Floods and their problems: Land uses and soil types perspectives

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Abstract. The phenomenon of flooding that occurs in almost all regions of the earth causes loss of property and damage to public facilities and causes the loss of many human lives. There are many reports related to the causes of flooding with various solutions offered to overcome the flood problem. However, it seems that these efforts have not been able to eliminate the flood problem. Hydrologists have widely reported various factors that are the cause of flooding with an extensive scope. Therefore, this paper is limited to discussing flooding and its problems, specifically the river flood, from the perspective of land use and soil types. Changes in land use in a watershed can cause an increase in the runoff coefficient. Likewise, different types of soil have different abilities in passing water into the ground. Open land (without land cover) tends to be prone to erosion, reducing the soil's infiltration capacity and increased surface runoff. Increasing the runoff coefficient will increase the peak discharge in a watershed. The decrease in the river capacity due to sediment can cause a river flood. To support this argument, a rainfall-runoff model, particularly the tank model, is also discussed, taking into account the various uses and types of soil in a watershed. Efforts to anticipate the river flood are also considered for formulating flood disaster control policies in a watershed.

1. Introduction

Flood events recently hit almost all regions of the world. Flooding is one of the most significant natural risks with high impact and concern in the global community [1]. Floods can not only cause property loss and damage to public facilities but can cause loss of life. Floods are the most expensive natural disaster event in the United States in terms of lives and property losses [2]. A very significant flood event could cost more in Queensland 2010–2011 causing over $2 billion in infrastructure damage and even greater indirect costs to the economy [3]. The occurrence of floods not only caused damage to infrastructure and property but also claimed thousands of lives in South Asia [4]. Floods are one of the deadliest disasters affecting people's welfare and livelihoods in China. River floods cause a significant threat to road transport infrastructure in Europe. The estimated annual direct damage from major river flooding to road infrastructure in Europe is EUR 230 million per year [5].

Four types of primary floods are categorized according to where they occur, namely coastal flooding, urban flooding, flash flooding, and river flooding [6]. Discussing all types of floods is very complicated because they have different causes and characteristics. Therefore, this paper only discusses a river flood from the perspective of land use and soil type.

Analysis of the factors that causes flooding is widely reviewed by researchers around the world. Climate change is intensifying the frequency and severity of floods worldwide [7]. Globally projected river flood risk in the world as a result of global warming 4°C, countries that represent more than 70%
of the global population and global gross domestic product will face increased flood risk of more than 500% [8]. The increased impermeable surface area prevents rain from seeping into the underlying soil, causing urban watertight areas to show faster and larger [9]. Floods are usually caused by the inability of natural flows and drainage systems to drain excess water after heavy rains. Other causes of flooding may include, among other things: the low capacity of watercourses or river networks to convey runoff, catchment areas, weather conditions before rainfall events, land cover, and topography [1]. Floods occur due to hydro-meteorological and natural factors, but in recent years, human intervention has added a new dimension to it [4].

A watershed that experiences significant land use changes from year to year can cause an increase in the runoff coefficient. Open land (without land cover) tends to be prone to erosion to minimize infiltration. Different soil types have different infiltration capacities. The type of soil that has a dominant sand texture will have a greater infiltration capacity than the type of soil that is dominated by clay. In the context of passing water into the soil, one parameter mentioned with the runoff coefficient becomes important to analyze. This is because the runoff coefficient can describe what percentage of the rainfall becomes surface runoff and which can infiltrate into the soil. The higher runoff coefficient from year to year in a watershed tends to be the main cause of river flooding in a watershed. To discuss river flooding from the perspective of land use and soil types can also be associated with a rainfall-runoff model, especially the tank model, which considers various types of uses and types of soil in a watershed. Based on the previous description, the paper that discusses river floods and their problems from the perspective of land use and soil types is important and interesting to discuss.

