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Effect of Vegetation Hydromechanics on Soil Reinforcement on Hillsides as Prevention of Shallow Landslides: A Systematic Literature Review

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Abstract:
The landslides phenomenon due to rainfall is a global hazard that causes damage to infrastructure and the ecological environment, economic losses, and endangers human life. This incidence tends to increase every year due to the effects of climate change and land use. Landslides caused by these rainfalls commonly occur in mountainous environments around the world. This is usually triggered by a decrease in the shear strength of the soil after an intense heavy rain event. Therefore, it is necessary to implement priority mitigation and remediation measures. The vegetative method has proven to be an effective landslide mitigation measure, as it increases the shear strength of the soil through a series of mechanical and hydrological effects. Many reviews of the mechanical and hydrological role of vegetation in slope stability have been carried out over the decades because the installation of vegetation on slopes has been widely recognized as an environmentally friendly, low cost, and sustainable engineering method. This systematic literature review uses the Web of science and Science Direct as databases to store and analyze existing research on the hydromechanical role of vegetation on slope stability, particularly shallow landslides. The purpose of this review is to provide an updated picture for the period 2016 to 2021 to determine the relationship between the presence of plant roots and the quality of soil mechanical properties and the relationship between rainfall and soil hydrological properties that can affect slope stability. The results of this study can be used as a reference for further researchers in developing research related to the topic of slope stability using the vegetative method.

Keywords **—vegetation, hydromechanics, slope stability**

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I. INTRODUCTION

Landslides caused by rainfall are common in mountainous area around the world. The phenomenon of landslides due to rainfall is a global hazard that causes damage to infrastructure and the ecological environment, economic losses, and endangers human life. This incidence tends to increase every year due to the effects of climate change and land use (Van Beek et al., 2008; Sidle

&Bogaard, 2016). This is usually triggered by a decrease in the shear strength of the soil after heavy rains on sloping land. Therefore, it is necessary to implement mitigation measures to prevent landslides.

Installation of vegetation on slopes has been widely recognized as an environmentally friendly engineering method to improve slope stability. The particular stabilizing effect of tree roots is supported by many studies based on landslide inventories. Vegetation has proven to be an effective landslide mitigation measure as it increases the shear strength of the soil through a series of mechanical and hydrological effects (Norris et al., 2008; Ng et al., 2013; Leung et al., 2015). Many reviews of the hydrological and mechanical role of vegetation on slope stability have been carried out over the decades. The results of the study have found that the hydrological and mechanical effects of roots are important in analyzing slope stability. The contribution of vegetation to soil strengthening has been widely recognized, particularly on steep slopes prone to erosion and shallow landslides. Vegetation functions can significantly control processes, both above and below ground, such as interception, evapotranspiration, soil aggregation and root strengthening, which of course correlate with plant growth (Graf, Frei and Böll, 2009). Rainwater that falls on plants does not directly reach the ground surface to turn into surface runoff. Vegetation with a high ability to absorb water from the soil and release it into the atmosphere through the transpiration process will reduce pore water pressure and increase slope stability. Then, vegetation with deep root anchors and strong root binding has a more significant potential to maintain slope stability (Mulyono et al., 2018).

The hydrological effect refers to a change in pore water pressure through water absorption by roots resulting in a decrease in the hydraulic conductivity of groundwater and an increase in the shear strength of the soil (Ng et al., 2013). The mechanical effect refers to the increase in the shear strength of the soil with increasing soil cohesive forces exerted by the roots (Fatahi, Khabbaz and Indraratna, 2009). The main hydrological mechanism that contributes to slope stability is plant water uptake because vegetated slopes are on average 12.84% drier and have three times higher matrix suction than bare slopes (Gonzalez-Ollauri&Mickovski, 2017). Other studies have shown that hydrological effects play a significantly greater role than mechanical reinforcement (Ni et al., 2018). This is because plants can increase soil suction which will increase slope stability, and a longer drying process will achieve higher suction matrix and Factory of Safety (FoS) (Yang et al., 2020). Hydrological reinforcement by transpiration has been shown to be important for slope stability. Plant roots can absorb water through the process of photosynthesis and respiration, as a result the soil around the plant roots gets dry which causes soil suction. (Pollen and Simon, 2005) concluded that slope mechanical reinforcement increased FoS by 25%, while hydrological reinforcement significantly increased FoS by 52%. (Ng et al., 2016) found that ignoring the pre-rain transpiration effect would lead to a reduction of FoS by up to 50%.

