Jurnal Geofisika (2023) Vol. 21, No. 01 hal. 1-9

Modeling Of Liquefaction Potential Zone Using The Global Geospatial Model (Case Study: Special Region of Yogyakarta and Klaten Regency)

Adelia Saras Nugraheni[1], Nugroho Budi Wibowo[2] dan Didik Yudianto[1]

[1]Geophysical Engineering, Brawijaya University, Malang, East Java, Indonesia
[2]BMKG (Meteorological, Climatological, and Geophysical Agency), Sleman, Special Region of Yogyakarta, Indonesia
*Email: adelia.sarasn@gmail.com

Submit: 12 Januari 2022; Revised: 04 Maret 2022 ; Accepted: 26 Mei 2023

Abstrak: Likuefaksi merupakan bencana susulan yang terjadi akibat gempa bumi. Likuefaksi yang terjadi di Daerah Istimewa Yogyakarta dan Kabupaten Klaten pasca gempa tahun 2006 berupa semburan material pasir dan lempung, serta perubahan muka air tanah dan kualitas air tanah pada sumur-sumur masyarakat. Tujuan dari penelitian ini adalah untuk mengetahui zona potensi likuefaksi berdasarkan metode global geospasial di Daerah Istimewa Yogyakarta dan Kabupaten Klaten. Metode global geospasial memodelkan potensi likuefaksi berdasarkan parameter Vs_{30}, PGA, dan CTI. Model kemudian divalidasi dengan data kedalaman air tanah dan litologi bawah permukaan berdasarkan data mikrotremor. Proses validasi menghasilkan zona potensi likuifaksi di Daerah Istimewa Yogyakarta dan Kabupaten Klaten. Hasil penelitian menunjukkan zona dengan potensi likuefaksi tinggi terjadi di wilayah pesisir selatan Kulon Progo dan Bantul. Zona tersebut berada pada formasi aluvium, Vs_{30} 180 hingga 270 m/s, CTI 7 hingga 11.5, PGA 660 hingga 840 gal, kedalaman air tanah 0.26 hingga 4.49 mdpl dan didominasi oleh material pasir. Zona yang berpotensi tinggi terjadinya likuefaksi juga terdapat di daerah sesar Opak Sleman dan Bantul. Zona tersebut berada pada formasi Gunung Merapi Muda, Vs_{30} 180 - 315 m/s, CTI 7-13.5, PGA 960-1140 gal, kedalaman air tanah 0.89-4.7 mdpl, dan didominasi oleh material tanah, abu, dan tuf.

Kata kunci: Zona Potensi Likuefaksi, Model Geospasial Global, Vs_{30}, PGA, CTI

*Abstract***:** *Liquefaction is a subsequent disaster that occurred due to an earthquake. Liquefaction that occurred in the Special Region of Yogyakarta and Klaten district after the 2006 earthquake in the form of sand and clay material bursts, changes in groundwater levels and groundwater quality in community wells. The purpose of this study was to determine the potential zones of liquefaction based on global geospatial methods in the Special Region of Yogyakarta and Klaten districts. The global geospatial method models the potential for liquefaction based on the parameters Vs_{30}, PGA, and CTI. The model was validated with groundwater depth and subsurface lithology data based on microtremor data. The validation process produces a zone of potential liquefaction in the Special Region of Yogyakarta and Klaten district. The results showed a zone with a high potential for liquefaction occurring in the southern coastal areas of Kulon Progo and Bantul. The zone is in the alluvium formation, Vs_{30} 180 to 270 m / s, CTI 7 to 11.5, PGA 660 to 840 gal, groundwater depth 0.26 to 4.49 masl, and dominated by sand material. Zones with high potential for the occurrence of faction are also found in the fault areas of Opak Sleman and Bantul. The zone is in the formation of the younger Merapi volcano, Vs_{30} 180 to 315 m/s, CTI 7 to 13.5, PGA 960 to 1140 gal, groundwater depth 0.89 to 4.7 masl, and dominated by material earth, ash, and tuff.*

Keywords: *Liquefaction Potential Zone, Global Geospatial Model, Vs_{30}, PGA, CTI*

1 INTRODUCTION

Liquefaction is a soil layer phenomenon because of increased pore stress caused by dynamic loadings in the form of earthquakes (Mase, 2014). Liquefaction phenomena can lead to subsidence, collapse, soil cracks, landslides and others. Some examples of liquefaction events that have occurred in Indonesia are the damage caused during the earthquakes in Bengkulu between 2000 and 2007, the 2004 Aceh earthquake, the 2005 Nias earthquake, the 2006 Yogyakarta earthquake. Liquefaction phenomena are known to occur, usually in areas formed by a granular sediment layer with a low saturated air density (Misliniyati et al., 2019).

The Yogyakarta earthquake in 2006 followed another disaster. The phenomenon of the following disaster is liquefaction. Several factors that influence liquefaction potential include soil grain grading and relative density (Rd). Grain gradation and relative density (Rd) are major soil parameters that have a significant impact on soil quality and resistance to various events, including liquefaction (Mase, 2014).

The liquefaction event in the Special Region of Yogyakarta during the earthquake in 2006 that occurs is in the area of the Opak fault line, where this fault is a control for seismic events in the area (Adawiyah, 2008). The Global Geospatial Model models the degree of liquefaction which focuses on identifying widely available geospatial variables (e.g. derived from digital elevation models) and earthquake specific parameters (e.g. Maximum ground acceleration, PGA). This Global Geospatial Model method will later be able to help determine liquefaction disasters in the research area (Zhu et al., 2015).

