. Data used in this research are existing bench mark, earthquake history, Digital Elevation Model and land use. Existing bench mark is obtained from Alif et al. (2019) which is shown on Table 1 and Figure 2.

Table 1. Existing bench mark coordinates to monitor southern segment of Sumatran Fault (Alif et al., 2019)

Bench Mark Name	Longitude (o)	Latitude (o)
BM 2	104.67130	-5.51085
BM 3	104.35752	-5.61762
BM 4	104.11054	-5.43015
BM 5	103.94192	-5.16513
BM 6	104.49392	-4.99969
CTCN	104.72700	-5.91300
K601	103.96100	-5.14300
K602	104.03800	-5.07600
K603	104.08100	-5.03600
K604	104.03300	-4.93700
KRPN	104.81100	-5.59900
KTJW	104.34000	-5.60000
NRUI	103.93500	-5.18900
CKRI	103.93087	-5.19615

Earthquake history is obtained from USGS (2019) which is earthquake occurred on southern segment of Sumatran Fault Zone in last 100 years. and shown on Table 2, Digital Elevation Model and land use is obtained from Geospatial Agency of Indonesia which is measured in 2016.

Decent location is determined by overlaying land use and slope processed from Digital Elevation Model. Decent location for bench mark to be built is location with low slope (Floyd, 1980), dry land use (Gatto, 1987), the distance from river, and clear canopy obstacle (NPS-URI, 2019). The distance from river has been also used as support for dry land use since soil close to the river is unstable enough to be used as bench mark location. Clear canopy has been used as a factor since built bench mark which is used to monitor Sumatran Fault Zone uses GNSS technology using waves from satellites. These factors take effect on giving weight in GIS analysis. The land uses which have high weight are settlements, bushes, and vacant lands while the land uses which have high weight are forests, jungles, and farms.

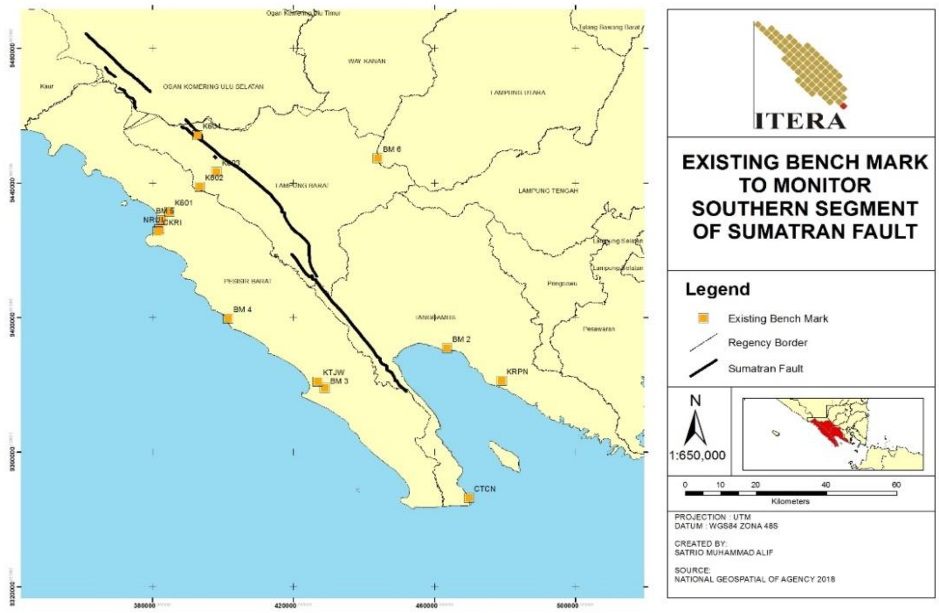

Figure 2. Existing bench mark to monitor southern segment of Sumatran Fault (Alif et al., 2019)

Table 2 Earthquake occurred on southern segment of Sumatran Fault Zone in last 100 years (USGS, 2019)

Latitude (°)	Longitude (°)	Depth	Magnitude	Time
-5.885	104.711	101.4 km	6.4	14-08-99 0:16
-4.967	104.302	23.1 km	6.9	15-02-94 17:07
-5.801	104.288	33.0 km	6.2	28-12-85 23:10
-5.226	104.596	20.0 km	7.6	24-06-33 21:54
-5.561	104.062	45.4 km	6	23-09-95 16:05
-5.763	104.191	24.5 km	6.5	27-12-85 5:38
-5.496	104.487	20.0 km	6.4	02-04-19 0:34

Representative location is determined by into taking account the distance to the Sumatran Fault Zone and earthquake history. The affected area is modeled by using function as follows (Beon, 2008).

$$v_{gsf} = \frac{V}{\pi} tan^{-1}(\frac{r}{D}) \qquad (1)$$

Where v_{gsf} is point displacement due to fault movement, V is fault slip rate, r is perpendicular distance between bench mark and fault, and D is fault locking depth. Fault parameter is used from Alif et al. (2016) which shown in Figure 3, with slip rate is 1.4 cm/yr and locking depth is 16 km. The distance to Sumatran Fault Zone is calculated by using buffer technique. The buffer technique is generally used to reclassify based on distance (Duggal, 2007).

