Research in Marine Sciences
Volume 9-Issue 1- 2024
Pages 355-367

Fluvial geomorphology and floods in the Kan River basin, Tehran

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Received: 2023-11-18 *Accepted: 2024-02-03*

Abstract

Floods are a destructive disaster in Iran. The case of Kan River Basin is a representative example of the dynamics of seasonal and extraordinary rains in floodplains associated with the Niña phenomenon, storms, low pressure systems and tropical cyclones. The tectonic, geological, geomorphological, biological and climatological characteristics draw this relief with intense dynamics. They along with the population growth without effective planning of the territory generate ideal risk scenarios for the disaster occurrence with greater intensities. A morphometric and morphogenetic analysis is carried out, which gives a flood hazard map of the basin with four susceptibility types: the apparent seasonal beds, the maximum floodplain, the extraordinary floodplain, and the areas of low susceptibility to occurrence. This map is validated through the DesInventar disasters database with a 95.08% of confirmation. This cartography and its respective analysis are a basic input for the risk management and the territorial ordering of this river basin.

Keywords: Natural hazard; risk assessment; disasters; Kan River; Tehran.

1. Introduction

The Kan River Basin has located between latitude 35°45′ and 35°58′, longitude 51°10′ and 51°23′, with a total length of 33 km^2. The basin can be divided into 10 sub-basins with three hydrometric stations include Kiga, Keshar, and Sulaghan (Figure 1). The highest point of the

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basin is 3823m, and the lowest point is 1328 m with an average of 2377m above sea level. The area of the basin is 216 km^2 in the vicinity of the Hesarak Watershed at east, Jajroud at north and eastern north, the watershed of Karaj dam at north and western north, and Vardij watershed at west. This basin is located in the west-north of Tehran Province and East-south of Alborz province (Jahangir *et al*., 2019). The average annual precipitation is 640 mm, and the average annual discharge is 78.23 m^3/s at Sulaghan station. The Kan River is located between two physiographic regions that determine its geomorphological dynamics. It tracks from Tochal mountain range in south Alborz and flows into this basin. It can be claimed that this river has the largest amount of water among all other rivers crossing Tehran province (Mahmoudian, 2005; Jafari, 2005).

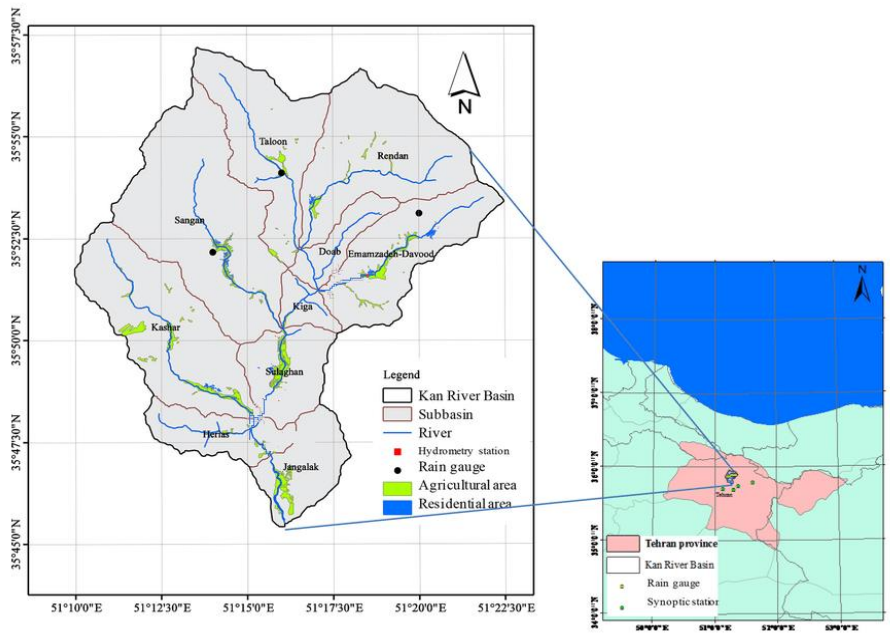

Figure 1. Location of the Kan River basin in the north of the Tehran plain, Iran (Hooshyaripor *et al*., 2020)

The Kan River is one of the most important basins located in the north of Tehran city and an area vulnerable to flooding. In general, according to the available data, during a period of 66 years (from 1954 to 2020), at least 10 flood events that resulted in loss of life (in total 2350 people) were reported in the Kan River basin and central Tehran areas. Existence of many restaurants, demographics, and recreational, tourist, and pilgrimage centers adjacent to the sloping Kan River have exacerbated the potential for damage (Boudaghpour *et al*., 2015; Khosravi *et al*., 2016).

