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UPDATING OF SURAKARTA SEISMIC SITE CLASS MAP BASED ON STANDARD PENETRTION TEST

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ABSTRACT

Surakarta is one of the cities in Java island with a high population growth rate, triggering the increase in the construction, especially for high-rise buildings. The city is close to several earthquake sources, causing a high level of seismic hazard. One of the main parameters of earthquake resistant buildings design is the value of peak ground acceleration at surface level. It is obtained by multiplying the peak ground acceleration in the bedrock by a multiplier factor that depends on the site class conditions of the location. A previous study has been conducted in 2015 using 32 boreholes indicating that around 19.5% of Surakarta area is classified as *SC* (hard soil), and 80.5% of the rest is *SD* (medium soil). To increase the accuracy, another 31 additional boreholes data are adopted. The new result shows that Surakarta is divided into three different seismic site class. Around 4.80% the area is classified as *SC* (hard soil), 94.50% is *SD* (medium soil), and 0,70% is *SE* (soft soil). The southern part of Surakarta has a higher level of vulnerability to earthquakes, especially in the border area between Banjarsari, Laweyan, and Serengan subdistricts which have a *SE* (soft soil) seismic site class.

Keywords: Seismic site class map, updating.

ABSTRAK

Surakarta merupakan salah satu kota di Pulau Jawa dengan tingkat pertumbuhan penduduk dan sektor konstruksi yang tinggi. Kota ini cukup rentan terhadap gempa karena relatif dekat dengan sumber-sumber gempa. Salah satu parameter utama disain bangunan gedung tahan gempa adalah percepatan puncak di permukaan tanah. Percepatan ini diperoleh dari perkalian percepatan puncak di batuan dasar dengan suatu faktor pengali yang tergantung pada kondisi kelas situs suatu tempat. Studi sebelumnya yang dilakukan pada tahun 2015 menggunakan 32 lubang bor menunjukkan bahwa sekitar 19.5% area Surakarta digolongkan sebagai tanah SC (tanah keras), dan sisanya 80.5% merupakan lapisan tanah SD (tanah sedang). Untuk meningkatkan akurasi, 31 data bor baru telah ditambahkan. Hasilnya menunjukkan bahwa sekitar 4.8% merupakan tanah SC (tanah keras), 94.5% merupakan tanah SD (tanah sedang), dan 0.7% merupakan tanah SE (tanah lunak). Tanah SE ini terlatak di bagian selatan Surakarta yaitu di perbatasan Kec. Banjarari, Laweyan, dan Serengan, dan merupakan area dengan tingkat kerentanan terhadap gempa paling tinggi.

1. INTRODUCTION

Java island is one of the islands in Indonesia, which is very close to the earthquake source. The study conducted by Tim Revisi Peta Gempa 2010 indicated that there are 10 major faults in Java (Irsyam, 2010). Further research was carried out by PusGeN to update the 2010 Indonesia hazard map. It was found that there are 16 new major sources of earthquake (faults) in Java (PusGeN, 2017). In addition to the source of the fault, Java is also relatively close to the subduction zone located in the south of Java island. The number of earthquake sources which are a threat to Java island makes it as a very high risk of seismicity.

The high risk of seismicity of Java prompts seismic studies for big cities in Java such as Jakarta (Aldiamar et al., 2013, and Asrurifak et al., 2013), Semarang (Jananda et al., 2014), etc. Surakarta is one of the main cities in this island with a high population growth rate of 1.23% per year which is much higher than the population growth of Central Java Province in 2018, which is only 0.68% per year (Disdukcapil Kota Surakarta, 2018). That increasing development in Surakarta especially in building construction needs the intensive study of seismic hazard of this city. Design of earthquake-resistant building construction in Indonesia currently refers to SNI 1726-2012 standard, which is referring to ASCE 07-2010 on design for minimum load for buildings and non-buildings. One of the main parameters of earthquake resistant buildings design is the value of peak ground acceleration at surface level. It is obtained by multiplying the peak ground acceleration in the bedrock by a multiplier factor that depends on the site class conditions of the location. The site condition is generally determined through Standard Penetration Test value (N_{SPT}) from the bore hole, shear wave velocity (*Vs*), and undrained shear strength (*Su*) of the soil layer at a thickness of 30 m from the surface.

