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Physical and Hydraulic Properties of Soil in Flooding Areas, Shah Alam, Malaysia

(Sifat Fizikal dan Hidraulik Tanah di Kawasan Banjir, Shah Alam, Malaysia)

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ABSTRACT

Floods is a major concern in Shah Alam, Malaysia, affecting communities in terms of duration, frequency and impact. Knowing the nature of the soil and the rate of infiltration can help predict the rate at which water enters the soil, thus, providing information for better flood management. The purpose of this study was to characterize the physical and hydraulic properties of soil in flooding areas. Natural land areas along the banks of Sungai Klang was selected, where this river plays an important role in flooding in Shah Alam. The subsurface lithological layer was developed from the interpretation of borehole log data. The disturbed sample was taken using hand augers until it reached the water table, and a standpipe was installed at each location for water table measurement. The infiltration rate is determined using a double-ring infiltrometer. The results showed that the soil types in the eight study locations were dominated by sand and silt, with shallow water tables. The groundwater level fluctuated during high and low rainfall. Infiltration rates vary, with L1, L2, and L6 having rates of 108 mm/h to 179 mm/h, while L3, L4, L5, L7, and L8 have rates from 60 mm/h to 75 mm/h. Time to soil saturation varies. In dry conditions, all locations take 10 to 25 h for soil to reach saturation level except at L6. During the rainy season, saturation was reached in 2 to 5 h, except for L1, L5, L7 and L8, which took 7 to 10 h.

Keywords: Flood; groundwater-surface water interaction; physical and hydraulic properties of soil; potential of flood

ABSTRAK

Bencana banjir merupakan antara masalah utama di Shah Alam, Malaysia; yang telah meninggalkan impak yang besar terhadap komuniti dari segi tempoh dan kekerapan banjir berlaku. Dengan mengetahui sifat fizikal tanah dan kadar penyusupan air permukaan ke dalam tanah dapat memberikan maklumat untuk pengurusan banjir yang lebih baik. Justeru, kajian ini adalah untuk mencirikan sifat fizikal dan hidraulik tanah di kawasan banjir. Beberapa lokasi banjir di sepanjang tebing (semula jadi) Sungai Klang telah dipilih dengan lapisan litologi subpermukaan dibangunkan daripada tafsiran data log lubang gerudi. Sampel yang terganggu diambil menggunakan auger tangan sehingga mencapai paras air bawah tanah dan paip PVC berslot dimasukkan ke dalam lubang gerudi di setiap lokasi untuk pemantauan paras air bawah tanah. Kadar penyusupan ditentukan menggunakan gelung berganda. Hasil kajian menunjukkan bahawa jenis tanah di lapan lokasi kajian didominasi oleh pasir dan lodak, dengan paras air bawah tanah yang cetek iaitu hampir dengan permukaan. Paras air bawah tanah berubah-ubah mengikut jumlah hujan yang turun. Kadar penyusupan berbeza-beza, dengan L1, L2 dan L6 mempunyai kadar 108 mm/j hingga 179 mm/j, manakala L3, L4, L5, L7 dan L8 mempunyai kadar dari 60 mm/j hingga 75 mm/j. Masa yang diambil untuk tanah menjadi tepu adalah pelbagai. Dalam keadaan kering, semua lokasi mengambil masa 10 hingga 25 jam untuk tanah tepu dengan air kecuali pada L6. Manakala semasa musim hujan, tahap ketepuan dicapai dalam masa 2 hingga 5 jam, kecuali L1, L5, L7 dan L8 yang mengambil masa 7 hingga 10 jam.

Kata kunci: Banjir; interaksi air permukaan-air bawah tanah; potensi banjir; sifat fizikal dan hidraulik tanah

