Sumatra Journal of Disaster, Geography and Geography Education June, 2023. Vol.7. No.1. pp. 1-8
Disaster, Geography, Geography Education http://sjdgge.ppj.unp.ac.id/index.php/Sjdgge
ISSN : 2580 - 4030 (Print) 2580 - 1775 (Online), Indonesia

GIS-BASED LAND CAPABILITY FOR SETTLEMENTS AREA IN PIYUNGAN, YOGYAKARTA

* Januar Aziz Zaenurrohman[1], I Gde Budi Indrawan[2], Indra Permanajati[1]

[1]Department of Geological Engineering, Universitas Jenderal Soedirman, Purwokerto, Indonesia
[2] Department of Geological Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia
Email: januar.aziz@unsoed.ac.id

*Corresponding Author, Received: April 10, 2023. Revised: May 11, 2023. Accepted: June 05, 2023

ABSTRACT: The development of the areas for settlement needs to be performed to meet the needs of the land. Research on the characteristics of engineering geology as a basis for determining the capability of land for settlements. The bearing capacity of rocks is based on the Geological Strength Index (GSI) rock mass classification, while the bearing capacity of soils is based on Dynamic Cone Penetration (DCP). Bearing capacity of the research areas, consisting of sandstone 135 tons/m2, lapilli tuff 135 tons/m2, tuffaceous sandstone 45 tons/m2, andesite breccia 45 tons/m2, sand deposits 11-35 tons/m2, and silty clay deposits 6,5-8,6 tons/m2 with a liquid limit of 27-32,3%, and plastic index of 7,25-10,2%. Zoning of land capability is conducted using the Analytical Hierarchy Process (AHP) with criteria of bearing capacity, excavatability assessment, depth of groundwater level, slope, and geological disaster vulnerability. The land capability zone in the research areas consists of a high capability zone with an area of 33%, medium capability zone of 45%, and a low capability zone of 22% of the total research area in Piyungan, Yogyakarta.

Keywords: Settlement, Engineering geology, Bearing capacity,Lland capability zone, Yogyakarta

1. INTRODUCTION

The settlement area must be developed very carefully even if housing demands increase due to population growth in Piyungan District, Bantul Regency [1]. To ensure the sustainability of the development of settlement in the area, the characteristics of engineering geology need to be determined to determine the land capability for settlement. The purpose of this research is to generate information on the characteristics of engineering geology in the form of engineering geological maps and zone of land capability for settlement in Srimartani and the surrounding area. This research includes primary data collection based on engineering geological maps and slope analysis. Secondary data in the form of geological disaster vulnerability map (flood, landslide, and earthquake).

1.1 Regional Geology

Physiographic Central Java, a south-eastern part, is divided into two zones; they are Depression Central Java Zone, Solo Sub Zone, and the Southern Mountains Zone [2]. The second zone covers the area of Merbabu and Merapi Volcano in the north, Yogyakarta, Surakarta, and South Mountains in the south. On the plains of Yogyakarta, the south-eastern part of the foot of Merapi Volcano is a plateau composed of alluvial deposits derived from Mount Merapi [3].

According to Geological Maps of Yogyakarta Sheet [4] and Surakarta-Giritontro Sheet [5], the research area is composed (from old to young) by Kebo Butak Formation, Semilir Formation, Nglanggran Formation, Sambipitu Formation, and Merapi Volcano Deposit.

Kebo Butak Formation consists of layered sandstone, siltstone, claystone, shale, tuff, and agglomerate at the bottom. The upper part consists of interlude sandstone, claystone, and a thin layer of acid tuff. Semilir Formation consists of tuff, breccia pumice, tuffaceous sandstone, and shales [6]. Nglanggran Formation consists of volcanic breccias, flow breccias, agglomerate, andesite-basalt lava, and tuff. Volcanic breccias and agglomerates dominate the presence of lithology of this formation. The youngest formation is the Merapi Volcano Deposit, composed of tuffs, ash, volcanic breccias, agglomerates, and lava.

1.2 Regional Engineering Geology

Based on the Engineering Geological Map of the Yogyakarta-Klaten Area and the Surrounding

Area [7], the research area consists of 3 (three) engineering geology units; they are tuff (Semilir Formation) and breccias tuff (Nglanggran Formation), volcanic breccias and silt (Young Merapi Deposit).

Tuff has a brownish yellow colour with fine-coarse grain size and cohesive and rather hard property. While tuffaceous breccias have a dark brown colour, the fragments are in dacite and andesitic tuff rocks. Engineering geological constraints encountered are weak zone area, steep slope with potential ground movement [7].

