Water Holding Capacity of Karst Valley Soil in Gunungsewu Karst Landscape, Indonesia

Eko Budiyanto[1], Nugroho Hari Purnomo[1], Muzayanah[1], Aida Kurniawati[1], Muhammad Alfaruqi[1], and Nova Kamelia Syazwana[1]

[1] Geography Education-Social Science and Law Faculty-Unesa, Surabaya, Indonesia
ekobudiyanto@unesa.ac.id

Abstract. The eastern Gunungsewu karst landscape generally has characteristics that are vulnerable to environmental degradation problems. Soil is one of the natural elements that can be a protector against the potential threat of degradation. Water holding capacity is an important factor that must be considered in efforts to preserve soil and control its continued impacts. This study aims to determine the nature of soil hydraulics in the Gunungsewu karst valley from the parameters of water holding capacity. The study population is the bottom soil of the karst valley located in the western, central and eastern Gunungsewu karst region located in Gunungkidul Regency – Yogyakarta Special Region Province, Indonesia. The test results showed that the water holding capacity value of karst valley bottom soil ranged from 76% to 96% with an average of 85.33%. Spatially, there are differences in the large pattern of water holding capacity values in the Gunungsewu karst area. The water holding capacity value of the western Gunungsewu karst valley soil is generally higher than the central and eastern parts. On the north side, the central and eastern Gunungsewu karst areas generally have a higher water holding capacity value than the south side.

Keywords: Water Holding Capacity, Gunungsewu karst, soil

1 Introduction

Karst landforms are formed by carbonate rocks that are easily dissolved by acidic water [1–6]. The process of dissolving carbonate rocks will intensify with the higher concentration of CO2 in water [4]. This CO2 comes from the scattering of CO2 in the atmosphere bound by rainwater and also from the decomposition of organic matter in the soil [7]. The nature of carbonate rocks that are easily soluble results in the weathering process into soil does not occur much in the karst region. The conclusion of [8] shows that most of the soil that develops in the Gunungsewu karst region does not come from bedrock. The development of soil derived from bedrock in this region only occurs in areas in the form of layered limestone. This shows that soil development does not occur much in karst landscapes such as the Gunungsewu karst.

The land in the Gunungsewu karst area is currently under threat due to erosion and intensive population activities [9]. The impact of this is the emergence of soil not

A. Mustofa et al. (eds.), *Proceedings of the International Joint Conference on Arts and Humanities 2023 (IJCAH 2023)*, Advances in Social Science, Education and Humanities Research 785,
https://doi.org/10.2991/978-2-38476-152-4_159

protected by vegetation, thin soil layers, and rock outcrops (rock desertification). Karst soil erosion increases in line with the rain that hits the soil directly. The conclusion of [10] shows that at this time there is an increase in rainfall intensity in the Gunungsewu karst area. Rain of varying intensities that falls on the karst soil surface will be partially infiltrated into soil aggregates [11]. Findings from [12] suggest that low-intensity rain produces erosion in the form of dissolved particles in underground water streams. While high-intensity rain will form erosion in the form of dissolved particles and grain erosion on the surface.

The soil in the Gunungsewu karst area is proven to contain a lot of clay texture [7]. Soils with clay texture tend to have a higher level of water holding capacity [13]. This results in a lot of water being trapped by karst soil. Soil moisture persists for a relatively longer time, because water is firmly bound by soil particles. However, the presence of water in karst soils can trigger high wrinkles. The higher clay content in karst soils has been shown to increase the potential for soil development when it meets water [14,15]. The nature of soil wrinkles can result in difficulties in technical soil use on the land [16,17,18]. The problem of land utilization is not only in the use related to buildings, but also in maintaining soil fertility for agriculture.

Soil has a very important role for the karst environment. The soil covers many holes that are naturally formed because the nature of bedrock is easily dissolved by acidic water. Surface water is bound by soil grains and prevents contaminants from entering the karst underground water system. The filtration ability will increase with the thickness of this soil layer.