INTRODUCTION

A flood can be defined as the accumulation of water in an area or the overflow of water due to excess volume on the ground (Buslima et al. 2018). Floods are natural disasters that often occur in various regions of the world, and become recurring natural disasters that often occur and have a large impact, affecting billions of people, public facilities and economic activities. (Olanrewaju et al. 2019; Sharir & Roslee 2023; Tripathi 2015; Zeleňáková et al. 2019). Based on the Center for Research on the Epidemiology of Disasters from 2006 to 2015, natural disasters, including floods often occur with an average proportion of 50.5%, often occurring from other types of disasters (Guha-sapir et al. 2016). Floods can be predicted up to a certain time, except for flash floods, although currently the occurrence of rain due to changes is a challenge to predict floods (Muzzamil et al. 2017; Tingsanchali 2012). Flood factors are interconnected with each other. Flood occurs due to the interaction between water and soil which makes infiltration calculations is essential in assessing the soil's capacity to absorb water. (Uloma, Samuel & Kingsley 2014). Understanding flooding is inseparable from the relationship between groundwater and surface water. Groundwater is water that fills pores and fissures in geological formations underground, which comes from rainfall directly or indirectly from surface water (Ojo, Otieno & Ochieng 2012).

Surface water is all water that exists on the surface of the earth, such as rivers, lakes, wetlands, reservoirs, and the ocean (Dooge 2009; Syeed et al. 2023). In general, surface water and groundwater interact when surface water recharges groundwater or groundwater flows out to the surface (Sechu et al. 2022). The process of surface water entering the soil is called infiltration (Mangala, Toppo & Ghoshal 2016; Moazeni et al. 2021). The infiltration rate is the speed at which water moves into the soil, where the speed will decrease when the soil is saturated (Mangala, Toppo & Ghoshal 2016). Soil characteristics such as soil texture and vegetation cover can influence the infiltration value. Infiltration has an important role in flood analysis; if the infiltration rate is smaller than the intensity of rainfall, it has the potential to produce water accumulation on the ground surface (Jagdale, Tukaram & Vidyapeeth 2012).

In Malaysia, floods are the most significant natural disasters in terms of duration, frequency, and impact on the surrounding population (Maqtan et al. 2022; Zhang & Wang 2022). In general, floods in Malaysia are caused by heavy rains, which are currently exacerbated by rising temperatures and changes in rainfall distribution patterns (Buslima et al. 2018; Talib et al. 2024). Shah Alam City is one of the areas in Selangor that often experiences floods. According to the Department of Drainage and Irrigation Malaysia Report 2012-2022 (Jabatan Pengaliran dan Saliran 2022), flooding in Shah Alam is caused by various factors such as rain, drain system problems, river overflow, high tides, high river levels, low areas, and development. Shah Alam is also an area that is drained by many rivers, with the main river being Sungai Klang. Sungai Klang is the main river connected to tributaries in the Central to South area of Shah Alam, therefore it becomes one of the factors (Zeffry 2023). Therefore, the purpose of this study was to characterise the physical and hydraulic properties of soil in flooding areas.

MATERIALS AND METHODS

DESCRIPTION OF THE STUDY AREA

There are eight sampling locations, namely Taman Sri Muda (L1), Lombong 1 (L2), Lombong 2 (L3), Bunga Siantan (L4), Thangamalay (L5), Hicom (L6), Seksyen 23 (L7), and Seksyen 17 (L8), which is in a flood zone as shown in Figure 1 (Zeffry 2023). These localities have been chosen because they are located at the riverbank of Sungai Klang, where it is assumed to be natural ground (not a fill). This area is an area with low topography, which is lower than 7 m above sea level, therefore, it is vulnerable to flooding. Based on regional geology, Shah Alam is in the Kenny Hill Formation as a major formation with lithology; it is interbedded sandstone and shale that have been metamorphosed into quartzite and phyllite caused by granite intrusion (Hutchison & Tan 2009).

BOREHOLE LOG INTERPRETATION

The interpretation of the borehole log was carried out to determine the lithology and groundwater level in Shah Alam area in general. There are 94 borehole logs retrieved from 37 reports collected from the Minerals and Geosciences Department of Selangor. These borehole logs will later be interpreted and used to develop the geological conceptual model; 2-dimensional subsurface profiles.

SOIL SAMPLING AND WELL MONITORING

Soil samples at all locations are disturbed samples taken using hand augers (Chinonso et al. 2023). The hand auger allows taking soil samples vertically to a certain depth. Hand augers are used by connecting extension rods with augers, which are then rotated until they enter the ground, and then the auger is pulled out with the soil sample as shown in Figure 2(a). In this study, soil samples were taken at 30 cm intervals until they reached the water table. After the sample is extracted from the hole, the PVC pipe is then installed for groundwater level measurement (Figure 2(b)). The monitoring is done at least twice a year during the hot and rainy season.

