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REVIEW ARTICLE

The Role of Factors Affecting Flood Hazard Zoning Using Analytical Hierarchy Process: A Review

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Abstract
Flood hazard zoning is an important problem that has received much attention from environmental researchers. This problem requires complex spatial analysis; hence, numerous criteria have to be assessed. Factors contributing to the flood formation includes both natural and socioeconomic ones. However, the central question is what factors are important in creating a flood and how to quantify these factors. To answer this question, one of the popular approaches is the analytical hierarchy process (AHP) developed by Saaty. The usage of the AHP algorithm to calculate the weight of each factor is one of the main steps in the process of creating a flood hazard map. This paper will provide an overview of the factors that affect flood formation and analyze their weight by selecting and evaluating the degree of effect of factors in various research using the AHP algorithm. The results can be used as a reference for studies on flood risk zoning in different basins when selecting the impact criteria.

Keywords Flood hazard zoning · Flood-affected factors · AHP method · Lam river basin

1 Introduction

The flood is a natural disaster that occurs quite frequently and has caused negative impacts on the economy as well as society in numerous nations all over the globe for thousands of years. Facing such threats, it is important to study scientifically the underlying parameters triggering the floods and also find the solutions for predicting and; thus, minimizing its effects on the human lives and the properties. To prevent and alleviate damages caused by flood, it is essential to evaluate and map the flood hazard zones.

The search results based on the keyword "Flood hazard zoning" on the Sciendirect Digital Library from 2005 to 18/9/2020 are 1813 works. The number of research published each year is shown in Fig. 1. The chart in Fig. 1 shows that the number of studies on zoning flood hazard is increasing significantly, from 37 studies in 2005 to 227 studies in 2019 and the first 9 months of 2020, the number is 248. Obviously, there has been a growing interest in zoning flood hazard from scientists all around the globe.

There have been numerous methods to map the flood hazards zones that have been simultaneously applied in various regions all over the world. Each method has its own advantages and disadvantages and application conditions. The choice of the appropriate method depends on the input data, the project's requirements and the technician's skill set.

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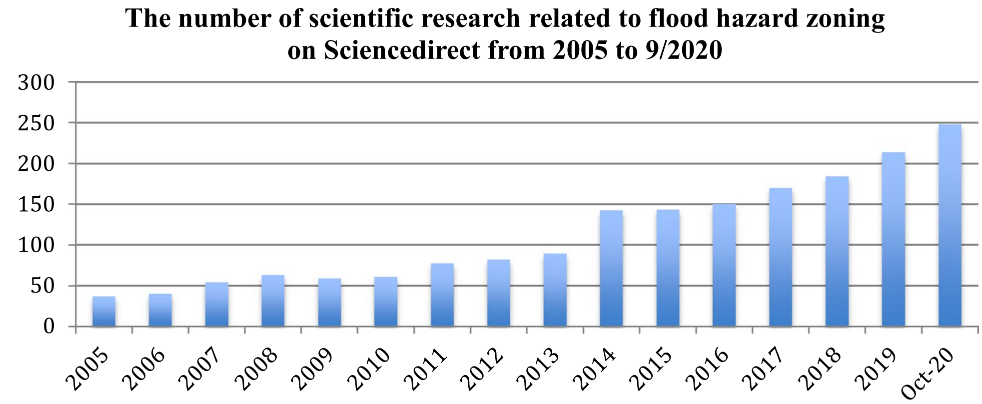

Fig. 1 The number of scientific research related to flood hazard zoning on Sciencedirect from 2005 to 9/2020

Besides popular methods such as using remote sensing data and GIS (Islam and Sado 1998, 2000a, b; Loan and Umitsu 2011; Uddin et al. 2012), hydrological and hydraulic models (Gholami et al. 2016; Kardavani and Qalehe 2013; Nyarko 2000; Shahiriparsa et al. 2013; Shahiriparsa and Vuatalevu 2013), statistical models (Marchesini et al. 2016; Pradhan 2010; Tehrany et al. 2013), analytic hierarchy process methods are also applied in the flood risk zone.

Flood hazard studies are generally based on the meteorological, hydrological, and geomorphological data and typically use hydraulic modeling to predict flood depth based on the rainfall–runoff relationships (Vojtek and Vojteková 2016). However, in many developing nations, there is a lack adequate sets of such data (Skilodimou et al. 2019), so the use of hydraulic modeling is limited in these contexts; thus, a GIS-AHP combination-based flood hazard analysis is more appropriate and can be used to estimate flood hazards. All of the above methods are easy to perform on GIS due to the fact that the data used is in the form of vector or raster maps. However, in terms of openness and flexibility, the AHP method is most appreciated because of the unlimited number of parameters and ease of adjustment. In addition, the area of research is also an issue of concern. Although the hydrological and hydraulic model is recommended only for small areas, the remaining methods can completely build-up for a large river basin. Moreover, the data acquisition is also an important problem in flood hazard zoning. It is undeniable that the preparation of data for the implementation of statistical models and hydrological and hydraulic models will be difficult because at some flood areas, monitoring and information recording equipment are missing or asynchronous. Therefore, the choice of the AHP method in the flood hazard zoning is the appropriate method that can be applied in the large river basin and inadequate data collected.

A number of studies on zoning flood hazards are listed in Table 1 based on the searching on the Sciendirect Digital Library from 2005 to 9/2020 with the keyword “Flood hazard zoning by AHP”. The search results have shown that the use of the AHP method in flood risk zoning is increasingly common, from 1 study in 2005 to 29 studies in September 2020.

The analytic hierarchy process method (AHP) is a structured technique for organizing and analyzing complex decision, based on the mathematics and psychology. It was developed by Saaty in the 1970s and has been extensively studied and refined since then (Saaty and Peniwati 2008). The AHP is a multiple-criteria decision-making tool that has been used in many applications related to decision making. More specifically, AHP is a decision-making approach based on the genuine ability of people to make critical decision (Saaty 1987). AHP is a semi-quantitative method, but analyzing, evaluating, and calculating provide a complete quantitative method. Thus, it is possible to compare different criteria to each other relatively. This algorithm has been applied to a wide range of fields including environmental resources. The combined usage of GIS, remote sensing data, and AHP in researching, managing, evaluating, and mapping the flood hazard zones has gradually grown more popular since then. This method does not restrict the number of input criteria. Depending on the research field, these criteria can be hydrological data, such as rainfall, rate of rainfall, flood rate, etc. or physical geography data, such as slope, elevation, vegetation cover, river density, etc. or socio-economical data such as population density, land use, etc. Moreover, an

Table 1 The number of scientific research related to flood hazard zoning using AHP method on Sciencedirect from 2005 to 9/2020

Year	2005	2006	2007	2008	2009	2010	2011	2012
Number	1	1	2	3	2	2	1	7
Year	2013	2014	2015	2016	2017	2018	2019	9/2020
Number	6	7	10	13	4	9	18	29

indisputable advantage of the AHP method is its variability, AHP can easily modify the number of criteria in the model. Hence, choosing this method in flood hazard zoning is an appropriate method that can be applied to large river basins, small scale, and those which a lack of data.

To implement AHP in flood hazard zoning, the choice of the appropriate criteria which contribute to the formation of a flood is necessary. Yet, the factors that affect the formation of the flood have different roles and importance, it is essential to precisely evaluate those differences and select the most important among others. Different research areas with various natural, economical, and social features will have different factors that directly affect floods. To evaluate the flood hazard, it is necessary to investigate a series of flood triggering and causal factors and their relationship with flooding. The literature indicates that there is no specific guideline for selecting parameters that affect flood occurrence. The selection of flood-controlling criteria is an important step for flood hazard mapping and depends on the physical and natural characteristics of the study area and data availability (Liuzzo et al. 2019).

