International Journal on Advanced Science Engineering Information Technology

Vol.15 (2025) No. 1
ISSN: 2088-5334

Soil Permeability Tank Testing on Landslide Early Warning System

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Abstract*—Landslides cause harm both to society and the environment. Landslides usually occur during the rainy season with high rainfall and damaged soil structure. An Early Warning System (EWS) has been adopted to mitigate landslides. However, few monitoring systems include complete sensor integration related to the causes of landslides and an independent supply of information. Therefore, the development involves complete information on all these characteristics is important. To learn about landslides, it is always suggested to prepare a landslide model in the laboratory before executing it in a real environment. This study aims to to obtain a correlation of all the sensors for parameters induced landslide i.e. groundwater level, soil moisture, pore water pressure, rainfall, and ground movement with a permeability tank experiment. The sensors were set and placed in the permeability tank with a debit of 21.27 m^3/liter water. The silica sand was used and poured into a permeability tank with a set of slope models. The warning alarm was set to 20 mm for the ground movement sensor. The groundwater flow was also observed from the tank pipes. The results show that all sensors work well and correlate with each other to read the value. However, the ground movement detects no movement because the value of the sensor shows 0 mm until the end of the experiment. The silica sand has a narrow grain, causing water to flow fast. Even so, the sensors work well and can be deployed for landslide prevention.

***Keywords*—Early warning system; landslide; permeability tank; soil.**

Manuscript received 7 Aug. 2024; revised 18 Oct. 2024; accepted 21 Nov. 2024. Date of publication 28 Feb. 2025.

I. INTRODUCTION

Global climate change is changing, and the changes also exhibit in risk of weather-related hazards. Indonesia is a country island that morphologically consists of lowland (0-500m), hilly land (500-1000m), upland (1000-2000m), and mountains (more than 2000m), with a population of over 281million in 2024 [1], [2], [3], [4]. The problem of global climate change with the increase of population and economic development has inflicted rapid urbanization. Rapid urbanization with unplanned construction has an impact on the natural balance of the city causing landslides. Besides, the factors of heavy rainfall, earthquakes, and cut slopes may also play a role in landslide occurrence [5].

Landslides are known as a disaster with the highest prevalence in the world [6]. In Indonesia as of 2023, landslides have happened 591 times with the deaths of 149 people, and injured 767 excludes the loss of facilities and houses [7]. Natural disasters such as landslides are inevitable. Nevertheless, mitigation can help people prepare and prevent bigger losses. Thus, an urgent need exists for a landslide Early Warning System (EWS) for disaster risk reduction and robust evaluation.

EWS has been employed in natural disasters such as landslides by using soil moisture sensors related to a relative increase of soil moisture content induced by rainfall [8], [9]. The result shows that soil moisture sensor value increases with an increase in slope angle. However, a landslide is also affected by pore water pressure [10], rainfall, soil-shifting, and vibration [11]. Rainfall induces landslides by reducing soil shearing resistance due to increased soil moisture content and unit weight. Therefore, the increase in soil moisture content brought by precipitation infiltration plays a central role in slope failure. Besides, it is also because soil moisture content reads full saturation.

In Paswan and Shrivastava [12], EWS for landslide uses rainfall and tilt sensors. The tilt sensor used; it is based on ground movement. Importantly, the groundwater level is a crucial part of the landslide early warning system as the groundwater level impacts the various stages of landslide movement. According to statistics, 30-40% of dam failures are impacted by damage from groundwater seepage, and in China, 55% of soil landslides are caused by the effect of groundwater [13]. Another cause of landslides is a result of the structural conditions of the soil or rock, allowing the soil mass to move to the top moves [14]. It is seen from the soil permeability which plays an important role in determining the soil characteristics of an area, as well as the factor of ground movement causing landslides.