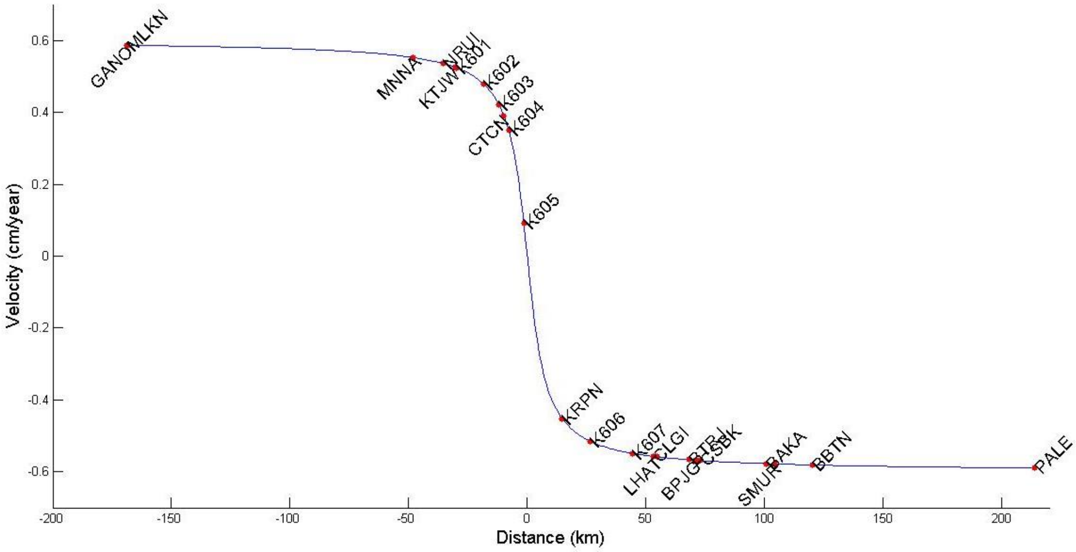

Figure 3. Sumatran Fault Zone slip model (Alif et al., 2016)

Decent location and representative location is analyzed by using GIS overlay technique to obtain optimal distribution of bench mark to monitor Sumatran Fault Zone. The result is then compared to existing bench marks and the last process is determining location which lacks bench marks.

C. RESULTS AND DISCUSSION

Decent location to build bench marks considering low slope, dry land use, far enough from river, and clear canopy is shown on Figure 4. Very decent locations in the study area are around 10.5 percent of the total area while 39.3 percent of total area is decent location. Most decent location are located on Tanggamus Regency since West Pesisir Regency and West Lampung Regency have wide area of forest which is bad for GNSS technology to monitor the fault. Moreover, West Lampung Regency and West Pesisir Regency have mountainous landscape so that the slope is not good enough for bench mark to be built.