DETERMINATION OF SOIL PROPERTIES

Soils taken from the field were analysed using the sieve analysis method for grain size distribution analysis for soils with a size of more than 2 mm. Hydrometer analysis is used for fine-grained soil (silt and clay particles). This soil test uses the ASTM D 422 standard. Referring to USDA specifications, the size of sand ranging from 2 to 0.050 mm, silt 0.050 to 0.002 mm, and clay less than 0.002 mm has been considered for their particle size analysis (García-Gaines & Frankenstein 2015).

INFILTRATION MEASUREMENT

Field infiltration measurements are carried out using a double ring infiltrometer following the ASTM D3385 standard (Bergeson et al. 2022; D18 Committee 2018; Morbidelli et al. 2017). The double-ring infiltrometer consists of two rings, namely the outer ring with a diameter of 60 cm and the inner ring with a diameter of 30 cm, as shown in Figure 2(c). Prior to the test, vegetation is removed from the surface to increase infiltration (Saputra, Wibowo, & Lisnawati 2021). The ring is then inserted into the soil to hold the ring in place and to prevent water from escaping the ring. The infiltration rate is obtained by measuring the movement of water in the inner ring, while the water in the outer ring serves to ensure the water is moving vertically (Alfa et al. 2022). Infiltration measurements were carried out around the location of the sample hand auger and were tested twice at each location. Infiltration rates are recorded every minute by reading the floating ruler. The measurement is stopped when the water in the inner ring runs out or when it shows a constant rate (Uloma, Samuel & Kingsley 2014). In this study, the infiltration rate is calculated based on the depth of the water seeping and the time it takes for the water to reach a certain depth. The calculation of the infiltration rate is carried out using the formula in Equation (1):

$$f = \frac{h}{t} \tag{1}$$

where f is the infiltration rate (mm/h); h is the depth of water seeping into the soil (mm); and t is the time required (h). The infiltration rate measurement was carried out twice at each location and then the average value was taken, where the measurement distance was not far from the hand auger sampling location.

RESULTS AND DISCUSSION

SUBSURFACE PROFILE OF SHAH ALAM

Figure 3 shows the subsurface profiles of the study areas, which are A-A' (north to south) and B-B' (northwest to southeast), as shown in Figure 3(a). The subsurface lithology along A-A' comprises interbedded clay, silt and sand, where silt is very dominant in the north and south