EWS has become the main pillar of disaster prevention, especially when mitigation strategies are not reliable. Data collection through sensor integration with an independent supply of information from EWS has become a challenge [15], [16], [17], [18], [19]. However, few monitoring systems include complete sensor integration related to the causes of landslides as well as an independent supply of information. Therefore, developing an EWS that involves complete information on all these characteristics is important. This research develops EWS for landslides with the combination of sensors for groundwater level, soil moisture, pore water pressure, rainfall, and ground movement integrated with a monitoring website as the supply of information.

A fitted experimental setup was developed to analyze the sensor readings, and the results can be reflected in real-life landslide situations. To learn about landslides, it is always suggested to prepare a landslide model in the laboratory before it is executed in a real environment [8], [20]. Therefore, this study aims to obtain a correlation of all the parameters that induce landslides, i.e., groundwater level, soil moisture, pore water pressure, rainfall, and ground movement, with a permeability tank experiment.

II. Materials and Method

A. EWS Sensors

The landslide EWS was created using a wireless sensor network design (Fig. 1).

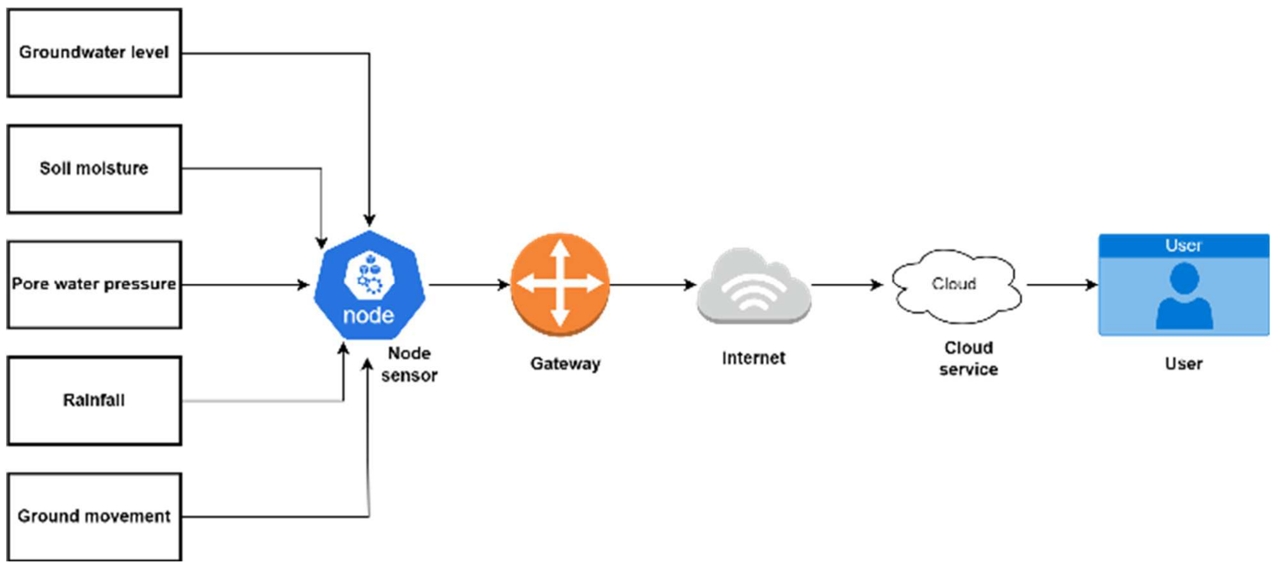

Fig. 1 System diagram block of landslide Early Warning System (EWS)

The system consists of 5 sensors namely groundwater level, soil moisture, pore water pressure, rainfall, and ground movement. The parameters of rainfall, ground movement, groundwater pressure, groundwater level, and soil moisture are parameters as causes of landslides. So, this is the basis for sensors created to detect landslides. The communication of the sensors uses wireless/Wi-Fi. Each tool is equipped with a display that shows the sensor reading value. Apart from that, each of these tools has its function and is connected to website monitoring with the address www.ewspolines.com. The sensors used are groundwater level with JSN-SR04T, soil moisture with capacitive soil moisture sensors, pore water pressure with modified soil tensiometer, rainfall with rain gauge, and ground movement with rotary encoder.