In line with the above conditions, the land in the Gunungsewu karst area really needs protection and preservation efforts. Meanwhile, land utilization has developed intensively for both residential and agricultural purposes. Based on this, to support soil conservation efforts, it is necessary to understand soil properties, especially related and water holding capacity that exists in Gunungsewu karst lands. Therefore, this study aims to examine the size of soil water holding capacity at the bottom of the karst valley in the Gunungsewu karst region.

2 Method

2.1 Population and Sample

The population in this study is karst soil scattered on the bottom of the karst valley in the Gunungsewu karst area. Samples were taken from the eastern, central and western Gunungsewu karst valleys. Each of these parts was taken five sample locations, so that a total of fifteen samples were obtained. The coordinates of the sample location were planned based on multispectral imagery 5-4-3 from the most recent Landsat 9 OLI imagery. Identification of open karst land areas was carried out using digital analysis on band 4 imagery. The area of open karst land is specified in the pixel area with a value greater than 0.05 in the band 4 imagery pixel. Identification is strengthened through visual interpretation of multispectral imagery and contour analysis. The contour map is derived from SRTM image data that has been transformed into the UTM WGS 84 Zone 49S system. The sampling site plan is shown in Table 1.

Table 1. Sampling site Plan

Sample	Coordinates	
	x	y
S1	470777	9121253
S2	472910	9117650
S3	472528	9111468
S4	467980	9098279
S5	465272	9108029
S6	449096	9109071
S7	450063	9103547
S8	455670	9100522
S9	459673	9103051
S10	458457	9108357
S11	429654	9113246
S12	429790	9116399
S13	433684	9114927
S14	439109	9107155
S15	442315	9111843

The determination of the sampling point is done through the interpretation of the image by finding the location of the open karst valley floor, spatially dispersed, and easily accessible. The sample soil is surface soil at the bottom of the karst basin valley. Soil samples are taken at each sample point, either peaks, slopes or the bottom of karst valleys. Soil samples are taken at a depth of 0 to 10 cm from the surface. This sample is taken to the laboratory to be used as a basis for calculating water holding capacity.

2.2 Analysis

Water holding capacity measurement is carried out on soil samples from the field. This stage is carried out by heating the sample soil aggregate using an oven. The dry sample soil aggregate is then crushed into fine grains. The weight of the soil used for measurement is 25 grams per sample. The amount of water used for measurement is 50 ml per sample. Dry sample soil is placed on filter paper in a funnel above the measuring tube. Water is poured over the soil of the sample. Some of the water will go down through the ground and filter on the funnel to the tube. The water collected in the tube is measured. Furthermore, the measurement of water holding capacity uses the following formulation.

$$WHC = ((V1 - V2) / W) * 100\% \quad (1)$$

Information :

WHC : water holding capacity
V1 : weight of water used for measurement
V2 : weight of water accommodated in the cylinder after percolation
W : sample soil weight

The results of measuring water holding capacity using process units. This percentage value describes the amount of water that the soil can hold under normal gravity conditions. The description of soil color is based on the results of visual observations on the sample soil. Observations were made on soil samples that had been drained. The analysis is directed to obtain data on soil color and brightness. The results of the analysis are used to add and complete information on soil characteristics in the karst valley of the location.

Spatial analysis of the distribution of water holding capacity values was carried out using GIS devices. The water holding capacity value of each sample location was mapped and diovelay with Landsat OLI 9 satellite image data. The sample location is depicted using the dot symbol according to the coordinates of the sampling location. The value of water holding capacity at each sample location is visualized with color gradation. Spatial analysis was carried out based on the distribution pattern of water holding capacity values throughout the western, central, and eastern Gunungsewu karst areas. Morphological analysis was carried out based on the interpretation of SRTM image data. This image data is used to obtain elevation data of the sampling location and contour maps of the Gunungsewu karst area.

3 Result and Discussion

3.1 Results

The eastern part of the Gunungsewu karst which is included in the Gunungkidul Regency area is spread towards the north south. This area includes the Gunungsewu karst in eastern Kapanewon Ponjong, Rongkop, Girisubo, Semanu, and Tepus. The north side has a higher average elevation than the south side. The northern end meets the Panggung Massive volcanic landscape. The land in the karst valley of this area is generally agricultural land with sparse vegetation. The amount of water holding capacity at this location is indicated by five samples symbolized S1 to S5. The location of the S1a sample is located on the north side, while the location of the S4 sample is located on the southernmost side of the eastern Gunungsewu karst.