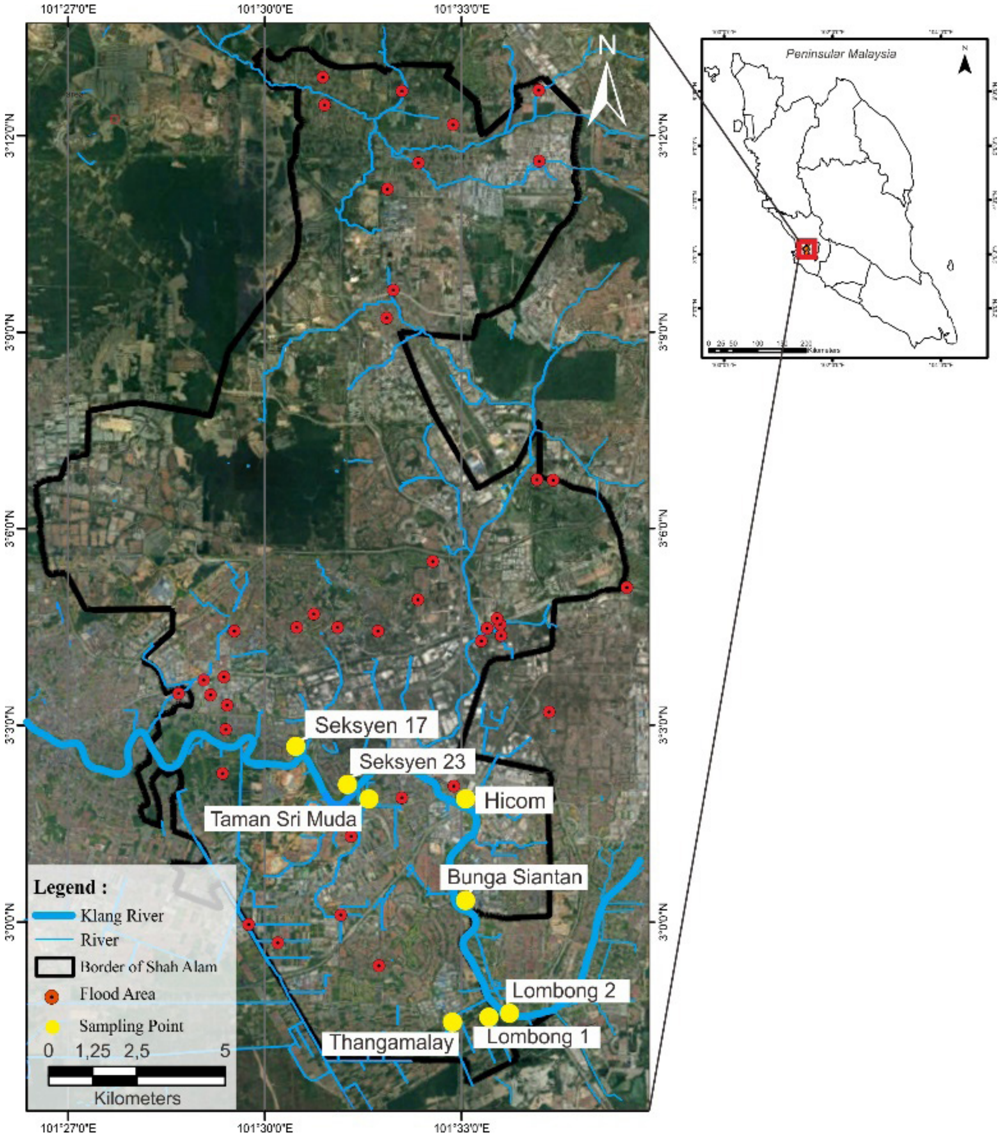

FIGURE 1. The location of flooding areas and sampling location in study area (Zeffry 2023)

FIGURE 2. a) Soil sampling using hand auger, b) water table measurement, and c) double-ring infiltrometer test

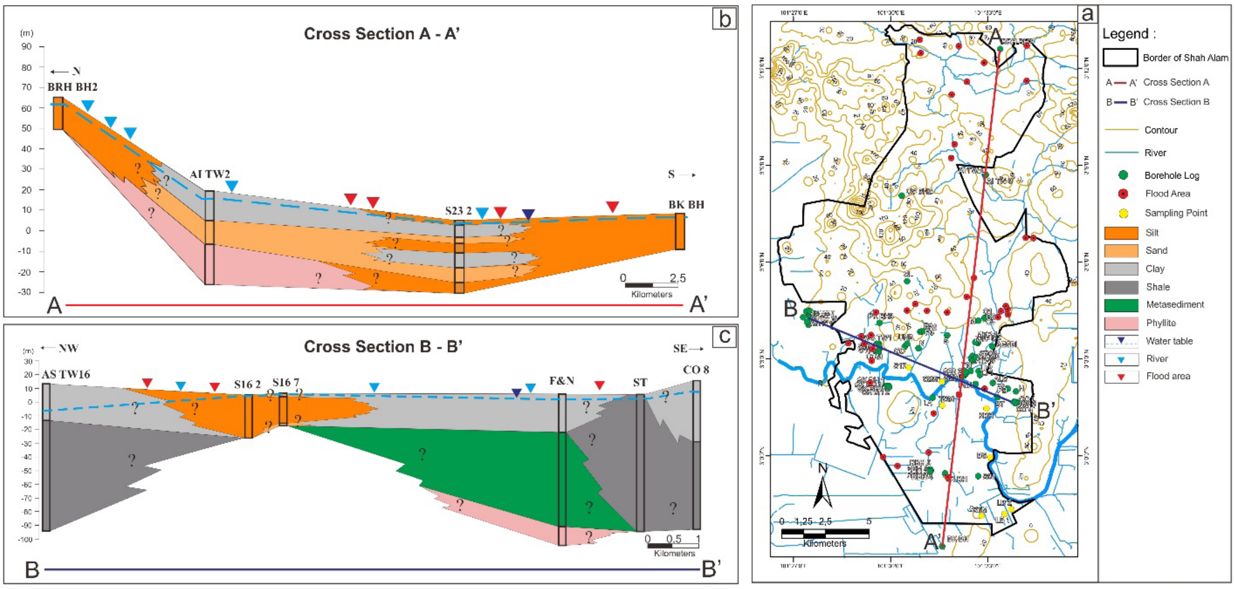

FIGURE 3. a) Borehole log distribution with lines of cross sections, b) lithology of cross section A-A', and c) lithology of cross section B-B'