2. Land uses and soil types perspective on floods

The stream flow can be expressed in the general form (equation 1) and it may be expressed in linear form (equation 2). Furthermore, multiple correlation equations are proposed (equation 3) and in linear form (equation 4) can be used to examine river floods in a watershed [4].

\[ Q = a x_{1}^{b_{1}} x_{2}^{b_{2}} x_{3}^{b_{3}} \ldots x_{n}^{b_{n}} \]  
\[ \log Q = \log a + b_{1} \log x_{1} + b_{2} \log x_{2} + b_{3} \log x_{3} \ldots + b_{n} \log x_{n} \]  
Where, \( Q \) = the discharge for a given recurrence interval (dependent variables)
\( X_{1} \) to \( X_{n} \) = basin and meteorologic characteristic (independent variables)
\( a, b_{1} \) to \( b_{n} \) = constants to be determined.

\[ Q_{T} = aA^{s}S^{i}I^{s}I_{s}^{f} \]  
\[ \log Q_{T} = \log a + b (\log A) + c (\log I) + d (\log I_{s}) + e (\log S) + f (\log S_{s}) \]  
Where, \( T \) = recurrence interval in years
\( A \) = drainage area in square miles
\( S \) = main channel slope in feet per mile
\( I \) = rainfall intensity in inches per 24 hours for recurrence interval of 2.33 years
\( I_{s} \) = soil index in inches per hour
\( S_{s} \) = percent of surface storage plus 1.0 per cent
\( a, b, c, d, e, f \) = derived constants.

The studies showed that the hydrologic characteristics affecting floods from large watersheds are drainage area size and main channel slope and for small watersheds are drainage area size, rainfall intensity, and soil index. It is well-known that the infiltration rate of soils and their permeability (as affected by land use and soil cover), is a good parameter or index to express soil characteristics [10]. Therefore, further discussion related to land uses and soil types are important to examine the factors that affect river flooding in a watershed.
2.1 Land use types

A watershed has several types of land use such as forest, shrubs, grass, settlements, and open land. Different types of land use show different responses to rainfall in a watershed. Types of land use that have cover crops such as forest, shrubs, and grasses tend to have the ability to pass water into the soil through a smoother infiltration process compared to types of land use without cover (settlement and open land). Urban areas that tend to have residential areas and other built-up areas that are impermeable to water will reduce the chance of water entering the soil through the infiltration process when it rains, on the other hand, the surface runoff will increase. Likewise, open land (without cover) tends to be prone to erosion and has an unstable soil structure. An intensive erosion process can cause soil pores to be closed, thus inhibiting the infiltration process.

Research conducted in several watersheds/sub-watersheds in Aceh Province of Indonesia such as Krueng Jru sub-watershed [11], Krueng Petoe sub-watershed [12], Krueng Seunagan watershed [13], Krueng Woyla watershed [14] provides information that land use changes characterized by a decrease in the area of land use types that have cover crops tend to increase the runoff coefficient in these watersheds/sub-watersheds. This is in line with the results of research [15], [16] which also concludes that changes in land use types that have a land cover (cover crops) to land uses without land cover (open land) affect the runoff coefficient and peak discharge of a watershed/sub-watershed.

According to the Law of the Republic of Indonesia Number 41 of 2007, the forest area is at least 30 percent of the total area or watershed area. However, the results of the analysis for several watersheds in Aceh, Indonesia show that the minimum area has not been achieved for several administrative areas such as the Krueng Kertoe watershed and the Singkil watershed. This is the cause of the frequent occurrence of river floods in the two areas. Data on land use change for the Kertoe and Singkil watersheds, Aceh Province, Indonesia can be seen in Table 1 and Table 2.

### Table 1. Land Use Changes in the Kertoe Watershed, Indonesia

| Land uses          | Area (Ha) | Deviation (1990-2019) |
|--------------------|-----------|-----------------------|
|                    | 1990      | 2000      | 2010      | 2019      |                     |
| Water body         | 126.60    | 126.60    | 126.60    | 100.40    | -26.20              |
| Scrub              | 3,380.21  | 5,483.20  | 7,035.83  | 43.43     | -3,336.78           |
| Swamp scrub        | 276.61    | 276.61    | 276.61    | 6,006.23  | 5,729.62            |
| Airport            | -         | -         | -         | 100.95    | 100.95              |
| Primary Dryland Forest | 14,001.59 | 7,871.56  | 7,871.56  | 11,063.03 | -2,938.56           |
| Secondary Dryland Forest | 39,427.18 | 35,220.55 | 30,264.08 | -9,163.10 |
| Settlement         | 865.33    | 865.33    | 865.33    | 6,164.82  | 5,299.48            |
| Plantation         | 12,839.65 | 13,739.39 | 13,739.39 | 15,420.07 | 2,560.42            |
| Dryland farming    | 4,300.66  | 4,300.66  | 4,300.66  | 1,019.92  | -3,280.74           |
| Mixed Dryland Farming | 10,338.62 | 15,994.45 | 15,994.62 | 14,839.67 | 4,501.05            |
| Ricefield          | 15,621.55 | 15,621.55 | 15,621.55 | 14,991.49 | -630.06             |
| Pond               | 4,905.72  | 4,905.32  | 4,905.32  | 5,309.07  | 403.75              |
| Open ground        | 576.84    | 542.98    | 722.15    | 1,357.00  | 780.16              |
| **Total (Ha)**     | **106,680.16** | **106,680.16** | **106,680.16** | **106,680.16** |