Soil characterization for seismic analyses has been conducted in some cities in Java, such as Jakarta by Asrurifak et (2013), and Aldimar et al (2013), Semarang by Jananda et al (2014), Surakarta by Purwana, et al. (2005), Sa'adah et al. (2015), Warman et al. (2016), and Kurniawan (2019). The seismic site classification map has been developed by Warman (2015) using 32 boreholes. Compared to the size of Surakarta, the amount of these boreholes are too small and most of the data were flocked in the central. This paper presents the updating of the seismic site class map using SPT from another 32 additional boreholes data.

2. SPT AND SHEAR WAVE VELOCITY

Standard Penetration Test (SPT)

Standard penetration test is a test carried out to find out the dynamic resistance of the soil through obtaining the number of blows needed to insert a 300 mm standard vertical tube. The SPT testing is generally accompanied by the borehole test as which is the process refers to SNI 4153-2008 (BSN, 2008). The standard split spoon sampler is penetrated using a hammer load of 63.5 kg which is dropped repeatedly with a height of falling of 0.76 m. The testing process is divided into three stages with a thickness of 150 mm for each stage. The first stage (N_1) is recorded as a stand, while the second stage (N_2) and the third stage (N_3) are summed to obtain a standard penetration value (N_{SPT}) expressed in blows/0.3 m (BSN, 2008). The scheme for each step of the N_{SPT} test can be seen in Figure 1.

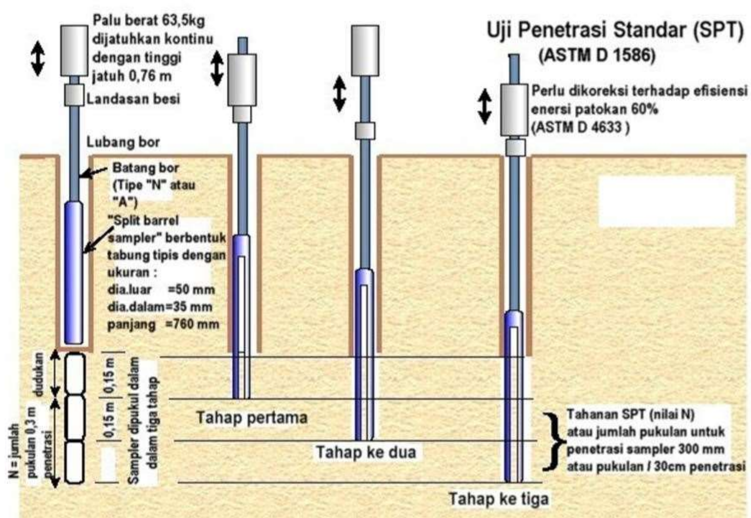

Figure 1. Standard penetration testing stage (BSN, 2008)

The average values of $\bar{N}$, is calculated using the following equation:

$$\bar{N} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} N_i} \qquad (1)$$

where N_i is standard penetration resistance in the i-th layer (blows/0.3 m), and d_i is thickness of soil layer i (m)

As the average values of $\bar{N}$ is obtained, the classification of site class is determined using the criteria given by SNI 1726-2012 as shown in Table 1.