In addition to the studies that select the flood causative factors in accordance with the physical conditions of the study area (Kittipongvises et al. 2020; Kazakis et al. 2015; Kamonchat and Sarintip 2018; Mayaja and Srinivasa 2016; Nitin 2018), some studies only give impact criteria without analyzing and explaining (Lawal et al. 2012) or mentioning factors contributing to the flood hazard that are not suitable with the characteristics of the study area (Generino et al. 2014; Catherin et al. 2017; Ghosh and Kar 2018; Dask and Sar 2020; Fernández and Lutz 2010; Jean et al. 2016; Kazakis et al. 2015; Lappas and Kallioras 2019). Catherin et al. (2017) have confirmed that urban flooding occurs when rainfall falls on impervious surfaces in the study area with the uneven distribution of rainfall, yet their study only uses factors related to terrain without mentioning one of the flood triggering factors, rainfall. Likewise, Generino et al. (2014) insisted that the natural features in climate and terrain are the main factors causing flood hazard in the studied area with an obvious seasonal variation on precipitation. They did not use data related to such features in their research such as precipitation, drainage density, slope, etc., yet considered population density one of the three main factors affecting flood creation in the study area. George et al. (2016) also assessed the rainfall as a criterion causing a severe flood where more than 100 mm of rainfall was locally recorded in 5 h. However, this variable was not included in the study to analyze. According to Ghosh and Kar (2018), the study area with the annual rainfall pattern gradually decreases due to the variations in topography, vegetation character but the authors only consider the landform and slope factors without using the vegetation cover in the calculation model. Besides, population density—a factor that is considered the prime reason for flood hazard because of the high rate of urbanization and human interventions, is also not mentioned though the decadal growth of population is 20.6% (Dask and Sar 2020), or the study region is one of the most densely populated cities and urbanization has spread rapidly (Fernández and Lutz 2010; Jean et al. 2016). Moreover, some areas with the dense, well developed, diverged, and dendritic drainage network, but the drainage density factor is not considered when studying flood hazard zoning in those places (Kazakis et al. 2015; Lappas and Kallioras 2019). The region has characterized by a diverse geomorphological setting, with elevated topography of hills along the border, yet some other criteria were taken as the causative factors in the study of Md.Yousuf et al. (2019) without geomorphological factor.

Previous literatures focus on different paramaters and their impact on flood hazard. However, there is unclear explanation for why choosing those factors in many studies. Based on the literature, factors affecting flood hazard will be divided into seven groups related to hydrological and orographic characters, geomorphologic characters, meteorological characters, cover characters, soil characteristics, infrastructure, and socioeconomic characters. The objective of this paper is to review, analyze, evaluate, and synthesize the flood causative factors and their influencing degree into a coherent piece, and give suggestions to choose factors contributing to flood generation in accordance with the geographical and socioeconomic characteristics of each area. The study results are beneficial for future studies for choosing criteria and calculating their weight in zoning flood hazard using the AHP method in different areas, particularly for sparse data.

2 Data and Methodology

The research methodology is shown in Fig. 2. The research objectives were achieved through a literature review and analysis of the previous research in the world. The method is designed by dividing this study work into three primary stages, as presented below.

In the first stage, achievement research aim and methodology will be determined. The research begins with a literature review relating to the flood hazard examining previous research journals, articles, papers, projects, and reports. The Google Scholar, Web of Science/Knowledge and Scopus databases were searched for appropriate research works via the following keywords: flood hazard, flood risk, flood vulnerability, flood hazard zoning, factors affecting flood hazard, flood hazard zone map. The above-mentioned electronic databases include numerous published studies from local and international scenarios in a variety of fields. Account has been taken of studies published over the last 15 years to determine the trends in research on flood hazard zoning.

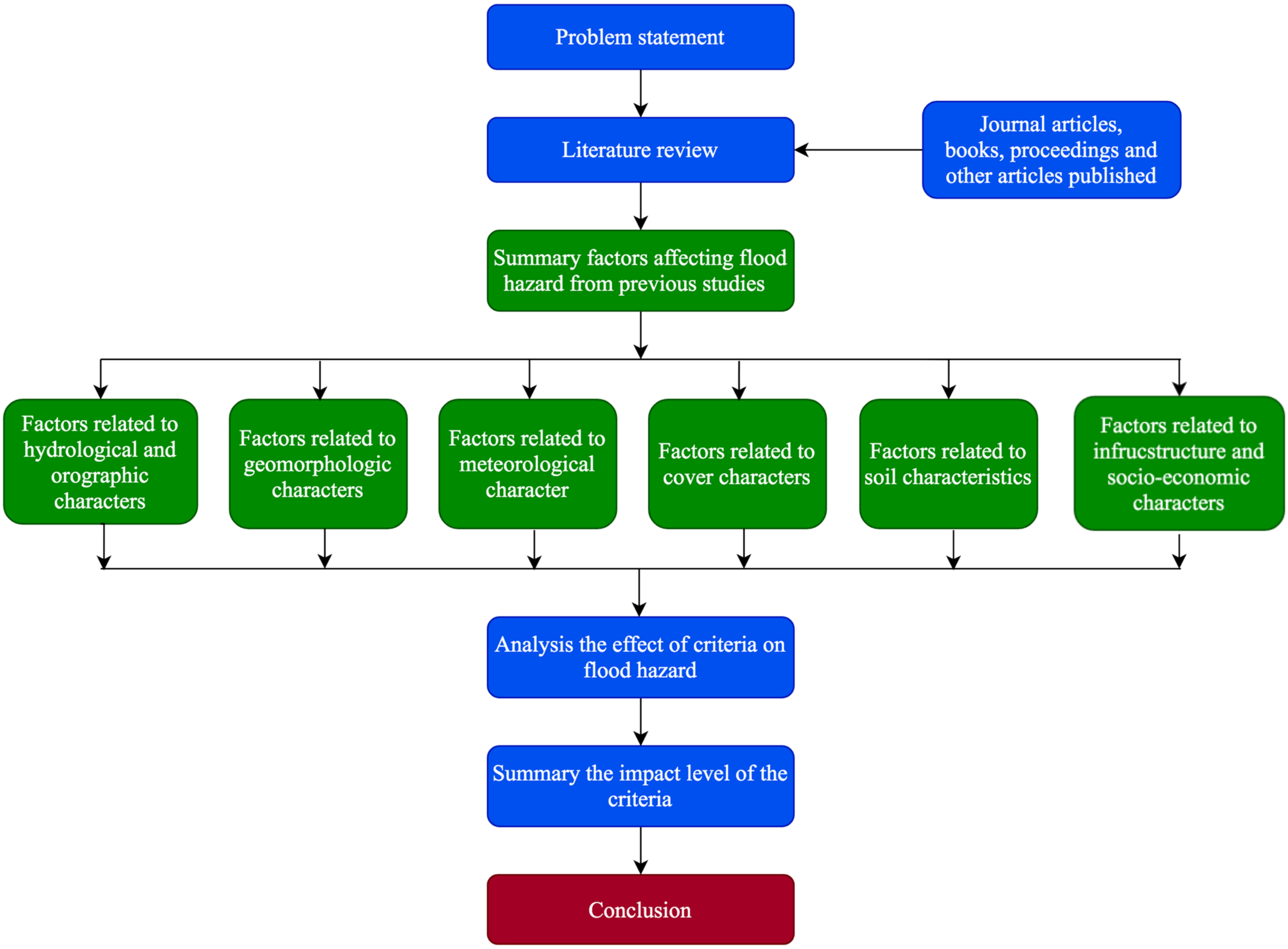

Fig. 2 Research methodology flowchart

During the second stage, it is necessary to identify the criteria leading to the formation of a flood. Scientific literature was found from journal articles, books, proceedings, and other published articles during the period 2005–2020. The major materials included in this review paper were from different journals such as Environmental and Socio-economic Studies, Geography, Environment, and Sustainability, Journal of Geographic Information System, Scientific Research, Engineering Geology, Journal of Hydrology, Caspian Journal of Environmental Sciences, Environmental Earth Sciences, Civil Engineering research journal, Physical Geography Research Quarterly, Natural Hazards, Water, Desert, Geomatics, Geomatics Natural Hazards Risk, etc. Although the articles published in the last 15 years were the prime concern initially, information from a few older books or papers were also extracted to provide meaningful documents to this research.

