POTENTIAL EARTHQUAKE HAZARD MICROZONATIONS OF THE JAKARTA CITY

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ABSTRACT

Jakarta, the capital city of the Republic of Indonesia, is a potential earthquake hazard area. The city lies on the very thick (>294 M) Quaternary sediments. Destructive earthquakes influenced this city were generated from the subduction and active faults with the Maximum intensity of VI - VII MMI. A microtremor investigation to the shallow soft Quaternary sediment results in the dominant period of 0.05 – 0.85. The classification of this dominant period is the basic classification of rock and soil site and as an important factor of the earthquake hazard susceptibility in a region.

Dynamic site responses, which are presented by the multiply of amplification factors and natural dominant periods of this city are divided into five microzonations, these are :

- Very high susceptibility microzonation (index's > 10), covers the area of 7.58 km^2 or 1.15 % of the total region of Jakarta occupies a small area of North Jakarta.
- High susceptibility microzonation (index's 7.5 – 10), covers the area of 18 km^2 or 2.73% of the total region of Jakarta consisting of small area of North Jakarta city (Kapuk resort), Central Jakarta including the area of Setiabudi.
- Moderately susceptibility microzonation (index's 5-7.5), covers the areas of 86.59 km^2 or 13.11 % of the total region of Jakarta, including the North, Central, East and South Jakarta and the small area of West Jakarta .
- Low susceptibility microzonation (index's 2.5 - 5), covers the area of 324 km^2 or 49.18 % of the total region of Jakarta, and it occupies the western part of North Jakarta, eastern part of west Jakarta and the central part of central Jakarta.
- Very low susceptibility microzonation (index's < 2.5), covers the area of 223.47 km^2 or 33.83 % of th total region of Jakarta , the area includes a small part of the central Jakarta and the eastern part of west Jakarta.

These earthquake hazard microzonations are one of important data base for regional planning in order to mitigate earthquake hazards and risks of the Jakarta city.

Keywords: Earthquake hazard microzonation and regional planning

SARI

Jakarta, ibu kota Republik Indonesia, terletak di atas sedimen Kuarter tebal (> 294 m) dan merupakan daerah potensi bencana guncangan gempabumi. Gempabumi merusak yang mempengaruhi daerah ini berasal dari aktifitas tunjaman dan sesar aktif dengan maksimum intensitas VI – VII MMI. Penelitian mikrotremor di atas sedimen Kuarter tersebut mempunyai periode dominan 0,05-0,85 detik. Klasifikasi nilai perioda dominan ini merupakan dasar klasifikasi batuan dan tanah setempat dan merupakan faktor penting kerentanan bencana gempabumi di suatu wilayah.

Respons dinamika batuan dan tanah, yang diperlihatkan oleh perkalian faktor amplifikasi dan perioda dominan di kota ini, dapat dibagi atas 5 mikrozonasi:

- *Mikrozonasi Kerentanan Sangat Tinggi (indeks kerentanan > 10) meliputi 7,58 km2 atau 1,15 % total wilayah Jakarta, yakni sebagian kecil Jakarta Utara*
- *Mikrozonasi Kerentanan Tinggi (indeks kerentanan 7,5 - 10) meliputi 18 km^2 atau 2,73% total wilayah Jakarta yakni sebagian kecil Jakarta Utara (Wilayah Kapuk, Jakarta Pusat dan termasuk daerah Setia Budi)*

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- *Mikrozonasi Kerentanan Sedang (indeks kerentanan 5 - 7,5) meliputi 86,59 km^2 atau 13,1% total wilayah Jakarta, yakni Jakarta Utara, Jakarta Pusat, Jakarta Timur dan Jakarta Selatan, serta sebagian kecil wilayah Jakarta Barat.*
- *Mikrozonasi Kerentanan Rendah (indeks kerentanan 2,5 - 5) meliputi 324 km^2 atau 49,18 % total wilayah Jakarta, meliputi bagian barat Jakarta Utara, bagian timur Jakarta Barat, dan bagian tengah Jakarta Pusat.*
- *Mikrozonasi Kerentanan Sangat Rendah (indeks kerentanan < 2,5) meliputi 223,47 km^2 atau 33,83% total wilayah Jakarta. Daerah ini meliputi sebagian kecil Jakarta Pusat dan bagian timur Jakarta Barat.*

Mikrozonasi bencana gempabumi ini merupakan data dasar penting untuk perencanaan regional sebagai upaya memitigasi bencana dan risiko gempabumi di kota Jakarta.

Kata kunci: Mikrozonasi bencana gempabumi dan perencanaan regional

INTRODUCTION

Jakarta, the capital of the Republic of Indonesia, has a population more than 10 million people and a lot of infrastructures. This city lies on thick, soft Quaternary sediments. Historically, several destructive earthquakes that were generated from subduction and active fault activities influenced this city (Maximum intensity of VI - VII MMI).

Based on these conditions, Jakarta as the central of governmental activities has to be protected from earthquake hazards and risks. This paper presents dynamic responses of rock and soil to the natural ground noise based on a microtremor analysis. Microtremor data used in this paper based on the result of joint research between the Centre for Geological Survey and the Mining Department of Special Capital City of Jakarta (2007). These microzonations of earthquake hazards are one of the important basic data for regional planning in order to mitigate earthquake hazards and risks in this area.

METHODOLOGY

Methodology applied on this research consists of two importants parts:

- Research, evaluation and analysis of secondary data consisting of geology, geophysics, land use and administrative data. The result will explain the potential hazard and risk conditions of this area.
- Research, evaluation and analysis of primary data containing geological and geophysical data. The geological data is geomorphology, stratigraphy and lithology (physical characteristics of rock and soil) of Quaternary deposits, active faults and the geophysical data including seismicity and microtremor analysis.

Geology of Jakarta

The geology of Jakarta and its surrounding areas consists of three main geological aspects including geomorphology, stratigraphy and lithology, as well as structure geology. The Quaternary geology map and the cross sections of Jakarta (Puslitbang Geologi, 1995) are shown in Figures 1, 2, 3, 4 and 5.

Geomorphology

The geomorphology analysis of Jakarta area results in five units including Denudation hills, Eroded river valleys, Parallel hills of beach sand, Marsk basin and Coastal plain. These geomorphological units are sometimes difficult to find in the field, due to the cultivated conditions, especially in Central Jakarta.