Volcanic breccias have a grey colour with fragments of 5-30 cm andesite rocks embedded in a basic mass of coarse-grained tuffaceous sand, open and hard fabric. The engineering geological constraints consist of weak zone area, steep slope, and slope stability [7].

Silt to sandy silt has blackish brown colour, firm, medium plasticity, bearing capacity value between 20–27 kg/cm2. Silty sands are light brown with fine to moderate grain size, rather solid to solid property, slightly pebbly, and the bearing capacity value of the soil is between 32–64 kg/cm2. Sand has grey colour with fine to coarse grain size, loose nature, high porosity, and bearing capacity value between 60–120 kg/cm2 [7].

2. RESEARCH METHODS

Data collection used in this research was classified as primary and secondary data. Primary data were derived from field investigation and laboratory analysis, while secondary data were collected from geological disaster vulnerability.

2.1 Engineering Geological Mapping

Engineering geological research is related to 2 (two) terms between the geological conditions around the existing construction engineering and can be developed. The engineering properties in lithology and geological structure result from data analysis taken in mapping and laboratory tests. The engineering properties of rocks and soil determine the characteristics of engineering geology [8].

2.2 Physical and Engineering Properties

The physical properties of rocks are colour, texture and mineral composition through petrographic observation [8]. The engineering properties of rocks are rock strength, weathering, and rock mass classification using the Geological Strength Index (GSI) method [9]. The result of GSI classification can determine the bearing capacity of a rock.

The physical properties of soil are soil colour megascopically and grain size classification according to The Unified Soil Classification System (USCS) based on grain size test. The soil's engineering properties are plasticity and soil strength through the DCP (Dynamic Cone Penetrometer) penetration test generates bearing capacity value [10].

2.3 Analysis Evaluation of Land Capability

Analysis evaluation of land capability uses The Analytical Hierarchy Process (AHP) semi-qualitative evaluation method. AHP can resolve complex problems, more structure and systems as described in groups [11]. Prioritization criteria are performed in each group by arranging the paired comparisons by comparing among criteria or parameters for each alternative hierarchical system in the form of a matrix for numerical analysis [12].

Tabel 1. The score for each classification parameters

Parameters	Classification	Grade	Quality	Score
Slope	< 8º	3	0.12	0.36
	8-30º	2		0.24
	>30º	1		0.12
Bearing capacity	Rock (fresh-weathered) Q_{all} > 1964 kg/m^2	3	0.26	0.78
	Hard soil, Q_{all} < 1964 kg/m^2	2		0.52
	Soft soil, Q_{all} < 1964 kg/m^2	1		0.26
Excavatability assessment	Easy digging	3	0.08	0.24
	Hard digging-extremely hard ripping	2		0.16
	Blasting required	1		0.08
Geological disaster vulnerability	Low	3	0.40	1.2
	Moderate	2		0.80
	Heigh	1		0.40
Groundwater level	>3 m	3	0.14	0.42
	1-3 m	2		0.28
	<1 m	1		0.14

The AHP method's parameters are the bearing capacity of the soil and rocks, depth of groundwater level, excavatability assessment, slope, and geological disaster vulnerability [13]. Each parameter has a different quality based on the sequence of the effect on engineering geology capability for settlement (Table 1).

3. RESULTS AND DISCUSSION

3.1 Engineering Geology of Research Area

Sandstone

Sandstone is the oldest among other rocks in the research area, and it is found in Kebo-Butak Formation [5]. Sandstone has a greyish black colour [14]. The massive property with moderate to a very coarse grain size of sand (1/2 – 2 mm). The composition of sandstone consists of lytic and crystal (quartz, plagioclase, and opaque minerals) [8] (Figure 1).

Rock strength with the point load method is 0.35 MPa, and the value of uniaxial compressive strength (UCS) of sandstone is 8.32 MPa. The excavatability assessment is in the criteria of easy digging with non-mechanical equipment [15]. The sandstone level of weathering is mild weathering (level II) [8]. GSI value of the sandstone is 47 with moderate rock mass quality [16], so it can be determined that the bearing capacity of sandstone is 135 tons/m2 [17].

Lapilli

The Lapilli is a member of the Semilir Formation exposed to be aligned above the sandstone of the Butak-Kebo Formation member [5]. Lapilli is greyish white colour [14], massive property. The texture of lapilli is 2-64 mm, white fragments, a matrix with fine sand size (1/16 -1/4 mm), and brownish grey. The composition of this rock consists of lytic and crystals (quartz, pyroxene).