Analysis of soil color showed that soils from S1 samples were red, while soils from S2, S3, S4, and S5 samples tended to be bright brown. The soil from sample S4, which is the southernmost sampling location, has the brightest brown color compared to the other samples. This indicates that there may be differences in the processes and elements forming the soil. The soil at the S1 sample site has a crumb structure with a smooth texture compared to other locations. Soils from S2, S3, S4, and S5 sample sites tend to have firmer crumb structures with a more rounded texture.

Based on the analysis of SRTM image data, it is known that the elevation of the location of samples S1 to S5 has successively a height of 332 meters, 424 meters, 389 meters, 223 meters, and 308 meters above sea level. Based on these data, it can be known that the highest sampling location is in the S2 sample and the lowest location is in the S4a sample. The results of SRTM image analysis also show that the morphology of karst valleys in samples S1, S2, S3, and S5 has characteristics interconnected with other karst valleys. The morphology of the karst valley at the sample location forms an elongated and terraced valley pattern in the direction of the slope. The morphology at the S4 sample site tends to form a separate basin pattern. The karst valley is separated by the surrounding karst hillsides. The hilly slopes in the S1 sampling location area tend to slope to steep with a large height difference between the peak and the valley floor. This condition is different from the hillsides in the sampling locations S2, S3, S4 and S5 which tend to vary. The calculation of the water holding capacity value of the eastern Gunungsewu karst area is shown in Fig. 1.

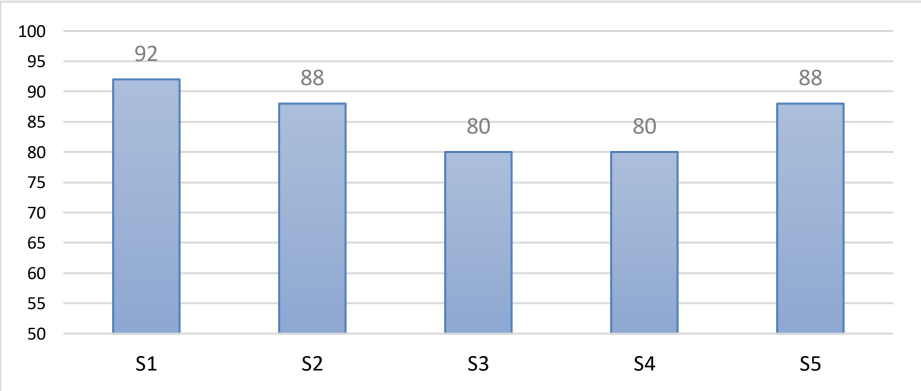

Fig. 1. Water holding capacity of eastern part of the Gunungsewu karst area

The calculation results show that the amount of water holding capacity ranges from 80% to 92% with an average of 85.6%. The lowest values are in S3 and S4 samples while the highest values come from S1 samples. The trend line in Figure 1 shows a downward trend from the location of sample S1 to sample S5. Spatially, this means that there is a decrease in the value of water holding capacity from north to south in the eastern Gunungsewu karst area. Based on this value, it means that the soils at the bottom of the karst valley on the north side of the eastern Gunungsewu karst have a higher water-binding ability than the soils in the karst valley on the south side.

The calculation of the value of water holding capacity in the central Gunungsewu karst area is based on sample values with codes S6 to S10. Geographically, the location of samples S6 and S10 is on the north side of the central Gunungsewu karst area. The southernmost sample location is the S8 sample, while the S7 and S9 samples are located in the middle between the north and south sides of this Gunungsewu karst. The floor elevation of the karst valley sampling locations was 287 meters, 210 meters, 26 meters, 92 meters, and 266 meters above sea level. The data shows that the karst valley area on the north side generally has a higher elevation than the south side. Based on SRTM image data, it is shown that the elevation of the central Gunungsewu karst area is generally relatively lower than the western and eastern ends of the Gunungsewu karst. All samples in this area were taken at the bottom of karst valleys, all of which functioned as agricultural land. The majority of land conditions are open and there is very little vegetation. This is because there is no water source that can be used for irrigation of agricultural crops in that place.