Hooshyaripor *et al*. (2020) showed that the period of 1951–2017, there were 161 months with El Niño and 128 months with La Niña events. The average monthly rainfall at Mehrabad station in El Niño episodes is 21.4 mm and in La Niña episodes 16.2 mm, while in normal conditions it is 19 mm. For further analyses, Mehrabad station was chosen because it has more data than the other stations.

Based on the available data, the Kan River basin had a flood with the volume of about 150 to 250m^3 happened in 2022. Although the flow rate of the flood was 35m^3/s, the volume of suspended materials of the flood was very large, which led to a lot of destruction. Due to the fact that the catchment area of Kan and Sulaghan region is mountainous and the intensity of rainfall was mostly high and accompanied by torrential floods, the outlet channel of Imamzadeh Davood was blocked and a large part of the mud caused by the flood spread on the surface of the basin and most of it also moved downstream.

In another resource, it was stated that the Kan River is located at an elevation of 1168.88 meters above sea level, and the basin has a Mediterranean, hot summer climate. The district's yearly temperature is 20.24 ºC and it is 1.81% higher than Iran's averages. Kan region typically receives about 52.42 mm of precipitation and has 114.53 rainy days annually (https://weatherandclimate.com/iran/tehran/kan).

Floods are the most recurrent phenomena in the study area; this is responsible for economic losses and severe damage to the infrastructure of the Kan River. The sudden activation of these processes, combined with the existence of human settlements at the bottom of the valleys, increases their physical vulnerability and makes the greater potential impact of geomorphological danger. The dynamics of this territory is influenced by events of intense seasonal rains and the indirect impact of floods (Saatsaz, 2020).

Although outside the urban areas the lands near the channels and streams are more vulnerable, as also confirmed by field observations, there are some other factors affecting the vulnerability of urban areas. The old texture is greatly important in the vulnerability because it does not have a suitable drainage ability. The available drainage networks are also mainly in the ending part of the areas. Thus, the inundation can intensify the floods or even cause them. The vertical slope surfaces and the curvature in north and northwestern areas of Tehran also show conformity and nonconformity with the drainage and watercourses (Ghahroudi Tali *et al*., 2016).

On the other hand, variables such as precipitation, vegetation and land uses constantly model this relief. The areas of greatest precipitation (between 500 and 600 mm annually) according to data from the Iran weather and climate organization (Figure 2), are directly related to extensive regions of slopes that are shaped by gravitational activity, and the processes that feed river sediment systems. In addition, the different ranges of precipitation are linked to changes in altitude and how they influence the development of different types of forests and areas of apparent stability to slope processes. Land uses concern agricultural areas with low slopes such as alluvial fans and alluvial plains (Fisher, 2013).

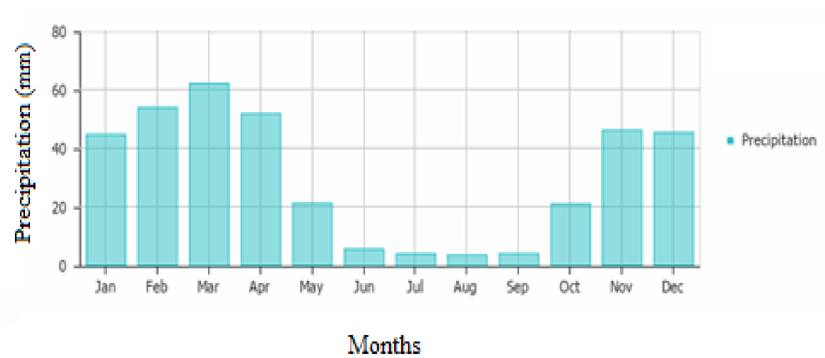

Figure 2. Average precipitation values per month in the study area (https://weather-and-climate.com)

2. Methodology

2.1. Morphometric Analysis

The flood zoning map is first analyzed based on the integration of morphometric values (dissection density, dissection depth, relief energy, potential erosion and total erosion). According to Solaimani (1996), the dissection density calculates the concentration of river channels in a specific area, its objective is to establish areas of greater or lesser concentration of river courses and therefore with greater river erosion. The depth dissection aims to measure the vertical erosive capacity or activity of rivers, since it analyzes the surfaces where river erosion has been more (or less) intense over time. Relief energy determines the maximum difference in relative height in meters in a specific area and represents the released potential energy. Potential erosion has the objective of showing territories vulnerable to river erosion; from the superposition and analysis using the GIS software, the density maps of the dissection and inclination of the terrain. Total erosion determines areas with greater or lesser erosion of the recorded relief through the density of the contour lines in a given area (per minimum spatial unit of analysis, in this case 1 km^2).