Rock strength with point load method on fresh lapilli is 1.86 MPa, on soft weathered rock is 0.95 MPa. While the value of uniaxial compressive strength (UCS) of fresh lapilli is 44.65 MPa, and on the soft weathered rock is 22.81 MPa. The excavatability assessment is in the criteria of very difficult to ploughed, so it is necessary to use exposing [15]. The level of weathering on the lapilli is fresh (level I), mild weathered (level II), moderate weathered (level III) and highly weathered (level IV) [8]. GSI value of the lapilli is 58 with moderate rock mass quality [16], so it can be determined that lapilli's bearing capacity is 135 tons/m2 [17].

Tuffaceous sandstone

Tuffaceous sandstone consists of layers of tuffaceous sandstone and siltstone inserts [5]. Tuffaceous sandstone has brown colour [14] with massive properties. The grain size of tuffaceous sandstone is very fine to fine (1/16 - 1/4 mm) with good sorting. This tuffaceous sandstone composition consists of lytic, crystal (quartz), opaque mineral and matrix (mineral glass). Siltstone is greyish in colour and grain size of 1/256 – 1/16 mm.

Rock strength with point load method on fresh tuffaceous sandstone is 0.78 MPa, soft weathered rock is 0.35 MPa, and medium weathered rock is 0.14 MPa. While the value of uniaxial compressive strength (UCS) of fresh tuffaceous sandstone is 18.60 MPa, the soft weathered rock is 8.28 MPa, and on medium weathered rock is 3.36 MPa. The excavatability assessment is in the criteria of difficult to digging up to difficult to be ploughed, so it is necessary to use mechanical equipment [15]. The level of weathering on the lapilli is fresh (level I), mild weathering (level II), moderate weathering (level III) and high weathering (level IV) [8]. GSI value of tuffaceous sandstone is 32 with poor rock mass quality [16], so it can be determined that sandstone's bearing capacity is 45 tons/m2 [17].

Andesite breccias

Andesite breccias have andesitic igneous rock fragments and sandstone matrix. Andesite has a greyish colour [14], porphyritic texture, and crystal (hypocrystalline). The rock composition consists of phenocrysts in the form of quartz, plagioclase, and pyroxene, while the basic mass was in the form of mineral glass. The Andesite breccias matrix is sandstone with black colour [14], the grain size is very fine-very coarse (1/16-2 mm). The rock composition consists of lytic and crystal.

Rock strength with the point load method on andesite breccias is 1.13 MPa. The uniaxial compressive strength (UCS) of andesite breccias is 27.04 MPa. The excavatability assessment is in the criteria of difficulty, so it is necessary to use mechanical equipment [15]. The level of weathering on the andesite breccias is mild weathering (level II), moderate weathering (level III) and high weathering (level IV) [8]. GSI value of the average tuffaceous sandstone is 27 with poor rock mass quality [16], so it can be determined that sandstone's bearing capacity is 45 tons/m2 [17].

Sand deposit

Sand Deposits are the result of weathering of young Merapi volcano sediment [7]. Sand Deposit has a brownish colour and grain size of from fine to coarse [14]. The result of the grain size test indicates that this deposit unit's grain size is sand with the percentage of 50% sand-sized soil (passes the sieve with a diameter of 4.75 mm and

Sumatra Journal of Disaster, Geography and Geography Education June, 2023. Vol.7. No.1. pp. 1-8
Disaster, Geography, Geography Education http://sjdgge.ppj.unp.ac.id/index.php/Sjdgge
ISSN : 2580 - 4030 (Print) 2580 - 1775 (Online), Indonesia

restrained of 0.075 mm sieve). The sand deposit has a uniform soil size distribution [18]. DCP testing and the calculation of soil bearing capacity value on sand deposit is 11188-35067 kg/m2.

Sandy clay deposit

Sandy Clay Deposit has a greyish black colour [14]. The result of the grain size test indicates that the grain size of this deposit is clay with a percentage of >50% of silt and clay-sized soil (pass the sieve with diameter 0.075 mm) [18]. Based on the atterberg limit test, this soil can be classified as non-organic clay with a symbol of CL and low to medium plasticity, gravelly loam, sandy clay with a liquid limit of <50%. The bearing capacity value permitted on sandy clay deposits obtains a value between 6576-8626.67 kg/m2.