The morphology of karst valleys is in the form of basins between karst hills with an elongated shape on the north side with relatively steep slopes. This condition is different from the morphology of the karst valley on the south side around from the S8 sample which has a relatively larger area with varying hillside walls. In the southern side area, especially close to the coast, there are many small karst hills separated by karst valleys. Soils from samples S6 and S10 representing the north side area have a redder color than soils from samples S7, S8, and S9. The soil from the S7, S8, and S9 samples is brownish-red. The characteristics of the soil structure are in harmony with the color of the soil. Soils derived from S6 and S10 samples have a more crumbly structure compared to soils from S7, S8, and S9 sampling locations. Soil grains at sampling sites S6 and S10 are more easily destroyed when dry. The graph of the water holding capacity value of the central Gunungsewu karst area can be seen in Fig. 2.

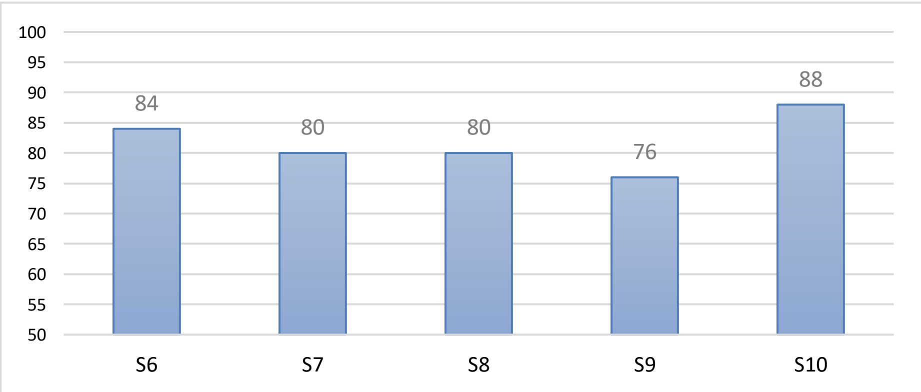

Fig. 2. Water holding capacity of center part of the Gunungsewu karst area

The value of water holding capacity in this area is spread between 76% to 88% with an average of 81.6%. The lowest water holding capacity value is found at the S9 sample location, while the highest value is at the S10 sample location. Fig. 2 shows that the water holding capacity value of sampling on the north side is relatively higher than sampling from the south side of the central Gunungsewu karst area. The S9 sample, which has the lowest water holding capacity value, comes from a closed karst basin valley surrounded by elongated karst hills with relatively dense canopy vegetation cover.

The water holding capacity level of the western Gunungsewu karst valley soil is known from samples S11, S12, S13, S14, and S15. The elevation of the sample locations was 314 meters, 197 meters, 279 meters, 385 meters, and 307 meters above sea level. The south side of this section is shown by samples S12 and S13, while the north side is shown by samples S11, S14, and S15. The elevation data shows that the western Gunungsewu karst landscape tends to slope towards the south. Multispectral image data from Landsat 9 OLI images shows a wider area of dense canopy vegetation cover than the central and eastern parts of the Gunungsewu karst. This condition covers the sample area S12 and S14. The hilly slopes around the karst valley have a lot of tall and dense woody vegetation. The type of vegetation on the north side is more varied and dense than the south side.

Based on field observations, it is clearly known that the morphology of the location of the sample on the south side and the north side has clear differences. The karst valley on the north side of the western Gunungsewu karst area is generally deeper and steeper. Karst hills have a larger size and height. Karst valleys form a single basin pattern on the south side and are partially elongated. Many hillsides are in the form of artificial terraces that are used to form agricultural land. The soil at the S12 sample site has a red-brown color with a crumb structure, easily crushed with a fine texture. The soil in the S11 sample has a bright brown red color, but is relatively firmer and not easily broken compared to the soil from the S13 and S14 sample locations has a dark dark brown color with a blocky and firm structure. Meanwhile, the soil at the S15 sample location has a dark brown color with a blocky structure and is firm and not easily destroyed. The data shows that further westward, the soil color at the bottom of the Gunungsewu karst valley is darker, especially on the north side of this region. This condition seems to be in aligns with the condition of denser vegetation cover on the north west side of this karst region. This area has a lot of woody vegetation with a dense canopy. The value of soil water holding capacity in the western Gunungsewu karst valley can be seen in Fig. 3.