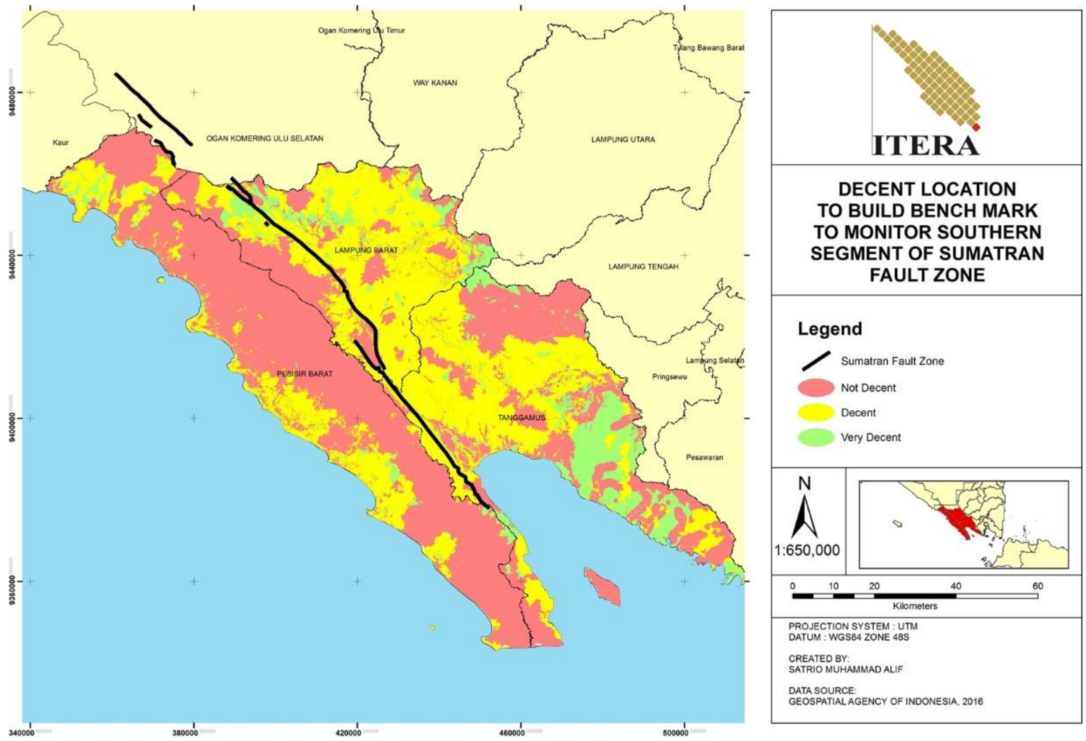

Figure 4. Decent Location to build Bench Mark to monitor Southern Sumatran Fault Zone

Representative location to build bench marks considering distance from Sumatran Fault Zone and earthquake history is shown on Figure 5. Very representative location in the study area is around 44.5 percent of the total area where the distance to Sumatran Fault Zone is closer than 15 km. The representative location is around 10.9 percent of total area where the distance to Sumatran Fault Zone is more than 15 km with records of past earthquake. 15 km threshold is obtained from Beon (2008) function for the southern segment of Sumatran Fault Zone. Location where bench mark built is not representative has distance to Sumatran Fault Zone more than 15 km and no earthquake history in last 100 years. That area is located on the northern part of West Pesisir Regency and southern part of Tanggamus Regency. Therefore, overlaying decent location and representative location generate Figure 6. Figure 6 shows decent and representative location considering all mentioned factors. The most decent and representative area is located in northern part of West Lampung Regency since its location is close to Sumatran Fault Zone and its landscape is less mountainous. The area is the capital city of West Lampung Regency, Liwa.