Stratigraphy and lithology

Jakarta city lies on the Quaternary sediment which consists of fluvial sediments of Gede and Pangrango volcanoes, river channel and river flood sediments, near shore sediments including beach ridge and shallow marine sediments. The thickness of this Quaternary sediment is > 294 meters. This sediment overlies the Tertiary (Miocene – Pliocene) sediments consisting of the intercalation of clay, shale, sandstone, marl, limestone, conglomerate and tuff (Puslitbang Geologi, 1995).

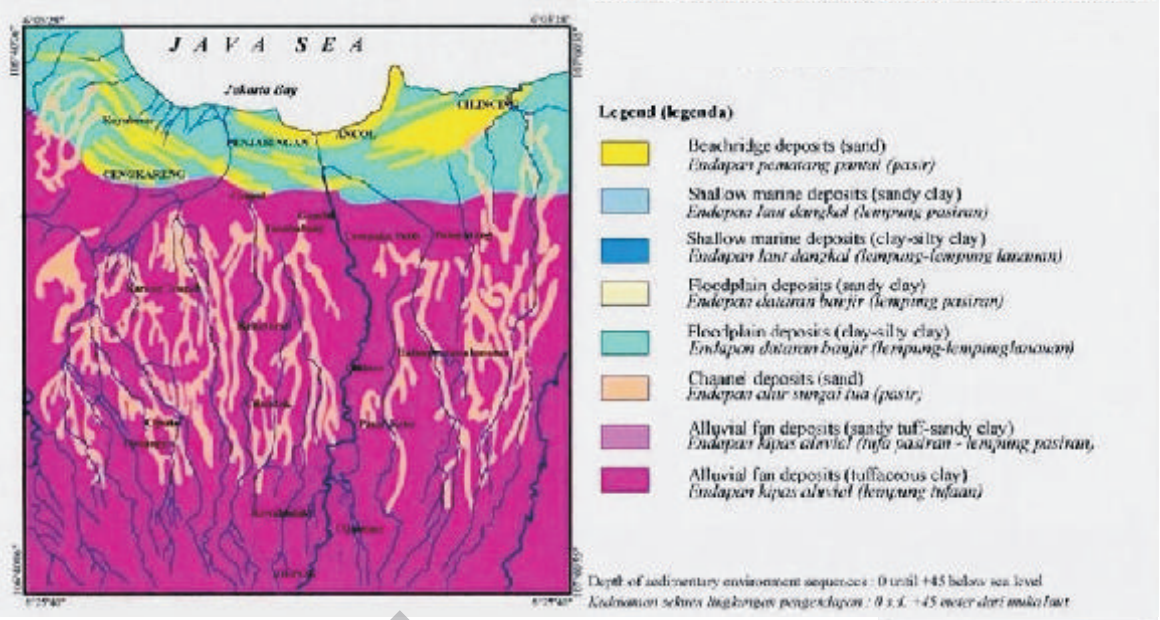

Figure 1. Quaternary geological map of Jakarta (Puslitbang Geologi, 1995).

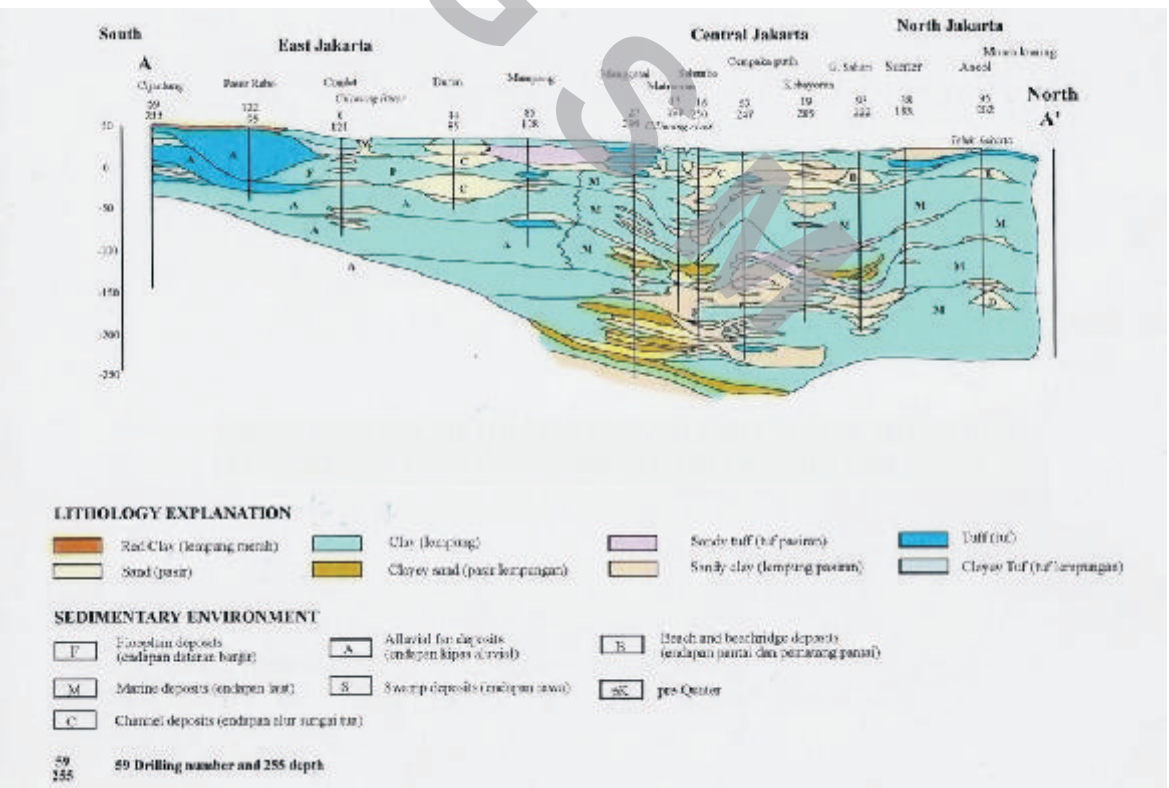

Figure 2. Cross section (south-north) Quaternary sediment of Jakarta (Puslitbang Geologi, 1995).