Fig. 3. Water holding capacity of western part of the Gunungsewu karst area

The western Gunungsewu karst area has a water holding capacity level between 84% and 96%. The average value of water holding capacity in this area is 88,8%. The lowest water holding capacity value is found in the S11 and the S13 sample location. The highest level of water holding capacity is found in the S15 sample location areas. The S15 sample location is the north side sample location of this area. The lower value is found in the location of the S14 sample which is also on the north side of the western Gunungsewu karst area. The S12 and S14 sample sites are surrounded by karst hillsides with dense, tall woody vegetation. The slope is in the form of an artificial terrace, some of which are used as agricultural land.

Mapping all water holding capacity sample values in the eastern, central and western Gunungsewu karst areas provides an overview of the characteristics of the ability of karst valley soils in Gunungsewu to bind water. Based on the map, it is known that the largest level of water holding capacity is in the western Gunungsewu karst area. In the central and eastern Gunungsewu karst areas, there is a tendency to differ in the level of ability of karst valley soils to bind water. The ability of karst valley soils to bind water tends to be in the northern side area of the central and eastern Gunungsewu karst region. Further south, the level of water holding capacity seems to tend to decrease. Map of Gunungsewu karst water holding capacity level can be seen in Fig. 4.

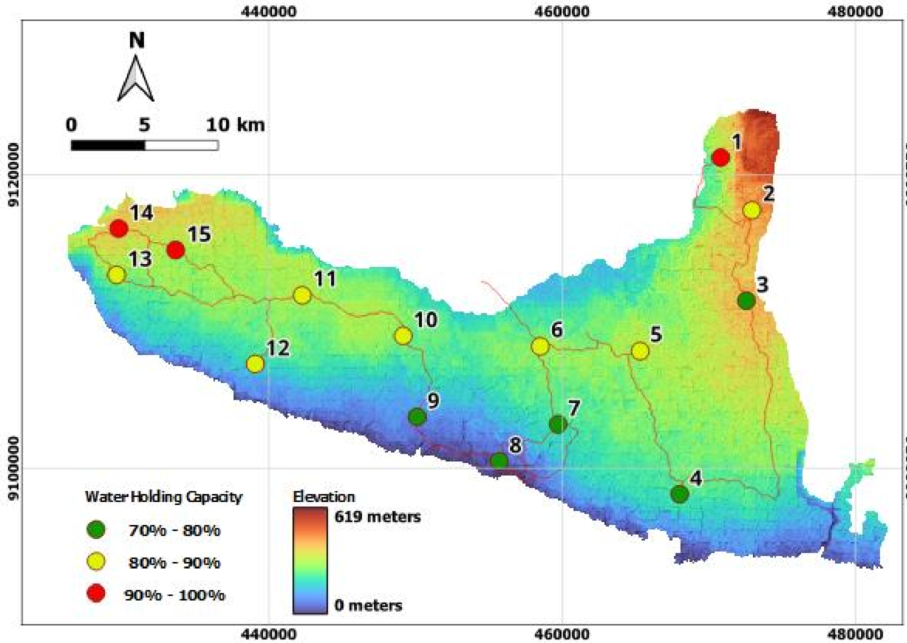

Fig. 4. Water holding capacity of Gunungsewu karst valley soil

Fig. 4. shows the location of all samples from east, central to west Gunungsewu. The image used on Fig. 4. is a SRTM image. Karst areas with low elevation are symbolized by blue, while high elevation is symbolized by red brown. The water holding capacity level of the sample soil is symbolized by green, yellow and red dots. The sample with the green dot symbol has the lowest water holding capacity level, while the red color is the highest water holding capacity level symbol. Based on the picture, it is clearly known the level of water holding capacity of each sample. The value of water holding capacity ranges from 76% to 96%. The lowest value of 76%

was found in samples S9. These two samples are spatially located on the south side of the central Gunungsewu karst. The highest water holding capacity value is found in S15 samples that enter the western Gunungsewu karst area.