The global geospatial model method was used by Wibowo (2019) in previous research to map the potential liquefaction zone in Bantul district. The results obtained indicate that there is a potential liquefaction zone in Bantul Regency in the Pundong, Jetis, Imogiri, Kretek, and southern coastal districts of Srandakan. Where the potential liquefaction zone in Bantul Regency is located on the southern coast of Bantul Regency and the Opak fault line.

Other research on liquefaction has been carried out by the Ministry of Energy and Mineral Resources regarding the liquefaction vulnerability zone of the Special Region of Yogyakarta. The results showed that the Yogyakarta Special Region has two zones of liquefaction vulnerability, namely high and medium vulnerability zones. The zone of high liquefaction vulnerability where zone located in the southern coastal area. This high liquefaction susceptibility zone can experience the phenomena of flow liquefaction, lateral displacement, land subsidence, and sand bursts. The second zone is the liquefaction susceptibility in part of the lowlands. The phenomenon of liquefaction that can occur in the liquefaction vulnerability zone is lateral displacement, land subsidence, and sand bursts (Buana et al., 2019).

Previous research on the liquefaction phenomenon that had occurred in the Special Region of Yogyakarta during the 2006 earthquake, which showed the location of liquefaction at that time. Research on the global geospatial model method in Bantul district has shown a potential zone of liquefaction in the area. The potential impact of a high liquefaction disaster in the Special Region of Yogyakarta and Klaten district, it is necessary to carry out further research by modeling the potential for liquefaction which is processed by a model validation process.

Global Geospatial Model (GGM) is a geophysical model that can be used to determine liquefaction opportunities in an area. This method uses the parameters Vs_{30} (shear wave velocity at a depth of 30 meters), PGA (Peak Ground Acceleration), and CTI (Compound Topographic Index). A shallow depth of groundwater level (¡10 meters) and material dominated by loose material such as sand are the supporting conditions for the implementation of liquefaction. Existing research using a global geospatial model hasn't used a validation process with the parameters, so this research conducted based on global geospatial model with a validation process for groundwater level data in the Special Region of Yogyakarta and Klaten Regency.

2 DATA AND METHODOLOGY

This research uses the GGM (Global Geospatial Model) method, which is used to model the potential liquefaction zone. In modeling the potential liquefaction zone, this study uses the Vs_{30} shear wave velocity data obtained from the USGS website. Vs_{30} data along with the coordinates of the value, then the coordinates of the data are used to have a PGA (Peak Ground Acceleration) valuable data on the PUSKIM website (Center for Research and Development of Housing and Settlements). The data next required CTI (Compound Topographic Index) data, which was obtained from the UK Center for Ecology & Hydrology website.

From the Vs_{30} shear wave velocity data, PGA value data, and CTI data are then used to perform calculations with the formulation of the GGM method, after getting the value from the formula calculations of the global geospatial model, modeling can make. In modeling using DEM (Digital Elevation Model) data. Zones can be known, namely areas that have the potential for liquefaction along with the shape of the model of the earth's surface of this research area. In addition, we also use geological maps for the Yogyakarta and Surakarta sheets from Rahardjo et al. (1995) and Surono et al. (1992) so that we can find out the geological structure of the research area so that it can be used for analysis of the results of our liquefaction potential zone map.

The model validation process was carried out by comparing the global geospatial model with groundwater level. The groundwater depth data collection was carried out at points included in the potential liquefaction zones, so that it could analyze that the groundwater level of the area was by the potential liquefaction zone.

2.1 Liquefaction

Liquefaction is a phenomenon of loss of soil strength due to an increase in water pore stress caused by dynamic loads in the form of earthquakes. Liquefaction can occur when the earthquake strength is¿ 5 SR (Mase, 2014).

Liquefaction is present in 90% in seismically active areas located in sediment layers, 73% of thawed sites were in artificial fill or near streams, and 67% of thawed sites are at a groundwater level of less than 10 m (Zhu et al., 2015). According to Youd and Perkins (1978): sediment deposits of more than 10 m and a water level depth of less than 10 m are locations that have the potential for liquefaction.

The liquefaction zone has various phenomena that occur. Phenomena that can occur are flow liquefaction and can cause ground motion. In addition, lateral displacement can cause the land to shift generally reaching from 0.3 meters or more with a gentle slope (8%). Land subsidence can reach 0.1 m or more. The last phenomenon is sand bursts that can occur even in one area or even only in the form of sand blast points, for example in wells Buana et al. (2019).

2.2 Global Geospatial Liefaction Model

GGM predicts the probability and level of liquefaction for use in developing a liquefaction hazard map, so that it can be used for loss identification and quick response to liquefaction disasters. Getting a global geospatial liquefaction model, we identify and validate the degree of saturation (or water level depth), age of deposition, relative density and grain size. There are three broad factors that contribute to the probability of liquefaction (Youd and Perkins, 1978; Zhu et al., 2015): Acceleration of ground vibration, soil type, and soil hydrological parameters. The global geospacial liquefaction model or $P[Liq]$ used in Eq.1 has been calculated using following relation given by Zhu et al. (2015):

$$P[Liq] = \frac{1}{1 + e^{-X}} \tag{1}$$

with

$X = 24.1 + 2.067$ [ln(PGA)]+0.355 × CTI - 4.78[ln(Vs_{30})]

where, $P[Liq]$ is potential for liquefaction. PGA is accelerated ground vibration with (gal) as the unit. Vs_{30} is speed of shear waves at a depth of 30 meters from the surface or classification soil type with the unit is (m/s) or meters/second. And CTI is compound topographic index or soil wetness index.