parts (Figure 3(b)). The subsurface lithology along B-B' shows a thick layer of clay and shale, as well as silt in the center (Figure 3(c)). The water table of the study area is at shallow depth and follows the topography of the area.

CORRELATION OF PARTICLE SIZE DISTRIBUTION AND AVERAGE INFILTRATION RATE

In general, the data shows that the soil is dominated by high sand content in all locations, which ranges from 64.4% to 88.1%. The silt content is also quite high, ranging from 7.6% to 30.5%, followed by clay 1.9% to 7.8%. Locations L1, L5, L6, L7, and L8 show sand content above 80% with a silt of 13.6%. While the L2 and L3 sites showed a higher composition of silt and clay particles than the other sites, with L3 having 30.5% silt and L2 having 7.8% clay. The presence of silt and clay indicates a finer soil texture, which generally has a higher water retention capacity and slower infiltration than sandy soils. Only L4 has a high gravel content, which is 14% (Table 1).

The average infiltration rate data showed significant variations. The highest values were recorded at locations L1, L2, and L6, with values of 160 mm/h, 108 mm/h, and 179 mm/h, respectively, indicating that the area has a better ability to absorb water. Locations with lower infiltration rates, such as L3, L4, L5, L7, and L8, with values of 75 mm/h, 60 mm/h, 73 mm/h, 66 mm/h, and 60 mm/h, respectively (Table 1).

The data showed large variability in the average infiltration rate across different areas, rates from 60 mm/h to 179 mm/h. This difference is directly related to the distribution of soil particle size, including gravel, sand, silt, and clay content, which influences the soil's physical qualities and ability to absorb water.

Figure 4(a) shows the pattern of infiltration at each location (L1-L8) with time. In general, all locations show a similar pattern except for L1 at an earlier hour of the test. Locations with the highest infiltration rates, such as L1 and L6, have high sand content 81.7% and 85.8%, respectively, and low clay concentration 1.9% and 6%, respectively. The L2 location has a high average infiltration rate with a high sand (75.7%) and silt composition (16.2%), where the composition is still enabled to produce a high rate. Locations with lower infiltration rates, such as L3, L4, and L5, have sand content less than 80% and more silt (11.6%-30.5%); this can cause the soil to be less efficient in absorbing water. The location of L7 and L8 is quite unique because it produces an average infiltration rate in the slow category, but has a very high amount of sand, 85.1% and 88.1%, respectively. At the L1 location, it appears to have a very high initial infiltration rate, but it decreases and stabilizes rapidly as well. The other locations, L2 to L8, show a low initial infiltration rate and are stable at the end of time, with some minor fluctuations.

Overall, the type of soil plays an important role in controlling the infiltration process. The study area is dominated by silty sand; therefore, the value of the infiltration rate is high. However, the location of sampling also plays a role. For example, L4, L5, L7, and L8, which are plantation areas and areas that are often visited by people, so that they cause soil compaction, which can affect infiltration (Alaoui et al. 2018; Yang & Zhang 2011; Zhao et al. 2010).

Figure 4(b) shows the infiltration rates of different soil types from all around the world. It shows that the infiltration rate values for silty sand soil, which is similar to the study area, have lower value ranges from 12 mm/h to 21 mm/h. The highest infiltration rate (160 mm/h approximately) is in the sand. Some studies show different rates on the same type of soil. Differences in infiltration rates can be caused by other factors such as texture, slope, and type of vegetation. Conditions such as land use, aggregate stability, and vegetation cover also play an important role (Basri et al. 2021; Folorunso & Aribisala 2018). Wulan Ayu and Prijono (2013) added that density, organic matter content, and porosity affect the infiltration rate, where soil with more stable aggregates has higher infiltration. According to Manuel and Otoko (2016), the hard layer caused by prolonged ploughing can reduce the infiltration rate.