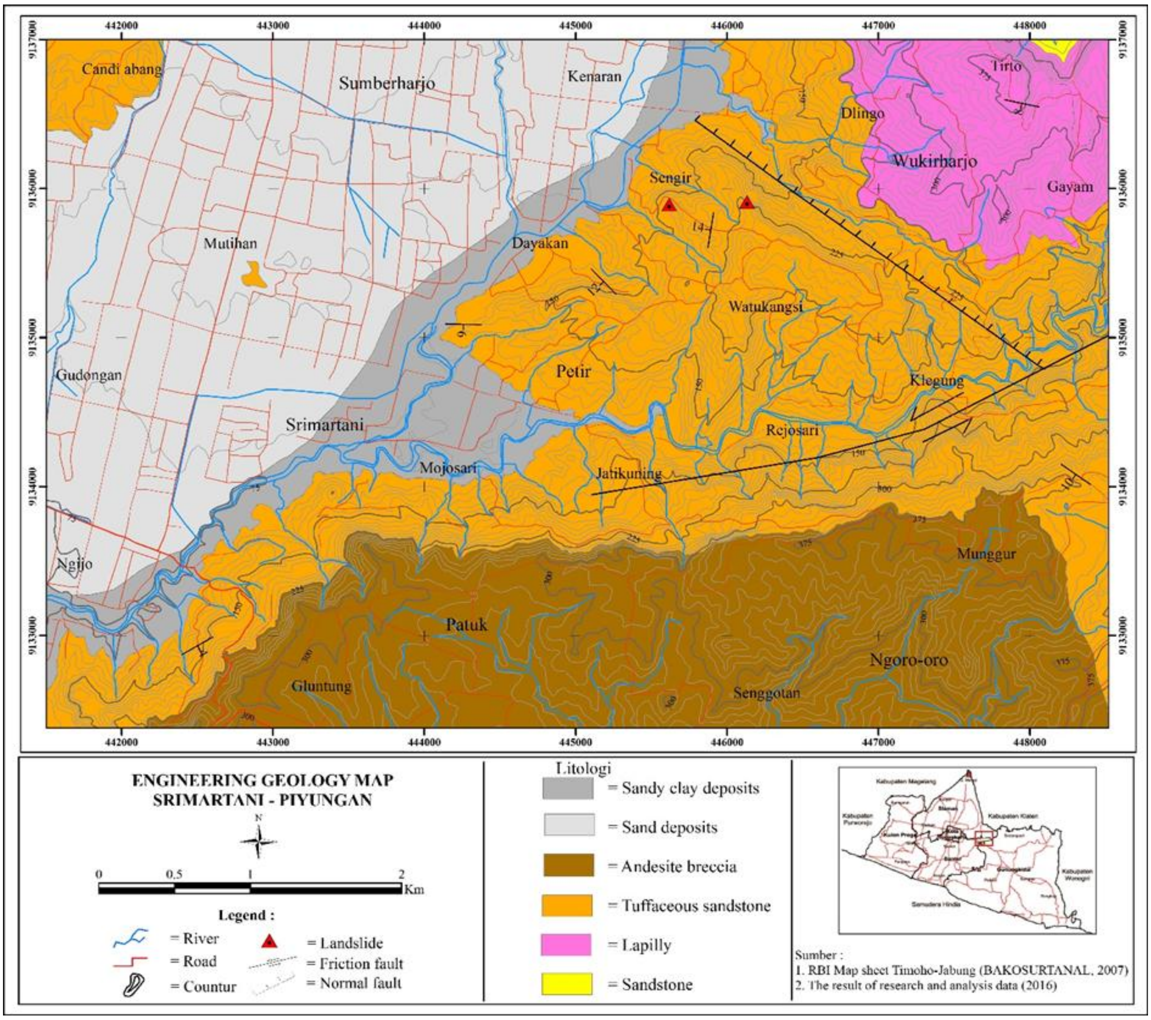

Fig. 1 Engineering Geology Map

3.2 Geological Structure

The geological structure of this area is a sinistral fault in the Nongko River (Kali Petir). The sinistral fault leads to the northeast-southeast [19]. The field investigation in the research area also found a shear joint on the observation location. The shear joint is revealed in tuffaceous sandstone (Figure 1).

3.3 Hydrogeology

The groundwater level distribution can determine the gradation of the groundwater level layer in the research area. Hilly area generally has a deeper groundwater level than a plain area [20].