The necessary inputs for the development of this method are the contour lines at a scale of 1:25,000 and the river channels inferred from said isohypses- A line of equal geopotential height (Quesada-Román and Barrantes, 2017). This cartography represents the first approach in the zoning of morphological regions and areas susceptible to flooding (Lugo, 1988). The analysis of the information is carried out once the low values chosen based on a geomorphological criterion had been differentiated. In each of the morphometric maps, with the low values being those used to determine the areas susceptible to flooding.

In this way, a new cartographic version was obtained and it was on this map where areas with incidence of morphometric values were categorized. The starting point to organize the crossing of variables in the following way: the territories where up to two morphometric indicators coincided were considered as potential areas; the areas where three indices overlapped were classified as frequently occurring; and the spaces classified as having maximum occurrence where four or five variables were present. Flood zoning represents the analysis of all morphometric categories together, within the framework of morphological regions. The results allow to direct field work towards the territories linked to the floods, in order to characterize their dynamics and verify the first version of the geomorphological cartography on the ground (Asl and Abbassi, 2018)

2.2. Morphogenetic Analysis

Both the development of the cartography, the definition of the geomorphological legend, as well as the analysis of the relief forms of the Kan River were based on the earlier work such as Hooshyaripor *et al*. (2020). For this, it was necessary to interpret aerial photographs at a scale of 1:25000 under a geomorphological criterion. In this way, a preliminary map was obtained from a category that was verified in the field. Subsequently, all linear and point elements associated with the mapped relief forms were digitized using the ArcGIS 10 program (Rahmati *et al*., 2016; Taesiri *et al*., 2020). Regarding the classification of the relief (morphogenesis) and its legend, the criteria of Simonov (1985) were taken into account. In this way, the forms were concentrated in two of three large genetic groups: endogenous-modeling and exogenous. For this work, only exogenous morphologies of fluvial origin are explained, which are directly related to flooding.

2.3. Zoning of Geomorphological Hazards

The creation of a geomorphological hazard map is based on the geomorphological interpretation of the morphometric and morphogenetic elements that were mapped through an extensive analysis of the study area. All this information was contrasted based on variables such as topography and slopes to determine the flood hazard map. From the resulting cartography, the conditions that favor the existence of lands susceptible to flooding are described, as well as differentiating the different degrees of real and potential affectation of these territories. The processes and method of doing this study have been shown in Figure 3. Using the available data in different stations and through the morphometric and geomorphological analysis the related maps were explored.

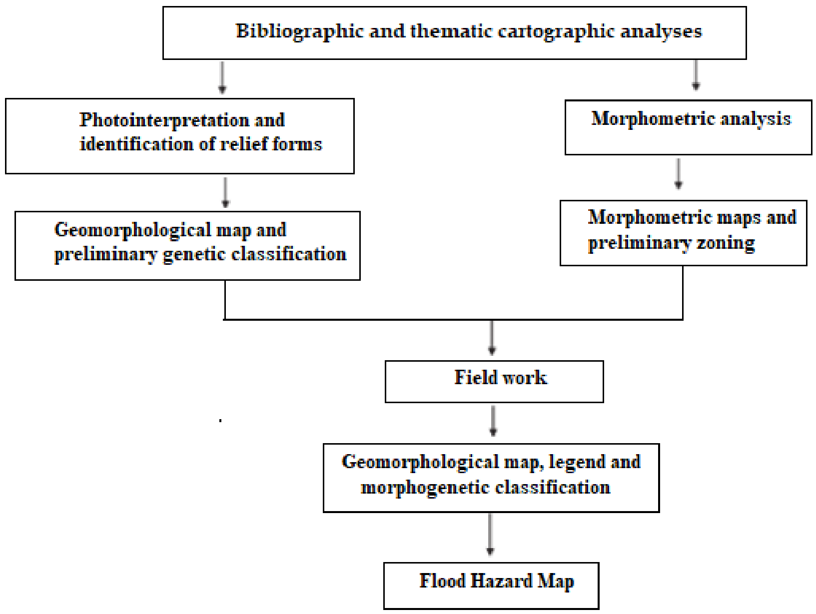

Figure 3. Method for determining areas susceptible to flooding

3. Results and Discussion

3.1. Morphometric Mapping

This aspect was interpreted from the analysis of the spatiality of the low morphometric values, which are located in the center-southern of the study area. This sector includes the alluvial plain and alluvial fans. The reliefs involved are homogeneous in morphology, inclination and lithology. These characteristics determine its dynamics; When intense rains occur, the volumes of water are distributed throughout the lower portion in a turbulent manner in most cases.