GROUNDWATER LEVEL IN STUDY AREA

Water table measurements were carried out at each location between September 2023 and July 2024 as shown in Table 2. The water level is close to the surface as observed at L1, L3, L4, and L8 (Figure 5) while the water level at L1, L2, L5, and L7 is at a deeper depth (> 1 m). The elevation of these wells ranges from 4 to 7 m above sea level. The groundwater level measurement is plotted against daily rainfall data of three stations nearby, which are Taman Sri Muda station, Kemuning station and Lombong station. Taman Sri Muda and Kemuning stations are near L1, L6, L7, and L8, while Lombong stations are near L2, L3, L4, and L5. The rainfall data for Lombong station is only available for 2024. The rainfall data for the day before and the day of water level measurement was used for analysis (Figure 5). In general, the groundwater level shows a positive correlation with rainfall, where the water level increases with heavy rainfall and decreases with low rainfall. The water levels at L3, L4, and L6 are close to the surface, which eventually flooded (water level is higher than the surface) on 15 and 22 Nov 2023 and on 10 July 2024. This shows that the rise of groundwater at L3, L4 and L6 does not require a lot of rainfall. Therefore, these areas will be flooded even if the rainfall is not heavy due to the high groundwater level.

POTENTIAL OF FLOOD EVENT TO OCCUR

The receding time of floods is greatly influenced by the soil saturation level. When the soil reaches a saturated condition, its ability to absorb water is lost, resulting in standing water lasting longer and slowing down the infiltration process. This indicates that, in addition to the initial causes of flooding, the infiltration process also plays an important role during flood events. By knowing the depth of the water table (Wt) and the infiltration rate (f), the duration of the unsaturated zone becomes fully saturated, or the potential for flood to occur can be calculated. Potential of flood was calculated according to Equation (2):

$$t = \frac{Wt}{f} \qquad (2)$$

The calculation was carried out using the deepest and the shallowest groundwater levels that have been measured (Table 2) to represent the range of the period of flood to occur after the rainfall event. Figure 6 shows the range of periods for flooding to occur in the study area. Results show that the flooding will be unlikely to occur during the dry period (the deepest groundwater level) for all locations, as it takes 10 to 25 h for the soil to reach the saturation level, except at L6. Besides, L5 and L7 also have low infiltration rate values, resulting in a long-time duration.

However, during the rainfall season (where the groundwater level is shallowest), it only takes 2 to 5 h of rainfall for a flood to occur, except at L1, L7, L5, and L8, which take longer hours of rainfall for a flood to occur (7 to 10 h). L1, L5, and L7 have deeper water levels compared to other locations thus requires longer period of soil to become saturated. Meanwhile, in L8, there was no significant change between deep and shallow groundwater levels.

TABLE 1. Percentage of particle size distribution and average infiltration rate in study area

Location	Average infiltration rate (mm/h)	% Gravel	% Sand	% Silt	% Clay
L1	160	2.2	85.8	10.1	1.9
L2	108	0.3	75.7	16.2	7.8
L3	75	0	64.4	30.5	5.2
L4	60	14	70.6	11.6	3.9
L5	73	0	80.5	13.6	5.9
L6	179	0.5	81.7	11.8	6.0
L7	66	0.3	85.1	10.4	4.2
L8	60	1	88.1	7.6	3.3