The abstracts, introductions, discussions, and conclusions of the selected research were reviewed. That enabled the establishment of an initial list of criteria that could potentially impact flood hazard as well as their basic characteristics and features. The literature review analysis and summary of criteria that have contributed to form a flood based on the previous studies from domestic and foreign experience. The analysis summary from preceding research involved flood hazard zoning by the AHP method in countries where flood occurrence is frequent such as China, Iran, Japan, India, Malaysia, Philippines, Thailand, Vietnam, etc. Some studies often divided criteria affecting flood hazard into 3 groups including physical geographical factors, socio-economic factors, and infrastructure factors. However, such a division will not cover all the flood causative parameters because it will be difficult to arrange them in the appropriate group. Therefore, in this study, there are six groups of criteria affecting flood hazard, namely (1) criteria related to hydrological and orographic characters; (2) factors related to the geomorphologic character; (3) factors related to the meteorological character; (4) factors related to cover characters; (5) factors related to soil characteristics; (6) factors related to infrastructure and socioeconomic characters.

In the third stage, the analysis of the impact level of the criteria which can cause a flood needs to be considered during the valuation process. As the final stage, these findings can be suggestions for researchers when deciding on the selection of factors affecting in creating a flood for their study.

3 Results and Discussion

Flood hazard assessment requires an understanding of the causes of a potential disaster. The flood is mostly associated with rain and the terrain dividing the basin. Factors that generate floods including (1) necessary conditions: the rain reaches the critical condition to form normal excess flows and (2) sufficient conditions: surface structure (Cu 2003). The basic elements that form the buffer surface include topography, geomorphology, river basin, rock soil, vegetation, the system of shallow underground water tanks, artificial structures (reservoirs, levees, dams, canals, ditches, etc.). In the flood disaster, the natural features and the change of the surface play a decisive role in the redistribution of rainfall to form floods of different types on each basin (Thang and Bach 2005).

Depending on the study area, it is possible to choose the variables that directly impact the flood hazard. The selection of the flood-controlling parameters varies from one study region to another based on the different characteristics of each place. In general, the majority of the reviewed studies in various geographical areas are concerned with factors that contribute to flood formation including Slope, Elevation, Land use/Land cover, Rainfall, Drainage density, Soil. Besides the common factors influencing flood formation that has been studied since the early years of the previous decade, some criteria have only been mentioned for 3 years (2018–2020) such as the Channel area, Flowlength, Topographic Wetness Index, Rainfall intensity, Flow accumulation, Relative slope length, etc. In addition, some parameters are rarely seen in the flood hazard zoning studies using the AHP method such as Depth to the groundwater table, Soil texture, Runoff, Distance from River Confluence, Capacity of the existing Drainage and channel capacity, Size of the watershed, Road quality, Road density, Relative slope length, Distance from open channel streams, Distance from water surfaces, Distance from roads, Hydro lithological formations, and Past flood events.

Based on a summary study of literature reviews, the main reasons for a flood can be divided into various categories. These factors do not have to hold the same importance across different geographical areas. As one criterion can have a high degree of influence in flooding in a specific region, it can be without any impact in another area. Thus, the factors affecting flood can be divided into groups in which the criteria of each group have similar characteristics and properties or are related together as follows:

3.1 Factors Related to Hydrological and Orographic Characters

Factors of this type include those related to basin morphology, flow characteristics, direction, etc. The total number of studies mentioned the factors related to these characteristics and the percentage of studies ranking criteria at three levels: high, medium, and low shown in Table 2 and Fig. 3.

The drainage density, a fundamental concept in hydrologic analysis, is a key parameter, which actively contributes to flood occurrence. The results in Table 3 and Fig. 3 show that many scientists take account into the drainage density factor, but up to 80% of them believe that this criterion has a low and moderate impact on flood hazard.

The spreading domain of the flood can be ascertained by regarding the distance from the rivers (Pal et al. 2020). Mostly, the highly flood prone zones are those near drainage networks due to overflow. Thus, the distance from the drainage network, drainage distance, and main channels are mentioned in more studies and also are assigned with high and medium weight in the calculation of flood potential areas. According to summary information in Table 3, while the distance from some objects related to water concentration and drainages such as rivers, river confluence, water surfaces, and open channel streams are considered to only have a low effect, distance from the riverbank, totally covered streams, main river, active channel, and tributary have a significant influence on flood generation. In particular, distance to the discharge channels is assessed to have the highest effect by Fernández and Lutz (2010). However, there are not many authors who considered these factors in their works.

Because of differences in geographical areas, the high effect of some factors is not consistent in different areas and is even considered to have the lowest effect on flood formation. Catherin et al. (2017) have considered the distance to the main channel to have a relatively low effect with ranking 6/6 criteria. However, there are studies where this factor has the highest effect in creating a flood with a weight of 28.3% (Ghorbanzade et al. 2018) and the moderate impact on creating a flood with a weight of 9.5% (Jonathan and Han 2019). Likewise, the weight generated reveals that distance from channels, weighted 24.9%, have the greatest influence on flood occurrences in a study of Nitin (2018) but this is a less important cause of flooding with a weight of 12% in a study of Niyongabire and Rhinane (2018).

Flow accumulation and runoff have been considered the important factor in identifying or detecting flood susceptibility areas in flood hazard zoning relevant studies. Although not many studies mention these factors, the results reveal that up to nearly 90% even 100% (for runoff) of the research

Table 2 Criteria related to hydrological and orographic characters using AHP in studies related to flood hazard zoning