### Table 2. Land Use Changes in the Singkil Watershed, Indonesia

| Land Uses          | Area (Ha) | Deviation (1990 – 2019) |
|--------------------|-----------|-------------------------|
|                    | 1990      | 2000      | 2010      | 2019      |                     |
| Airport / Port     | -         | -         | -         | 56.22     | 56.22               |
| Water body         | 4,736.65  | 4,736.65  | 4,736.65  | 7,607.42  | 2,870.77            |
| Scrub              | 40,160.93 | 39,614.48 | 62,227.63 | 47,055.56 | 6,894.63            |
| Swamp Scrub        | 22,593.10 | 32,847.03 | 33,938.45 | 35,003.33 | 12,410.23           |
| Primary Dryland Forest | 254,599.51 | 253,320.66 | 249,764.37 | 251,519.95 | 2,920.44            |
| Secondary Dryland Forest | 210,516.84 | 173,500.13 | 129,723.51 | 104,500.04 | -106,016.81         |
| Secondary Mangrove Forest | 5.52     | 5.52      | 5.52      | 452.20    | 446.68              |
| Primary Swamp Forest | 3,038.09  | 3,605.81  | 3,274.46  | 997.38    | -2,040.71           |
| Secondary Swamp Forest | 103,934.69 | 90,115.89 | 68,454.08 | 63,130.32 | -40,804.37          |
The zoning mapping of flood-prone areas in Aceh Singkil Regency from the total area of the research area is dominated by the very vulnerable class with a percentage of 90.74%, the vulnerable class 9.22%, and the moderately vulnerable 0.04%. Factors that greatly affect flood vulnerability in Aceh Singkil Regency are high rainfall and flat topographic conditions as well as changes in land use [17]. Deviations in the use of existing land in 2012 to the spatial allocation of the RTRW of West Aceh Regency in 2012-2031 covering an area of 25,319.21 ha (9.16%), including protected areas into secondary forests covering an area of 22,199.35 ha (8.03%), protected areas used as a plantation area of 1,079.44 ha (0.39%), used for agriculture an area of 1,723.28 ha (0.62%), and utilized for a residential area of 317.14 ha (0.11%). The causes of deviations are due to the lack of socialization of the 2012-2031 West Aceh Regency spatial plan to the community and illegal logging activities around protected forest areas [18]. The causes of the conversion of agricultural land to non-agriculture in Biruen Regency include increasing land prices and population [19].

The Government of Indonesia has issued Law No. 26 of 2008 concerning the National Spatial Planning which regulates the utilization of space allocation for an area [20]. However, some previous studies [21],[22] provide information that there has been a mismatch between the direction of space utilization and the utilization of existing space. The main cause of this inconsistency is the lack of public understanding of the rules for using space.

### 2.2 Soil types

A watershed has various types of soil that have certain characteristics in response to rainfall. Infiltration, which is known as the process of entering water into the soil, will differ from one soil type to another. Many researchers from all over the world report research related to infiltration and the factors that influence it. Infiltration rate studies that have been carried out in the province of Aceh, Indonesia [23], [24], [25] provide information that different soil types have different infiltration rates which are influenced by the characteristics of the soil. Soil physical properties such as texture, organic matter, structure, and type of land use.

Research conducted in China [26] concluded that soil moisture and plant roots significantly affected the infiltration process at different stages in the three grasslands. The observed soil infiltration capacity was higher in leguminous grasslands than in gramineal and mixed grasslands.

Research conducted in Eastern Iran [27] concluded that soil infiltration prediction has a strong relationship with channel network, sand content, distance from the main river, Normalized Difference Salinity Index, elevation, and Normalized Difference Vegetation Index in the study area. Infiltration capacity depends mainly on soil texture, soil structure, vegetation cover, soil compaction, rainfall time, soil moisture content [28]. Infiltration studies in urban areas in China [Ren et al 2020 [29]] concluded that changes in soil infiltration rates in urban green open spaces can reduce runoff coefficients and peak runoff, thereby reducing the risk of urban flooding and water accumulation. Research conducted in Ethiopia [30] stated that changes in soil structure caused by compaction of surface soil due to tillage and trampling of animals coupled with lower soil organic carbon content may be the main factor causing the decrease in infiltration and soil moisture content after forest conversion to cultivation and grazing.