2.3 Vs_{30} Shear Wave Velocity

The value of the shear wave velocity at a depth of 30 meters (Vs_{30}) is applied as a determination of Geotechnical parameters. Shear waves are slower body waves or S-waves. This happens because the direction of the vibrations of the particles is perpendicular to the centering of the wave propagation. These waves can only propagate in solid substances. The velocity of propagation of shear waves is more depressed than that of longitudinal or primary waves. Vs_{30} is the speed of the shear waves up to a depth of 30 meters from the airfoil. The value of Vs_{30} is used to determine the classification of rocks based on the intensity of earthquake vibrations due to local effects. Vs_{30} is an important and most widely used data in geophysical engineering to determine the characteristics of subsurface structures up to a depth of 30 meters. Layers of rock up to a depth of just 30 meters determine the magnification of the earthquake waves (Nurrahmi et al., 2015). The value of Vs_{30} can be fixed using Eq.2:

$$Vs_{30} = \frac{30}{\sum_{i=1}^{n} \frac{h_i}{Vs_i}} \quad (2)$$

where, h_i is the thickness of the i layer. Vs_i is the velocity of the i layer shear wave. Number of layers is n.

2.4 Peak Ground Acceleration (PGA)

Peak Ground Acceleration (PGA) is worked by three things, namely: the source of the earthquake, the wave propagation path, and local factors which can be geological conditions or characteristics of an area. This indicates that there are differences in PGA values in an area related to differences in geological characteristics (Ulfiana et al., 2018).

In this study, the PSHA model is based on earthquake sources that cause an influence in the Yogyakarta Special Region Province and Klaten Regency which originate from earthquakes due to subduction zone activity and local faults. Earthquake data used in this modeling is referenced to earthquake data from 1907 to 2009.

The PSHA model is obtained from processing using data on the magnitude or seismicity distribution of the area. The magnitude data are then separated between mainshock, foreshock, and the aftershock for analysis of data completeness. Finding the attenuation function needs to be done using a logic-tree that is available in the USGS PSHA software. The maximum ground acceleration value will be obtained from the USGS software. The PSHA method theory in Eq. 3 has been calculated using following relation given by Center for Research and Development of Housing and Settlements (PuSGeN, 2017):

$$P[I \geq i] = \int_r \int_m P[I \geq i|\text{m and r}] f_M(m) f_R(r)\, dm\, dr \quad (3)$$

where, f_M is the distribution function of the magnitude. The f_R is distribution function of the hypocenter distance. $P[I \geq i|\text{m and r}]$ is the conditonal probability of the intensity or exceeding the value I at a given location for an earthquake with magnitude M and a hypocenter distance R.

PGA is the value of the acceleration of ground shaking that has occurred in a place due to an earthquake. The ground acceleration due to the earthquake will show the inertia force that will act on the mass of the structure. The inertia force is the force that arises on the building due to the tendency of the building mass to defend itself. These results must be adjusted to the geological conditions and characteristics of the seismic zone of the location used as the research area (Kumala and Wahyudi, 2016).

2.5 Compound Topographic Index (CTI)

Compound Topographic Index (CTI), which is an index of viscosity or can be referred to as the Topographic Contour Index (TCI), which is an index of wetness. Topography, which is a function of the slope and the upstream contributor area per unit orthogonal width in the flow direction. This index is applied because it is proven to be highly correlated with several soil attributes such as the depth of the horizon, the percentage of silt, the content of organic matter and phosphorus. CTI aims to model groundwater content.

CTI represents conditions of slope, groundwater conditions, and groundwater flow direction. This usually high CTI value indicates the wetter the area is, so that areas that have a flat topography and are correlated with the existence of a river system are areas that have high CTI values (Wibowo, 2019).The CTI used in Eq.4 has been calculated using following relation given by:

$$CTI = \ln\left(\frac{As}{\tan \beta}\right) \quad (4)$$

where, CTI is the compound topographic index. As is flow accumulation. And β is slope.

3 RESULT AND DISCUSSION

The liquefaction potential zone modeling obtained after going through the data processing method of the global geospatial liquefaction model method. Processing of the model is done using shear wave velocity data (Vs_{30}), maximum ground vibration acceleration data (PGA), and wetness index data (CTI).

3.1 Shear Wave Velocity (Vs_{30})

The value of Vs_{30} can be classified based on the SNI 1726 criteria (Table 1) indicating that the Special Region of Yogyakarta and Klaten district have the criteria for medium soil sites (Vs_{30}, namely 175 m/s to 350 m /s), hard soil or soft rock (Vs_{30}, namely 350 m/s to 750 m/s), and rocks (Vs_{30} i.e. 750 m/s to 1500 m/s). Figure 1 shows a map shear wave velocity to a depth of 30 meters (Vs_{30}) in the Yogyakarta Special Region and Klaten regency.

Areas with moderate soil criteria (Vs_{30} 180 m/s to 350 m/s) are in alluvium formations, collovium formations, old

Table 1. Classification of Rock Sites based on the value of Vs. (BSN, 2012)

Site Classification	Vs (m/s)
SA (Rock hard)	> 1500
SB (Rocks)	750 to 1500
SC (Hard soil, very dense, and soft rock)	350 to 750
SD (Medium soil)	175 to 350
SE (Soft soil)	< 175

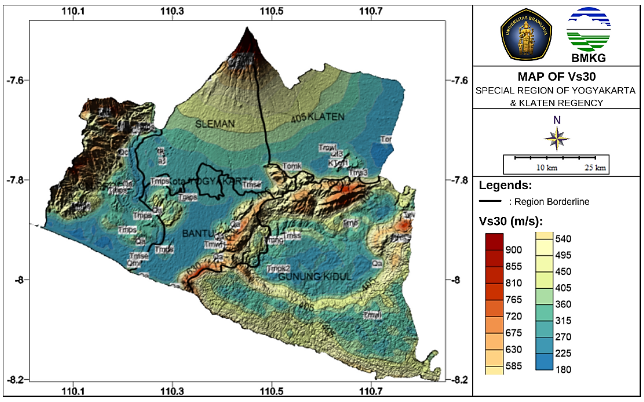

Figure 1. Speed Map of Shear Wave Vs_{30} Special Region of Yogyakarta and Klaten Regency.

alluvium formations, and young Merapi volcano sediments which will give a slower response to propagating seismic waves, this is because occurs in a softer medium that will absorb slower earthquake wave energy or the intensity of the earthquake will attenuate slower, the earthquake wave energy is absorbed more slowly because the soft medium has a low frequency and long wavelength, so it has a lower amplification higher at slower attenuation. Table 1 shows the low frequency values of soft sedimentary rocks.