The areas associated with floods have an area of 15 km^2, which represents about 45% of the total upper basin of the Kan River. From a statistical analysis of frequencies, a scenario of up to 25 possible crossings between low morphometric values was established. The variables that were repeated on the most occasions were the depth of dissection and total erosion.

Furthermore, among the highest morphometric values of total erosion and depth of dissection, there were 8 crossings with each other, being the ones that joined together more often. The fact that these two variables are the ones that have the highest correlation for the determination of the land associated with flooding, responds to the fact that both present the lowest (extreme) values of their records, even more so of other variables such as the density of the dissection, energy of the relief and potential erosion that do expose even average values.

From the frequency analysis it was also identified that crosses of two variables are the most common with 9 of 25 possible occasions. For their part, the variables once crossed on three occasions occurred on seven occasions, while when there were four crossings of high morphometric values it occurred on three occasions and only on one occasion were the five variables crossed.

The fact that the majority of crossings occur between 2 and 3 variables has direct geomorphological implications, since these areas account for 89% of the areas that favor flooding. Total dissection of erosion and depth, as the most recurrent variables, have the capacity to define sites where the weathering of the substrates is less. In addition, the dynamics of the relief is constantly changing given the geological and hydrometeorological conditions of the basin, which facilitates the development of dangerous processes for the communities of the basin such as sudden inundations, floods and overflows associated with low pressure systems and cold fronts. The areas where one or two low morphometric values coincide were considered potential areas; the regions where three variants overlapped were classified as low. The areas where one or two low morphometric values coincide were considered potential areas. The regions where three variants overlapped were classified as frequently occurring and the sites classified as having maximum occurrence were those where four or five variables were present (Figure 4).

The territories to present floods with a maximum occurrence, occupy most of the cumulative ramp that is formed by wide alluvial fans. The morphology of these structures allows the circulation of water in their central portion, while at the ends or lateral edges, the geometry is inverted and tends to be concave. Therefore, the water concentrates and slows its circulation, which favors flooding. This is the situation of the alluvial plains of the Kan River.

The areas of frequent occurrence are located to the north of the cumulative ramp in the form of a continuous and irregular strip. This arrangement reflects a morphological control of the fans over this area; That is, the slightly convex geometry of these structures functions as an obstacle and slows down the circulation of river currents. This condition will become important in the season of extraordinary rains, where this factor will favor flooding.

The potential area refers to those areas susceptible to flooding from a geomorphological point of view. However, because they are slightly higher in relation to the area of maximum occurrence, extraordinary conditions must exist or coincide to favor the dynamics, for example: season of intense rains and cyclones or the obstruction of a river by a process slope and sudden breaking of the natural dam.

Morphometry is a possibility for analyzing the territory, the results are valuable but it must be taken into account that the source is indirect. That is why without detailed geomorphological interpretation and strict field work, they cannot be taken as valid.