It has been revealed that weather conditions play an important role in these two effects (Zhan et al., 2013; Ng et al., 2015). (Liu et al., 2016; Ni et al., 2018) found that the hydrological effect was more pronounced outside the root zone (approximately 4 times the root depth), but the pattern of continued rainfall with an intensity of 394 mm/day was considered the most critical because of Hydrological vegetation is decreasing continuously due to its root architecture system. The behavior inherent in the hydromechanical parameters of the soil can be further used to estimate the reliability of vegetated slopes under various climatic conditions (Das et al., 2017). (Wang et al., 2017) concluded that riverbank vegetation can control sediment deposition. As a result, the flooded area in the valley is reduced (18-24)% and the dense and strong root network will stabilize the soil and improve the environment, thereby increasing the safety factor of the cliff. Root strength is strongly influenced by root diameter, root moisture, and the location of the growing species (Capilleri et al., 2016).

Another study found that the mechanical contribution to the strength exerted by vegetation is much greater than the influence of hydrological effects (Ali et al., 2012). Research that focuses on mechanical strengthening of vegetated slopes includes (Fan & Lai, 2014; Kokutse et al., 2016). Studies have also been carried out using root tensile strength tests which are effective in providing additional tensile strength to increase the shear strength of the soil (Temgoua, Kokutse and Kavazović, 2016). Pull stiffness decreases with root length and soil moisture content, because increasing soil moisture content causes a decrease in soil-root bond strength, where soil-root bond strength decreases with root length (C.C. Fan, et al., 2021).

These findings support the idea that hydrological and mechanical reinforcement of vegetation can improve slope stability. To better understand the hydromechanical reinforcement of a slope, it is necessary to clarify the relative role between hydrological and mechanical reinforcement on the stability of the vegetated slope. Mechanical strengthening of roots is only effective at shallow depths, which are the zones where root biomass is most abundant. The hydrological gain is much more significant at depths of more than 1 m, but this effect can be lost due to the increase in hydraulic conductivity induced by the roots (Ni et al., 2018). (S. Feng et al., 2020) conducted an analytical study to investigate the hydrological and mechanical effects of roots on slope stability and found that the hydrological effect decreased with increasing slope angle, while the mechanical effect showed the opposite.

Although the results of these studies have provided various perspectives in understanding the hydrological and mechanical role of vegetation on soil reinforcement, there is still a lack of quantitative studies and differences of opinion in understanding the hydromechanical role of vegetation on slope stability. In this study, we will systematically explore the factors that determine the hydrological and mechanical role of vegetation in soil reinforcement that will increase slope stability. The review will focus on the following research questions:

1. How does the mechanical role of vegetation affect slope stability?
2. How does the hydrological role of vegetation affect slope stability?
3.What is the trend of the analytical method used by the researcher?
4. What limitations exist in research on the hydromechanical role of vegetation on slope stability?

Based on these research questions, this paper is written by explaining the methodology followed in this review and the way the studies were selected based on the articles selected for this literature review. Having pointed out the possible limitations of this study, conclusions and recommendations are presented for future research on the hydrological and mechanical role of vegetation in soil reinforcement that can improve slope stability.

II. MATERIALANDMETHODS

A systematic literature review was used as a research method. The research problem was formulated to provide better research on the hydromechanical role of vegetation on slope stability. Another objective was to identify data gaps in the compiled documents about studying the effects of woody (trees, shrubs, and shrubs) and non-timber (shrubs, herbs, and grasses) vegetation on slope soil strengthening using this information as a basis for future research.

2.1 Search strategy

Searches were made through the Scopus and Science Direct journal databases to conduct a systematic review of this literature. The search is carried out by the following keywords:

- Scopus: TITLE-ABS-KEY ("hydromechanical" AND "stabili*" AND ("vegetation" OR "plant"))
- Scient Direct: "hydromechanics" AND "vegetation" AND "slope stability".The selection of keywords is intended to focus

on research on the hydromechanical role of vegetation on slope stability. Data mining was carried out in October - December 2021.

2.2 Study selection

The research process was carried out in stages according to the Systematic Literature Review method to produce several articles that became the object of this research. The initial search results yielded 117 articles consisting of 93 articles from Scient Direct and 24 articles from Scopus.