(a) (b) (c) (d) (e)

Fig. 2 Sensors used in EWS (Early Warning System) (a) Rain gauge for rainfall sensor (b) Rotary encoder sensor for ground movement (c) Modified tensiometer for pore water pressure (d) JSN-SR04T for groundwater level (e) capacitive soil moisture sensor

Fig. 2 shows the sensors used in the research. The sensors of the rain gauge, pore water pressure, and ground movement use a supply of accumulator 12V while the groundwater level and soil moisture use 24V. The rain gauge sensor reads in millimeter units, has a specification of a sample area of 200 cm^2, and an accuracy value of 0.5 mm/tick with reed switch type. The ground movement reads millimeters using a rotary encoder with an anchor embedded in the soil. The pore water sensor reads in unit kPa. Meanwhile, the groundwater level reads in centimeters and soil moisture in percentage (%). Each of the sensors is equipped with a data logger or a memory card. The sensor of rainfall, pore water pressure, and ground movement read every value change. Meanwhile the soil moisture and groundwater level update the reading of value every one minute. An early warning alarm is provided in the ground movement sensor, the threshold value of which can be set accordingly. All the sensors were tested for accuracy, and an average accuracy of 98% was obtained.

B. Experimental Setup

The experiment was conducted in the Department of Civil Engineering Laboratory, Politeknik Negeri Semarang. The permeability tank used in this research was intended to test the sensor parameters. The permeability tank type is permeability tank H312 from TecQuipment with dimensions 245 cm x 70 cm x 150 cm, and the weight is 230 kg [21].

The sand used in the experiment was silica sand. Its physical properties are already standardized, so calibrating the tool during testing is more manageable. If there is a data anomaly during testing, the tool can more quickly determine the cause of the anomaly. The small-scale ground model was prepared with a 20 cm wide, 150.5 cm long, and 65 cm high permeability tank (Fig. 3).

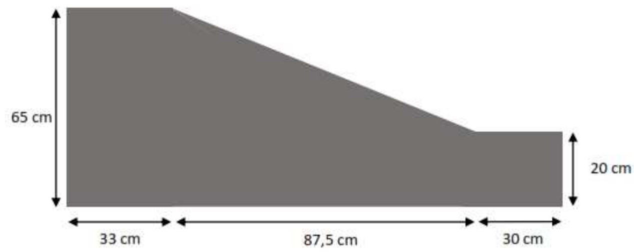

Fig. 3 The dimension of the soil slope model

Silica sand was poured into the permeability tank according to the slope model (Fig. 4).

Fig. 4 Sand structure in permeability tank

There are 14 groundwater outputs with pipe each (Fig. 5).

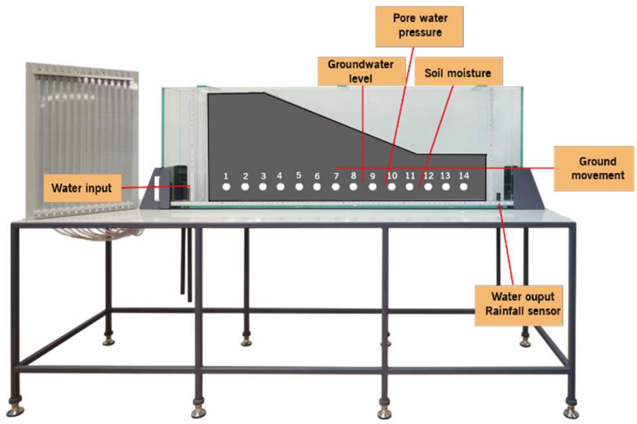

Fig. 5 Sensor setup in permeability tank

Each sensor, such as the groundwater level, was put between pipes 8 and 9 and near the pore water pressure between 9 and 10. Beside was a soil moisture sensor placed between pipes 11 and 12. The ground movement sensor was put at pipe 7. Lastly, the rain gauge was placed under the water output (Fig. 5).