Criteria	Authors	Number
Capacity of the existing drainage	Dask and Sar (2020) (2/8), Lawal et al. (2012) (2/6)	2
Channel capacity	Ghorbanzade et al. (2018) (5/6)	1
Channel area	Ghorbanzade et al. (2018) (5/6), Kanchan and Rajiv (2020) (4/5)	2
Drainage density	Amirahmadi et al. (2013) (5/8), Arianpour and Jamali (2015) (2/3), Catherin et al. (2017) (5/6), Dung and Minh (2017) (3/5), Dung et al. (2020a) (3/5), Dung et al. (2020b) (3/6), Dung et al. (2021) (3/6), Elsheikh et al. (2015) (2/4), Fatima et al. (2018) (3/6), Gemechu et al. (2020) (5/6), Ghorbanzade et al. (2018) (4/6), Jean et al. (2016) (3/4), Jonathan and Han (2019) (5/6), Kamonchat and Sarintip (2018) (2/6), Kittipongvises et al. (2020) (7/9), Nitin (2018) (3/6), Phuong et al. (2015) (4/5), Rimba et al. (2017) (2/5), Saini and Kaushik (2012) (2/5), Salma et al. (2019) (5/8), Sulaiman et al. (2015) (3/6); Tu et al. (2013) (4/6), Umar et al. (2019) (4/6), Yahaya et al. (2010) (2/5)	22
Distance from drainage network, drainage distance	Fatima et al. (2018) (2/6), Gigović (2017) (3/6), Kazakis et al. (2015) (2/7), Kumari et al. (2018) (4/7), Lappas and Kallioras (2019) (5/9), Md Yousuf et al. (2019) (5/6), Mehdi et al. (2020) (1/6), Somaiyeh and Mehra (2017) (2/7), Sanam et al. (2020) (2/7)	9
Distance to main channel	Catherin et al. (2017) (6/7), Ghorbanzade et al. (2018) (1/6), Jonathan and Han (2019) (4/6)	3
Distance from riverbank	Generino et al. (2014) (1/3), Rahmati et al. (2016) (1/4), Sulaiman et al. (2015) (5/6)	3
Distance from river	Ghosh and Kar (2018) (4/6)	1
Distance from open channel streams	George et al. (2016) (5/6)	1
Distance from totally covered streams	George et al. (2016) (2/6)	1
Distance from water surfaces	Gigović et al. (2017) (6/6)	1
Distance to active channel	Kanchan and Rajiv (2020) (3/5), Sinha et al. (2008) (2/6), Hoque et al. (2019) (1/5)	3
Distance to channel	Nitin (2018) (2/6), Niyongabire and Rhinane (2018) (4/4)	2
Distance to trinutary	Purnomo et al. (2020) (3/6)	1
Distance to main river	Purnomo et al. (2020) (2/6)	1
Distance from river confluence	Ghosh and Kar (2018) (6/6)	1
Distance to the discharge channels	Fernández and Lutz (2010) (1/5)	1
Flow accumulation	Dask and Sar (2020) (1/8), Fatima et al. (2018) (1/6), Kazakis et al. (2015) (1/7), Kumari et al. (2018) (1/7), Lappas and Kallioras (2019) (8/9), Sanam et al. (2020) (1/7), Somaiyeh and Mehra (2017) (1/7)	7
Flowlength	Md Yousuf et al. (2019) (6/6)	1
Past flood events	Kittipongvises et al. (2020) (8/9)	1
Runoff	Catherin et al. (2017) (1/7), Kittipongvises et al. (2020) (1/9)	2
Runoff depth, Runoff coefficient	Dask and Sar (2020) (6/8); Somaiyeh and Mehra (2017) (4/7)	2
Size of the watershed	Kittipongvises et al. (2020) (5/9), Lawal et al. (2012) (4/6)	2
Water drainage system	Niyongabire and Rhinane (2018) (2/4)	1

referred to these criteria evaluated flow accumulation and runoff have the greatest impact on flood occurrence. Flow accumulation shows the accumulation paths and the number of cells in the entire study area that contribute to the flow on a specific cell. This parameter represents the drainage network and its water accumulation potential. An increase in flow accumulation reflects an increase in flood susceptibility and higher susceptibility to being flooded (Lehner et al. 2006). Therefore, there are existed a relationship between flow accumulation and distance from drainage network and most studies that are concerned with the first one also take the last parameter to calculate the flood hazard zoning model. This can be verified in five research of Fatima et al. (2018), Kazakis et al. (2015), Kumari et al. (2018), Lappas and Kallioras 2019, Sanam et al. (2020), and Somaiyeh and Mehra (2017). Similar to flow accumulation and runoff, there are not many studies on zoning flood hazard using capacity of the existing drainage. However, the degree of influence of this factor is assessed relatively high and always ranked the first group of the impact criteria.

On the other hand, because the interaction process between rainfall and the land surface is very complex, therefore, a spatial variation in runoff coefficient was used to integrate the complex interactions of some surface factors such as land use, soil, and slope with rainfall (Asare-Kyei et al. 2015). However, the runoff coefficient is an uncommon parameter, this one is used for incorporation of the influence of soil types and slope to determine flood susceptibility. Currently, the number of studies used this factor is limited and its influence is also not significant. Hence, to establish a

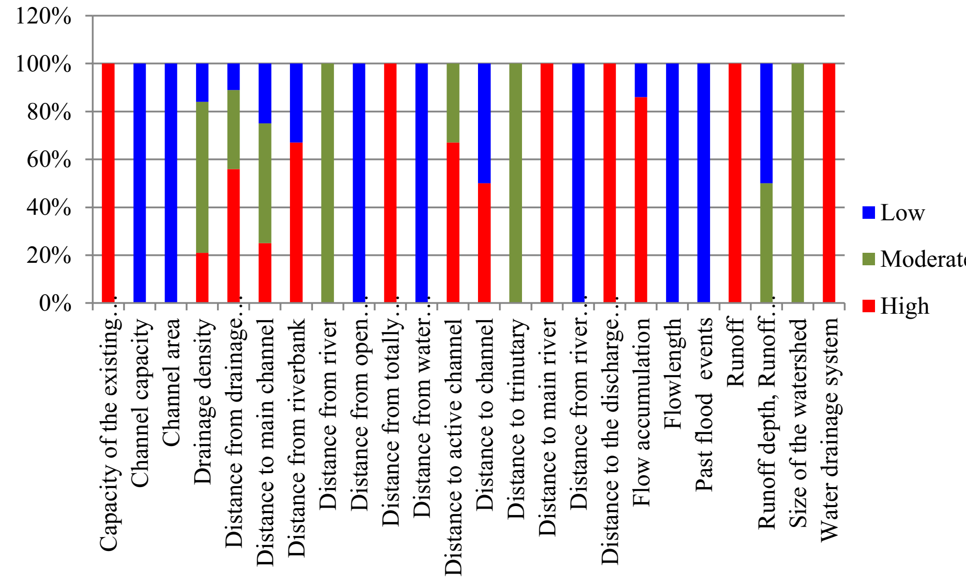

Fig. 3 The percentage of studies mentioned the factors related to hydrological and orographic characters being ranked at three levels: high, medium and low

Table 3 Criteria related to geomorphologic characteristic using AHP in studies related to flood hazard zoning