2.2.1 Inclusion and exclusion criteria

From the articles collected at the initial stage, inclusion and exclusion criteria were applied through screening based on the title and abstract as well as these criteria, as listed in Table 1 below. From the results of applying the inclusion and exclusion criteria, 84 articles were obtained.

Tabel 1
Inclusioncriteriaandexclusioncriteria.

Inclusion Criteria	Exclusion Criteria
Research work related to the hydromechanical effect of vegetation on slope stability	The research work is not related to the hydromechanical effect of vegetation on slope stability
Article written in English	Article written in a language other than English
Articles are research published in the period between 2016 and 2021.	Research articles are not published in the period between 2016 and 2021.
Articles are empirical research published through international journals	Proceedings, books, book chapters, theses, short reports, literature reviews.
The full version of this publication is available	The full version of this publication is not available
Published articles follow the research structure in accordance with the research method.	Published articles do not follow the research structure in accordance with the research method.

In addition, there are also quality criteria to be applied in obtaining articles that are in accordance with the topics and problems of this research.

2.2.2 Quality criteria

Articles that met all of the inclusion criteria were then reviewed to test compliance with the quality criteria in Table 2 below. Quality criteria were determined to ensure the relevance of the article to the research question. From the results of the application of quality criteria, obtained 33 articles. The process can be seen through the PRISMA flow in Figure 1 below.

Tabel 2

Quality Criteria
1. Is the concept of the hydromechanical effect of vegetation on slope stability clearly stated?
2. Are the research objectives clearly defined?
3. Is the research designed to achieve the objectives?
4. Were the research questions adequately answered?
5. Is the analysis done based on variables with a clear sample?
6. Did the author discuss the problems and limitations of the study?
7. Are the research results clearly stated?
8. Are future research plans presented?

The selection procedure can be seen through the following PRISMA flow:

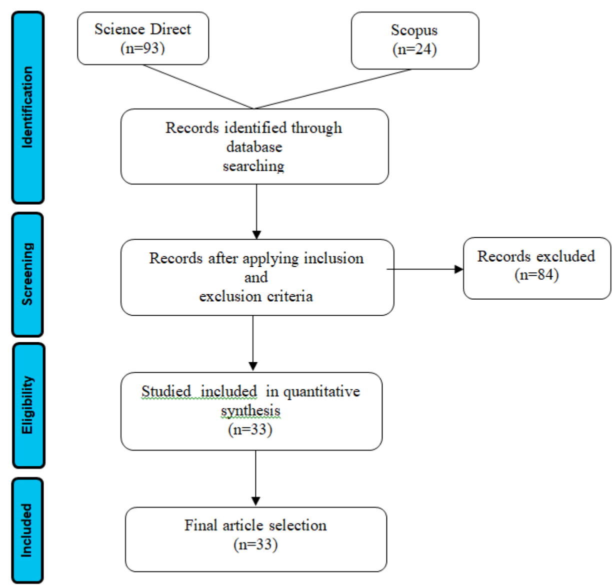

Figure 1.PRISMA (Flow Diagram: Data Extraction Procedure

III. RESULT ANDDISCUSSION

An analysis of previous research articles with a systematic literature review procedure was carried out to answer the research questions below.