The treatment for each sensor is as follows (Fig. 6). The groundwater level sensor was placed on the pipe, which was put into the soil. The tensiometer tube for the pore water pressure sensor was filled with distilled water and covered with a silicon lid. The soil was dug first before the tensiometer was put into the soil to prevent the ceramic from being damaged.

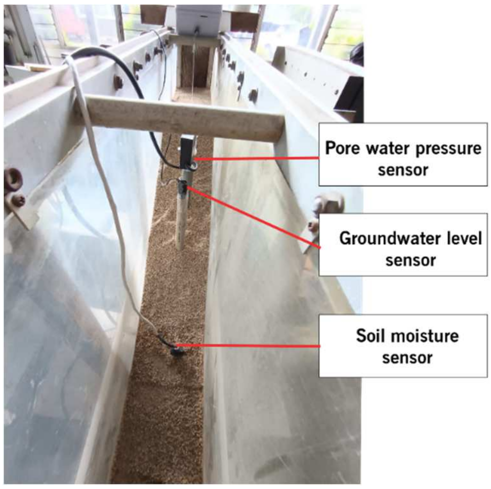

Fig. 6 Sensor's placement of pore water pressure, soil moisture, and groundwater level

The ground movement sensor used in this research was made by modifying a rotary encoder sensor and spring balancer. The measurement of the loads in the ground movement sensor resulted in a minimum of 1 kg, so the experiment should have a load for the ground movement sensor. Therefore, for the ground movement sensor, an anchor was made from four 30 cm long tent pegs, which served as the load for the ground movement sensor.

The experiment was carried out by induced rainfall powered by a water pump to the water input of the permeability tank. The debit set was 21.27 m^3/liter. Then the water will flow into the sand through the barrier. The groundwater flow that entered the sand was observed manually. The groundwater flow will slowly flow in each pipe, and the water flow comes out through the water output, which is caught by the tipping bucket and read by the rain gauge. The data collection of groundwater flow was taken every time there was a change in water level, and when the flow started being stable, the data was taken every 5 and 10 minutes. All data read in each sensor were then observed and analyzed to determine whether they were correlated in the landslide model.

The technical parameter for the landslide model in this research was that the ground movement sensor was set to 20 mm to ring the alarm. A landslide is considered to have occurred if the ground movement sensor shows a movement value at least 20 millimeters from the first place, which will displayed on the screen. The warning alarm will automatically ring if the movement occurs at least 20 mm or more. When a landslide occurs, there is a deviation between the first and last positions of the ground movement sensor. Regarding the mechanical parameter, when a landslide occurs, the anchor that was installed and the slope of the sand will also fall simultaneously. The movement of the anchor installed indicates that the landslide model with silica sand can move the loads of the ground movement sensor within 1 kg.

III. Results and Discussion

The experimental results have provision to change the slope angle from the start and hence by the changing slope angle, with the same amount of debt of water input, the value of the sensors reads and a landslide is detected by EWS and turns on the alarm. Due to the setup of the threshold alarm at 30 mm, the alarm should read if there is a movement with that threshold value.

A. Sensors Reading

The soil moisture value is shown in a graph (Fig. 7) and presented as a percentage.

