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ORIGINAL ARTICLE

Morphometric analysis of Colangüil river basin and flash flood hazard, San Juan, Argentina

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Abstract This work analyzes various morphometric characteristics of the Colangüil river basin in order to evaluate flash flood hazards. Such high-water events pose a risk to the similarly named small village located at the basin's foot area. For this purpose, the basin is divided into seven sub-basins and some basic measurements (surface, perimeter, basin length, river beds, elevations and slope of the main river bed, and of a number of minor river beds) are calculated. These measurements permit to predict approximately the behavior of the basin in the presence of a series of theoretical rainstorms that may generate unusual runoff volumes that make up such flash floods.

Keywords Colangüil river basin · Morphometry · Flash floods · Argentina

Introduction

One of the most important tools in hydric analysis is the morphometric survey of a basin, which allows establishing evaluation parameters on the behavior of the hydrological system of the basin areas. This study, when properly combined with geomorphology and geology, helps elaborate a primary hydrological diagnosis to predict the approximate behavior of the basin at the time of heavy rainstorms.

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Flows hastened by heavy rainstorms are often referred to as "flash floods", which, according to IAHS-UNESCO-WMO (1974) are defined as sudden floods with high peak discharges, produced by severe thunderstorms that are generally of limited areal extent.

Flash floods are one of the most common types of geological hazards in the region, and they are extremely dangerous because of their abrupt nature. Their characteristics are: short duration, small areal extent, high flood peaks and rapid flows, as well as causing of heavy loss to property. They occur because of high-intensity storms, steep slopes in the catchment, poor vegetation cover and high-velocity flows (Xiao Lin 1999). They turn even worse when the infiltration index is reduced by previous rainstorms. This is a yearly phenomenon, which causes severe damage to houses, irrigation systems, streets, crops and tap-water networks.

In various articles, morphometric analyses were used for basin characterization. They include Miller (1953), Boulton (1968), Gregory and Walling (1973), Gardiner (1975), Costa (1987); Topaloglu (2002), Moussa (2003), Sreedevi et al. (2004), and Mesa (2006).

The Colangüil basin and its drainage features were studied through topographical maps, air photographs and satellite imagery in order to describe and ponder their hydrological pattern.

Specifically, this analysis was aimed at calculating the potential magnitude of flash floods in relation to their associated hazard level.

Study area

The Colangüil river basin covers an area of 636.28 km^2 in Iglesia, a northwestern department in the Province of San

Juan, Argentina. This basin area lies between latitudes 29°48′–30°12′S and longitudes 69°12′–69°36′W, on the NE side of the Andean range (Fig. 1). The study area comprises the Cordillera Frontal geological province, characterized by an abrupt topography with peaks as high as 5,000 m asl.

Because of its geographical location on the rainshadow slope of the Andes, the Province of San Juan has a general arid and semiarid climate. The moisture-laden air masses from the Pacific are either blocked or depleted of their humidity by this high Cordillera, leaving only hot, dry airflows towards the east front. Thus, the total annual rainfall average is very small: about 93.3 mm per year. Winter temperatures are generally mild, ranging between 1.0 and 18.0°C, whereas summers are hot and very dry, with temperatures between 19.0 and 35.0°C. The Province is characterized by a seasonal rainfall pattern.

In the specific study area, the absolute maximum temperature for the region is 35.4°C in February, and the absolute minimum temperature (−12.1°C) was recorded in July. The precipitation level for most of the area is below 44.9 mm, annually (data recorded at the Meteorological Station ''Rodeo'', Iglesia, San Juan). Rivers such as the Colangüil are ephemeral, typically sourced on snowmelt of higher snowfields formed by winter storms. In the summer period of October–April, however, intense downpours of short duration feed torrential freshets and floods characterized by significant descending speeds, large flow rates and high transport ratios of alluvial matter. The region's steep gradient help drain quickly these precipitated volumes, funneling them towards the Rio Blanco, where they gain power as flash floods of a large magnitude as to cause severe damage to the area.