3.1 How does the mechanical role of vegetation affect slope stability?

The mechanical role of vegetation in slope stability is to stabilize the slope to strengthen it mechanically through the influence of the following parameters: root tensile; root architecture; root cohesion; root diameter; root density; surge; angle of slope and type of soil. Plants usually have a positive effect on mechanical properties due to the strengthening action by holding shallower to deeper soils. There are 2 articles that discuss the root architecture. (Liu et al., 2016) concluded that rain intensity is low (<181mm/day), exponential root arch is more significant than parabola and the hydraulic effect is more decisive in the root zone, intensity is between 181/day and 394mm/day, hydro effect is outside the root, and Intensity >394mm/day most critical, hydraulic effect decreased due to root ars system. The hydro and mechanical effects of exponential roots were more significant than uniform roots. (Feng et al., 2019) concluded that the mechanical effects of roots were more significant on slopes reinforced by an exponential root branching system than on slopes reinforced by a uniform root branching system. Four articles discuss the role of root tensile strength. Root tensile strength was correlated with root diameter, humidity and location of growth (Capilleri et al., 2016), while in young species, it was found that there was no correlation between root tensile strength and diameter but correlated with Young's modulus (Liang et al., 2017). The discussion of root cohesion is in 4 articles. Soil cohesion creates a dense and strong root network that stabilizes the soil and improves the environment (Wang et al., 2017). The mechanical strengthening of the root shear resistance is generally accepted for inclusion as additional cohesion, which is a function of the root strength across the potential shear plane and mechanical parameters (c, ϕ), and can be further used to estimate the reliability of vegetated slopes under various climatic conditions (Dias et al., 2017). Root cohesion obtained from its tensile strength has a higher effect in rivers with less fine sediment content (Andreoli et al., 2020). There are only 2 articles that discuss the mechanical role of vegetation from root diameter parameters. Root strength correlates not only with root diameter, but also with humidity and growing conditions (Capilleri et al., 2016). Meanwhile, in young species, there was no correlation between the tensile strength of roots and root diameter (Liang et al., 2017). Two articles also discuss the age of vegetation as part of the mechanical effect of vegetation on soil strengthening.

(Vergani et al., 2016) concluded from his research that 5-year-old tree species provided 40% reinforcement and bush species at 15-year-old post-harvest contributed 30% reinforcement. Therefore, regeneration is the key to the success of protected forest conservation. (Li et al., 2019) found that plant cover and new seedling increased over time, peaking at 57.3% and 682.9 seeds/m2, respectively, at the end of the fifth year. Regarding the root density parameter, there are 2 articles that discuss it. Root density is highly correlated with erosion reduction potential (Chau& Chu, 2017) and the crop effect is limited to topsoil, especially plants with dense root systems (Gonzalez-Ollauri&Mickovski, 2017). Two articles discuss the climate where vegetation grows which affects slope stability. (Niu et al., 2016) concluded that vegetation has a strong influence on soil moisture that varies between seasons: i) in summer, vegetation increases soil moisture, due to increased permeability and infiltration in the rainy season, some of which enter the vegetated slope; ii) in autumn, high evapotran effect due to low rainfall; iii) in winter, vegetation helps retain groundwater; iv) in the following spring, the difference in soil moisture between the vegetation and bare slopes decreases due to frequent rains. (Das et al., 2017) concluded that the mechanical parameters (c, ϕ) due to the presence of plant roots can be further used to estimate the reliability of vegetated slopes under various climatic conditions.

The stability of vegetation slopes is strongly influenced by climatic conditions and global warming due to climate change. This includes vulnerability to landslides taking into account extreme climate scenarios. The high rainfall in the last decade (100 year return period) due to climate change was included as a contributing factor in analyzing the stability of the vegetation slope (Ng, Tasnim and Wong, 2019). Meanwhile, in sub-tropical countries, climate change results in an increase in the frequency of droughts that cause tree death, forest fires, and freeze-thaw cycles. By 2100, it is predicted that climate change will increase atmospheric emissions exponentially by 700-1000 ppm (Keeling & Whorf, 2005; IPCC, 2013). The decrease in ground water level due to prolonged drought will make the vegetation on the slopes more susceptible to wilting and death. Thus, there will be a decrease in the hydrological effect and of course there will be root rot which has an impact on decreasing the mechanical effect on soil strengthening. Landslides are likely to occur during times of high rainfall because some areas of pore water pressure are concentrated on the slopes due to rotting of the root tissue.

Data on extreme wildfires occur in California (Williams et al., 2019) and in the Amazon (Fonseca et al., 2019) as well as in Australia (Nolan et al., 2020). (Doerr, Shakesby and Macdonald, 2009) concluded that the trigger for shallow landslides and debris flows is the change of the root zone to a hydrophobic layer with decaying or degraded root tissue. Changes in post-fire material properties and their implications for debris flow have been measured (Kean et al., 2011); (Graff, 2014). (Patton, Rathburn and Capps, 2019) say that climate change causes a transition from perpetual frozen soil to seasonally frozen soil and vice versa so that it will accelerate the effect of the thawing process on vegetated slopes. The degree of fracture, pore water pressure, and hydraulic conductivity also increase as a result of this cycle. In addition, this cycle will also reduce physical properties such as apparent cohesion and friction angle (Guo et al., 2014). Based on field observations, changes in rainfall patterns and rapid melting of snow/ice are likely to increase the frequency and magnitude of landslides (Patton, Rathburn and Capps, 2019). Especially hillsides that experience changes in vegetation cover after forest fires are vulnerable to landslides. (Archer & Ng, 2017) have developed a geotechnical centrifuge setup that can simulate freeze-thaw cycles.