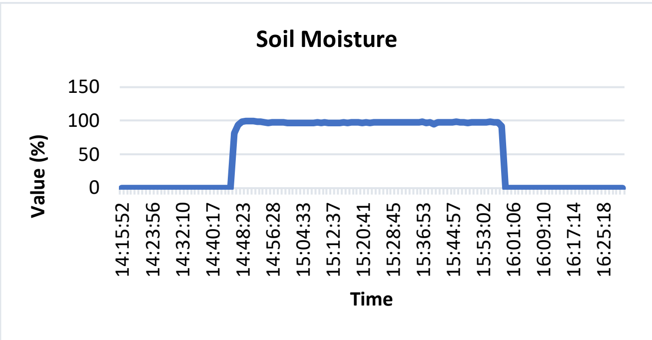

Fig. 7 Soil moisture sensor value

The data from the soil moisture sensor started at 14.15, and the value was read along with the increase in water level. At 14.46, the readings started to increase from 0% at 14.15 to 81.43% at 14.46. The value increased with the highest value of 99.47%; at 15.58, the reading was 91.78%. Afterward, starting from 15.59, the value decreased by 0%. The rainfall sensor reads the water from the permeability tank's water output. It reads the value after the water from the water input flows through all 14 pipes and drops into the tipping bucket (Fig. 8).

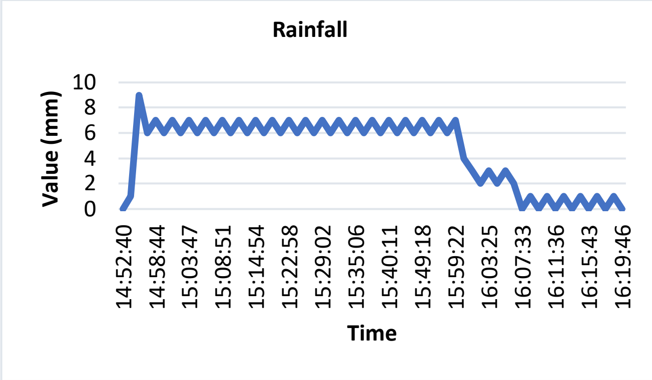

Fig. 8 Rainfall sensor value

The rainfall sensor value reads 0 mm until 14.52 because no water dries into the tipping bucket. It starts at 14.54 and reads the value of rainfall dripping into the tipping bucket. 14.56, the value increases to 9 mm, and at 15.59, it reads 7 mm. Afterward, the sensor value starts to decrease from 16.00 and keeps decreasing until the end.

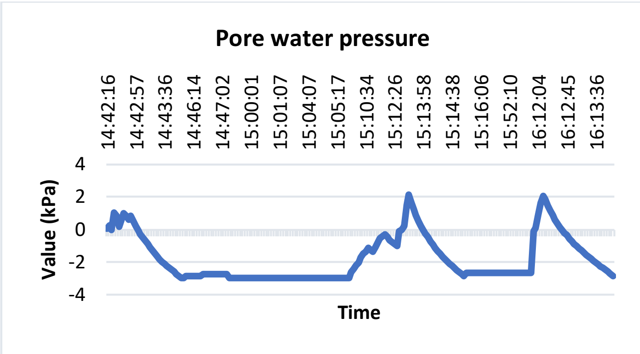

Fig. 9 Pore water pressure sensor value

The pore water sensor works with a reading system that uses a pressure sensor that can be measured based on air suction (vacuum) and air pressure. Suction measurement is based on the soil's suction power strength to the water in the measuring tube. Meanwhile, pressure is a measurement based on the strength of groundwater pushing against the water in the measuring tube (Fig. 9). The results of pore water pressure show that the higher the value, the more the soil is dry and vice versa (Fig. 10).