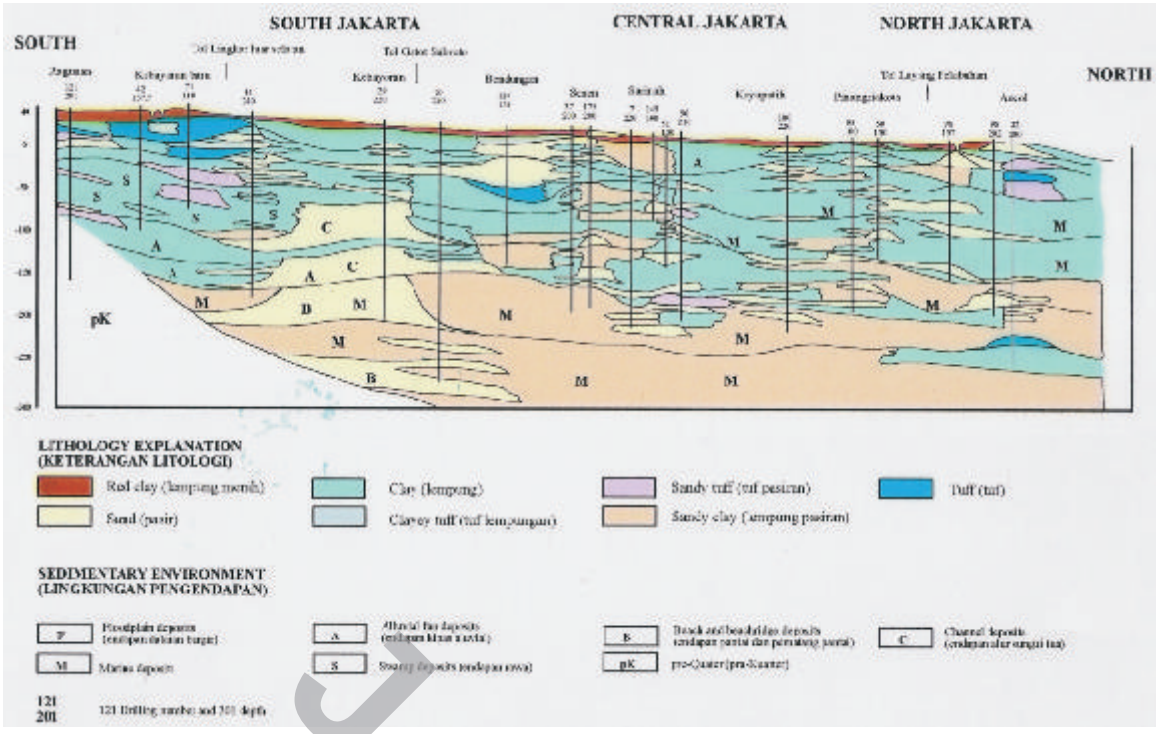

Figure 3. Cross section (south-north) Quaternary sediment of Jakarta (Puslitbang Geologi, 1995).

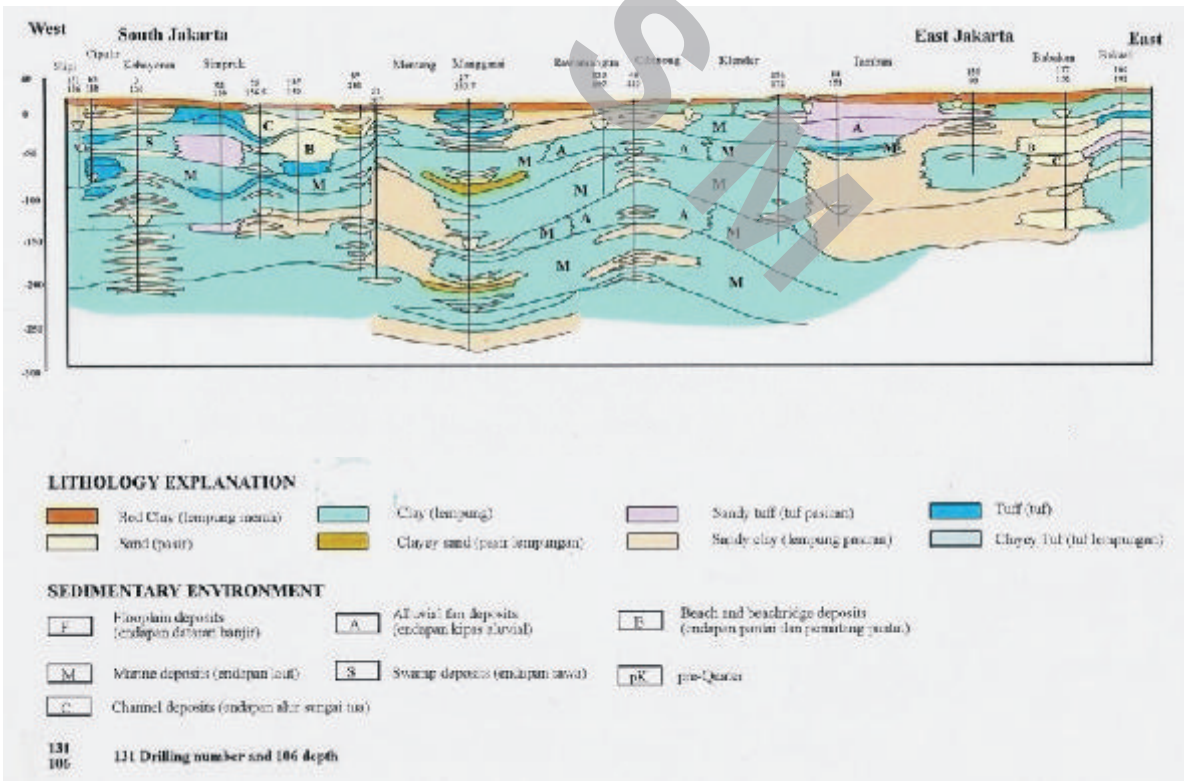

Figure 4. Cross section (west-east) Quaternary sediment of Jakarta (Puslitbang Geologi, 1995).