Areas with the criteria of hard soil and soft rock (Vs_{30} 350 m/s to 750 m/s) are in the young Merapi mountain deposit, Sentolo formation, Jonggrangan formation, Kebonbutak formation, Wonosari formation, Kepek formation, Oyo formation, Semilir formation, and formations. This Sambipitu will provide a moderate response to the propagation of seismic waves, this is because the vibrations that occur in the medium are not hard but are also not soft so that they experience not too high amplification.

Areas with rock criteria on the mountain top topography with the elevation values mentioned earlier. Areas with rock criteria (Vs_{30} 750 m/s to 900 m/s) are in the Nglanggran formation, Malihan rocks, Andesite rocks, Diorite rocks, and old Merapi volcanic deposits which will provide a faster response to propagating seismic waves, this is because they can absorb earthquake wave energy faster in hard rock or medium. From the Vs_{30} shear wave velocity map Figure 1. The value of Vs_{30} if it is related to the potential for liquefaction disasters, the areas that are more prone to liquefaction disasters are areas that have a Vs_{30} value of 175 m/s to 350 m/s or areas that have soft and medium soil types.

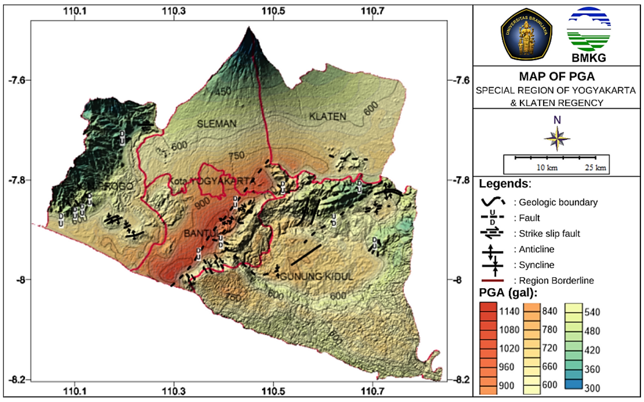

Figure 2. Ground Vibration Acceleration Map (PGA) for Yogyakarta Special Region and Klaten Regency.

3.2 Peak Ground Acceleration

The maximum ground vibration acceleration (PGA) value in the Special Region of Yogyakarta and Klaten Regency, has a PGA value that varies from 300 gal to 1,140 gal. The PGA value has a relationship with geological events in the form of earthquakes within a certain time. Then it relates to rock types that exist in the Special Region of Yogyakarta and Klaten district. Figure 2 shows the PGA map in the Special Region of Yogyakarta and Klaten district.

In areas that have a PGA value of 300 gal to 599 gal it is interpreted in green in Figure 2. The PGA values are scattered in several rock formations located in various district locations. The slopes of Mount Merapi have rocks that d, Qmo, na, and Qmi, which are located in Sleman and Klaten Regency. The KTm, Tmwl, Qt, Tpdi, Tew formations are also found in Klaten Regency. Kulon Progo Regency has a, Tmj, Tmok, Teon, Tmps, Qc formations which have values in this range. The Tmwl, Tmw, Tmo, Tms, Tmok, Tmng, Tmss formations in Gunung Kidul Regency also have a PGA value of 300 gal to 599 gal. The location of this PGA value has a Vs_{30} value of > 405 m/s which is included in the classification of soft rock hard soil sites.

The PGA value of 600 gal to 749 gal is indicated by the yellow color of Figure 2. This PGA value is in the Qvm or Qmi formation located in Sleman, Klaten, and a small part in Bantul and Kulon Progo districts. In addition, in Bantul, there are other formations in the form of Tmse and Tmn. In Kulon Progo Regency there are other formations, namely Tmps and Qa. Meanwhile, in Gunung Kidul Regency, namely Tmwl, Tmpk, Tmss, Tmo, and Tms. At this PGA value, there are several synclines and anticlines in Kulon Progo and Gunung Kidul Districts. Geological contacts are also found in Klaten and Gunung Kidul Regencies, as well as shear faults in Gunung Kidul.

PGA values from 750 gal to 899 gal are interpreted using the orange color on the PGA map in Figure 2. Most of the Qmi or Qmv Formations in Sleman, Klaten, Bantul and Yogyakarta districts have PGA values of 750 gal to 899 gal. The Tmps Formation in Bantul Regency also has this PGA value. Meanwhile, in Kulon Progo there is a Qa formation. The Tmwl, Tmpk, Tmss, Tmo, and Tms formations in Gunung Kidul Regency also have a PGA value of 750 gal to 899 gal which is located near the faults, synclines and anticlines in Gunung Kidul.