Table 1. Classification of seismic site classes based on SNI 1726-2012

Site Class	$\bar{V}_s$ (m/sec)	$\bar{N}$ or $\bar{N}_{ch}$	$\bar{Su}$ (kPa)
SA (hard rock)	>1500	N/A	N/A
SB (rock)	750 to 1500	N/A	N/A
SC (hard soil, very dense, and soft rock)	350 to 750	>50	≥100

SD (medium soil)	175 to 350	15 to 50	50 to 100
SE (soft soil)	<175	<15	<50
	Or each soil profile containing more than 3 m of soil with the following characteristics: 1. Plasticity index, *PI* > 20, 2. Water content, $w \geq 40$ %, 3. Non-flowing shear strength, $\bar{S}u$ < 25 kPa		
SF (special soil requiring specific geotechnical investigations and site-specific response analysis)	Each soil profile has one or more of the following characteristics: - Vulnerable and potentially fail or collapse due to earthquake loads such as liquefaction easily, clay is very sensitive, the soil is weakly cemented - Very organic clay and/or peat (thickness H > 3 m) - Clays with very high plasticity (thickness H > 7.5 m, with plasticity index PI > 75%) - Soft/half firm clay layer with a thickness H > 35 m and Su <50 kPa.		

Note: N/A = cannot be used

Shear Wave Velocity (V_S)

Shear wave velocity (V_S) is the main parameter used in determining the earthquake site class for a particular area. The value of V_S is also used as an initial reference to the problem of strains in seismic loading. Generally, V_S values can be obtained through the downhole test process, which is a geophysical test using direct seismic waves in the form of P-waves and S-waves to determine the character of subsurface layers (Kramer, 1996). In the case of the test is unavailable, the V_S values can be obtained through empirical correlation from SPT data as shown in Table 2

Table 2. Empirical correlations between *NSPT* and V_S

Reference	Correlations V_S (m/s)	Soil Sample
(Ohta & Goto, 1978)	$V_s = 85{,}3(N_{SPT})^{0{,}341}$	Clay and Sand (Japan)
(Imai & Tenouchi, 1982)	$V_s = 96{,}9(N_{SPT})^{0{,}314}$	Clay and Sand (Japan)

3. METODHOLOGY

The aim of this study is to develop the seismic site class map using N_{SPT} data. A previous study has been conducted using 32 boreholes, whereas in this study another 31 additional boreholes are utilized. All data are taken from a database in Soil Mechanics Laboratory, UNS. The process of data sorting was carried out to obtain required criteria for seismic analyses, such as the minimum 30 m of boreholes depth, and specified coordinate of boreholes. Due to the data of V_s is unavailable in the database, the V_S value for each layer and each borehole are correlated from N_{SPT} using the equation in the Table 2. Seismic site class is then determined using Table 1 for each borehole. The last step is plotting the result into the map.

4. RESULT AND DISCUSSION

Figure 2 shows the distribution of boreholes adapted from a previous study (Warman et al., 2015). Another 31 additional boreholes data (year 2015-2019) are plotted on the map as shown in Figure 3. Even though most of the new additional data are flocked in the central (business district), some blank spots in the north and south has been filled with the new ones.