3.2 Discussion

Karst Gunungsewu has many karst valleys which are mostly used as agricultural land by residents. The morphology of the Gunungsewu karst valley varies related to its shape and size [19]. The land at the bottom of the karst valley is the main land for agricultural activities and partly for settlement [9]. Agricultural activities on land at the bottom of the karst valley are mostly carried out during the rainy season or there is water as a source of irrigation .

The ability of the soil to store water in the Gunungsewu karst valley has different characteristics between the western, central and eastern parts. However, the entire Gunungsewu karst area is classified as having a high level of water holding capacity. This condition is possible with the high clay content in the soil in the Gunungsewu karst valley. The presence of a high clay content has been stated in [8,14]. Soils in karst valleys have kaolinite type, while soils in karst hilltops have haloysite type [8]. References [14,20,21] have explained the effect of clay content on increasing the value of water holding capacity. The ability of the soil in the high karst valley of Gunungsewu is very useful in relation to the function of the soil as agricultural crop media, karst subsurface water infiltration media and a pollutant filtration agent from the surface.

The soil in the western Gunungsewu karst valley tends to have a relatively higher level of water holding capacity than the central and eastern parts. This condition is possible in line with the condition of variation and denser vegetation cover in the region. This is in line with the conclusion of [22] which states the organic maters applications into the soil improve the soil water holding capacity. There are variations in woody vegetation with high density in the western Gunungsewu karst area, especially on the north side. Woody plants grow a lot on the slopes of karst hills surrounding karst valleys. Leaf fall from the vegetation turns into humus and disperses to the soil at the bottom of the karst valley which further increases the organic matter content in the soil. Jati is a plant that is widely found throughout the karst region of Gunungsewu. Vegetation in the western Gunungsewu karst region has a variety of types such as beringin, mahoni, eucalyptus, and sengon. Several types of fruit plants such as mango and jackfruit are found on the slopes of karst hills.

The distribution of water holding capacity levels in the central and eastern Gunungsewu karst areas has a different tendency from the western part. A relatively higher level of water holding capacity is spread on the north side of the region. This is in harmony with the structure and soil texture of the karst valley floor in the region. The soil on the north side tends to be more crumbly with a finer texture than the soil on the south side. The alignment of the level of soil water holding capacity with structure and texture is in line with the explanation [21] which states that water holding capacity is influenced by soil structure and texture. Soils with crumb, porous, and fine-textured structures have a greater degree of water-storing ability. The bottom soil of the central and eastern Gunungsewu karst valley on the south side, which is geographically close to the coast, has a relatively lower water holding capacity. This condition is possible due to the lower vegetation cover compared to the northern side of this region. This results in lower organic content in the soil along the southern side of the region.

4 Conclusion

The soil in the Gunungsewu karst valley has a high level of water holding capacity. The soil in the western Gunungsewu karst valley has a relatively higher water holding capacity level than the central and eastern parts. In general, the bottom soil of the karst valley which has a high level of water holding capacity is spread on the north side of the Gunungsewu karst area.

Acknowledgment
This research is funded by Unesa's Non-APBN funds in 2023 through the Unesa Rector's Decree Number B/31855/UN38. III.1/LT.00/2023.