PGA values of 900 gal to 1140 gal are shown as dark orange on the PGA map in Figure 2. Areas with this value are only found in Bantul Regency and a small part of Sleman Regency. The types of formations that have the PGA value are the Qmi formations in Sleman Regency, as well as the Qmi, Qa, Tmse formations in Bantul Regency. At this location, there is the Opak Fault, or a large fault in Yogyakarta which is experiencing continuous movement. Around the Opak Fault there are also several shear faults and other small faults. The Alluvium Formation (Qa) is a surface deposit consisting of crust, sand, silt and clay along major rivers and coastal plains. The Young Merapi Volcano Sediment Formation (Qmi or Qvm) has constituent rocks in the form of tuff, ash, breccia, agglomerates and inseparable melting lava. The Qa and Qmi formations at the same location have Vs_{30} values of 270 m/s to 315 m/s which are classified as moderate soils. Whereas the Semilir Formation (Tmse) in this location has a Vs_{30} value of 360 m/s to 450 m/s which is classified as soft rock hard soil. Even though the calcification is hard soil soft rock, it has a high PGA value due to the exact location there are faults and the shear fault to the east of the Opak Fault.

The high maximum ground vibration acceleration values are in areas where there are control or geological structures in the form of faults, shear faults, synclines, and anticlines. Because in that area, it is a location where the earthquakes usually occur. The type of soil or rock in the area cannot be ignored, because if the rock type is solid, the maximum vibration acceleration value is smaller than in areas with softer soil or rock types. This is caused by an amplification factor (amplification of waves in a particular medium). The amplification factor can be amplified more if it occurs in soft rock or sediment, so that geological events with rock types are a factor that greatly affects the value of the maximum acceleration of ground vibrations.

3.3 Compound Topographic Index

The wetness index value in the Special Region of Yogyakarta and Klaten Regency, has a CTI value that varies from -0.5 to 13.5. The CTI value is the level of wetness in a certain area which is influenced by water conditions both in the ground and above the surface (such as rivers). The slope of the area also has an influence on the value of this wetness index. The slope referred to is the topography of the area. Figure 3 shows a map of the wetness index (CTI) in the Special Region of Yogyakarta and Klaten Regency.

Klaten Regency has the Dengkeng Baru river. The flow of this river comes from two rivers. The first river flow is a fractional flow from the Bengawan Solo River. The second river flows from the Woro River, where the Woro River originates at Mount Merapi. The flow of the Dengkeng river produces tributaries of the Wedi river, Ujung River, Nglusah river, Gebang river, and Tempuran river. This river basin is in a lowland topography, so this also makes the wetness index value in this river flow high. This high wetness index value is indicated in red with a CTI value of 7.

The Gendol River and the Bedog River are also large rivers which have their upstream from Mount Merapi. Small rivers that head up on Mount Merapi include the Tepus, Sembung, Gajahwong, Pelang and Buntung rivers. The Gendol River, which is on the slopes of Mount Merapi, continues

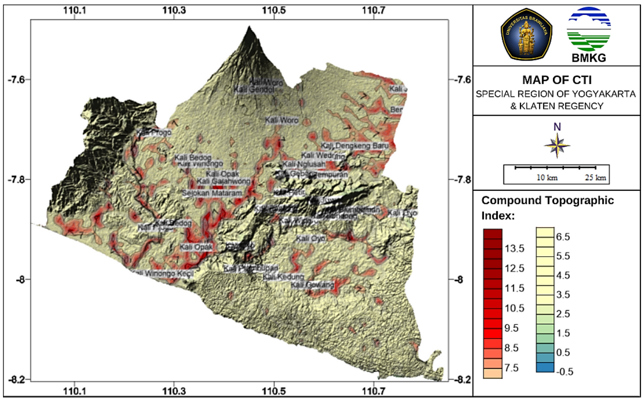

Figure 3. Compound Topographic Index Map (CTI) of Yogyakarta Special Region and Klaten Regency.

down the mountain until it reaches a lowland, and its flow is known as the Opak river which flows through districts, from Sleman district to Bantul district. The flow of the Gendol River which is on the slopes of Mount Merapi has a CTI value of >7. The Tepus River, Sembung river, Gajahwong river, Pelang river and Buntung river are streams from Mount Merapi which will join the Opak river. The compound topographic index value in these rivers is also high, namely CTI > 7 when the river flow is on a flat topography. In the flow of the Bedong river which also has a head on Mount Merapi, its flow leads to or joins the Progo river along with the Winongo river as its tributary.

The Oyo River is also a river whose flow joins the Opak River. The Oyo River originates from the upper reaches of the Gajahmungkur reservoir, Wonogiri, Central Java. This Oyo River crosses Gunung Kidul district before finally joining the Opak river in Bantul district. The Oyo River has small streams in Gunung Kidul district, namely the Prambupan river, Kedung river, and Gowang river. The wetness index value in Gunung Kidul district varies and there is a wetness index value >7. The high wetness index is in a flat topography even though it is in the limestone mountains. The Gendol River, Tepus river, Sembung river, Gajahwong river, Pelang river, Buntung river, and Oyo River have merged into the Opak river which then continues downstream, which is in the Indian Ocean through the Bantul district.

The next major river in the study area is the Progo River. The Progo River itself originates from Mount Sindoro and Mount Sumbing, Magelang district, Central Java. The wetness index value of the flow of the Progo river and the Krasak river from the upstream of Mount Merapi has a CTI value of >7. The flow of the Progo river is high because it is supported by its topography factor which is in a flat area. The Progo River then flows into the Indian Ocean and a high wetness index value also follows the flow of this river. In Kulon Progo district there is also the Serang river which is in the southwest part of this district. The direction of the flow from the mountains in the west to the south of the Indian Ocean.

In this research area, the wetness index in the provinces of Yogyakarta Region and Klaten Regency obtained high value wetness index results in large river flows in this research area. The factor that supports the high wetness index value is also due to its locations in areas that have flat topography.