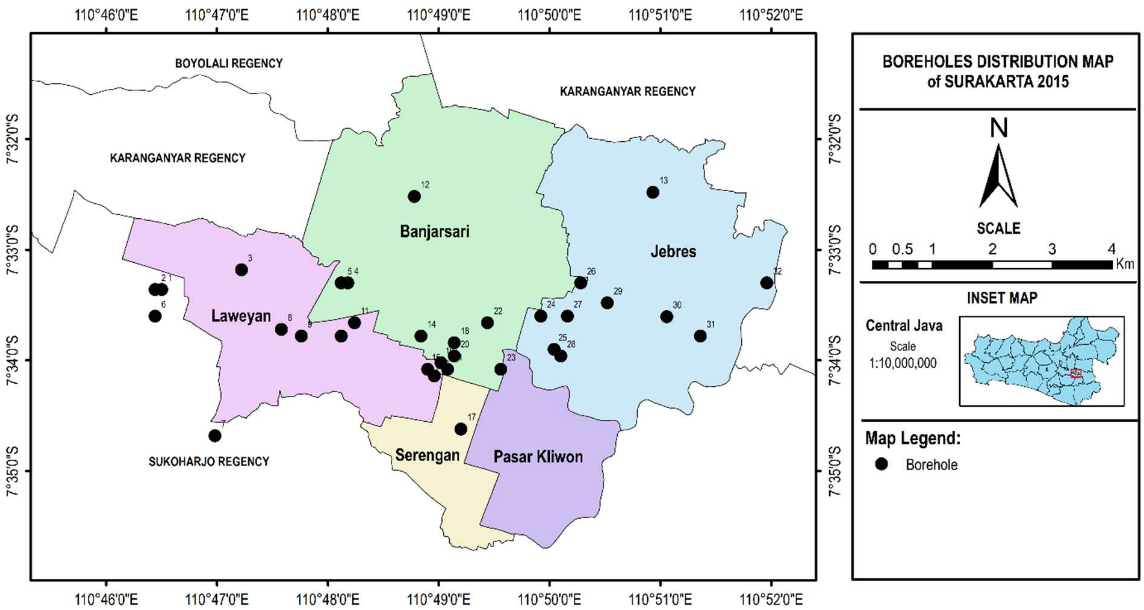

Figure 2. Previous boreholes distribution map of Surakarta 2015 (modified from Warman, et al. 2015)