References

1. de Waele, J.: Karst processes and landforms, The International Encyclopedia of Geography. John Wiley & Sons, London (2017).
2. White, W.B.: Geomorphology and Hydrology of Karst Terrain. Oxford University Press, New York (1988).
3. Ford, D.C., Williams, P.: Karst Hydrogeology and Geomorphology. John Wiley & Sons, Chichester (2007).
4. Adji, T.N.: Agresivitas Airtanah Karst Sungai Bawah Tanah Bribin Gunung Sewu. Cave and Karst Journal 1(1), (2003).
5. Endah, R., Yoseph, B., Sukiyah, E., Setiawan, T.: Karakteristik Sistem Hidrogeologi Karst Berdasarkan Analisis Hidrokimia Di Teluk Mayalibit, Raja Ampat. Bulletin of Scientific Contribution 15(3), 217 – 222(2017).
6. Parise, M., Grabrovsec, F., Kaufmann, G., Ravbar, N.: Recent advances in karst research: from theory to fieldwork and applications. Geological Society 466, 1–24(-).
7. Haryono, E.: Introduction to Gunungsewu Karst. In: Field Guide Asian Trans-Diciplinary Karst Conference, Faculty of Geography Universitas Gadjah Mada, Yogyakarta (2011).
8. Mulyanto, D.: Studi Ketidak Selarasan Antara Tanah dan Batuan Karbonat yang Membawahinya pada Jalur Baron – Wonosari Gunungkidul. Agrin 12(2), 180-190(2008).
9. Sunkar, A.: Forestation and Rocky Desertification Processes in Gunung Sewu Karst Landscape. Media Konservasi 13(3), 1-7(2008).
10. Cahyadi, A., Haryono, E., Adji, T.N., Widyastuti, M., Riyanto, I.A., Muhammad, D.T.N., Tastian, N.F.: Rainfall Variability in Gunung Sewu Karst Area, Java Island, Indonesia. Indonesian Journal of Forestry Research 8(1), 23-35(2021).

11. Khaerudin, D.N., Rispiningtati, Suharyanto, A., Harisuseno, A.: Infiltration Rate for Rainfall and Runoff Process with Bulk Density Soil and Slope Variation in Laboratory Experiment. Nature Environment and Pollution Technology 16(1), 219-224(2017).
12. Dai, Q., Liu, Z., Shao, H., Yang, Z.: Karst bare slope soil erosion and soil quality: a simulation case study. Solid Earth 6, 985–995(2015).
13. Li, H., Zhang, Z., Zhai, J., Yang, L., Long, H.: Correlation between Soil Structural Parameters and Soil Adhesion Based on Water Film Theory. Coatings 12(1743), 2-14(2022).
14. Sunarminto, H., Santosa, H.: Daya Mengembang dan Mengerut Montmorillonit I: Pengaruh Intensitas Curah-Embun Terhadap Pengolahan Tanah Vertisol di Kecamatan Tepus dan Playen, Pegunungan Seribu Wonosari - Riset Laboratorium. AGRITECH 28(1), (2008).
15. Tong, K., Guo, J., Chen, S., Yu, S., Li, S., Dai, Z.: A Simulation Study on the Swelling and Shrinking Behaviors of Nanosized Montmorillonite Based on Monte Carlo and Molecular Dynamics. Geofluids, 1-13(2021).
16. Widomski, M.K., Stępniewski, W., Horn, R., Bieganowski, A., Gazda, L., Franus, M., Pawłowska, M.: Shrink-swell potential, hydraulic conductivity and geotechnical properties of clay materials for landfill liner construction. Int. Agrophys. 29, 365-375(2015).
17. Christodoulias, J.: Engineering Properties and Shrinkage Limit of Swelling Soils in Greece. J Earth Sci Clim Change 6(5), 2–6(2015).
18. Bala, J., Patel, J.: Swelling And Shrinkage Phenomena in Soils. IIP Proceedings 2. Book 9, Chapter 25, 339-346(2022).
19. Haryono, E., Day, M.: Landform differentiation within the Gunung Kidul kegelkarst, Java, Indonesia. Journal of Cave and Karst Studies 66(2), 62-69(2004).
20. Sabareeshwari, V., Balasubramaniam, P., Geethalakshmi, V., Senthilraja, K.,: Assessment of water holding capacity of major soil series of Ponnaniyar reservoir Basin, Manapparai, Trichy, Tamil Nadu, India. Research Journal of Agricultural Sciences 9(9), 1333-1335(2018).
21. Xiu-kang, W., Xing-chao, Q., Yan-li, L., Zhi-guang, L., Fu-peng, S., Cheng-liang, L.: Soil structure and its effect on soil water holding property under three land use patterns in piedmont plain of mountain Tai. Journal of Natural Resources 33(1), 63-74(2018).
22. Leu, J., Traore, S., Wang, Y., and Kan, C.: The effect of organic matter amendment on soil water holding capacity change for irrigation water saving: Case study in Shelian environment of Africa. Scientific Research and Essays 5(23), 2554-3571(2010).