Criteria	Authors	Number
Elevation	Dask and Sar (2020) (3/8), Fernández and Lutz (2010) (2/5), Gemechu et al. (2020) (6/6), Generino et al. (2014) (2/3), Ghorbanzade et al. (2018) (2/6), George et al. (2016) (3/6), Ghosh and Kar (2018) (1/6), Gigović et al. (2017) (5/6), Hoque et al. (2019) (1/5Jonathan and Han (2019) (3/6), Kamonchat and Sarintip (2018) (4/6), Kazakis et al. (2015) (3/7), Kittipongvises et al. (2020) (9/9), Kumari et al. (2018) (3/7), Lappas and Kallioras (2019) (1/9), Mayaja and Srinivasa (2016) (2/8), Mehdi et al. (2020) (4/6), Md Yousuf et al. (2019) (1/6), Nitin (2018) (5/6), Niyongabire and Rhinane (2018) (1/4), Rahmati et al. (2016) (2/4), Salma et al. (2019) (2/8), Sanam et al. (2020) (7/7), Sinha et al. (2008) (3/6), Umar et al. (2019) (3/6), Yahaya et al. (2010) (1/5)	26
Geology, Geomorphic, Lithology	Amirahmadi et al. (2013) (8/8), Arianpour and Jamali (2015) (3/5), Dask and Sar (2020) (8/8), Fatima et al. (2018) (6/6), Kanchan and Rajiv (2020) (5/5), Kazakis et al. (2015) (7/7), Kumari et al. (2018) (7/7), Lappas and Kallioras (2019) (3/9), Saini and Kaushik (2012) (3/5), Sanam et al. (2020) (5/7), Sinha et al. (2008) (6/6), Salma et al. (2019) (3/8), Skilodimou et al. (2019) (3/7), Somaiyeh and Mehra (2017) (7/7)	14
Hydro lithological formations	George et al. (2016) (4/6)	1
Landform category	Ghosh and Kar (2018) (3/6)	1
Roughness	Catherin et al. (2017) (4/7)	2
Slope	Amirahmadi et al. (2013) (1/8), Arianpour and Jamali (2015) (1/5), Catherin et al. (2017) (3/6), Dask and Sar (2020) (7/8), Dung and Minh (2017) (2/5), Dung et al. (2020a) (2/6), Dung et al. (2020b) (2/6), Dung et al. (2021) (2/6), Elsheikh et al. (2015) (3/4), Fatima et al. (2018) (5/6), Fernández and Lutz (2010) (3/5), Gemechu et al. (2020) (2/6), George et al. (2016) (3/6), Ghosh and Kar (2018) (2/6), Gigović et al. (2017) (2/6), Jean et al. (2016) (2/4), Jonathan and Han (2019) (2/6), Kanchan and Rajiv (2020) (2/6), Kamonchat and Sarintip (2018) (3/6), Kazakis et al. (2015) (6/7), Kittipongvises et al. (2020) (4/8), Kumari et al. (2018) (2/7), Hoque et al. (2019) (2/5), Lappas and Kallioras (2019) (7/9), Lawal et al. (2012) (6/6), Mayaja and Srinivasa (2016) (3/8), Mehdi et al. (2020) (3/6), Nitin (2018) (6/6), Phuong et al. (2015) (1/5), Purnomo et al. (2020) (4/6), Rahmati et al. (2016) (3/4), Rimba et al. (2017) (1/5), Salma et al. (2019) (6/8), Sanam et al. (2020) (3/7), Saini and Kaushik (2012) (1/5), Somaiyeh and Mehra (2017) (3/7), Sulaiman et al. (2015) (2/6), Tu et al. (2013) (1/6), Umar et al. (2019) (2/6), Yahaya et al. (2010) (3/5)	40
Relative slope length	Dung et al. (2020a, b) (3/6)	1

more realistic flood hazard map, the studies should use the runoff coefficient along with land use by decomposing its direct effect (Dask and Sar 2020). Likewise, flowlength as well as runoff depth do not seem to be common factors and therefore is not of interest to scientists either. The number of studies using these variables is also limited and these factors have been assigned a low weight for occurring flood. In addition to runoff coefficient and flowlength, some others such as channel capacity, channel area, past flood events, size of the watershed, and water drainage system are also the rare factors in studies on flood hazard zoning by AHP method.

3.2 Factors Related to Geomorphologic Characters

Table 3 and Fig. 4 show the factors related to geomorphologic characters and the percentage of studies mentioned these factors ranked at three levels: high, medium, and low. The slope and its derivatives play an important role in recognizing the areas susceptible to flood occurrence (Pradhan 2010), so the slope is one of the crucial indicators of surface zones, which are highly prone to flooding. According to Table and Fig. 4, there are many works on flood hazard zoning using the slope criterion and the slope is considered one of the important factors affecting flood occurrence. The study results of 35 out of 40 studies (88%) have shown that the slope has a higher influence on creating flood compared to other factors (Fig. 4). Although the degree of influence of slope is comparatively lower only to some factors such as rainfall, elevation, flow accumulation, etc., there are a lot of studies suggest that the impact of slope factor to flood is the most or just rank the second after another. Thus, the impact of this factor on flood risk should be assessed with a high priority.

According to Dung et al (2020a, b), water concentrates gradually in the process of moving along the slope from high to low and since flood mostly only appear in the lower area, the slope length factor will affect both floods as well as the possibility of flooding. Hence, in addition to slope, slope length factor should take account into the studies related to flood hazard zoning.

The results obtained in Fig. 4 indicate that apart from slope have high priority, only elevation factor in this group is believed to have a large impact on flood hazard. Elevation has a main role in controlling the movement of the overflow direction and in the depth of the water level (Gigović et al. 2017). According to the summary of literature review in Table 4, while only 19% of the authors assessed that the elevation has low or the lowest influence on flood generation, many others recognized the elevation is also one of the most significant causative factors of flood occurrence with a weight of 40% (Niyongabire and Rhinane 2018),

Fig. 4 The percentage of studies mentioned the factors related to geomorphologic characters ranked at three levels: high, medium and low

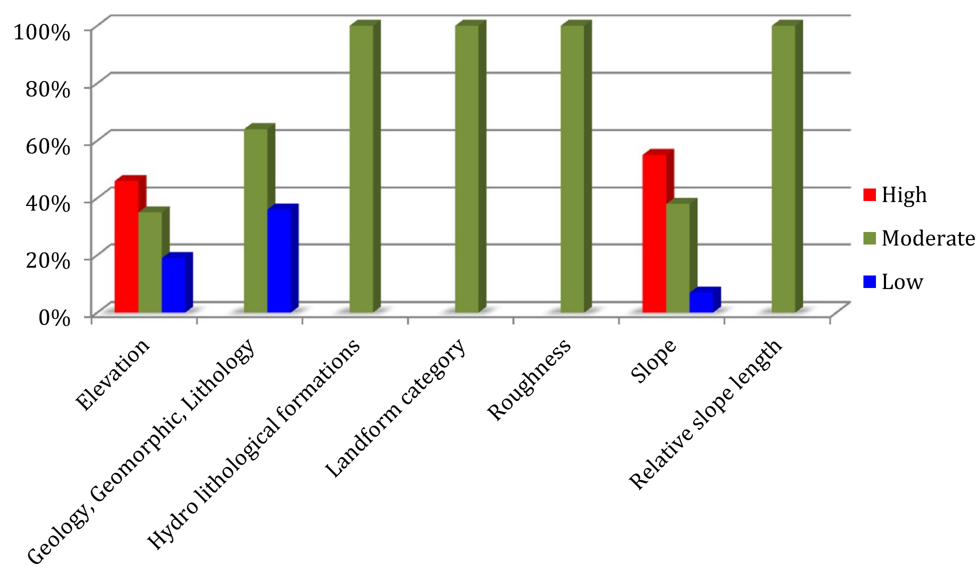

Table 4 Parameters related to meteorological characteristic using AHP in studies related to flood hazard zoning

Parameter	Authors	Number
Rainfall	Amirahmadi et al. (2013) (4/8), Arianpour and Jamali, (2015) (1/3), Dung and Minh (2017) (1/5), Dung et al. (2020a) (1/5), Dung et al. (2020b) (1/6), Dung et al. (2021) (1/6), Elsheikh et al. (2015) (1/4), Gemechu et al. (2020) (4/6), Ghosh and Kar (2018) (5/6), Hoque et al. (2019) (4/5), Jean et al. (2016) (1/4), Jonathan and Han (2019) (1/6), Kamonchat and Sarintip (2018) (1/6), Kanchan and Rajiv (2020) (1/5), Kittipongvises et al. (2020) (3/9), Lawal et al. (2012) (1/6), Mayaja and Srinivasa (2016) (5/8), Md Yousuf et al. (2019) (4/6), Nitin (2018) (4/6), Phuong et al. (2015) (3/5), Purnomo et al. (2020) (1/6), Salma et al. (2019) (4/8), Sanam et al. (2020) (6/7), Sulaiman et al. (2015) (1/6), Tu et al. (2013) (2/6), Umar et al. (2019) (1/6), Yahaya et al. (2010) (1/5)	27
Rainfall intensity	Kazakis et al. (2015) (5/7), Kumari et al. (2018) (6/7), Lappas and Kallioras (2019) (9/9), Rimba et al. (2017) (3/5)	4

38% (Ghosh and Kar 2018), 36.07% (Md Yousuf et al. 2019), 17.66% (Lappas and Kallioras 2019). Furthermore, if arranged in order from high to low, this factor often stands at the top group in many studies (Fernández and Lutz 2010; Ghorbanzade et al. 2018; Generino et al. 2014; Rahmati et al. 2016; Mayaja and Srinivasa 2016; Salma et al. 2019; Kazakis et al. 2015; Sinha et al. 2008; Jonathan and Han 2019; Kumari et al. 2018; Umar et al. 2019). It implies that elevation has more contribution to flooding than other factors.