Characteristics of various soil types are very useful in providing initial information regarding the ability of a soil type to pass. Several types of soil found on the island of Java, Indonesia with the main characteristics of each type of soil [31], [32], [33], [34] can be seen in Table 3. While the characteristics of soil types [23], [24], [25] in Aceh Indonesia can be seen in Table 4.
Table 3. Characteristics of Soil Types in Java, Indonesia

| Soil types | Location | Main characteristics | Erodibility | Permeability |
|------------|----------|----------------------|-------------|--------------|
| Oxisols    | Darmaga, Bogor | Soils with an oxic horizon to a depth of 150 cm from the soil surface | 0.02–0.04 | Rather fast |
| Vertisols  | Jegu, Blitar | Soils with a clay content of ≥ 30% and with the property of expanding and shrinking to a depth of 30 cm | 0.24–0.30 | Slow |
| Ultisols   | Jonggol, Bogor | Soils with an argillic or kandic horizon, base saturation (BS) < 35% to a depth of 200 cm or 75 cm below fragipan | 0.12–0.19 | Slow |
| Alfisols   | Punung, Pacitan | Soils with argillic, kandic or natric or fragipan horizons with clay skin, Base Saturation (BS) > 35% | 0.18–0.25 | Slow |
| Entisol    | Tanjung Harjo, Kulon Progo | Other types of soils, newly formed. | 0.11–0.16 | Slow |

Table 4. Characteristics of Soil Types in Aceh Province, Indonesia

| Location: Krueng Jreu Sub Watershed [23] | Location: Jeurango Sub District [24] | Location: Lawe Menggamat Sub Watershed [25] |
|------------------------------------------|--------------------------------------|-----------------------------------------------|
| Soil types | Land uses | Infiltration | Soil types | Land uses | Infiltration | Soil types | Land uses | Infiltration |
| Ultisol | Savanna | Slow | Ultisol | Citronella oil | Rather slow | Ultisol | Plantation | Rather slow |
| Inceptisol | Scrub | Slow | Inceptisol | Citronella oil | Rather slow | Inceptisol | Plantation | Rather slow |
| Entisol | Scrub | Slow | Inceptisol | Open ground | Slow | Entisol | Plantation | Medium |

Ultisol is a type of soil that has undergone advanced weathering which is characterized by the presence of an argillic horizon which has a high clay content. As a result, infiltration will decrease so that surface runoff will increase. This soil generally does not have a stable aggregate so it is easily eroded [33]. Furthermore, the amount and rate of water infiltration into the soil to the impermeable layer greatly determine the amount of surface runoff, and this greatly determines the destructive power and carrying capacity of the surface runoff. Shallow soils such as Entisols generally have relatively low water holding capacity. Meanwhile, in soils classified as Ultisols or Alfisols, the presence of an impermeable subsurface horizon (argillic horizon) can be a factor inhibiting the process of water infiltration into the soil [34].

The runoff coefficient or abbreviated as C is a number that shows the ratio between the amount of runoff water and the amount of rainfall. This runoff coefficient number is one indicator to determine whether a watershed has experienced physical disturbances. The higher the runoff coefficient, the greater the rainfall becomes surface runoff, otherwise the infiltrated water will be smaller. In simple terms, the Rational formula [35], [36] can be used to analyze the effect of the runoff coefficient on peak discharge as shown in equation (5).

\[ Q = 0.0028 \times C \times i \times A \]  \hspace{1cm} (5)

Where \( Q \) = peak flow (m³s⁻¹), \( C \) = koefisien runoff (0 ≤ C ≤ 1), \( I \) = rainfall intensity (mm hour⁻¹), \( A \) = watershed area (Ha).
The use of the rational formula has been widely used to analyze peak discharges in Indonesia [37], [38], [39] and in several other countries [40], [41], [42]. The results of these studies explain that the type of land use and soil type have a close relationship with the runoff coefficient value. The more open the soil without cover, the greater the runoff coefficient. Types of soil that contain high clay will be difficult to pass water into the soil. An unstable soil structure will easily erode and can inhibit the rate of infiltration into the soil. In other words, the type of land use and the type of soil affect the runoff coefficient and peak discharge of a river. When the river discharge exceeds its carrying capacity, river floods are expected to occur.