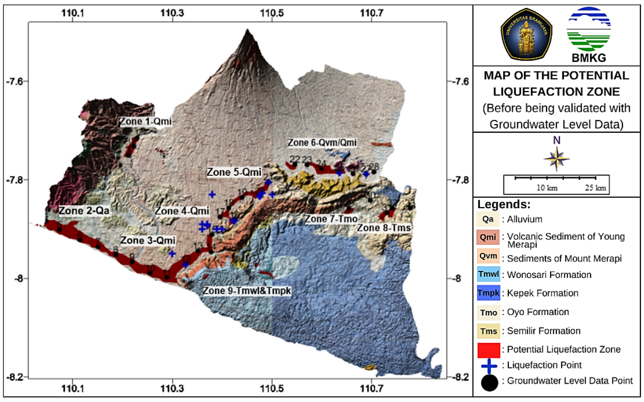

Figure 4. Map of Potential Liquefaction Zones (Before being validated using Groundwater Data).

River flows that are in high topography or areas that have a slope such as on the slopes of Mount Merapi can have low wetness index values due to these topographic factors.

3.4 Liquefaction Potential Zone Model

In the province of the Special Region and Klaten district, there are several areas that have the potential for liquefaction. The value of which the probability of occurrence is closest to 1. Map of the results of the potential liquefaction zone in Figure 4 The zone of potential liquefaction is divided based on the rock formations that comprise it and the location of the existing geological contact.

Zone 1 is a zone located in the Sendangagung Village, Sleman Regency and Banjararum Village, Kembang Village Kulon Progo Regency. Zone 1 of the liquefaction potential is on the edge of the Progo river. The elevation zone 1 is 101 masl to 110 masl. Zone 1 has a constituent rock underneath, namely the Young Merapi Volcano (Qmi) sediment. The rock constituents are inseparable tuff, ash, breccia, agglomerates and melted lava. This young Merapi volcano sediment, which is included in the medium soil type, is explained in the analysis of the Vs_{30} map. This zone has a Vs_{30} value of 270 m/s to 315 m/s which is shown by the green color in the figure 1. The Vs_{30} value is included in the medium soil site classification in the Vs_{30} value range, namely 175 m/s to 350 m/s. In zone 1 the potential for liquefaction is because the constituent rocks come from the sediment of Young Merapi Volcano (Qmi) which has a maximum ground vibration acceleration value of 570 gal to 630 Gal or which is interpreted as yellow in figure 2. Estimating by the wetness index value, zone 1 has a high wetness index value, namely CTI > 7, because its location is in a flat topographic area and adjacent to the Progo river flow. The Progo River itself originates from Mount Sindoro and Mount Sumbing, Magelang district, Central Java.

Zone 2 is located in Sindutan, Glagah, Ngarongan, Pleret, Karangsewu, Kulon Progo district. It is located on the southern coast of Kulon Progo district. The elevation zone 2 is 3 masl to 9 masl. Zone 2 is an Alluvium formation, where the alluvium (Qa) formation consists of crust, sand, silt and clay. This Alluvium formation has a Vs_{30} value of 225 m/s to 270 m/s and based on the Vs_{30} analysis, this formation is a medium soil type which has a green color on the Vs_{30} map. This area has a ground vibration acceleration value of 660 gal to 750 gal which is indicated by the yellow to orange color on the PGA map. The PGA value is supported by the existence of 4 faults near the zone and the existence of small mountains that appear which are the Sentolo formation. The mountains are small so that near zone 2 there are 2 synclines and 2 anticlines. Estimating from the results of the CTI map, the location of zone 2 has a wetness index above 7 in red on the CTI map. This result is due to its location in the Serang river in the southwestern part of Kulon Progo Regency and on the coast or coastal sediments.

The potential liquefaction zone 3 is in the Banaran village, Kulon Progo district, Gadingsari village, Tirtohargo, Bantul district. The location of zone 3 is still in line with zone 2, which is on the south coast in Kulon Progo and Bantul regencies and has an elevation of 3 masl to 16 masl. The geological formation in zone 3 is the volcanic sediment of Young Merapi (Qmi) which consists of tuff, ash, breccia, agglomerates and inseparable melting lava. Zone 3 is an area that has a Vs_{30} value, namely 270 m/s to 315 m/s, therefore in this formation it is classified as moderate soil interpreted by the green color on the Vs_{30} map. This area is also an area that has a maximum ground vibration acceleration value of 750 gal to 1140 gal which is shown in the dominant dark orange color on the PGA map. This can be related to the Opak Fault, which stretches on the eastern side of Bantul Regency. The Opak Fault runs from the eastern side of Sleman Regency towards the Southwest to the coast in Bantul Regency. The Opak Fault also contains shear faults on the East side of the Opak fault. Zone 3 also has a CTI value > 7 because it is a flow path of the Progo river in the western part of this zone, the Winongo River, which is in the middle of this zone, the Opak river which is in the east, and zone 3 is on the southern coast of the Special Region of Yogyakarta.

Zone 4, a zone located in the Kelurahan Panjangrejo, Sanden, Sriharjo, Mbendo, in the district of Bantul. The elevation of zone 4 is 13 masl to 38 masl which rises gently away from the coast to the north. Zone 4 has a formation as a volcanic sediment of Young Merapi (Qmi), which consists of tuff, ash, breccia, agglomerates, and inseparable melting lava. At this location, the Vs_{30} value is 270 m/s to 315 m/s which is interpreted in green on the Vs_{30} map. This then state that the volcanic sediment of Young Merapi is classified as moderate soil, according to the SNI 1726 criteria. Judging from the results of the maximum ground vibration acceleration value, zone 4 is in the Opak fault, right in the middle of this zone, the Opak fault extends from the northeast to the southwest. Making zone 4 has a high PGA value with a PGA value of 930 gal to 1140 gal. To the east of this zone there are also 3 shear faults and 1 fault. The medium soil type can be a factor affecting the high maximum ground vibration acceleration value where the amplification factor can be amplified if it occurs in soft sediments. Regarding the value of the wetness index, zone 4 has a CTI value of > 7, because of its location in the Opak river which then continues downstream, namely in the Indian Ocean through the Bantul district.