The mechanism of slope failure associated with post-fire and frozen soil conditions can be determined using these settings. Failure simulations were carried out by analogizing varied roots, artificial cracks, hydrophobic ground cover and rainfall patterns. (Keenan et al., 2013; Reef et al., 2016) concluded that increasing CO_2 concentration is generally expected to increase plant biomass, which should facilitate higher mechanical and hydrological reinforcement on vegetated slopes (Ng, Tasnim and Wong, 2019). However, to meet the higher biomass, it requires an increase in plant water uptake which will cause a decrease in the groundwater table, increase susceptibility to wilting and require a higher irrigation supply. Thus, it is necessary to change the water absorption efficiency of the plant, an expected change in biomass at higher CO_2 concentrations.

The mechanisms that cause post-fire landslides need to be investigated in the future. A prototype slope modeling centrifuge with hydrophobic soil layers in the top layer to root depth along with different slope geometries, rainfall intensities, root architectures and soil types, can reveal failures and triggering mechanisms associated with post-fire landslides. About four articles discussing types of vegetation with respect to their mechanical role in soil stabilization. (Zeng et al., 2018) concluded that vegetation type has a significant influence on soil aggregates under different rainfall conditions. (Yan et al., 2021) found that vegetation growing on the embankment reduced surface runoff and soil loss by 15.3–62.5% and 79.4–93.8%, respectively, compared to barren embankments. Meanwhile, (Emadi-Tafti et al., 2021) found that simulations show an increase in FoS up to 25% when the mechanical aspect of vegetation is considered and tends to be 10% larger for steep slopes. Two articles discuss the additional burden (surcharge) from trees. (Gonzalez-Ollauri & Mickovski, 2017) concluded that additional loads due to the weight of vegetation can increase or decrease slope stability. The effect of vegetation surcharge is to create slope stress (destabilization) due to the negative effect of additional load (decrease in stability up to 5% with additional load of 1.2 kPa) on slope stability. The magnitude of this impact varies according to soil properties, tree characteristics and slope geometry so overall results may vary. Generally, slope stabilization by planting artificial forest, native shrubs or trees with a greater reinforcing effect and a lower additional load will be more effective (Emadi-Tafti et al., 2021). Two articles discuss the types of soil from the mechanical role of vegetation on soil stabilization. Pioneer species, even with shallow root systems due to the influence of the local humid climate, can significantly reduce soil mass loss and landslides (Gonzalez-Ollauri & Mickovski, 2016). There is a relationship between the role of vegetation and soil stabilization, as well as vegetation and slope characteristics (Emadi-Tafti et al., 2021)

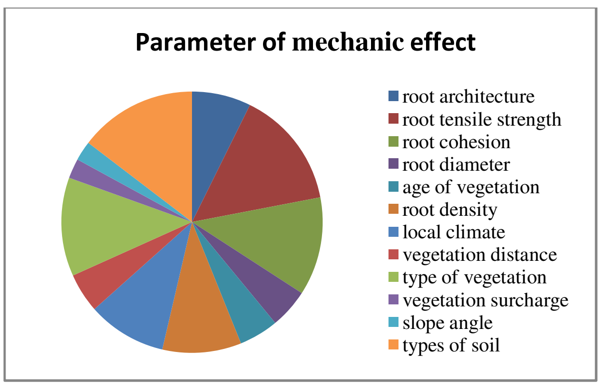

Figure2. Research subjects based on the mechanical effects of vegetation

Research subjects based on the mechanical role of vegetation were grouped based on the grouping of the root system (root architecture, root tensile strength, root cohesion, root diameter, root density), slope geometry (angle of slope), and vegetation load (surcharge of vegetation, tree distance, age of vegetation, types of vegetation, climate where vegetation grows) and research covering subjects from both groups of mechanical roles.

3.2 How does the hydrological role of vegetation affect slope stability?

The hydrological role of vegetation on slope stability is to minimize soil water content through the following parameters: matrix suction; root architecture; root density; rainfall pattern and type of soil. Vegetation can improve slope stability by influencing hydrological processes that determine stability conditions and directly modifying soil mechanical properties. The hydrological balance of the soil depends directly on vegetation because of its influence on interception, infiltration, evaporation, and transpiration. Root water absorption reduces soil moisture content.