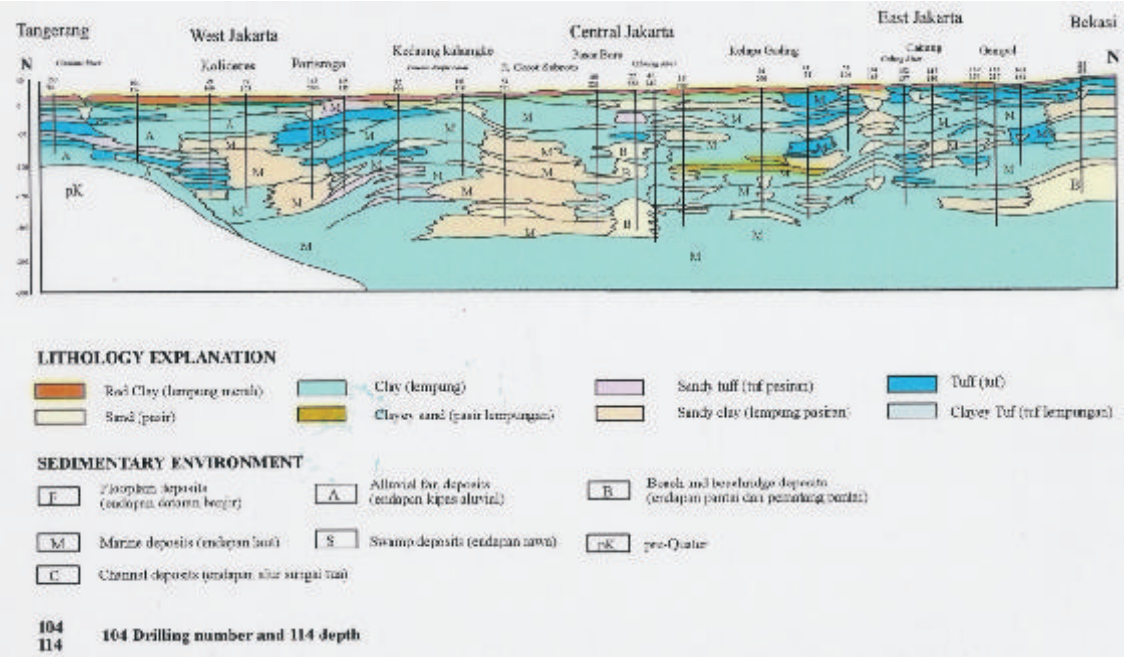

Figure 5. Cross section (Tangerang-Bekasi) Quaternary sediment of Jakarta (Puslitbang Geologi, 1995).

Structure Geology

Based on the topographic and landsat images, the structure geology of this area consists of lineaments, indicating faults and paleogeomorphologic features. Several southwest – northeast lineaments of these faults are the Cikeas , Cangkudu – Tangerang and Serpong – Dukuh faults. The other faults are northwest – southeast fault of the Ciliwung , Cisadane and Parung - Ciparay, which are cut by the east – west faults of the Jasinga – Cijantung – Tambun. These surface fault lineament patterns are also shown by the paleo- morphology of the basement which is expressed by the distributions of dominant periods (Figure 11).

Seismicity

The seismicity of Jakarta and surrounding areas can be classified into two seismic source zones, *i.e.*, the seismic source zone of the Indo-Australia Oceanic Benioff Wadati Plate and the seismic source zone of the active fault of West Java and surrounding areas. The earthquake characteristics of the Benioff Wadati mainly show the thrust fault earthquake focal mechanism. However, it is different with active fault earthquakes which generally show the strike slip and normal fault focal mechanisms. Based on the magnitude and the focal depths, the earthquake of Benioff Wadati can be divided in five zones, the are:

- Zone I, distributed in the off shore of southern West Java, the magnitudes are 4-6.5 Mb and the depths are 0 – 60 Km.
- Zone II, distributed along the southern coastal line of West Java, north of earthquake zone I, and has the magnitudes of 4-5 Mb and the depths are 60 – 100 Km
- Zone III, distributed in the north of earthquake zone II, along the volcanic arc until off shore of western Java, and the magnitudes are 5 – 7 Mb and the depth of 100 - 200 Km
- Seismic gap located in the northern of Zone III, the depth varies from 180 to 200 Km
- Individual zone, situated in the northern of seismic gap and magnitudes are > 6 Mb at the depths of 250-300 Km

Based on the earthquake history, the destructive earthquakes in this area are the Jakarta earthquake (1834), Bogor earthquake (1699), Pelabuhanratu earthquake (1900), Citarik earthquake (1973), Gandasoli earthquake (1982) and the Cibadak earthquakes (2000 and 2004). The distribution of the earthquake epicentre is shown in Figure 6, and these earthquakes influenced Jakarta and surrounding areas with having maximum intensity of VI to VII MMI.

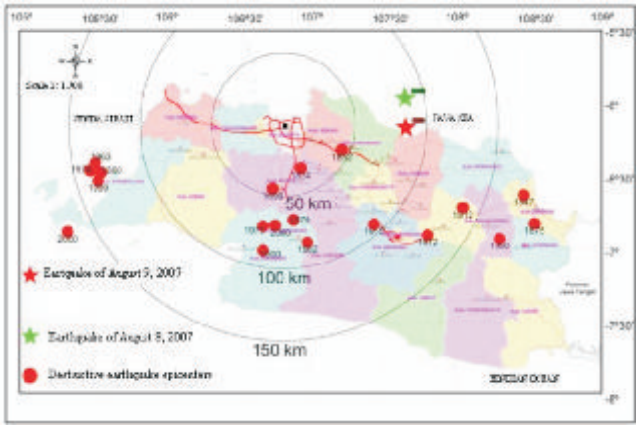

Figure 6. Destructive earthquake epicenter and the distance in km (circle) to Jakarta

Earthquake Probability

A probabilistic seismic hazard analysis (PSHA) of rocks, hard soil and soft soil of West Java has been calculated using the computer programme for seismic hazard estimation SEISRISK III (Bender *et al*., 1987) and attenuation formula of Fukushima and Tanaka (1990):

$$\text{Log}_{10} A = 0{,}41\ M - \text{Log}_{10}(R + 0{,}032 \times 10^{0{,}41M}) - 0{,}0034\ R + 1{,}30$$

A = pick acceleration (cm/det^2)
R = shortest of distance of seismic source zone
M = magnitude surface (Ms)

The input data of this analysis consists of the data of West Java seismicity, seismic source zones, focal mechanism, correction factor of Guttenberg-Richter, a and b values. The results of probabilistic seismic hazard analysis period of 100 years for hard rock and soft soil of West Java and South Sumatera are shown in Figures 7 and 8 respectively. The probabilistic seismic hazard analyses in various lithology in period of 50, 100, 200 and 250 years are shown in Figure 9.