Zone 5 is in Tegalrejo, Pleret, Jambitan, Sitimulyo, Piyungan sub-districts in Bantul district and Sumberharjo village, in Sleman district. The elevation in this zone is 46 masl to 102 masl, where the topography of zone 5 is flat with an elevation that continues to increase along with the direction to the north or towards Mount Merapi. The rock formation in this zone is the volcanic sediment of Young Merapi, which consists of tuff, ash, breccia, agglomerates, and inseparable melting lava. Zone 5 has a Vs_{30} value of 270 m/s to 315 m/s which is indicated by the green color on the Vs_{30} map. From the results of the Vs_{30} value, the Qmi formation is a medium soil type rock formation. The potential zone of liquefaction 5 is found in the Opak fault, so that the PGA value is high with a PGA value of 900 gal to 1080 gal. The high PGA value is due to several contacts and other geological events. First, its location is right on the Opak fault which stretches from northeast to southwest. Second, at point (S-16) it is right on a fault. Third, to the east of the points (S-17), (S-18), and (S-19) there are dip-slip faults and 2 strike-slip faults. These faults are mutually sustainable. Fourth, to the east of the point (S-21) there is 1 dip-slip fault in the Semilir (Tms) formation. At well point 17 (the well point can be seen in the Figure 4) in zone 5, it is in Karet hamlet, Pleret sub-district, Pleret district, Bantul regency. At point 17 is the meeting location of the two large river flows, namely the Gajahwong River and the Opak River so that in zone 5 there are two river flows that contribute to the CTI > 7.

The next zone is zone 6, this zone is in the sub-district of Gantiwarno, Pasung, Ngurkan, Paban, Banyuuripan, Jambakan, Nanggulan, in Klaten district. Zone 6 has a flat elevation with an altitude of 115 masl to 137 masl and there is Mount Kebo with an altitude of 126 masl to 257 masl. 126 meters above sea level is the height from the ground at the edge of the mountain. In zone 6 this is the sedimentation of Mount Merapi (Qvm) which has the same support as (Qmi) which consists of tuff, ash, breccia, agglomerates, and inseparable melting lava. This zone has a Vs_{30} value, namely 270 m/s to 315 m/s, in figure 1 this zone has a green color. The value of Vs_{30} is therefore classified as moderate soil. The PGA value that is owned is 600 gal to 870 gal. In this zone the PGA value is obtained from the soil classification which is medium soil and there are geological contacts at Mount Kebo. Some geological contacts in the Kebonbutak formation (Tmok) to be precise in the south of zone 6. The wetness index value in this area the height is CTI > 7. Zone 6 is the flow of the Woro River and the Dengkeng Baru river, where the Dengkeng Baru river has tributaries of the wide river, Ujung river, Nglusah river, and Gebang river. Apart from the presence of water flow, the cause of the CTI > 7 is also because the location of this zone is on a flat topography.

Zone 7 is a potential liquefaction zone Natah sub-district, Nglipar sub-district (S-29) and Kampung sub-district, Ngawen sub-district (S-30) in Gunung Kidul district. The elevation at the Natah village location has an altitude of 164 masl to 213 masl while in the village of Kampung it has an elevation of 203 masl to 229 masl. In zone 7 this is included in the Oyo (Tmo) formation, the rocks that make up this formation are tuff marl, andesite tuff, and conglomerate limestone. This is why this zone has a Vs_{30} value of 360 m/s to 405 m/s which is indicated by the yellow color in figure 1. The Vs_{30} value is included in the criteria for hard soil and soft rock sites. The PGA value here is 480 gal to 510 gal in figure 2 interpreted in green to light yellow. The PGA value is contributed by the existence of a large fault that crosses the two villages and at the point (S-30) there is one fault and several geological contacts in the North. The compound topographic index value in this zone is also high, namely the CTI is 6.5 to 8 because of its location on the Oyo River and the Blembeman and Dondong rivers. Although this area is a large flow of the Oyo River, the topography of this area is not flat or mountains and valleys (up and down).

Zone 8 is in Grogolan (S-31) and Keringan Kidul (S-32) hamlets, Bulurejo sub-district, Semin sub-district, Gunung Kidul district. The elevation at the location (S-31 and S-32) is 173 masl to 227 masl with a rugged topography. The CTI at this location has a value of 6.5 to 8 because it is in the Oyo River flow but has a mountainous or uneven topography. Apart from these two locations at MTS GUPPI Semin, the Gunung Kidul district has an elevation of 202 masl to 210 masl with a flat topography above the mountains at this location. The CTI value in this area is 7.5, where the south side of approximately 100 meters from this school is the Oyo River. Zone 8 is entirely a Semilir formation which has constituent rocks, namely alternating tuff-breccias, pumice breccias, dacite tuffs and andesite tuffs and tuff claystone. This formation is included in the soft rock hard soil type with a Vs_{30} value of 360 m/s to 540 m/s which is interpreted as light green to light yellow in Figure 1. This zone has a PGA value of 540 gal to 720 gal where in figure 2 it is shown in light green to yellow. The PGA value is due to geological contact, one cycline and because of the rock type.