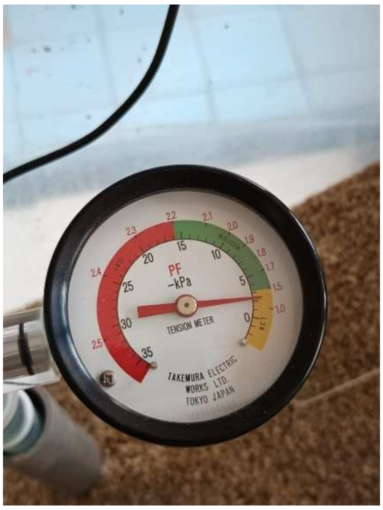

Fig. 10 Tensiometer

The value of pore water pressure from the start until 14.42 shows a positive value. The positive value shows that the soil is dry. After that, at 14.44, the value starts to drop to -2.96 until 15.07. The water supply in the tube of tensiometer starts to reduce, indicating that the pressure in the tube is low, and the value is higher meaning that the soil is dry. The tensiometer type used should be filled with water if the water has reduced to half. So, then after 15.07, the water is filled in again with distilled water. Therefore, the pressure in the tube is high and positive, which can be seen in 15.13 with the value of 2.17 kPa. Again, the value is negative when the water in the tube drops into the ceramic (Fig. 9). The ground movement result shows that no movement was detected from the beginning until the end of the experiment at 16.00-16.20 (Fig. 11).

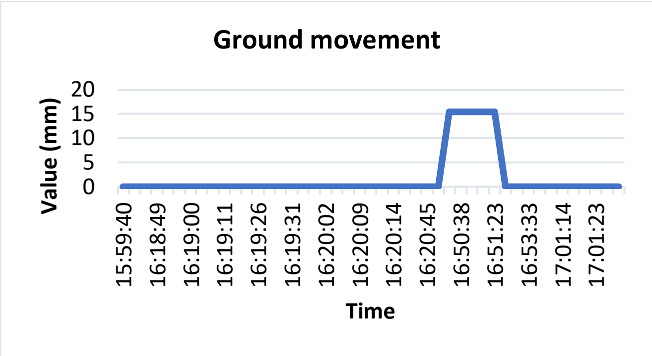

Fig. 11 Ground movement sensor value

As no movement was detected by the ground movement sensor, the experiment was improved by giving a landslide trial by pushing the sand manually. As the set threshold was 30 mm, the sand was gradually forced to 20 mm, resulting in alarm ringing. When the sand was pushed 30 mm more, the alarm in the ground movement sensor rang, too. The threshold can be set using the application Setting EWS, specially built to ease the threshold setting (Fig. 12).

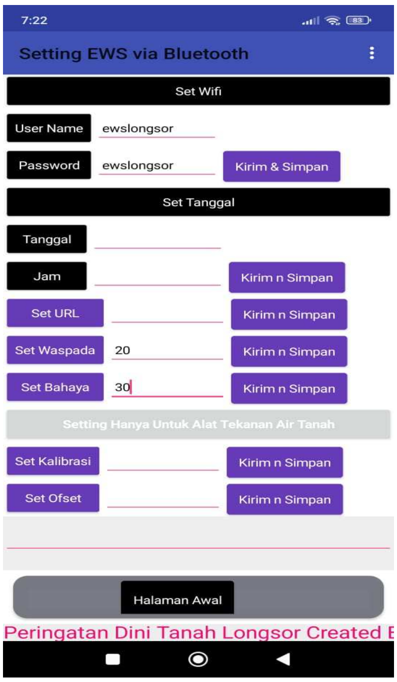

Fig. 12 Setting Early Warning System (EWS) application to set a threshold of alarm

Groundwater level data is used to observe the height of water flow in the ground. The maximum water level that can fill the permeability tank is 60 cm. The pipe number used is 1-13 because pipe numbers 4, 12, and 14 are clogged with sand. Pipe number 1 is the closest pipe to water input and pipe 13 is located near water output. Water flow should infiltrate first on pipe 1 and follow by the next pipe with a graph value decreases and it will be stable when the water flow in the sand is stable and decrease when the water pump is turned off. The groundwater level can be seen that pipe 1 is higher than pipe 2 and followed by another pipe (Fig. 13).