Geodynamics of the shallow Quaternary sediment of Jakarta

Geodynamics of shallow Quaternary soft sediment of Jakarta defined by microtremor investigations and the distribution of measurements is shown in Figure 10. To determine the dominant period of microtremor analysis, the Nakamura's formula (1989) was used :

$$r(f) = \frac{\sqrt{H_{EW}(f) X H_{NS}(f)}}{V_{UD}(f)}$$

Where $r(f)$: spectrum ratio / amplification factor as the function of frequency

$H_{EW}(f)$: east-west horizontal spectral component
$H_{NS}(f)$: north-south spectral component
$V_{UD}(f)$: vertical spectral component

The spectral analysis H/V used the HV max software. Based on this analysis, the dominant period of rocks and soils in Jakarta can be determined, that is between 0.05 and 0.85 seconds and can be divided into three main regions as shown in Figure 11:

- Region I (dominant period of < 0.2 second) consists of the area of South and East Jakarta and western part of West Jakarta.
- Region II (dominant period of 0.2 – 0.4 second) covers the area of Central Jakarta and north of western part Jakarta.
- Region III (dominant period > 0.4 second) occupies the eastern and western part of North Jakarta.

The distribution of predominant periods is consistent with the character and variation of sediments in Jakarta. The dominant period of < 0.2 second is belongs to the hard rock and assumed to be the basement of Jakarta. This basement is overlain by hard the sediment which has dominant period of 0.2 – 0.4 second, and the soft sediment has dominant period of > o.4 second. The paleo morphology of this area shown by the distribution of basement is controlled by Ciliwung River Strike Slip Fault as one of a main fault which has a southwest - northeast direction. The secondary normal fault of this system shows the northwest-southeast direction. This tectonic system is controlled the distribution of the Quaternary sedimentary basin, which is evidenced by the distribution of soft sediment in this area.

The dynamic character of soft the sediment in the Jakarta basin is expressed by the basic value of earthquake ground shaking susceptibility index, which is calculated by the multiply of the amplification factor and natural dominant period of rock and soil shown by equation of Nakamura's (2000) :

$$K = A^2/f$$

where K : indexs of susceptibility
A : amplification factor
f : natural dominant frequency of soil (Hz)

The ground shaking susceptibility index of Jakarta can be divided into five microzonations as shown in Table 1 and Figure 12.

– Very high susceptibility microzonation (index of > 10) This zone covers the area of 7.58 km^2 or 1.15% total region of Jakarta and including a small part of north Jakarta. The land of this region is used for residency, river and marine facilities (private small harbour).

– High susceptibility microzonation (index of 7.5 – 10).This zone covers the area of 18 km^2 or 2.73% of the total region of Jakarta city including a small part of North Jakarta (Kapuk resort). The land of Nort Jakarta is used for residency, river and marine facilities. The Central Jakarta which covers the area of Setiabudi has the land use as residency, business and industrial areas. East Jakarta has the land use as park, industrial and upstream development and their facilities.

– Moderately susceptibility microzonation (index of 5-7.5). This zone covers the area of 86.59 Km^2 or 13.11 % of the total region of Jakarta city and is distributed in north, central, east, south and a small area of West Jakarta. The land of these regions is used for residency, industrial, government offices and upstream development and their facilities.

– Low susceptibility microzonation (index of 2.5 - 5). This zone covers the area of 324 Km^2 or 49.18% of the total region of Jakarta, including the western part of North Jakarta, eastern part of West Jakarta and central part of Central Jakarta. The land is used for region consisting of residency, industries, government offices, parks, canals and all of their facilities.

– Very low susceptibility microzonation (index of < 2.5). This zone covers the area of 223.47 Km^2 or 33.83 % of the total region of Jakarta city, where the areas includes part of Central Jakarta and eastern part of West Jakarta. The land is used for residency, industries, government offices, irrigation, park and all of their facilities.

Table 1. Ground shaking Susceptibility Area of Jakarta City

Areas	Wide area (Km^2) based of land susceptibility				
	Very high	High	Moderately	Low	Very low
North Jakarta	7.58	9.9519	25.195	65.75	13.365
West Jakarta	0	0.02657	4.7	57.81	63.17
South Jakarta	0	0.0419	10.1328	73.04	79.132
East Jakarta		5.555	42.834	99.034	47.7645
CentralJakarta	0	0.7504	3.697	25.24	20.04
DKI Jakarta	7.58	16.0051	86.5658	324.334	223.4715
Wide area of DKI Jakarta					660.5

DISCUSSION

Potential earthquake hazards in Jakarta are basically expressed by the maximum peak ground acceleration of probabilistic seismic hazard analysis (PSHA). In order to calculate deterministic seismic hazard analysis (DSHA) in its microzonation of Jakarta city, important parameters have already been known, such as the classification of predominant periods as the basic data to determine correcting factors of rock and soil and regional coefficient zone based on the maximum intensity and the existing of seismic source zone (Pusat Penelitian dan Pengembangan Sumberdaya Air, 2004). The Jakarta city is located at the area which has the maximum peak ground acceleration 0.20 gal (100 years), coefficient zone (z) of 0.9 – 1.20, and the predominant period of >0.4 second for region III and is classified as the diluvium and has the correction factor 1. Therefore, the maximum deterministic acceleration of this city in the region III is 0.24 gal.

CONCLUSIONS

- Jakarta, which is one of earthquake hazard prone area (maximum intensity of VI - VII MMI), lies on the very thick (>294 m) Quaternary soft sediment and has the dominant period of 0.05 – 0.85 second, that is divided into three main regions, Region I (dominant period of < 0.2 second); Region II (dominant period of 0.2 – 0.4 second); Region III (dominant period > 0.4 second).
- The earthquake intensity of the Jakarta city and its surrounding areas is mainly influenced by Benioff Wadati Earthquake Source Zones which consists of Benioff Wadati Earthquake Zone I, II, III and Individual (separated) of Benioff Wadati Earthquake Zone.
- Based on dynamic site responses of rock and soil, this city is divided into five microzonations, these are: Very high susceptibility microzonation (index of > 10); High susceptibility microzonation (index of 7.5 – 10); Moderately susceptibility microzonation (index of 5-7.5); Low susceptibility microzonation (index of 2.5 – 5) and Very low susceptibility microzonation (index of < 2.5).
- The microzonation of potential earthquake hazard areas in the Jakarta city is one of important data base in order to mitigate earthquake hazards and risks in a city planning.