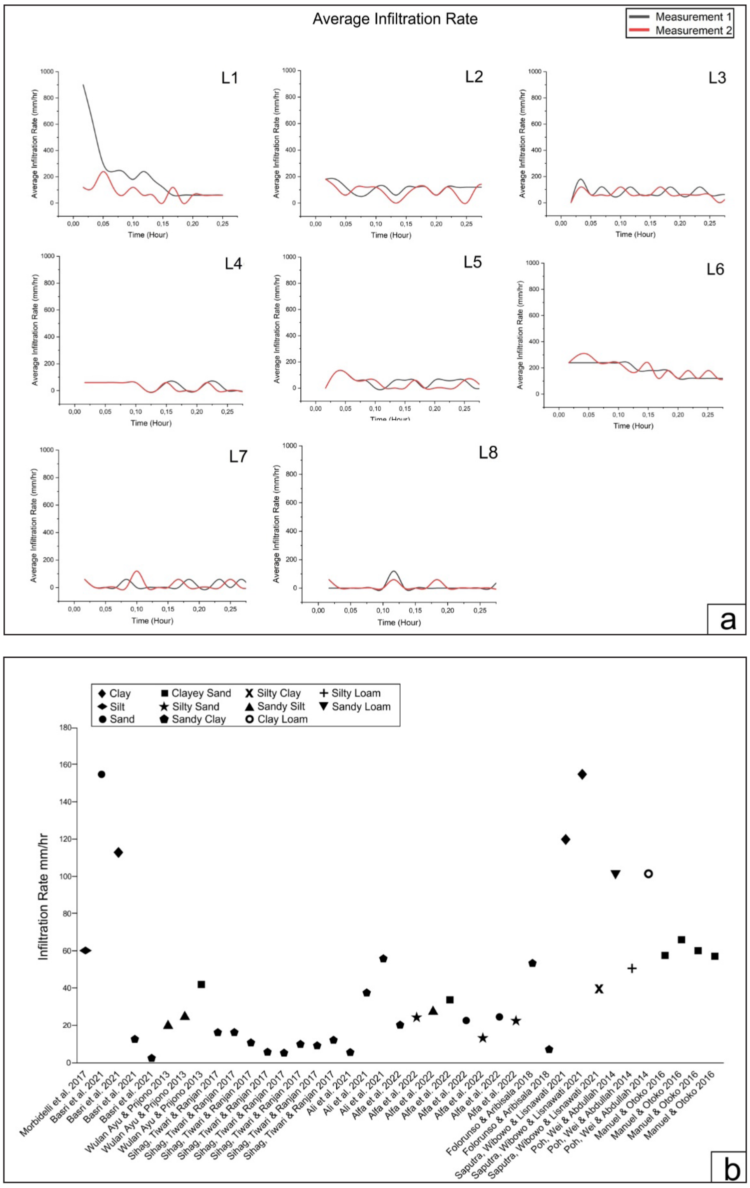

FIGURE 4. a) The curves of infiltration rate for 8 localities in study area and b) Comparison of infiltration rates of different types of soil

TABLE 2. Depth of groundwater level (in mm) each location

Location	12/09/2023	26/09/2023	01/11/2023	15/11/2023	22/11/2023	22/02/2024	07/03/2024	10/07/2024
L1	*1560	1530	1480	1430	1420	**1080	1520	1100
L2	1760	1710	1570	1410	1370	1200	*1790	**500
L3	*960	750	400	**200	280	310	830	-730
L4	*660	480	380	-90	-80	**280	280	280
L5	1670	*1740	1470	1310	1360	1600	1580	**730
L6	-	490	*820	**330	670	620	450	-20
L7	-	-	**560	1220	1550	1640	*1650	1390
L8	-	-	**580	590	690	740	*810	630

* = deep groundwater level

** = shallow groundwater level negative value of water table indicates that it is higher than ground surface

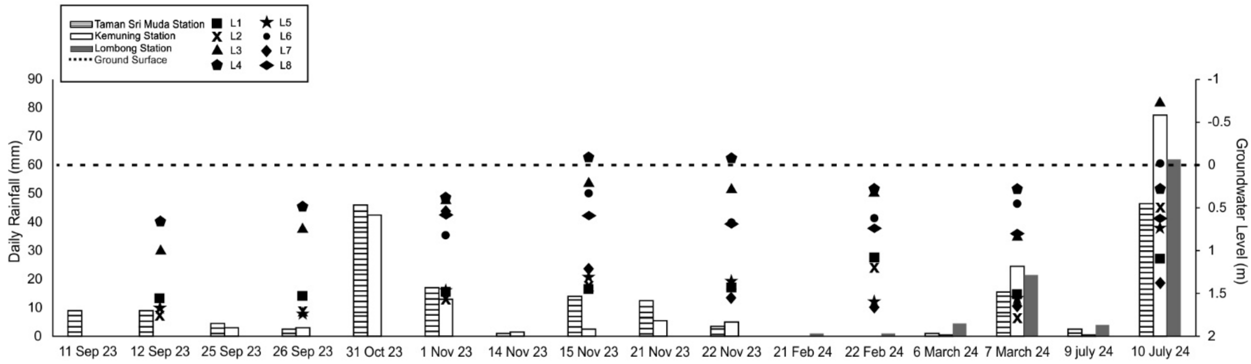

FIGURE 5. Groundwater level measurement from ground surface (dashed line) in study area