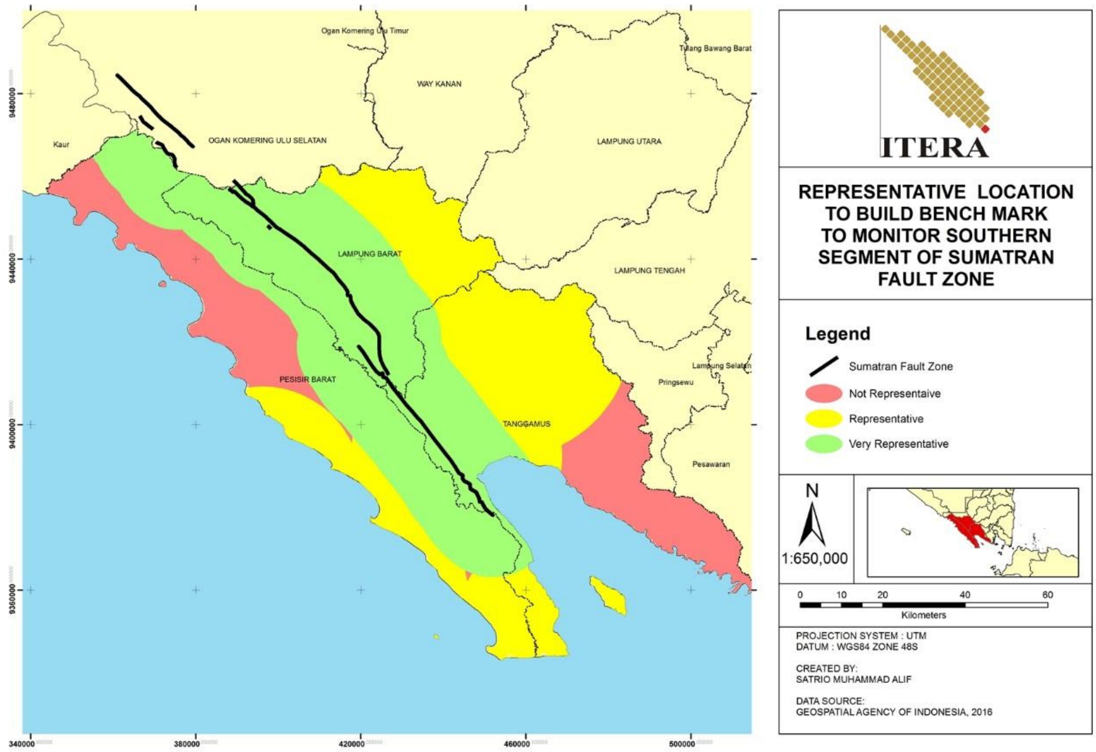

Figure 5. Representative Location to build Bench Mark to monitor Southern Segment of Sumatran Fault Zone

The result of decent and representative location are analyzed with existing bench mark. Existing bench mark from Alif et al. (2019) combined with bench mark location from Geospatial Agency of Indonesia is used to consider location lacking monitoring bench mark. They are shown on Figure 7 as orange rectangles. The other existing bench marks were built in 2019 and are shown as red rectangles. From those existing bench marks, the segment of no monitoring bench marks can be derived. It is shown as gray thick lines on Figure 7.

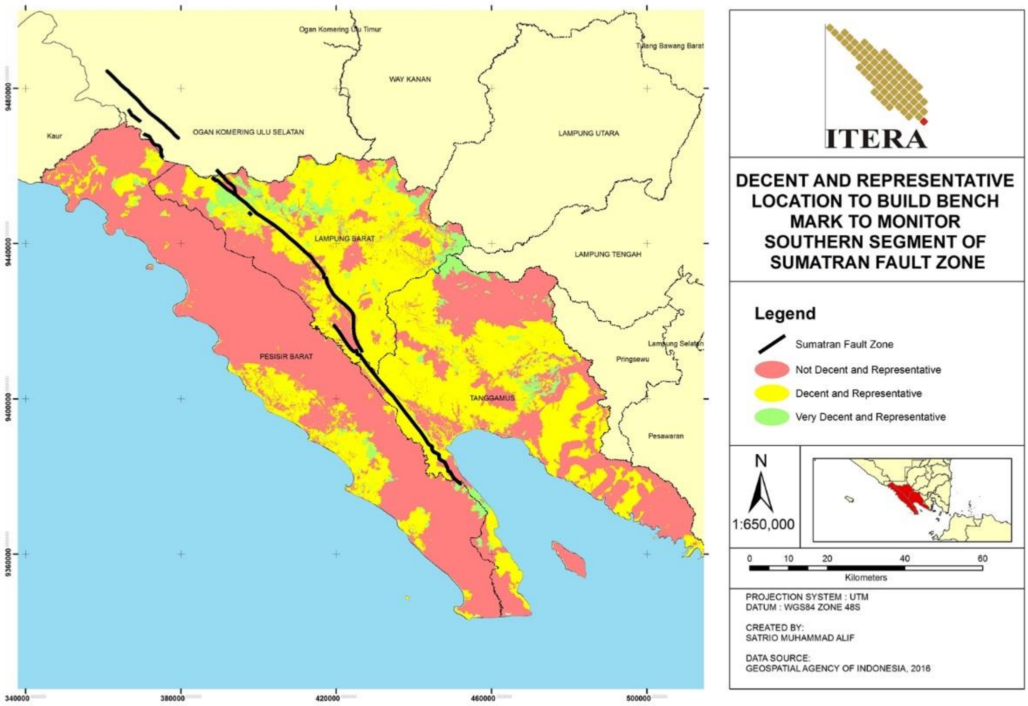

Figure 6. Decent and Representative Location to build Bench Mark to monitor Southern Segment of Sumatran Fault Zone

Sumatran Fault Zone is strike-slip fault (McCaffrey, 2009) so that optimal monitoring bench mark must be located for at least one on one side, at least one on top of the fault, and at least one on the other side. Since Sumatran Fault Zone stretches from north to south, three required location to monitor Sumatran Fault Zone are west side, on, and east side of the fault. Therefore, existing bench marks is also used in analyzing which segment that has less than three bench marks on three parts of the fault. The segments which have enough monitoring bench marks are shown as green thick lines on Figure 7.