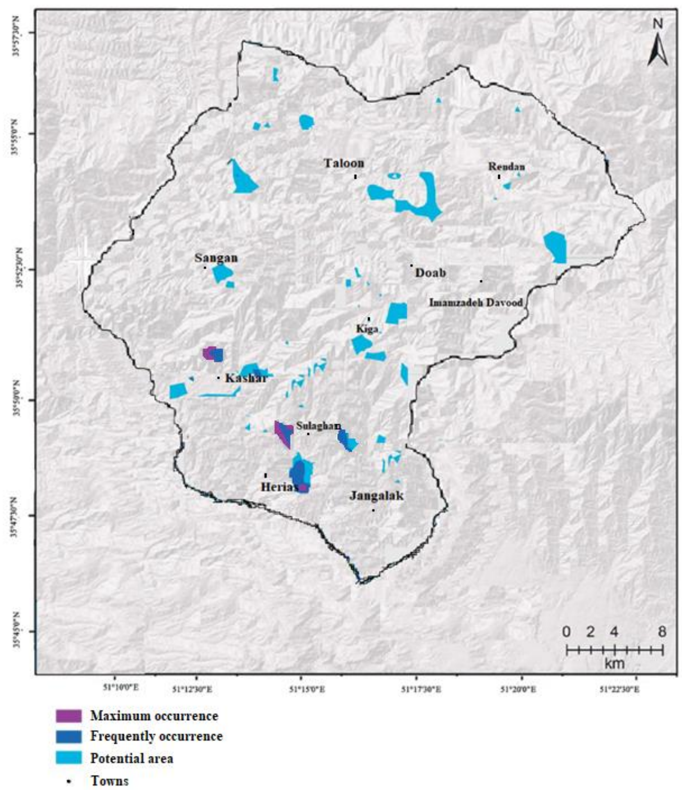

Figure 4. Flood susceptibility map by combining morphometric values

3.2. Morphogenetic Mapping

Fluvial forms are the result of the action of rivers, which when acting together with gravitational movements form depressions known as valleys. In this process of vertical and horizontal erosion, an important role is played by lithology, permeability, the existence of disjunctive structures and the inclination of the terrain. Valleys are not isolated structures, they are linked to other fluvial forms, both erosive and cumulative, such as valleys, headwaters, abysses and channels.

The cumulative fluvial relief begins to emerge at the moment when the longitudinal profile of the river decreases its inclination; that is, when you change transit region; from mountain to plain or from foothills to plain. Another possibility is when the channel approaches its local or general base level. In both cases, the runoff loses its erosive and drag capacity, and begins to deposit debris on the bottom, on the banks or at the mouth. Under this premise, alluvial fans, alluvial plains, flood terraces and alluvial cones are associated.

Alluvial fans are formed when the channel recognizes a significant change in slope, which favors the deposit of load. Its origin and evolution is directly conditioned by tectonics and climate. This condition, added to the wide and dense network of channels, has favored erosion and the transport and accumulation of important detrital deposits to the south of the most extensive mountain range in the country.

Another significant feature is the lateral displacement of up to 2.1 km, caused by the trans-current fault that affects this entire sector with a right lateral movement. Alluvial plains are reliefs that occupy the bottom of wide valleys, which in most cases are flood zones in the rainy season or in extraordinary periods of precipitation that were classified as intermountain, transitional between alluvial fans and large surfaces. The alluvial plains alternate with flood terraces that are characterized by being symmetrical and asymmetrical. Three levels of terraces are recognized: seasonal, extraordinary and exceptional. These characteristics reveal lateral and vertical erosion associated with intense neo-tectonic movements. This relief corresponds to ancient alluvial fans, which are the foundation for the location of other similar, but more recent structures composed of detrital ramps modeled by a dense river network and partially modeled.

3.3. Zoning of Geomorphological Hazards

From the integration of morphometric and morphogenetic analysis, four categories were established: apparent beds (seasonal), the maximum flood plain, the extraordinary flood plain and areas of low susceptibility of occurrence (Figure 5). The conditions that allow the development of lands susceptible to flooding and their different degrees of tangible and potential impact on the flood plain of several rivers that make up the Kan River are explained.

The apparent beds are lands that are located in the lower sections of the Kan River, where flooding and overflow processes occur each year during spring and early of summer. when rainfall varies from 500-600 mm annually, which have slopes less than 15° and in some cases even less than 1°. This river is combined into drainage hierarchies, responsible for evacuating seasonal rainfall through a system of channels interconnected between the mountain area, the cumulative ramp and the alluvial plains.

From meteorological data in extreme events, it has been determined that sometimes these rainy periods can even exceed 60% of the monthly precipitation and affect towns in intermountain plains, transition between alluvial fans and large surfaces. Many times, its development is associated with the unexpected transition between mountains and flood plains.