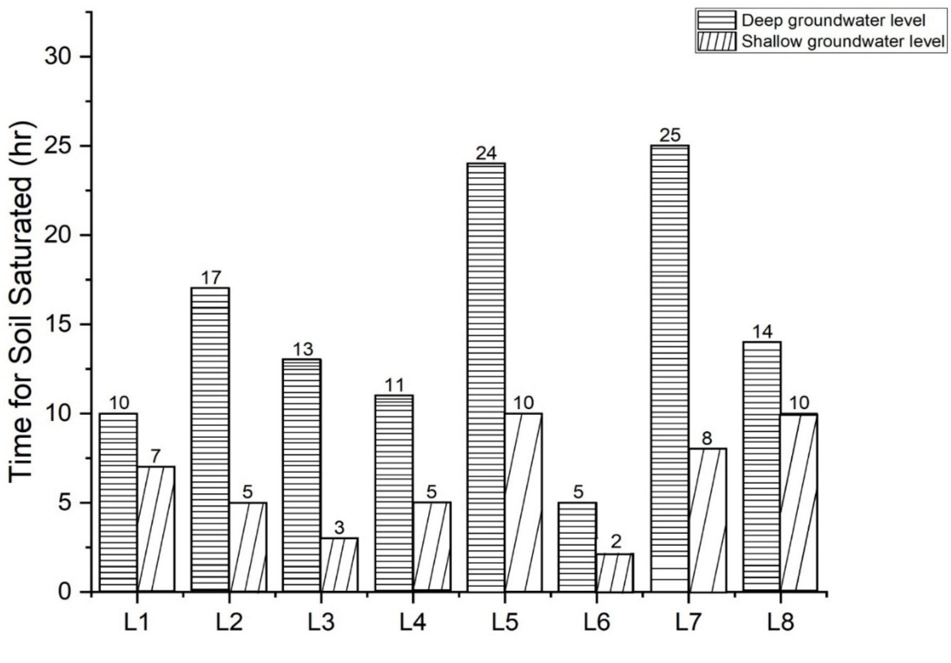

FIGURE 6. Time for soil to reach saturation level in the study area

CONCLUSION

Shah Alam's lithology is dominated by interbedded silt, clay and sand in the northern to southern area, and clay and shale dominates in the northwest to southwest area. The floods often occur in the northwest to southwest section, where the area is dominated by fine soil type.

Eight sampling points have been chosen because they are located at the riverbank of Sungai Klang, where it is assumed to be natural ground (not a fill). The results of particle size distribution analysis on soil samples L1 to L8 showed that they were dominated by sand, and there was low silt (silty sand). Infiltration rate shows a positive relationship with soil type. L1, L2, and L6 have rates of 108 mm/h to 179 mm/h, while L3, L4, L5, L7, and L8 have rates that range from 60 mm/h to 75 mm/h. In the comparison of infiltration rates with the same soil type in different researchers, this rate is in the fast infiltration rate. The water table in the study area is close to the surface (shallow groundwater level). The groundwater level shows a positive correlation with rainfall where water level increases with heavy rainfall and decreases with low rainfall. Flooding will be unlikely to occur during dry period for all locations as it takes 10 to 25 h for soil to reach saturation level except at L6. However, during the rainfall season, it only takes 2 to 5 h for a flood to occur after a rainfall event, except at L1, L7, L5 and L8, which take longer hours for a flood to occur (7 to 10 h). The area with water level that is close to the surface, such as L3, L4 and L6, will be flooded even with a smaller amount of rain.

In conclusion, knowing the nature of the soil and the rate of infiltration can help predict the rate of water entering the soil. Together with the information on water table fluctuation, it can predict the potential for floods to occur for better flood management. The physical properties in this area show a good response to flooded areas, which has a fast infiltration rate. However, this becomes negative due to the shallow groundwater, so that the soil saturation becomes faster and has the potential to cause flooding.

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