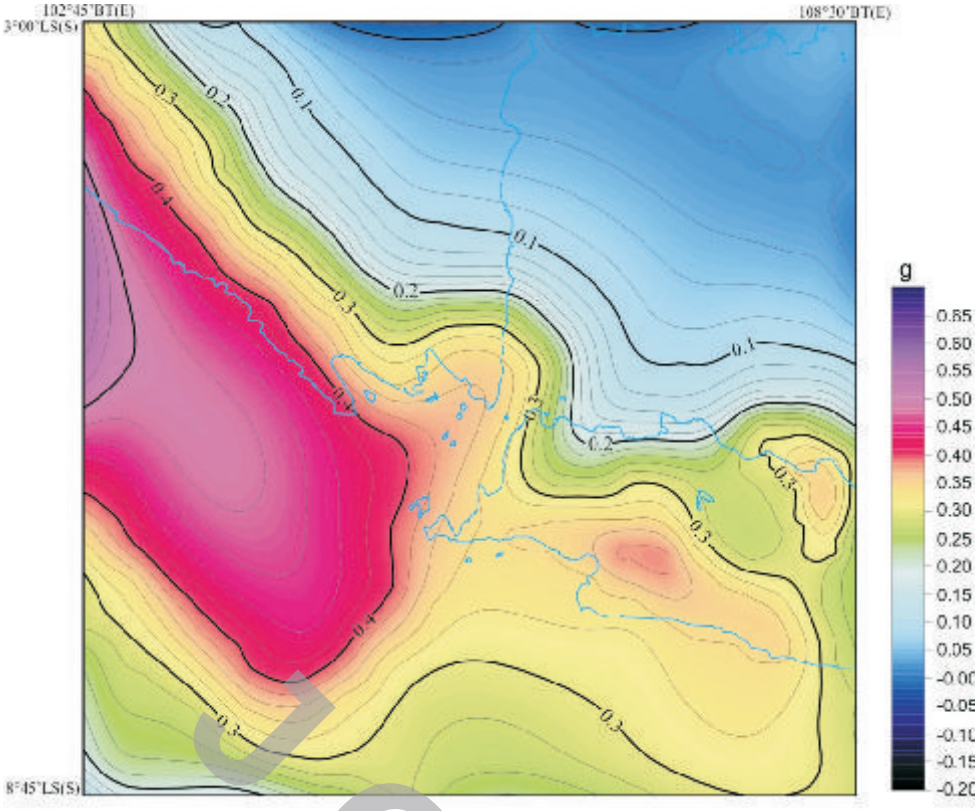

Figure 7. Maximum ground acceleration map of hard rock, period of 100 years (contour interval 0.02g).

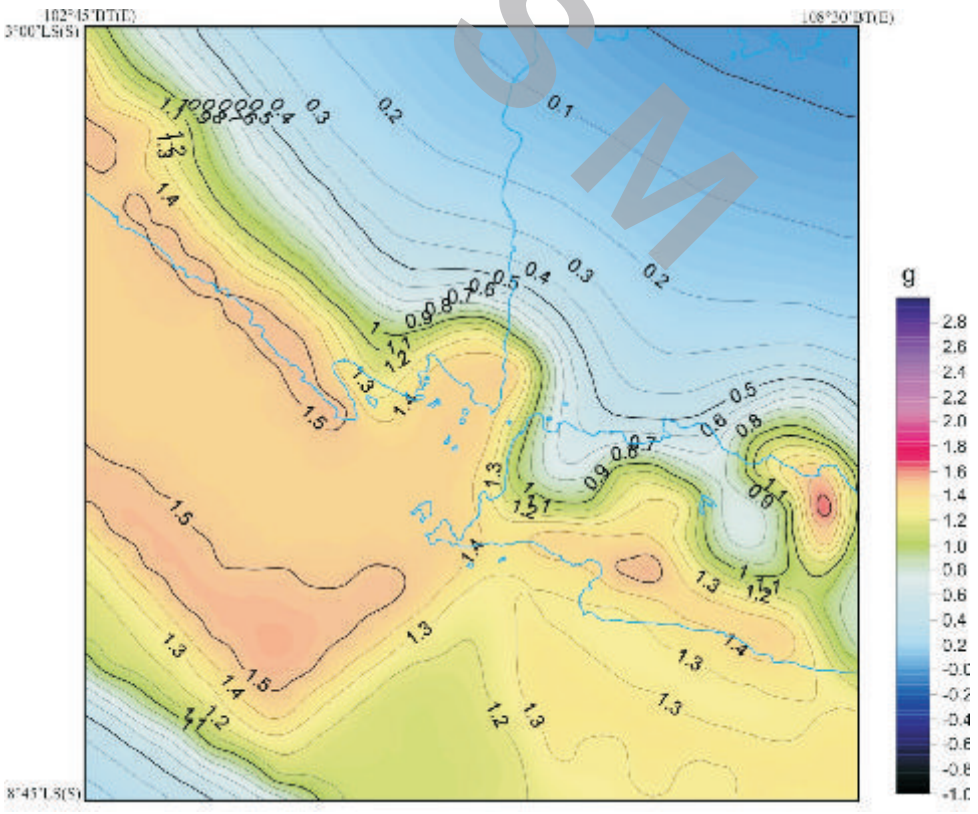

Figure 8. Maximum ground acceleration map of soft sediment, period of 100 years.