3.4 Geological Disaster Vulnerability

Geological disaster vulnerabilities of research area according to BAPPEDA D.I. Yogyakarta [21] has the potential for flooding, landslides, and earthquakes. Flood vulnerability with medium potential has the morphology of sloping plains, while the low potential has the morphology of hills. Landslide vulnerability with high potential has a steep slope, medium potential has a slightly steep slope, while low potential has a low slope. Earthquake vulnerability with high potential has been affected by geological structure (faults) in the research area. The medium potential has a relatively close distance of the fault structure,

Sumatra Journal of Disaster, Geography and Geography Education June, 2023. Vol.7. No.1. pp. 1-8
Disaster, Geography, Geography Education http://sjdgge.ppj.unp.ac.id/index.php/Sjdgge
ISSN : 2580 - 4030 (Print) 2580 - 1775 (Online), Indonesia

whereas a low potential has a distance from the fault structure.

3.5 Zone of land capability for Settlement

The engineering geological zone's capability is based on an overlay of 5 (five) parameters (Figure 2), namely the bearing capacity of the soil and rocks, excavatability assessment, slope, depth of groundwater level, and geological disaster vulnerability.

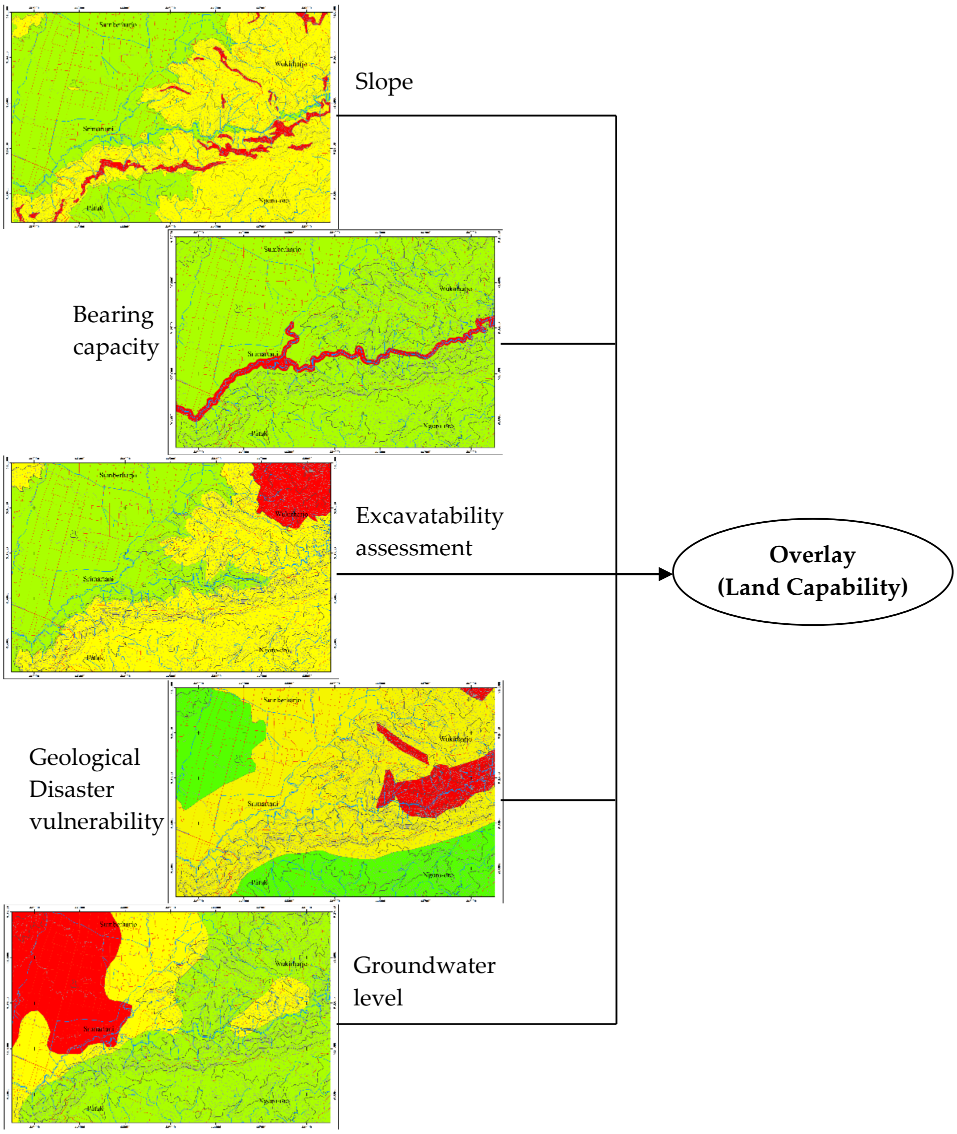

Fig. 2 Overlay parameters of land capability

Bearing Capacity of Soil and Rock

By assuming that the weight of a simple house is 1964 kg/m2, all the research areas have an adequate bearing capacity and the impassable terrain river, where the high bearing capacity of soil with the lowest value is sandy clay deposit value of 6576 kg/m2.