Geology

The Cordillera Frontal geological province is mainly made up of a suite of Triassic to Miocene volacanic rocks (Ramos 1995). The Colangüil river basin shows a wide range of geologic units. The oldest ones are carboniferous sedimentary rocks, mainly composed of lutites and sandstones. This unit are unconformably overlain by a Permo-Triassic volcanic complex, composed of piroclastic, subvolcanic and intrusive rocks. The Paleogene–Neogene is represented by sedimentary units, composed of alluvials and colluvials deposits. The modern deposits, conglomerates, sands, limes and clay, occupy the valleys and riverbeds.

Materials and methods

The analysis of flash floods was made using weather records and, due to a lack in flow-rate gauging data, the mathematical simulation model of Rain-Discharge

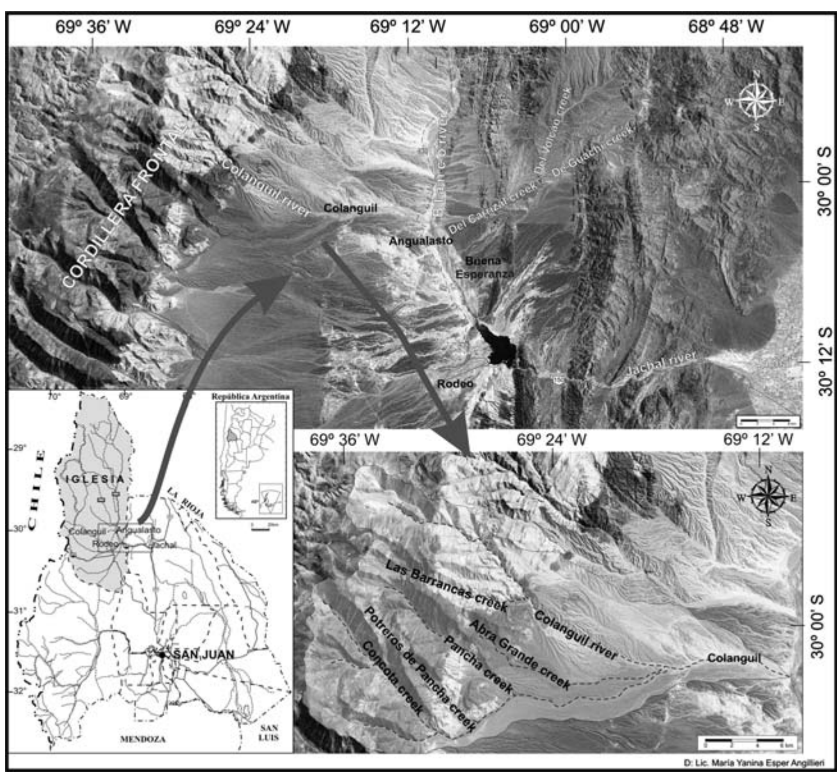

Fig. 1 Location of the study area

Transformation (Arhymo) was applied. The storms selected were that of 26 December 1967, with 52 mm precipitated and 104 mm/h rain intensity, and that of 26 February 1981, with 40 mm precipitated and 48.9 mm/h rain intensity. Since this model was designed for simulation of small basins, the author decided to split the Colangüil basin into a number of sub-basins, thus composing a more comprehensive morphometric and lithologic study.

Both the morphometric characterization and basin delineation were made using 1:100,000 topographic maps, 1:15,000 aerial photographs, and digital satellite imagery (Landsat 7-TM). These were on-screen digitalized using GIS technology. The stream ordering of the basin was made after Strahler (1964).