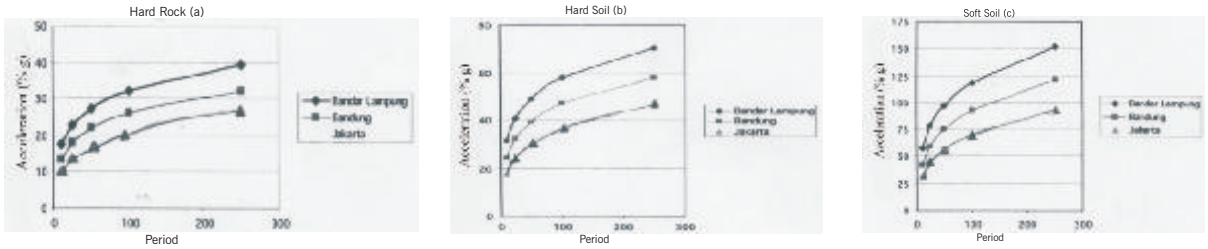

Figure 9. Graph of maximum ground acceleration hard rocks (a), hard sediments (b) and soft sediments (C).

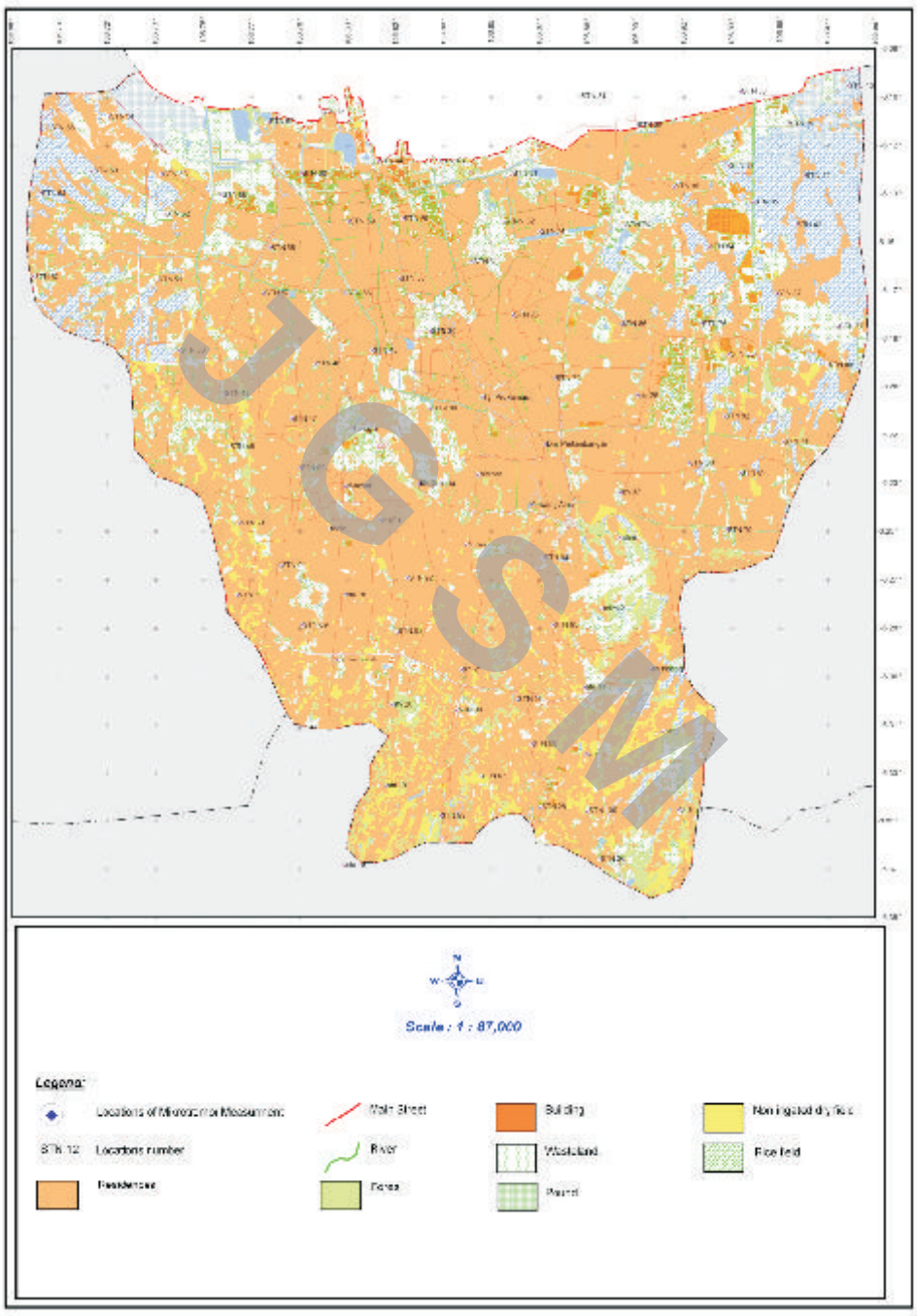

Figure 10. A distribution of microtremor measurements and land use maps of Jakarta.