Excavatability Assessment

Excavatability assessment has 3 (three) classes based on relationship curves between point load index value and the distance between discontinuities [15], namely, easy to dig, hard to dig, and extremely hard to be ploughed, and the need of explosive.

Slope

The slope is divided into 3 (three) classes based on the ease of simple house construction work that is less than 8º, 8-30º, and more than 30º [22] [23].

Depth of Water Table

The depth of WT is divided into 3 (three) classes based on its effect on the construction of the foundation (0.8 m) and the construction of septic tank (3 m), that is: <1 m, 1-3 m, >3 m [24].

Geological Disaster Vulnerability (floods, landslides, and earthquakes)

Disaster vulnerability data is secondary data of the overlay result on disaster vulnerabilities of floods, landslides, and earthquakes issued by the Local Development Planning Agency of the Special Region of Yogyakarta [1]. Geological disaster vulnerability is divided into 3 (three) classes: low, medium, and high based on the disaster's intensity.

The overlay result of five parameters may generate the final score of the sum score for each parameter. The engineering geology capability for the settlement (Figure 3) in the research area is divided into 3 (three) classes: high, medium, and low based on the final score.

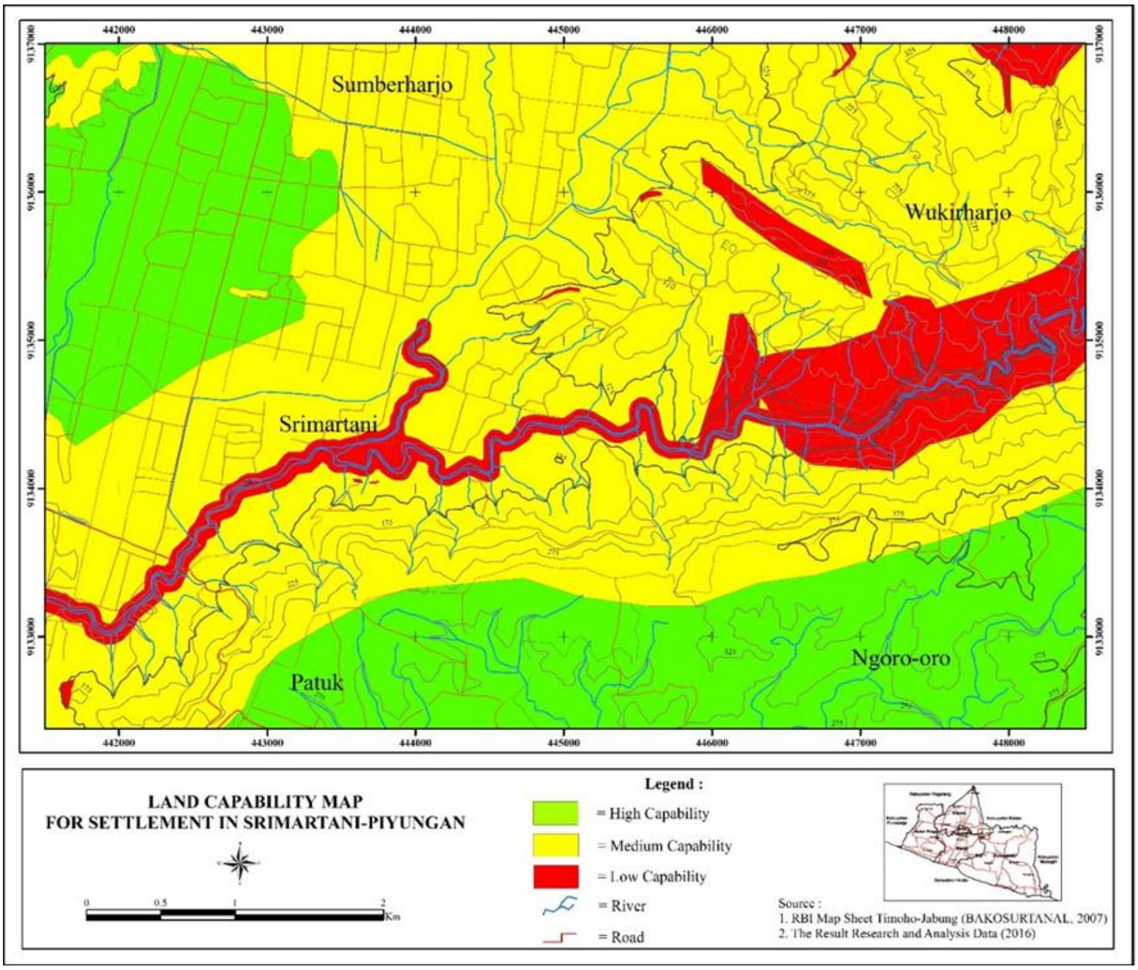

Fig. 3 Land Capability Map

1. High capability zone

Zone of land capability for high settlement has 33% of the total research area. Positive control of this zone is low disaster vulnerability, relatively gentle slope (<8º) and adequate bearing capacity of soil and rock (more than 1964 kg/m2). Negative control of this zone is the depth of groundwater level that is relatively less than 3 m. The area development for settlement can be implemented in this zone.

2. Medium capability zone

The capability of engineering geology zone for reasonable settlement has 45% of the total research area. The main positive control in the medium capability of engineering geology zone is low disaster vulnerability, the depth of groundwater level of >3 m and adequate bearing capacity of soil and rock (> 1964 kg/m2). This zone has the engineering geology capability for a quite good settlement in the plain area to be developed. The implementation of the construction needs more detailed investigation and appropriate geotechnical engineering in this zone.

3. Low capability zone

The capability of engineering geology zone for low settlement has 22% of the total research area.