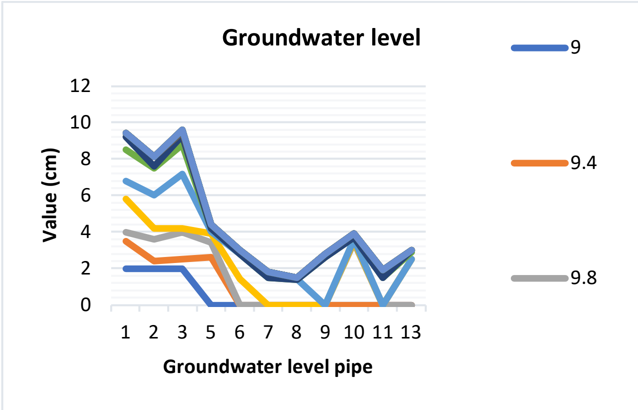

Fig. 13 Groundwater level pipe

The groundwater level is stable at 12.1 cm, filling the water input. The data show that after the water level at 12.1 cm was obtained, the sensor readings at 5-minute and 10-minute intervals were the same, indicated by overlapping lines. The groundwater level sensors read the value shown in Fig. 14. The value of the groundwater sensor increased to 15.07 with a 1.5 cm value, subsequently reading 1.22 cm and tending to be stable. This number is in line with the readings from the pipes of the permeability tank (Fig. 13).

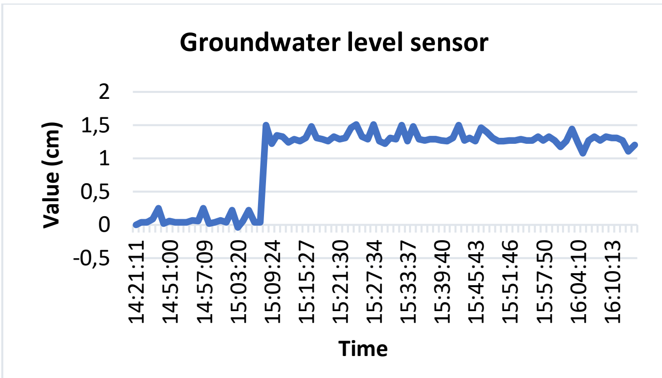

Fig. 14 Groundwater level sensor reading

Landslides in Indonesia occur mostly due to high rainfall intensity [22], [23], [24]. A landslide is indicated by the movement of slope-forming material in the form of rock, and debris soil down the slope. Water infiltration into the ground influences the saturated soil, which causes increased water levels, especially during the rainy season. This also causes the soil pores to be easily destroyed, weakening the soil aggregation and decreasing the shear resistance [25], [26], [27], [28].

Land management is required to reduce soil damage to prevent landslides [29]. Landslides are dangerous natural disasters that can endanger citizens and disrupt community activities. EWS with the supply of information has become a challenge in mitigation. The EWS for landslides developed in this research has combined the parameters of landslides including soil moisture, groundwater level, pore water pressure, rainfall, and ground movement with the supply of information through a website www.ewspolines.com for people to access (Fig. 15), as well as warning system by an alarm when the threshold is met.