The last zone in the results of this global geospatial liquefaction model is zone 9, this zone is located in Panggang, Gunung Kidul district. The elevation at this location is 128 masl to 156 masl with mountainous topography. Zone 9 is in the Wonosari (Tmwl) formation consisting of reef limestone, calcarenite, and tuff calcarenite. Most of the Wonosari formations are in Gunung Kidul district. The Kepek Formation (Tmpk) consists of marl and layered limestone, located adjacent to the Wonosari formation in Gunung Kidul district. Looking at the results of the Vs_{30} map, this zone has a Vs_{30} value of 360 m/s or is included in the types of hard, very dense soil and soft rock. This zone also has a PGA value of 660 gal to 720 gal in yellow in Figure 2 this value is due to the type of rock, and there are synclines and faults in the zone. The CTI value of 6.5 to 8 in this zone is due to the flow of the Oyo River and its tributaries, namely the Prambupan River, Kedung River, and Gowang River. The following are the potential liquefaction zones where the data will be validated using groundwater level data.

3.5 Validation of The Liquefaction Potential Zone Model with Groundwater Data

The results of the liquefaction potential zone that have been obtained for the Special Region of Yogyakarta and Klaten district. The zone of potential for liquefaction is then validated using groundwater level data. Table 2 shows the data from the measurement of groundwater level and groundwater depth in the liquefaction potential zones in the Yogyakarta Special Region and the Klaten Regency.

The potential liquefaction zone has a criterion that the groundwater level is less than 10 meters deep. These results indicate that the zone of liquefaction potential which has groundwater, surface water of more than 10 meters is eliminated. The wells that experience elimination is at wells 29, 30, 31, and 33. These wells are located in high topogra-

Table 2. Groundwater Level and Groundwater Baseline Data in the Rainy Season and the Dry Season.

Well Table	Rainy Season Surface (m)	Rainy Season Base (m)	Dry Season Surface (m)	Dry Season Base (m)	Dry Season Characteristic
1	5.8	12.94		12.94	Not dry
2	2.28	4.29		4.29	Dry during the long dry season (7 months)
3	2.37	10.47	8.74	10.74	The height is reduced to 1-2 m
4	0.31	5.28		5.28	-
5	0.53	2.99		2.99	Not dry
6	4.49	6.66		6.66	Usually dry
7	0.26	2.51		2.51	Usually dry
8	2.09	3.98		3.98	Dry during the long dry season (7 months)
9	1.93	5.33		5.33	Usually dry
10	2.93	4.38	2.88	4.38	The height is reduced to 1.5 m
11	6.68	7.3		7.3	Dry during the long dry season (7 months)
12	0.6	3.98		3.98	Not dry
13	3.05	1.01		1.01	Not dry
14	1.5	7.18		7.18	Not dry
15	4.7	6.96		6.96	Not dry
16	1.59	8.36		8.36	-
17	3.1	4.92		4.92	Not dry
18	1.16	2.66		2.66	Not dry
19	1.79	3.25		3.25	Not dry
20	0.89	2.28		2.28	Not dry
21	0.38	2.38		2.38	Dry
22	1.36	4.37		4.37	Dry during the long dry season (7 months)
23	1.35	2.92		2.92	Not dry
24	0.83	2.67	1.67	2.67	The height is reduced to 1 m
25	2.58	5.68		5.68	Not dry
26	3.55	8.6		8.6	Not dry
27	0.65	9.56		9.56	Not dry
28	2.95	13.77	11.77	13.77	The height is reduced to 1-2 m
29	0.68	14.82		14.82	Usually dry
30	4.77	10.77		10.77	Usually dry
31	4.7	12.82		12.82	Usually dry
32	1.94	8.57		8.57	Not dry
33	4.64	14.07	12.07	14.07	Ussualy dry

phy, namely limestone hills. The constituent rocks also come from the Oyo (Tmo) formation and the Semilir (TMs) formation, which makes this zone a moderate Vs_{30} value with hard and soft rock types. In well 1 and well 28, no elimination was carried out even though the groundwater level was more than 10 meters, considering that the location of the well was included in the sediment of Young Merapi Volcano (Qmi / Qvm) which had a low Vs_{30} value. Wells 1 and 28 are also in the lowland topography. Figure 5 shows a map of the potential liquefaction zones in the Yogyakarta Special Region and Klaten Regency.

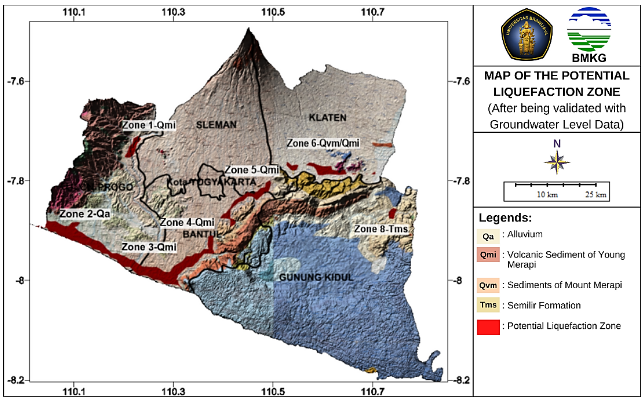

Figure 5. Map of Liquefaction Potential Zones in Yogyakarta Special Region and Klaten Regency.

4 CONCLUSION

From the research that has been done, it can be concluded that the liquefaction potential zone model in the Special Region of Yogyakarta and Klaten district has been obtained from the global geospatial model method. The results obtained are liquefaction potential zones in areas with low Vs_{30} values, high PGA values, and high wetness index values.

ACKNOWLEDGEMENT

The author would like to sincerely thank you for BMKG (Meteorological, Climatological and Geophysical), Special Region of Yogyakarta, and Brawijaya University, Malang, which have supported this research. Thank you also for providing open-source data that we can use. The Vs_{30} data used were obtained from the U.S. Geological Survey, PGA data were obtained PUSKIM's Indonesia Spectra Design, CTI data were obtained from the UK Center for Ecology & Hydrology, DEM data were obtained from Consortium for Spatial Information (CGIAR-CSI), and Geological map of the Yoyakarta, Surakarta and Giritronto from Geological Research and Development Centre.

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