The main negative control in the low capability of engineering geology zone is high geological disaster vulnerability, steep slope of more than 35º, and the excavatability assessment with medium value. This zone is not recommended for the development of residential areas.

3.6 Comparison Between Settlement Area and Land Capability

The land use of the Srimartani residential area and its surroundings based on the Indonesian Topography Map or Peta Rupa Bumi Indonesia [25] are mostly located in engineering geological capability zone for a medium level of settlement. Only small settlement areas (10%) are in low geological capability zone for the settlement. The settlement area in a medium level of engineering geological zone capability is in the area with a very low-low slope. The capability of engineering geology zone for high settlement is only used for the settlement of ±25% of the total high engineering geological capability zone.

4. CONCLUSION

Lithological condition in the research area consists of (from old to young): sandstone unit (qall=135 tons/m2), lapilli unit (qall=135 tons/m2), tuffaceous sandstone unit (qall=45 tons/m2), andesite breccias unit (qall=45 tons/m2), sand deposit (qall=11 tons/m2), and sandy clay deposit (qall=6.5 tons/m2). The study area has been classified into three zones:

1. High capability in the plain has an area of 33% spreading in the northwest and south part.
2. The medium capability has an area of 45% spreading from the northeast-southwest part.
3. The low capability has an area of 22% in the central part of the research area.

5. ACKNOWLEDGEMENTS

We want to thank The Department of Geological Engineering, Universitas Gadjah Mada, for supporting and facilitating this research and the Department of Geological Engineering, Universitas Jenderal Soedirman, who is also acknowledged for providing working place.

6. REFERENCES

[1] Badan Pusat Statistik D.I. Yogyakarta. D. I. Yogyakarta Dalam Angka Tahun 2013. Badan Pusat Statistik Provinsi D I Yogyakarta. Yogyakarta, 2014.

[2] van Bemmelen, R.W. The Geology of Indonesia. Martinus Nijhoff The Hague, 1949.

[3] Bronto, S. and Hartono, H.G. Panduan Ekskursi Geologi Kuliah Lapangan 2. STTNAS: Yogyakarta, 2001.

[4] Rahardjo, W., Sukandarrumidi, and Rosidi, H.M.D. Peta Geologi Lembar Yogyakarta, Jawa, Skala 1:100.000. Pusat Penelitian dan Pengembangan Geologi. Bandung, 1995.

[5] Surono, Toha, B., and Sudarno, I. Peta Geologi Lembar Surakarta- Giritontro, Jawa, Skala 1:100.000. Pusat Penelitian dan Pengembangan Geologi. Bandung, 1992.

[6] Bronto, S., Mulyaningsih, S., Hartono, H.G., and Astuti, B. Gunung Api Purba Watuadeg: Sumber erupsi dan posisi stratigrafi. Jurnal Geologi Indonesia, 2008.