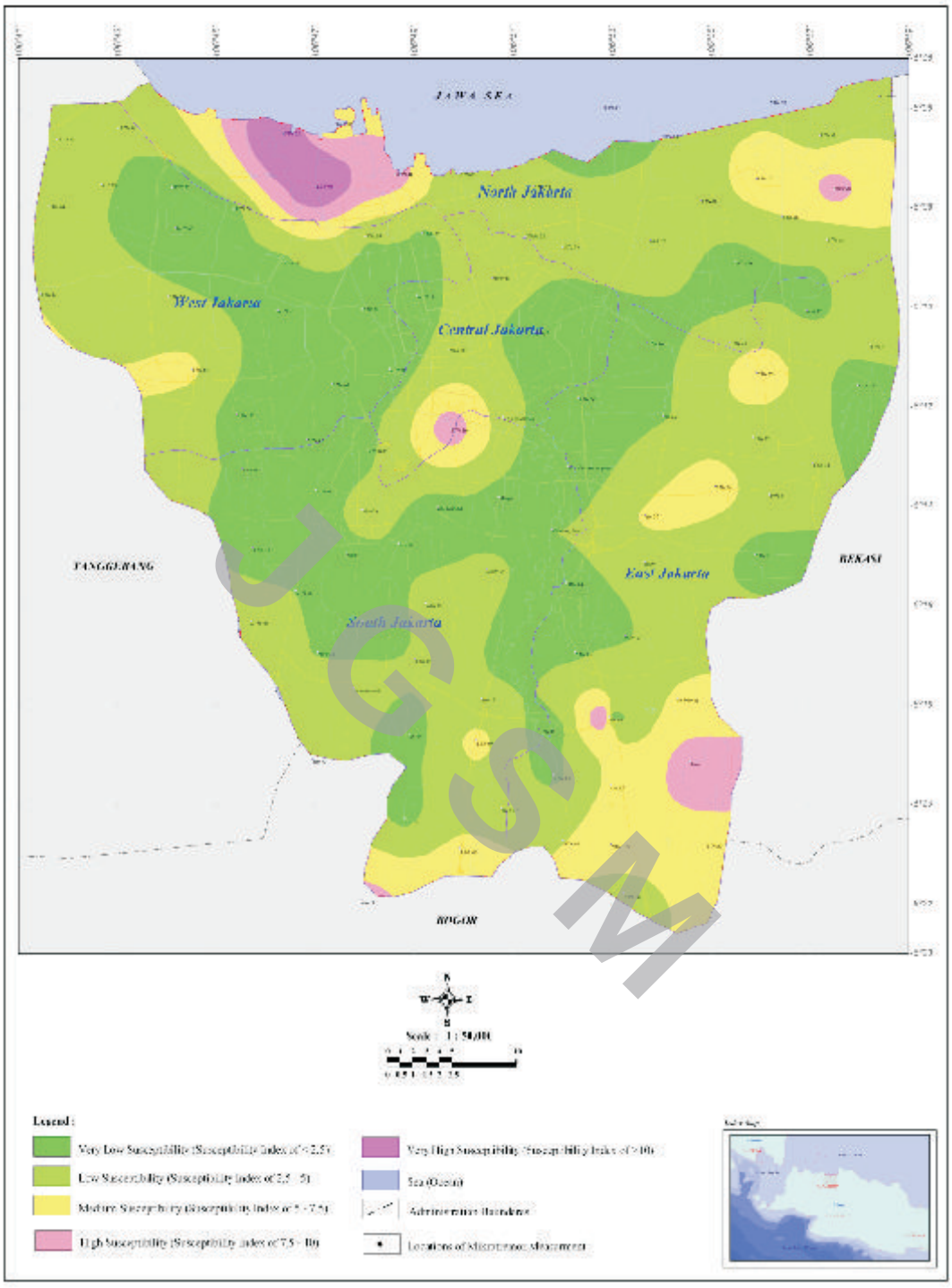

Figure 11. A dominant period map of Jakarta

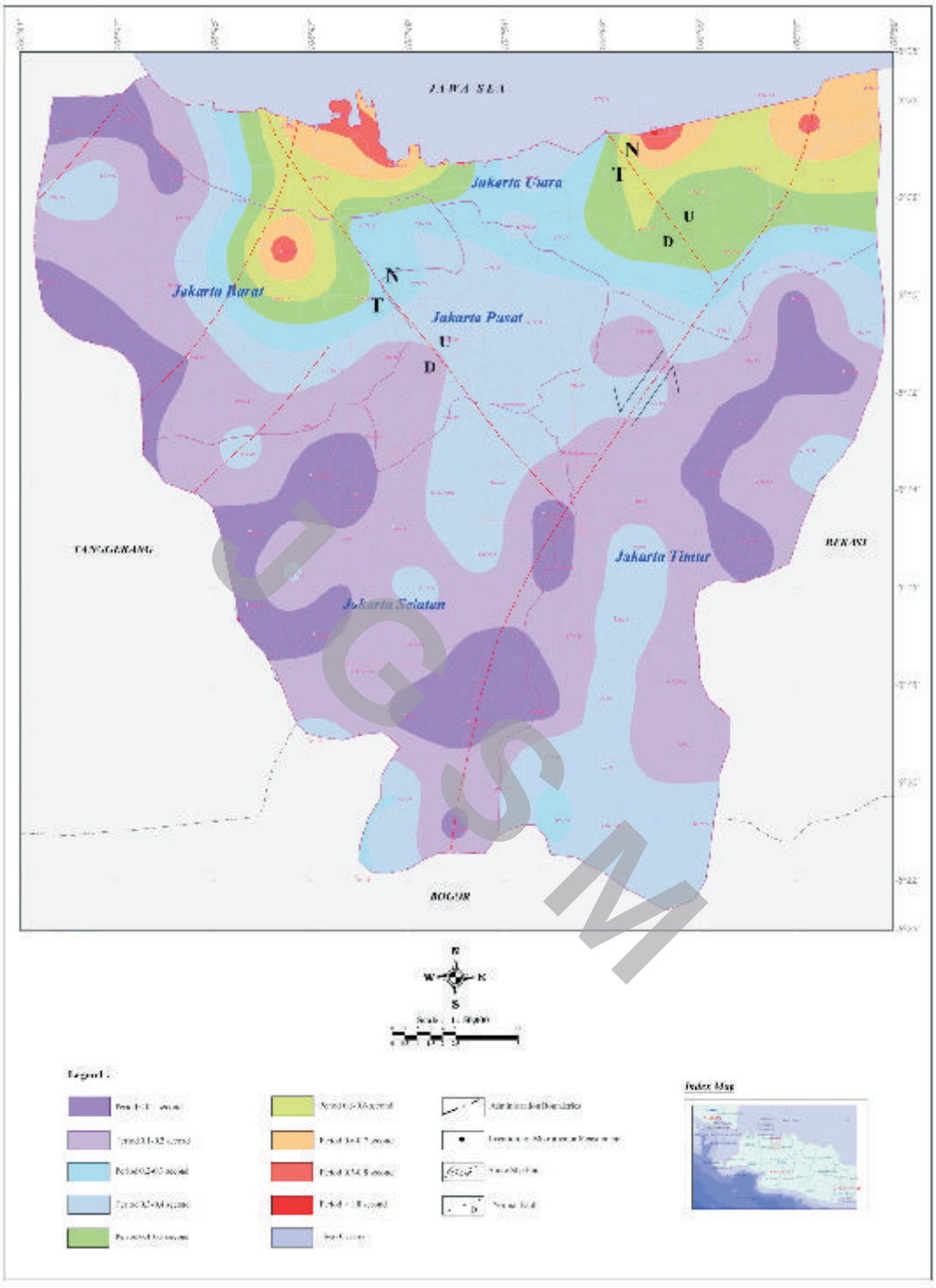

Figure 12. A susceptibility ground shaking microzonation map of Jakarta.

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