3. Rainfall runoff model for floods analysis

The rainfall runoff model for floods analysis has been introduced by many hydrologists. However, discussions that explain the effect of land use type and soil type on fluctuations in water discharge in rivers are still rare. Therefore, one of the rainfall run off models, namely the tank model, which considers the existence of various types of land use and soil types, becomes a challenge and interesting to be discussed by hydrologists. Since its introduction by [43], a Japanese hydrologist, the use of model tanks has been used by many experts around the world. The use of model tanks takes into account the types of land use and soil types [44], but the tank models that have been cited by other experts have not explained which part of the tank structure must be adjusted. A forest land use and Ultisols soil type that is set with a tank that has several layers may differ in the structure of the tank with the use of shrub land and Entisol soil type. In other words, the hole coefficient values for infiltration, percolation, and deep percolation need to be adjusted to the real conditions in the field. Research conducted in several locations in the world [11], [45-49] gives different values for the hole coefficients as shown in Table 5.

Analysis of the coefficient values for infiltration, percolation, and deep percolation provides an overview of a particular soil type and land use that can significantly contribute to river floods. The coefficient values which tend to be very small compared to the runoff coefficient values for surface runoff give a signal that rainfall tends to become surface runoff in a watershed under review, and vice versa. Therefore, the logic of the magnitude of the hole coefficients needs to be evaluated based on the nature of the soil that affects the infiltration. There is a tendency for certain soil types and land uses in a watershed that has a large runoff coefficient value (> 0.5) which tends to stimulate high surface runoff. In conditions of high rainfall, river flooding events will increase in frequency in a watershed that has wider open land and soil types that have slow infiltration capacity. Integrated watershed management as efforts that can be considered to anticipate and mitigate river floods for a watershed include: 1) controlling land use change, 2) socializing and overseeing the implementation of spatial plans, 3) rehabilitating degraded lands, 4) implementing soil and water conservation for agricultural cultivation, 5) build reservoirs and dams as water sources and control floods, 6) protect protected areas from being used illegally.

### Table 5. Coefficient of tank holes

| Four layers tank model | Coefficient of tank holes | Components of water balance | Krueg Jre Sub Watershed Indonesia [43] | Cidanau watershed Indonesia [45] | The basin of Gao-Ping Creek, Taiwan [46] | Two layers tank model | Mimico creek watershed, Canada [47] |
|-----------------------|--------------------------|-----------------------------|---------------------------------------|---------------------------------|----------------------------------------|-------------------------|----------------------------------|
| First tank            | f2                       | Surface flow                | 0.15                                  | 0.10                           | 0.173                                  | Surface flow            | 0.07                             |
|                       | f1                       | Subsurface flow             | 0.10                                  | 0.10                           | 0.068                                  | Subsurface flow         | 0.01                             |
|                       | f0                       | Infiltration                | 0.36                                  | 0.20                           | 0.148                                  | Infiltration            | 0.90                             |
| Second tank           | fb                       | Intermediate flow           | 0.17                                  | 0.03                           | 0.067                                  | Base flow               | 0.01                             |
|                       | fb0                      | Percolation                 | 0.125                                 | 0.06                           | 0.086                                  |                         |                                  |
| Third tank            | fc                       | Sub baseflow                | 0.035                                 | 0.06                           | 0.014                                  |                         |                                  |
|                       | fc0                      | Deep percolation            | 0.025                                 | 0.012                          | 0.023                                  |                         |                                  |
| Forth tank            | fd                       | Base flow                   | 0.002                                 | 0.001                          | 0.001                                  |                         |                                  |
4. Conclusions
Floods and their problems, especially flood rivers, from the perspective of land use and soil types have shown that land use and soil types in a watershed contribute to the runoff coefficient. A watershed that tends to have a runoff coefficient that is increasing from year to year indicates that the watershed is physically damaged. Types of soil that have a slow infiltration capacity and are open (without cover crops) will be prone to erosion due to surface runoff. This will increase the peak discharge which in turn can cause river floods (river floods). The rainfall runoff model that uses a tank model to analyze river floods (river floods) needs to consider the characteristics of land use types and soil types in a watershed. Integrated watershed management needs to be carried as efforts to anticipate and mitigate the river floods in a watershed.

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