Terrain roughness is an essential input factor for flood simulation. Reduced roughness leads to increasing flow velocity and decreasing permeability, thus raising the flood hazard. Morever this element is empirical value, so that there are not many scientists considered this one in their research on flood hazard.

The lithology, hydro-lithological formation, geology, and geomorphic of flood hazard areas are the important criteria because they may amplify/extenuate the magnitude of flood events. These factors are also mentioned with a level of medium, low effects in all previous studies mentioned in this paper, even some authors also believe that their impact on flood creation is lowest (only 2–3%).

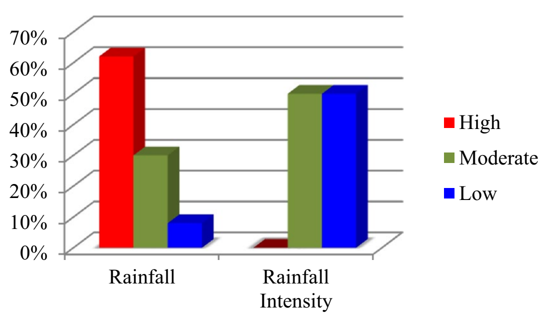

Fig. 5 The percentage of studies mentioned the factors related to meteorological characters ranked at three levels: high, medium, and low

3.3 Factors Related to Meteorological Characters

Rainfall and rainfall intensity are two parameters related to meteorological characters. Table 4 and Fig. 5 presented the number of studies, authors, as well as the percentage of studies mentioned the factors related to these characters ranked at three levels. Rainfall is a triggering factor in flood generation and in the absence of this factor, no flooding will be generated. This means that floods are associated with extremes in rainfall**,** flood occurs after heavy rainfall when natural watercourses cannot carry excess water (Ouma and Tateishi 2014)**,** so that rainfall is one of the primary causes of creating flood hazard. In other words, rainfall is one of the most commonly considered factors by many researchers when assessing the flood hazard zoning by the AHP method. The results of Table 5 show that there are 60% of the total number of authors using this factor in studies believed that rainfall has the most impact on the flood hazard or is evaluated with the highest weight.

Rainfall intensity constitutes one of the parameters affecting directly the flood formation mechanism (Kastridis and Stathis 2016). Rainfall intensity is determined as the average rainfall rate in mm/h or mm/min for specific rainfall duration and a selected frequency (Ramke 2018). The rainfall intensity is generated by spatially distributing the average annual rainfall values (Pal et al. 2020). However, it is difficult to collect the data on rainfall intensity, many studies have not taken into account this factor when analyzing flood hazard. Furthermore, in the same basin, there is no significant difference in precipitation intensity, i.e. the influence of this criterion does not differ greatly in space. Hence, if the objective emphasizes more about the possibility of flooding, it will be acceptable to ignore the rainfall intensity (Minh 2019).

Table 5 Criteria related to cover characteristic using AHP in studies related to flood hazard zoning

Criteria	Author	Number
Land use, Land cover	Amirahmadi et al. (2013) (2/8), Arianpour and Jamali (2015) (4/5), Catherin et al. (2017) (2/6), Dask and Sar (2020) (5/8), Dung and Minh (2017) (5/5), Dung et al. (2020a) (5/5), Dung et al. (2020b) (6/6), Dung et al. (2021) (6/6), Fatima et al. (2018) (4/6), Gemechu et al. (2020) (1/6), George et al. (2016) (1/6), Gigović et al. (2017) (4/6), Ghorbanzade et al. (2018) (3/6), Kamonchat and Sarintip (2018) (5/6), Kazakis et al. (2015) (4/7), Kittipongvises et al. (2020) (6/9), Kumari et al. (2018) (5/7), Hoque et al. (2019) (3/5), Lawal et al. (2012) (3/6), Lappas and Kallioras (2019) (4/9), Mayaja and Srinivasa (2016) (6/8), Mehdi et al. (2020) (6/6), Md.Yousuf et al. (2019) (2/6), Nitin (2018) (1/6), Niyongabire and Rhinane (2018) (3/4), Purnomo et al. (2020) (5/6), Rahmati et al. (2016) (4/4), Rimba et al. (2017) (5/5), Saini and Kaushik (2012) (4/5), Salma et al. (2019) (1/8), Sanam et al. (2020) (4/7), Sinha et al. (2008) (4/6), Somaiyeh and Mehra (2017) (5/7), Sulaiman et al. (2015) (4/6), Umar et al. (2019) (5/6), Yahaya et al. (2010) (5/5)	36
Cover type	Fernández and Lutz (2010) (5/5)	
Vegetation cover	Amirahmadi et al. (2013) (3/8), Phuong et al. (2015) (2/5), Somaiyeh and Mehra (2017) (6/7), Tu et al. (2013) (5/6)	4

3.4 Factors Related to Cover Characters

Factors that contributed to creating flood related to cover characters include land use, land cover, cover type, and vegetation cover. The number of research, the authors, and the percentage of studies mentioned the factors in this group ranked at three levels shown in Table 5 and Fig. 6.

The human activities that break the ecological balance and thus changing the land cover, the flows of the water, and the ability to withhold water of the land also trigger the flood. In areas with numerous rainfall or high humidity, the soil type, hydrological, and environmental condition are generally saturated enough to reduce their abilities to absorb water and thus increases the flood flow. Therefore, besides the factors that are concerned by many scientists and are often assigned to the high and the highest weight such as elevation, slope, rainfall, etc., land use/land cover is also evaluated as the main contributor to flood formation. The results in Table 6 indicate that land use/land cover is dependent on the physical geographical conditions of the research area with a degree of effect fluctuating from high to medium or even is assigned by the lowest influence weight.

In contrast to land use/land cover, there is not much research using vegetation cover and cover type to model flood hazard zoning by the AHP approach. These factors are only considered to have only medium or low effect when categorizing in above-mentioned studies (Fig. 6).