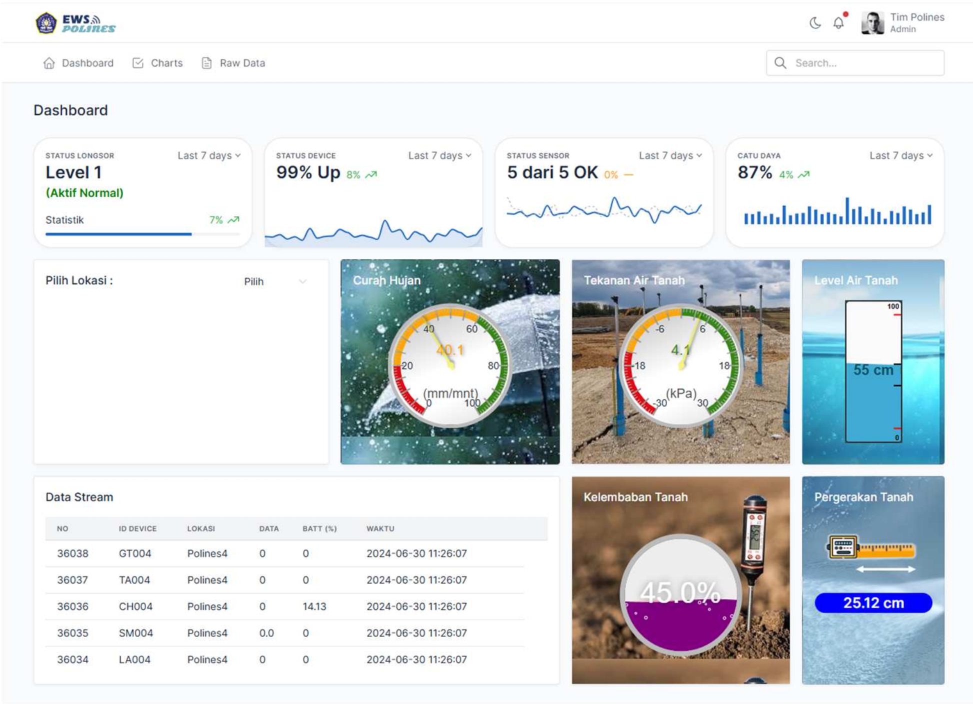

Fig. 15 Early Warning System (EWS) landslide monitoring website

The experiment in the permeability tank shows that the five sensors are correlated. First, when water flowed through the water input in the permeability tank, the water infiltrated the soil from pipe 1 to pipe 13. Along the pipes, four sensors were placed: ground movement, groundwater level, soil moisture, and pore water pressure. Meanwhile, the rain gauge was placed under the water output of the permeability tank.

All the sensor's work is correlated, in which the soil moisture value is increased at 14.43 and stable until around 15.56 (Fig. 7). The increased value of soil moisture indicates that water is flowing in the area. This is in line with the value of the groundwater level at 14.46, and the highest value is at 15.08, with 1.5 cm of groundwater. This number is according to the groundwater level reading from the permeability tank, which shows the number 1.5 cm at pipe 8, near the location of the groundwater level sensor where it was placed (Fig. 5). Meanwhile, in the pore water pressure sensor, when the soil moisture value increases at 14.43, the reading in pore water pressure is decreasing at a negative value around 14.42. The decreasing value of pore water pressure indicates that when water from the tube drops into the soil, the pressure in the tube is reduced, meaning that the water has fallen into the ceramic and infiltrated the soil.

The ground movement resulted in no movement at all, with a value of 0. This is because the water flow is fast, about the sand used for the experiment. Silica sand typically but not exclusively contains more than 95% SiO_2. Silica sand normally has a narrow grain size distribution, in the range of 0.1 – 2 mm [30], [31]. Smaller grains have a bigger ratio of surface area to volume, so the water flow from the pipes of the permeability tank ran fast. It takes about 30 minutes to achieve stable conditions, as indicated by the same water flow and the sensor readings tending to be the same. However, the alarm reading worked well when the sand was moved manually along 20 mm and more.

IV. Conclusion

The implementation of EWS has increased widely to prevent more significant losses and victims. This research has conducted an EWS experiment for landslides with a combination of 5 sensors as landslide cause parameters. The experiment was done using a permeability tank. The results show that the sensors are correlated with each other. However, no movement was detected by the ground movement sensor. This is due to the sand used, which employed silica sand. Silica sand has a narrow grain size where the water can flow fast because it has a greater ratio of surface area.

Acknowledgment

This research is funded by *Penelitian Terapan Penugasan* 2024. We want to thank the Department of Civil Engineering, Politeknik Negeri Semarang, for permitting us to use the hydrology laboratory for the experiment. We would also like to thank Politeknik Negeri Cilacap and Universitas Gadjah Mada for their support during the research.

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