The morphometric parameters were divided in basic parameters: area (A), perimeter (P), length (L), wide (W), river network (Rn), maximum and minimum heights (H, h), total channel length (Tcl), and main channel length (Mcl); and derived parameters: the circularity index (Rc), the elongation ratio (Re), the form factor (Ff) and drainage density (Dd). The latter were obtained operating with the following equations:

$\mathrm{Rc} = 4\pi A/P^2$ (Miller 1953)
$\mathrm{Re} = \sqrt{4A/\pi}/L$ (Schumm 1956)
$\mathrm{Ff} = A/L^2$ (Horton 1945)
$\mathrm{Dd} = \mathrm{Tcl}/A$ (Horton 1945)

The analysis of basin slope was performed in GIS environment. The slope functions calculate the maximum change in elevation over the distance between the cell and its eight neighbor. The output slope dataset was calculated as degree of slope.

$$\mathrm{Slope}(degree) = \theta$$

$\tan\theta = e/d$
e = elevation
d = distance

Once the sub-basins were delineated, it was necessary to calculate the area (A), the main channel length (Mcl), the basin relief ($R = H-h$) and the curve number (CN) for each sub-basin. CN is a parameter standardized by the soil conservation service (1986), and it is linked to the soil characteristics (humidity, infiltration, etc.). Its value ranges from 0 (high infiltration) to 100 (no infiltration) and it gives a picture on the water retention capacity of the basin.

The following step entailed the simulation of the production of discharges down into the basin's collector (Rio Blanco), and down to the Town of Colangüil. Different scenarios were considered as regards the rainstorm area: a homogeneous precipitation for the entire basin; in just two sub-basins; in three sub-basins; and in only one sub-basin without any previous humidity condition. Besides, the previous rain was also considered (i.e, infiltration reduction).

Results and discussion

The Colangüil river basin (Fig. 1) is composed, from North to South, of Conconta, Potreros de Pancha, Pancha, Abra Grande, Barrancas and Colangüil creeks. The basic parameters are shown in Table 1. The circularity index, the elongation ratio and the form factor have values much lower than the unit (0.49, 0.62 and 0.31, respectively), which show an elongated basin, with steep relief, fast discharge and long main channel. The drainage density (2.12 km) indicates structural controls, resistance to erosion, low infiltration capacity, high surface drainage and high waterflow speed, which is reflected on the great likelihood for flash floods and associated hazards.

The basin was divided into seven sub-basins (I to VII) (Fig. 2). In order to be able to assign a representative CN to each sub-basin, and keeping in mind that, as mentioned above, the Colangüil river basin shows a wide range of lithological units and that the CN is closely related to the constituent material of the sub-basins, the criterion for sub-basin selection was mainly lithological. The parameters calculated to apply the mathematical model Arhymo are shown in Table 2.

The peak discharges resulting from the application of the mathematical model Arhymo are just mathematical approximations. Their validity is controversial because it is difficult to predict the spatial extension of rainstorms without counting with more comprehensive hydro-meteorological records. Besides, the morphological features of flow paths and depositional areas are subject to constant modification due to further erosion and deposition after a flash flood event (Crosta 2001). But local people say that this a yearly phenomenon, which takes place in the rainy season, and they also refer to serious floods in the 1960s, 1970s and 1980s, when there were severe damages to houses and crops (Table 3).

Table 1 Basic parameters of Colangüil river basin

A (km^2)	636.28
P (km)	127.33
L (km)	45.33
W (km)	14.03
Rn (order)	5th
S (degree)	4° 39′
H (m asl)	5,340
h (m asl)	1,654
Mcl (km)	49.26
Tcl (km)	1,352.35