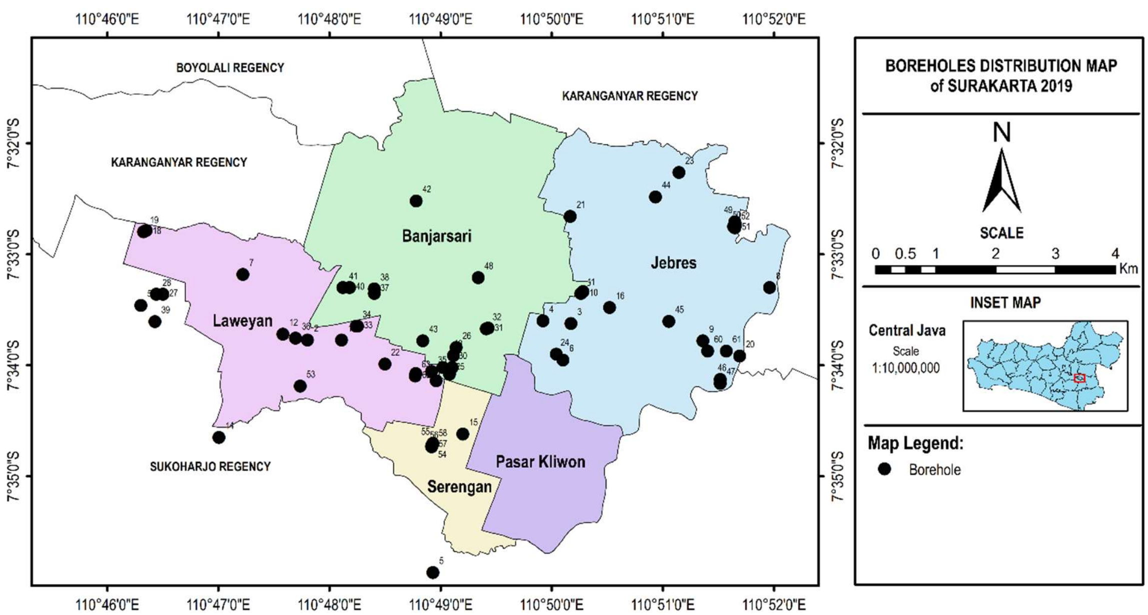

Figure 3. Recent boreholes distribution map of Surakarta 2019

The values of $\bar{N}$ and $\bar{V}_S$ for each borehole point are calculated based on equation 1 and equation in the Table 2. The results are then plotted on the map using QGIS 3.4.8 as shown the Figure 4 and 5 respectively. Figure 4 shows the distribution of hard soil with the high $\bar{N}$ values (> 50) are found in Jebres subdistrict, the eastern part of Surakarta. The soft soil layer with the low of $\bar{N}$ values (<15) are found along the border between Serengan subdistrict and Laweyan subdistrict. Figure 5 shows that the highest $\bar{V}_S$ value of Surakarta with a range of 350 m/s to 380 m/s is found in the northern part of Surakarta, especially in the northern side of Jebres subdistrict and the northern side of Banjarsari subdistrict which is the border with Karanganyar district. It is seen from both figures that there is some difference of the seismic site classes area between direct N_{SPT} and correlated *Vs*. However, it is indicated that Surakarta has 3 areas with different seismic site class, i.e. *SC*, *SD*, and *SE*.