There are eight articles that discuss the role of changes in matric suction by evapotranspiration on soil stabilization. One of the hydrological effects of vegetation on stability is matric suction. Matric suction will equalize the water content throughout by applying pressure from the unsaturated soil to the surrounding soil. The shear strength of the soil will increase with the presence of matric suction, and the hydrological regime of the soil can also affect the overall root strength of the soil (Gonzalez-Ollauri&Mickovski, 2017). After rain, the presence of roots on vegetated slopes maintains matric suction resulting in higher shear strength compared to bare slopes (Ni et al., 2018). There is a strong correlation between matric suction and soil shear strength in the form of a non-linear relationship, even though initially it was not directly related. In addition, runoff and evaporation of vegetation are favorable for the stability of shallow vegetated slopes (Huang et al., 2021). The stomatal conductance was inversely proportional to the observed increase in matric suction, which initially increased according to the volumetric field capacity. After that, a large decrease in stomatal conductance was found with an increase in suction, then disappeared at the wilting point (VK Gadi et al., 2019). When the precipitant rainwater infiltration can increase soil moisture, then under delayed and normal rainfall patterns, the capillary barrier system performs much better than Vetiver grass in maintaining soil matric suction and slope stability (Y. Li et al., 2021). Vegetation monitoring can be a useful tool to identify crack locations along embankments that are prone to cracking due to drying conditions (Jamalinia et al., 2020). Rainfall infiltration causes a decrease in FoS and matric suction. Slope stability, and longer drying process will achieve higher matrix suction and FoS. Hydrological reinforcement is three times greater than mechanical reinforcement for the contribution of FoS (Yang et al., 2020). The hydrological and mechanical effects of roots are more significant on slopes reinforced by an exponential root branching system than on slopes reinforced by a uniform root branching system (S. Feng et al., 2020).

Furthermore, there are three articles that discuss the influence of the root architecture. The PWP difference in between vegetated slopes and bare slopes decreases with depth. The hydrological effect of roots is more significant on slopes with exponential root architecture because of the presence of larger roots near the slope surface and causing more water uptake by roots (S. Feng et al., 2020). The pattern of continued rainfall with increasing intensity is the most critical condition, where the hydraulic effect of vegetation decreases continuously due to its root architecture system (Liu et al., 2016). The factor of safety (FoS) increases with increasing drying time and decreases with increasing depth while the minimum FoS is at the intersection of the rootless zone (Huang et al., 2021).

Discussions related to the rainfall pattern from the hydrological role of vegetation were obtained from three articles. Rainwater infiltration can increase soil moisture under delayed and normal rainfall patterns, where the capillary barrier system works much better than Vetiver grass in slope stabilization (Y. Li et al., 2021). Vegetation growing on bunds reduced surface runoff and soil loss by 15.3–62.5% and 79.4–93.8%, respectively, compared to bare bunds (Yan et al., 2021). Vegetation runoff and evaporation are favorable for shallow stability of vegetated slopes (Huang et al., 2021).

Type of soil is one of the parameters of the hydrological effect on slope stability which has been discussed in two articles. (Gonzalez-Ollauri&Mickovski, 2016) have confirmed that vegetation exerts its maximum effect in terms of hydrological strengthening during the dry season, where plant water uptake is the main hydrological mechanism contributing to slope stability. Plant roots have a strong direct effect on increasing soil cohesion (B. jun Zhang et al., 2019).

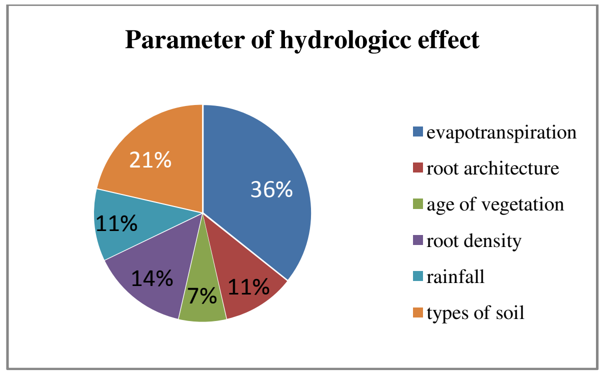

Figure3.Research subject based on hydrological effect of vegetation

Research subjects based on the hydrological role of vegetation were reviewed based on parameters that have a transpiration effect which is a parameter for tree water consumption. Roots can absorb water from the soil and release it into the atmosphere through the process of transpiration which can reduce pore water pressure. Tree water consumption is different for each species, which depends on the age of vegetation, root architecture, rainfall pattern, and types of soil. Soil moisture reduced by vegetation can reduce pore water pressure in the soil mantle on natural slopes and increase stability.