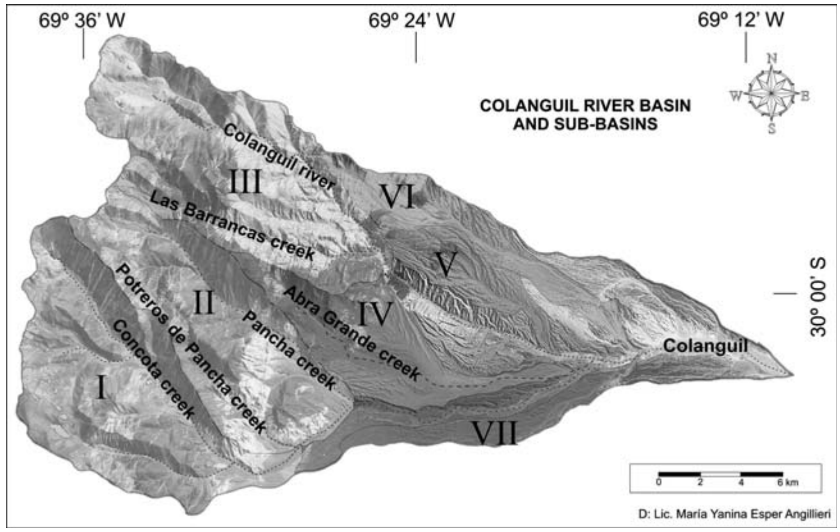

Fig. 2 Colangüil river basin and sub-basins

Table 2 Parameters of sub-basins

Sub-basin	*A* (km^2)	Mcl (km)	*R* (m)	CN	CN[a]
I	132.53	25.24	2,590	70	85
II	108.60	21.11	2,758	70	85
III	135.51	18.76	2,729	75	89
IV	59.34	23.96	2,315	60	78
V	26.45	14.54	899	51	70
VI	38.14	23.59	1,164	51	70
VII	21.98	19.92	770	60	78

[a] Previous humidity

Table 3 Peak discharges (m^3/s) resulting from the application of the mathematical model Arhymo

	Rain 52 mm		Rain 40 mm	
	s	*h*	*s*	*h*
Up to Blanco river				
The whole basin	174.2	568.2	73.8	341.4
Sub-basins I and II	55.6	176.0	22.1	107.2
Sub-basins I, II and IV	84.5	293.3	32.2	173.3
Sub-basins V and VI	0.3	75.6	0.1	22.9
Up to Colangüil town				
The whole basin	202.1	632.9	86.4	384.5
Sub-basins I and II	78.8	249.5	31.3	151.8
Sub-basins I, II and IV	105.7	367.2	40.3	216.7
Sub-basins V	0.5	79.3	0.13	29.8

s No previous humidity conditions, *h* previous rain

The rainfall data show that in 5 years—out of 28 years of data recording—there were rainstorms equal to or higher than 40 mm. This indicates a 5.8-year recurrence interval ($T = (28 + 1)/5$) and a 17.24 probability ($P = 1/T$) for rainstorms to happen in any given year. Considering that the Colangüil river has a mean discharge not larger than 3 m/s, though just a 50% validity is considered, the results obtained indicate that there is a high probability for flash flood hazard, except in the special case that a storm concentrated exclusively in sub-basins V and/or VI, whose results are low, but expected, considering that such sub-basins are of lesser areal extent and that they are composed of high permeability materials, mainly modern deposits, conglomerates and sands with low CN (greater infiltration); while the rest of the sub-basins have larger areal extent and are mainly composed of granodiorites, riolites and granites with high CN (low infiltration).

Conclusions

The computed morphometric characteristics show that lower order streams mostly dominate the basin. The river network is of fifth order. The general pattern of the basin is parallel dendritic. It is an elongated basin with highly dissected areas, and the Dd of the basin indicates that the general nature of rocks is impervious.

The values obtained from the rain-discharge simulation point to a high probability for serious flash flood hazard, with peak discharges greater than 170 m/s. Such flash floods can certainly affect the town of Colangüil, with the additional possibility of causing serious damage to other villages and towns located downstream the Colangüil-Blanco rivers confluence. When one considers conditions of previous humidity, i.e., rainstorms of previous days, the peak discharges of basin outflows can triple or quadruple their average values.

A natural occurrence thus featured would certainly wash away the locality of Colangüil, mainly because its inhabitants have concentrated their settlements and farm lots on the small alluvial terraces along the Colangüil riversides.

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