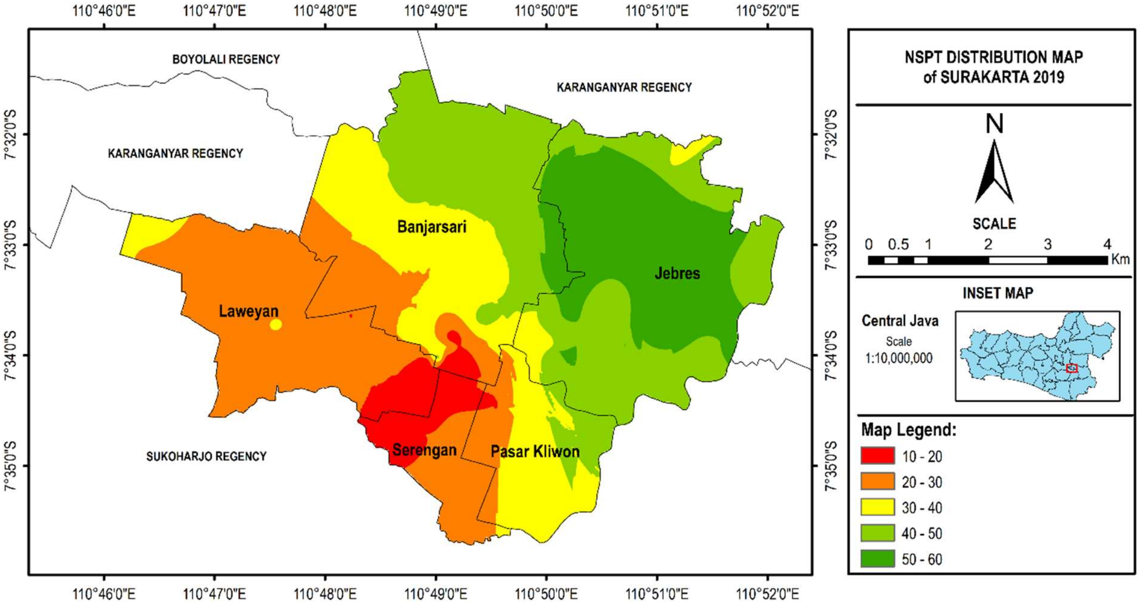

Figure 4. $\overline{N}$ distribution map of Surakarta2019

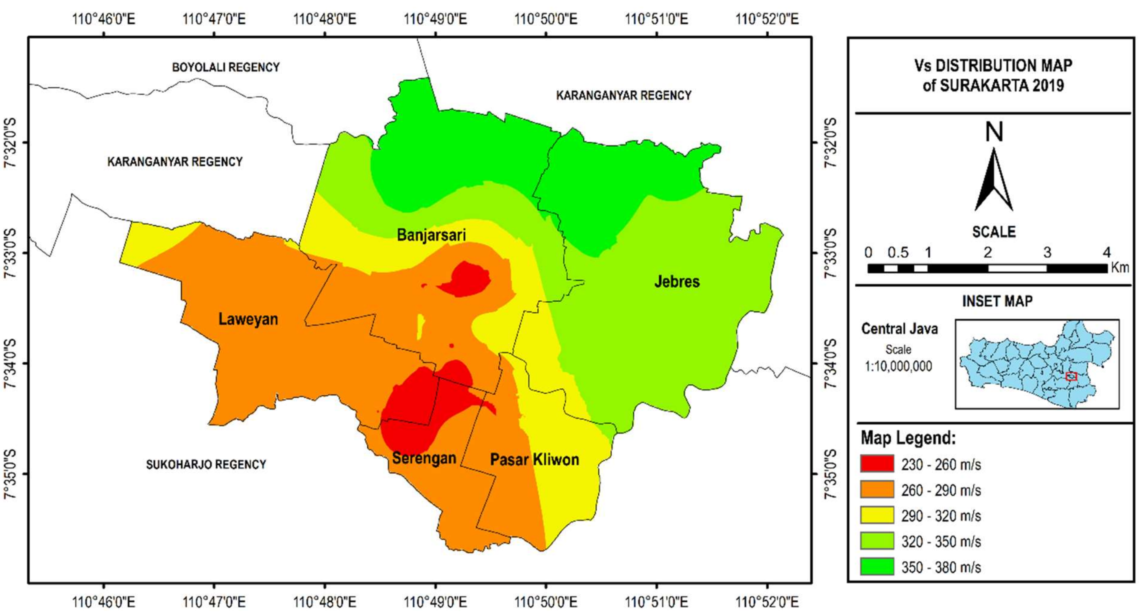

Figure 5. $\overline{V}_S$ distribution map of Surakarta 2019

Figure 6 shows the map of Surakarta seismic site class from a previous study (Warman, et al., 2015). Based on their study, Surakarta was divided into 2 seismic classes, i.e *SC* which is found in most of Jebres subdistrict, and *SD* which covers almost 80% of Surakarta. However, with the additional data of boreholes, there are some areas of Surakarta which are classified as soft soil (*SE*) as shown in Figure 7. It is shown that that *SD* site class (medium soil) is dominating Surakarta with the percentage of 94.50% (the northern side of the Jebres subdistrict area and a small portion of the border between Banjarsari subdistrict, Laweyan subdistrict, and Serengan subdistrict). Some area of the north side of Jebres subdistrict has an *SC* (hard soil) seismic site class with a percentage of the area of 4.80%, while the border between Banjarsari, Laweyan, and Serengan subdistricts has a *SE* (soft soil) seismic site class with a percentage of the area of 0.70%. It can be concluded that southern part of Surakarta has a higher level of vulnerability to earthquakes, especially in the border area between Banjarsari, Laweyan, and Serengan subdistricts which have a *SE* (soft soil) earthquake site class.

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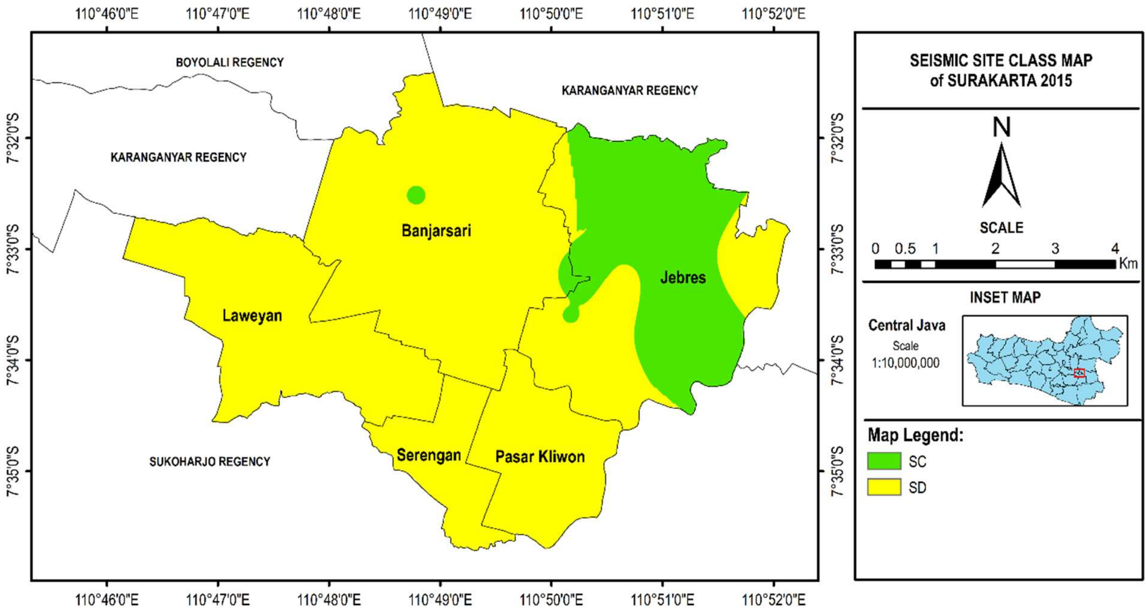