3.5 Factors Related to Soil Characteristics

Soil, depth to groundwater table, water table, topographic wetness index are criteria connected with soil characteristics. The number of these factors, researchers, and the degree affecting flood hazard of each criterion indicated in Table 6 and Fig. 7. Soil is an important parameter that contributes to the ability of the soil to absorb water in the process of preventing the flood flow. The effect of the land structure is moderate and low with a weight of 23.1% (Arianpour and Jamali 2015), and has ranking 6/6 criteria (Mehdi et al. 2020). Similarly, the effect of soil type is only medium and low with the ranking order always ranked in the last place of the factors. Besides, in some articles, this parameter is assigned to the lowest rank of risk which is less susceptible for flood hazard (Dung et al. 2020a, b; Elsheikh et al. 2015; Jonathan and Han 2019; Kamonchat and Sarintip 2018; Saini and Kaushik 2012; Umar et al. 2019). The ability to absorb water is also affected by the depth of the groundwater table or water table. The higher this value, the faster the land reaches saturation when there is rain; hence the surface

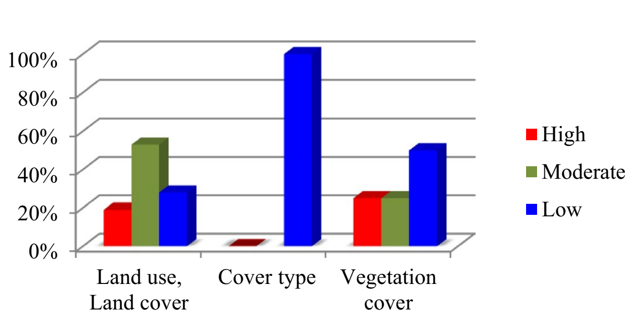

Fig. 6 The percentage of studies mentioned the factors related to cover characters ranked at three levels: high, medium, and low

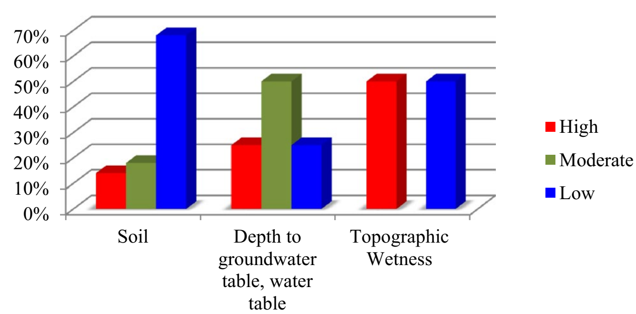

Fig. 7 The percentage of studies mentioned the factors related to soil characters ranked at three levels: high, medium, and low

Table 6 Criteria related to soil characteristic using AHP in studies related to flood hazard zoning

Criteria	Author	Number
Soil	Arianpour and Jamali (2015) (2/5), Catherin et al. (2017) (2/6), Dung and Minh (2017) (5/5), Dung et al. (2020a) (6/6), Dung et al. (2020b) (6/6), Dung et al. (2021) (6/6), Elsheikh et al. (2015) (4/4), Gemechu et al. (2020) (3/6), Jean et al. (2016) (3/4), Jonathan and Han (2019) (6/6), Kamonchat and Sarintip (2018) (6/6), Lappas and Kallioras (2019) (6/9), Lawal et al. (2012) (5/6), Mayaja and Srinivasa (2016) (4/8), Mehdi et al. (2020) (6/6), Phuong et al. (2015) (5/5), Rimba et al. (2017) (4/5), Saini and Kaushik (2012) (5/5), Salma et al. (2019) (7/8), Tu et al. (2013) (3/6), Umar et al. (2019) (6/6), Yahaya et al. (2010) (4/5)	22
Depth to groundwater table, water table	Dask and Sar (2020) (4/8), Fernández and Lutz (2010) (4/5), Gigović et al. (2017) (6/6), Salma et al. (2019) (1/8)	4
Topographic Wetness Index	Lappas and Kallioras (2019) (2/9), Mehdi et al. (2020) (5/6)	2

flow will increase, and the risk of flood increases as well. The results of the literature review exposed that there are a few studies which included this factor and its effect is not considered high therein also.

The Topographic Wetness Index (TWI) is frequently used to quantify topographic control on hydrological processes and allocate the soil moisture status in a given area (Pal et al. 2020; Lappas and Kallioras 2019). This element indicates the amount of flow accumulation at any location in a drainage basin and the ability of the water to go downslope with gravity. There are not many authors including this parameter in their research on flood hazard. According to Lappas and Kallioras (2019), high values show drainage depressions (lowlands with low slope) with the wet ground while low ones illustrate crests and ridges (highlands with high slope gradient). Therefore, the higher value of TWI the more susceptible areas to flooding. This implies that the relatively flat lowland areas with low slope should take into account this criterion in calculating the model.

3.6 Factors Related to Infrastructure and Socioeconomic Characters

Criteria belong to the infrastructure and socioeconomic group included road quality, road density, and population density**.** The building of infrastructure without planning can result in the blockage of the flow of water, hence obstructing the way out for the flood. Irrational urbanization, population distribution, and land use will replace the old land cover, which can absorb a significant amount of water, with a layer of concrete that is unable to absorb water. The traffic system is also considered a cover that will prevent or reduce the ability to absorb water, increase the flow of water. Therefore, the traffic system, such as road quality, road density (Mayaja and Srinivasa 2016; Sulaiman et al. 2015) and population density (Tu et al. 2013; Generino et al. 2014; Md Yousuf et al. 2019) are still needed to be put into the calculated model but with the lowest weight of all the criteria. However, in the densely populated and highly urbanized regions (with a density of population more than 3000 persons/km^2), it can be inferred that the prime reason for flood hazard is the high rate of urbanization and human interventions in this region. This can identify in studies of Mayaja and Srinivasa (2016) and Sinha et al. (2008), population density has been given a high weightage of 35 and 49%, respectively.

Refer to the impact criteria of published researches, the total number of studies considered flood-affected parameters and their ranking listed in Tables 3, 4, 5, 6 and 7, flood-affected factors and their weights are evaluated relatively as Table 8. The weight of the influencing factors is assessed based on the number of studies and the ranking of the criteria in those studies. If the criterion that many scientists are interested in and its ranking level is assessed by more than half (50%) of the number of studies, this ranking can be considered as the weight of that factor, such as the rainfall, slope, elevation, etc. However, for high-weight criteria that there are not many studies mentioned, besides the high impact level, the authors may consider a medium ranking when using these factors to calculate such as the capacity of the existing drainage, distance from totally covered streams, Distance to the main river, Distance to the discharge channels, Water drainage system, etc. In addition, for criteria that not only a few authors consider but also they have low weight will be ranked low such as channel capacity, channel area, Flowlength, etc.

The obtained results in Table 8 show that when zoning flood hazard by AHP method, most of the criteria related to hydrological and orographic characteristics, geomorphologic characteristics, and meteorological characters have high and medium influence on the flood occurrence, such as Distance from riverbank, distance to main river, Runoff, Water drainage system, Elevation, Slope, Rainfall, etc. However, it is difficult to collect some kinds of hydrological and orographic data; therefore, in case of insufficient data, it is necessary to integrate these data with others to create a flood hazard database. Factors in the remaining group are mainly assessed at the low impact level or medium low. The results can be seen clearly in Figs. 3, 4, 5, 6, 7 and 8.