There are total 15 planned bench marks location to make southern Segment of Sumatran Fault Zone monitoring bench mark more optimal based on the analysis with five bench marks planned to be built on west side of the fault, 3 bench marks on top of the fault, and 7 bench marks on east side of the fault. The planned bench mark which is shown as green rectangles on Figure 7 and listed on Table 3 consider:

- Segments which have no or few bench marks
- Decent and representative locations resulted from Geographic Information System analysis.

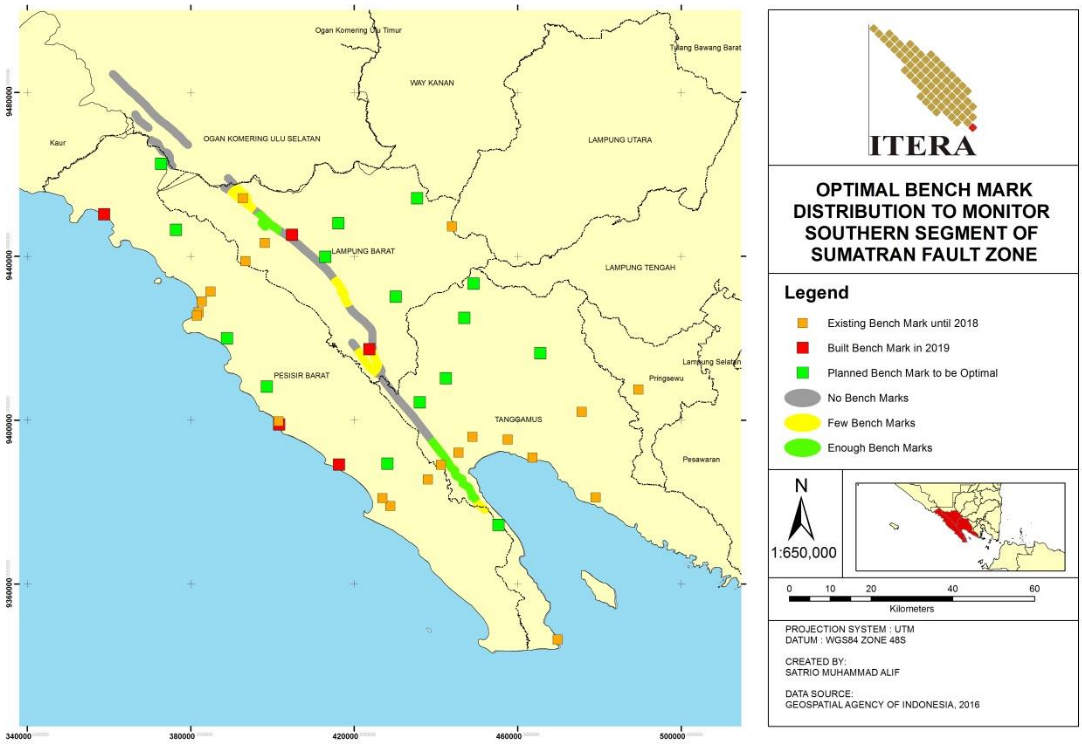

Figure 7. Optimal Bench Mark Distribution to monitor Southern Segment of Sumatran Fault Zone

Table 3 Planned Bench Mark Location to make southern Segment of Sumatran Fault Zone monitoring bench mark more optimal

No	Location	District	Regency
1	West	Lemong	West Pesisir
2	West	Pesisir Utara	West Pesisir
3	West	Pesisir Selatan	West Pesisir
4	West	Pesisir Selatan	West Pesisir
5	West	Bengkunat Belimbing	West Pesisir
6	On	Pematang Sawa	Tanggamus
7	On	Ulu Belu	Tanggamus
8	On	Belalau	West Lampung
9	East	Batu Ketulis	West Lampung
10	East	Pagar Dewa	West Lampung
11	East	Air Hitam	West Lampung
12	East	Ulu Belu	Tanggamus
13	East	Ulu Belu	Tanggamus
14	East	Ulu Belu	Tanggamus
15	East	Pulau Panggung	Tanggamus

D. CONCLUSIONS

Optimal monitoring bench mark distribution can be achieved by adding 15 new bench marks. The location of new bench marks is analyzed so that segments which lack monitoring bench marks can be monitored. It is located on three parts of the fault. It considers existing bench mark and location which is decent and representative, resulted from Geographic Information System analysis, to monitor Sumatran Fault Zone movement by considering on its position relative to Sumatran Fault Zone, earthquake history, Digital Elevation Model and land use. The process od monitoring bench mark on existing bench marks and planned bench marks using GNSS technology should be conducted at least once a year to describe fault parameter and behaviour more precisely so it can be used to update earthquake hazard map.

E. ACKNOWLEDGMENTS

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