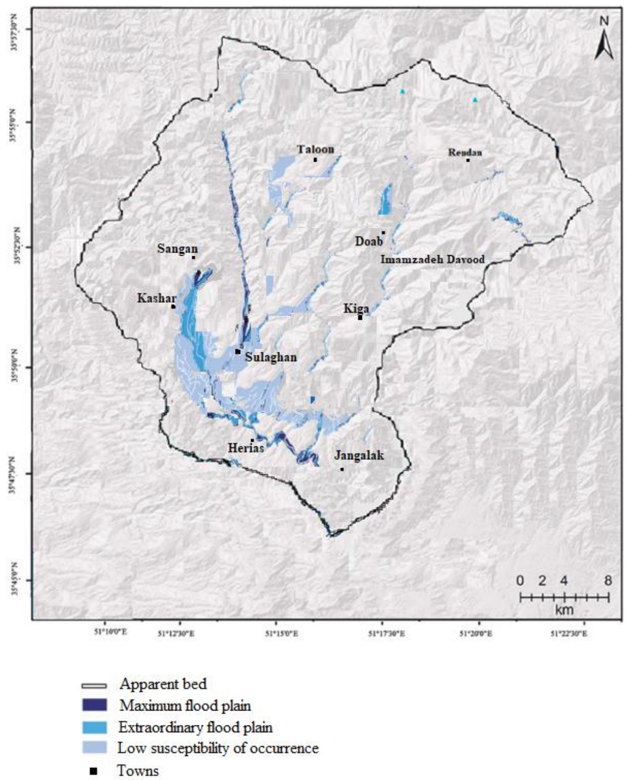

Figure 5. Flood hazard map derived from the crossing of the morphometric and morphogenetic (geomorphological) maps.

The extraordinary flood plains are lands located in the Kan River basin which are related with sub-horizontal morphologies that are within the alluvial plains. These regions are activated during extraordinary rainy seasons in conjunction with extreme events such as atmospheric anomalies. The surfaces with low occurrence of flooding are made up of sections that do not belong to the alluvial plains of the channels that feed the Kan River. Therefore, these lands are subjected to flooding once a series of hydroclimatic factors combine, such as the effects of the intense rainy season.

3.4. Validation

Based on the analysis of 102 records generated between 1970 and 2020 that are related to floods, these data were located with the greatest possible precision according to each report in Kan River, then they were superimposed on the different maps. The analysis determines that 85.15% of the reports coincide with the flood-prone areas according to the morphometric values and 95.08% with the flood hazard map.

According to the results, quick and 3-D growth in inhabitants of major cities occur on fundamentals which mainly depends on the local conditions; environment, geomorphology, and geology. The sandy geology of the cities suggests simplicity of diggings and consumable materials of the structures, as well as absorbency of the urban soils, whereas the set of neo-tectonic identifies the appropriate regular landforms and routs that the city has to grow which is mentioned also by Tricart (1972). Early simple urban development of the Tehran was supported by the ancient Ray city, while Tehran's rapid growth between the mid-twentieth and early twenty-first century took on a complex pattern affected by the natural background factors. Geology and geomorphology have enforced restrictions for expansion of the city which are revealed both in the lands and the urban (Ghassemi, 2023). It is therefore recommended that the environmental grain of the city is partially recorded by its infrastructure. Temporarily, protecting the geological inheritance using the geo-sites is extremely suggested for such quickly developing metropolises. Some locations of the city in an active tectonic setting imposes earthquake, flood, and landslide hazards to the city. An unexpected event of such urban development history and the resulting emerging threats indicate an "unforeseen growth" or "intuitive development" of the city which is pushed over its resiliency bounds.

Conclusions

Geomorphology is an integrative science of the endogenous and exogenous dynamics of the Earth system. It favors the determination of zones where the geological conformation, the activity of the past, the responses of the modeling processes of the present and the result of relief modeling are taken into account to plan the territory and reduce the impact of extraordinary natural processes on the population. The tectonic and geological characteristics of the Kan River have built a complex relief where various predominant morphological regions intervene. It has been shaped by different factors such as ice, water, gravity and weathering alternating between erosion and deposition that have resulted in landforms with a particular genesis, morphology, age, evolution and dynamics. This endogenous and exogenous conformation of this territory is influenced by the events of intense seasonal rains and the indirect impact of strong winds that could affect the population.

Morphometry grouped the results of dissection density, separation depth, relief energy, potential erosion and total erosion, from which the first map on flood dynamics in the Kan River was derived with three categories: maximum occurrence, frequent occurrence and potential area. Subsequently, based on morphogenetic mapping, relief forms where flood action could occur at different levels (flood plains, terraces, alluvial fans and debris ramps) were delimited and characterized. At the end of the procedure, it is through the integration of both the morphometric and morphogenetic map that four levels of flood susceptibility are determined: apparent beds (seasonal), the maximum flood plain, the extraordinary flood plain and the areas of low susceptibility of occurrence. The zoning of different degrees of susceptibility to floods by morphometric and morphogenetic methods had a validation with historical events of 95.08%, between 1970 and 2020, which approves this geomorphological approach as a base input for disaster risk management as well as in territorial planning at regional and local levels.

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