Moreover, the literature review revealed that when studying the factors affecting the flood, it is necessary to consider the characteristics of the natural and socioeconomic conditions of the study area to select the appropriate affecting factors. Since rainfall intensity is associated both with the frequency and the amount of precipitation, it is crucial in identifying flood-prone areas. The larger the precipitation and the greater the rainfall intensity, the stronger the potential for runoff and the higher the flood intensity. Therefore,

Table 7 Criteria related to infrastructure and socioeconomic characters using AHP in studies related to flood hazard zoning

Criteria	Author	Number
Road quality	Mayaja and Srinivasa (2016) (7/8), Purnomo et al. (2020) (6/6)	2
Road density	Kittipongvises et al. (2020) (2/9), Mayaja and Srinivasa (2016) (8/8), Sulaiman et al. (2015) (6/6)	3
Population density	Generino et al. (2014) (3/3); Mayaja and Srinivasa (2016) (1/8), Md Yousuf et al. (2019) (3/6); Sinha et al. (2008) (1/6); Tu et al. (2013) (6/6)	5

Table 8 Affected factors and their weights in flood risk zoning studies by the AHP method

Group	Affected factors	Weight
Factors related to hydrological and orographic characteristic	Capacity of the existing drainage	High
	Channel capacity	Low
	Channel area	Low
	Drainage density	Moderate
	Distance from drainage network, drainage distance	High–moderate
	Distance to main channel	Moderate
	Distance from riverbank	High
	Distance from river	Moderate
	Distance from open channel streams	Low
	Distance from totally covered streams	High
	Distance from water surfaces	Low
	Distance to active channel	High–moderate
	Distance to channel	High–moderate
	Distance to trinutary	Moderate
	Distance to main river	High
	Distance from river confluence	Low
	Distance to the discharge channels	High
	Flow accumulation	High
	Flowlength	Low
	Past flood events	Low
	Runoff	High
	Runoff depth, Runoff coefficient	Moderate–low
	Size of the watershed	Moderate
	Water drainage system	High
Criteria related to meteorological characters	Raifall	High
	Intensity rainfall	Moderate–low
Criteria related to geomorphologic characteristic	Elevation	High–moderate
	Geology, Geomorphic, Lithology	Moderate–low
	Hydro lithological formations	Moderate
	Landform category	Moderate
	Roughness	Moderate
	Slope	High–moderate
	Relative slope length	Moderate
Criteria related to cover characteristic	Land use, Land cover	Moderate–low
	Cover type	Low
	Vegetation cover	Moderate—Low
Criteria related to soil characteristic	Soi	Low
	Depth to groundwater table, water table	Moderate–low
	Topographic Wetness Index	Moderate–low
Criteria related to infrastructure and socioeconomic characters	Road quality	Low
	Road density	Low
	Population density	Moderate–low

the first factor to consider is rainfall and rainfall intensity if the average precipitation is large.

In addition, in areas of complex terrain with high slopes and mountains, when heavy rains, steep slopes tend to reduce the amount of infiltration of water into the ground, this water then flows quickly and ragingly down to downstream and rivers as overland flow. In contrast, gentle slopes or flat land allow water to penetrate the soil and increase lag times. Moreover, the Manning theory stated that the flow rate is inversely proportional to the roughness coefficients. That means when the flow resistance increases because the roughness coefficient increases, resulting in lower value in runoff.

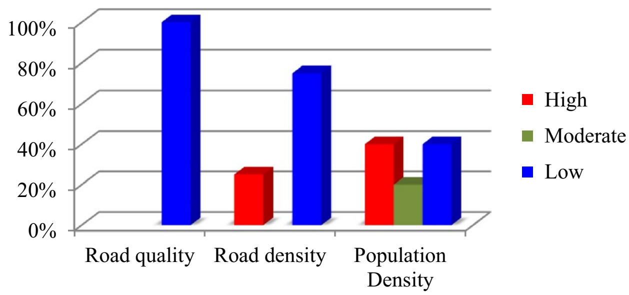

Fig. 8 The percentage of studies mentioned the factors related to infrastructure and socioeconomic characters ranked at three levels: high, medium, and low

Hence, it is necessary to take into account the three factors of slope, elevation, and roughness when deciding the impact criteria.

The percolation rate is generally dependent upon how water interacts with the particle structure and volume of porous space. Areas with many types of soils that are less permeable will increase the time of water concentration, so as a result there is a high risk of flooding. Thus, it is indispensable to consider the soil-involved factors such as permeability rate, soil type, soil structure in the areas with these characteristics. Changes in land use and land cover usually affect the characteristics of a flood, surface runoff, and flood peak. It is observed that spatial variation in the amount of groundwater storage occurs due to these changes. Land use can help determine how much water can be intercepted and how much water can be translated into the runoff. For this reason, in areas with many different types of land use, a proper understanding of this factor is necessary to assess the flood hazard.

Furthermore, the drainage density plays a major role in affecting the concentration of flood runoff in the basin. According to Glenn et al. (1998), areas with high permeability and thick cover of vegetation have low drainage density and vice versa. Therefore, in areas of arid or water-repellent surfaces (such as rocky mountains) and sparse vegetation density, the drainage density is dense, and the accumulation of runoff is higher. Consequently, for these areas, drainage density, flow accumulation, and runoff will have a great impact on flood formation. Population growth leads to the accumulation of assets, as a result, infrastructure and economic activities will increase, thereby natural seepage of the land is hindered and the likelihood of flooding will be increased. And so, the areas having a high population density, rapid urbanization speed, it is essential to consider population density when studying flood hazard zone. Although there has not been much reported research interest in some factors such as geology, geomorphology, groundwater level, transportation system, distance to the discharge channels, distance from river confluence, hydrological formation, relative slope length, etc., it is necessary to mention these factors when zoning flood risks, if there is enough data.

The results also show that the influencing factors and the level of influence on flood hazard are not the same completely for each different area. Although some factors are considered flood causative factors by many sicentists, namely, slope, rainfall, elevation, drainage density, soil, land use, and land cover, some are rarely mentioned in studies although their effects are assessed very high and even the highest, such as distance from riverbank, distance to the discharge channels, flow accumulation, Runoff, etc. However, the collection of these data is not easy, so if there are enough data, it is recommendable to include them to calculate the model. In addition, some factors have the highest weight in this area, but are assessed to have the least impact in other areas, such as Population Density, Water table, Land use, and Land cover, etc. Therefore, it is advisable to carefully study geographical and socioeconomic conditions to choose the appropriate influencing factors.

All criteria may have an additional role in the election of the best solution. The study results are useful information for flood hazard researchers when choosing the factors and assessing their influencing level. However, the selection of evaluated data depends not only on the geographical characteristics of the area but also on the availability of data (Generino et al. 2014; Gigović et al. 2017). In addition, it is not recommended to use too many criteria when zoning flood hazard by AHP approach, only a maximum of 9 criteria is sufficient because psychologists conclude that nine objects are the most that an individual can simultaneously compare and consistently rank (Pawel 2010).

4 Conclusion

In this paper, we have reviewed and synthesized factors that contributed to flood generation, assessed their impact level on flood hazard into a coherent piece, and give an overview of recent literature related to flood hazard assessment. Using the methodology of literature review, 100 articles were retrieved using Pub med, Sciendirect Digital Library, and Google Scholar database. 74 articles were included in the initial review. 26 articles were excluded from the review after reading the whole content because they did not match the objectives of the literature review and the inclusion criteria.

Flood hazard zoning is a complex spatial analysis problem and several factors are contributing to the flood formation that needs to be evaluated including factors related to hydrological and orographic characters, geomorphologic characters, meteorological characters, cover characters, soil characteristics, and infrastructure and socioeconomic characters. The use of AHP helps to identify the factor that has the biggest effect and quantifies the influence of other factors.

The paper has listed most of the factors that affect flood formation and relatively evaluate their level of effect in creating a flood. According to research results in different river basins, it is observed that some factors connected with hydrological and orographic characters, geomorphologic characters, meteorological characters, such as rainfall, flow accumulation, slope, and elevation are the most impactful factors to flood. Meanwhile, some others in the remaining three groups only have moderate or low influence on flood occurrence. Also, it is observed that some parameters are very rare in studies such as the capacity of the existing drainage, distance from totally covered streams, distance to the main river, distance to the discharge channels, runoff but are evaluated to have a large degree of influence. Therefore, if there is enough data, these factors should be included to calculate the model. However, choosing the appropriate factors to determine the flood hazard areas by the AHP method is dependent on the physical geography condition of the research area as well as the available data. The content of the paper can be used as a reference when deciding the impact factors and their level of effectiveness in flood hazard zoning.

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Data Availability Some or all data and models that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare no conflict of interest.

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