Figure 6. Surakarta seismic site class map (modified from Warman, et al. 2015)

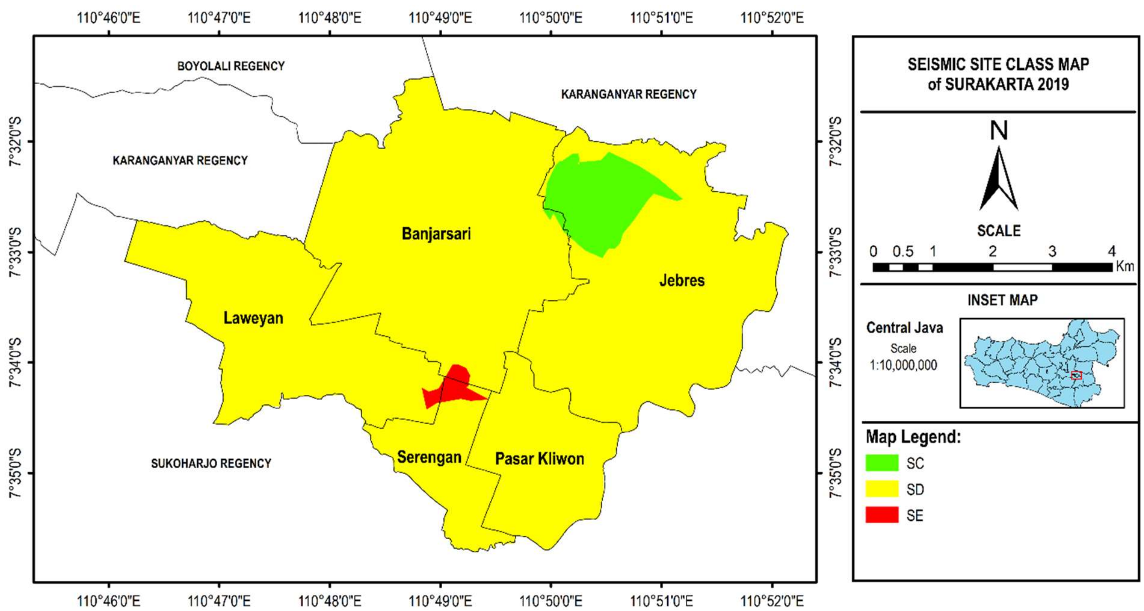

Figure 7. Updated Surakarta seismic site class map, 2019

5. CONCLUSION

Previous studied indicated that Surakarta was divided into two seismic site classes; 19.5% of *SC* (hard soil) and 80.5% of *SD* (medium soil). A recent study indicates that there are some areas in Surakarta with soft soil layer (*SE*). Surakarta is divided into three site classes; 4.80% *SC* (hard soil), 94.50% *SD* (medium soil), and 0.7% *SE* (soft soil). The southern part of Surakarta has a higher level of vulnerability to earthquakes, especially in the border area between Banjarsari, Laweyan, and Serengan subdistricts which have a *SE* (soft soil) seismic site class.

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