3.3 What is the trend of the method of analysis used by researchers?

The analytical methods used are qualitative research, quantitative research, and mixed-method. There are twenty studies using quantitative methods, eight studies using qualitative methods and three studies using mixed-methods.

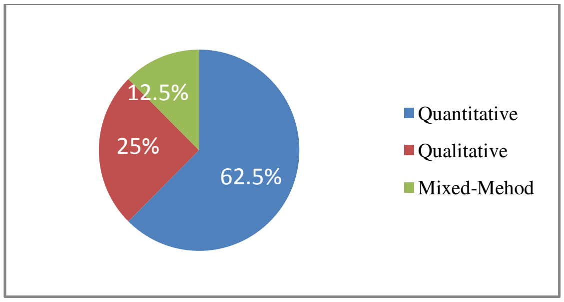

Figure 4.Research Method

Quantitative methods use analytical and simulation methods (Liu et al., 2016; Gonzalez-Ollauri&Mickovski, 2017; S. Feng et al., 2020), numerical analysis and simulation (Ni et al., 2018; Shao et al., 2017; Yang et al., 2020; Huang et al., 2021; Emadi-Tafti et al., 2021), laboratory tests, and simulations (Wang et al., 2017; Capilleri et al., 2016; Vergani et al. , 2016; Gonzalez-Ollauri&Mickovski, 2017; Chau& Chu, 2017; Liang et al., 2017; Zeng et al., 2018; Li et al., 2019; Fan et al., 2021; Gadi et al., 2019). Quantitative methods are widely used to explore the mechanical role of vegetation on slope stability. The qualitative method uses field observations (Gonzalez-Ollauri&Mickovski, 2017, Tardío et al., 2016, Niu et al., 2016, Andreoli et al., 2020) and statistical analysis (Das et al., 2017; Cui et al., 2019) which is widely used to explore the hydrological role of vegetation on slope stability. Combined quantitative and qualitative methods were used for statistical analysis and simulation (B. jun Zhang et al., 2019) and field experiments and simulations (Y. Li et al., 2021, (C. Zhang et al., 2019). Combination method is widely used to explore the hydromechanical role of vegetation on slope stability.

IV. LIMITATIONS

This systematic literature review is limited to research articles for the last six years (2016-2021) from two databases, namely Scient Direct and Web of Science with keywords according to the research theme, “The Hydromechanical Role of Vegetation on Slope Stability”. First, this review only studied publications from the two selected databases, and therefore not all existing publications on the subject were included. Second, it should be mentioned that the limitation of the search year mentioned above is focused on publications written in English in the form of research articles.

V. CONCLUSIONS

Based on the systematic literature review that has been carried out, it can be concluded that:
a. Research that examines at the same time the hydrological and mechanical roles of vegetation is still lack. Most studies examine these roles separately.
b. Several researchers explored the same factors in conducting studies on the role of hydromechanics of vegetation on slope stability
c. There are differences in research results regarding the more dominant role of hydrological and hydrological influences vegetation mechanics on slope stability. This is caused by differences in climate, soil type and the location of vegetation growth. In addition, the factors reviewed and the methods used in the study will affect the final results.

VI. IDENTIFIED GAPS AND FUTURE RESEARCH

This systematic review identifies gaps in research and provides opportunities for developing research on slope stability by exploring more of the hydromechanical role of vegetation. First, most of the selected articles explore the hydromechanics of vegetation on slope stability. However, most of the researchers evaluate it with a separate hydromechanical role which may not show optimal results. Second, according to the results of this systematic literature review, many articles use only one research method. A quantitative combined with a qualitative data approach can offer more comprehensive results on the hydromechanical role of vegetation on slope stability. Further research can be done by reviewing the factors that are more dominant from the two roles, but not separately.

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