[7] Sugiyanto and Hermawan. Peta Geologi Teknik Daerah Yogyakarta, Klaten dan Sekitarnya. Pusat Lingkungan Geologi. Bandung, 2006.

[8] Dearman, W.R. Engineering Geological Mapping. Butterworth-Heinemann Ltd. Oxford: United Kingdom, 1991.

[9] Hoek, E., Strength of Rock, and Rock Masses, ISRM News Journal, 2(2), 4-16., 1994.

[10] Amini, Farshad. Potential Applications of Dynamic and Static Cone Penetrometers in MDOT Pavement Design and Construction. Department of Civil Engineering, Jackson State University, 2003.

[11] Zaenurrohman, J.A., and Permanajati, I. Zona Kerentanan Gerakan Tanah (Longsor) Di Daerah Kedungbanteng Menggunakan Analytical Hierarchy Process (AHP). Prosiding Seminar Nasional dan Call for Papers. LPPM Universitas Jenderal Soedirman Vol. 9 No. 1, 2019.

[12] Saaty, T. L. The Analytic Hierarchy Process. McGraw-Hill, New York. (This book has been translated into Chinese by S. Xu et al.; information is available from them at the Inst. of Systems Engineering. Tianjin Univ., Tianjin, China.) (A translation into Russian by R. Vachnadze is currently underway), 1980.

[13] Zaenurrohman, J.A., Irawan, J.F., Permanajati, I., and Iswahyudi, S. Tata Kelola Taman Nasional Meru Betiri (TNMB) Berdasarkan Aspek Geologi Lingkungan. Jurnal Tanah dan Sumberdaya Lahan. Universitas Brawijaya Vol. 7 No. 1, 2020.

[14] Munsell, A.H.. Munsell Soil Color Book. Grand Rapids (US): X-Rite, 2009.

[15] Pettifer, G.S. and Fookes, P.G. A Revision of The Graphical Method For Assessing The Excavatability of Rock. Quarterly Journal of Engineering Geology 27, 1994, pp. 145–164.

[16] Marinos, P. and Hoek, E. Estimating The Mechanical Properties Of Heterogeneous Rock Masses Such As Flysh. Bulletin of Engineering Geology and the Environment 60, 2001, pp. 85-92.

[17] Bieniawski, Z.T. Engineering Rock Mass Classifications. John Wiley and Sons. New York, 1989.

[18] Das, M.B. Advanced Soil Mechanics. Hemisphere Publishing Corporation and McGraw-Hill. New York: USA, 1983.

[19] Ismail, K. and Pramumijoyo, S. Karakteristik Sesar Kali Petir dan Sekitarnya Kecamatan Prambanan, Kabupaten Sleman. Daerah Istimewa Yogyakara. Procedding Seminar Nasional Kebumian Ke-8, Yogyakarta, 2015.

[20] Kristanto, W.A.D. Karakteristik Geologi Teknik Daerah Prambanan dan Sekitarnya, Kecamatan Prambanan, Daerah Istimewa Yogyakarta Jurnal Technology of Civil, Electrical, Mechanical, Geology, Mining, and Urban Design Vol. 3 No. 2, 2018.

[21] Badan Perencanaan dan Pembangunan Daerah D.I. Yogyakarta. Potensi Bencana Geologi Provinsi D.I. Yogyakarta. Yogyakarta, 2008.

[22] Phyu, H.T., Hendrayana, H., Indrawan, I.G.B., and Kamai, T. Simulation of Kalirejo Roadside Slope based on Altered Andesite Characters, Kulon Progo Regency, Indonesia. Journal of Applied Geology. vol. 5(2), 2020, pp. 101–112.

[23] Montello, D. R. A new framework for understanding the acquistion of spatial knowledge in large-scale environments. In Spatial and Temporal Reasoning in Geographic Information Systems. M. J. Egenhofer and R. G. Golledge, Eds. Oxford University Press. New York 1998. ch. 11, 1983, pp. 143–154.

[24] Utami, T.E. and Sutarjan, W. Rancangan Aplikasi SIG untuk Pembuatan Peta Zona Kemampuan Geologi Teknik: Studi Kasus Daerah Jember Skala 1:100.000. Buletin Geologi Tata Lingkungan V.11 No. 4, 2000, pp.179-184.

[25] BAKOSURTANAL. Rupa Bumi Indonesia, Badan Koordinasi Survey dan Pemetaan Nasional. Jakarta, 2001.