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Hydrographical characteristic of basins of Bahia de Navidad, Jalisco, Mexico

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Abstract: A physical characterization of the drainage area of the Bahía de Navidad, Jalisco, Mexico was carried out, based on different parameters and hydrographic indices. The results allowed to identify and define more precisely the baseline of the hydrographic behavior of three small "sub" basins that drain and flow into Pacific Ocean. 1) Arroyo El Pedregal, a high-risk creek, impacts independently on San Patricio-Melaque. 2) Arroyo El Organito, a moderate risk creek, runs into El Tule lagoon, and surrounds urbanized areas. 3) Arroyo Seco, its low hazard determines the hydrological conditions of Barra de Navidad lagoon. In conclusion, environmental deterioration, high degree of ecological fragmentation and deforestation, coupled with hydrographic specificities calculated by indexes, make them highly susceptible in different degrees to situations of risk and emergency due to floods and alluvial landslides, in face of increasingly frequent and powerful hydrometeorological events in recent years.

Key words: Bahía de Navidad; Jalisco; basin; hydrography; description; GIS

1 Introduction

Even though progress has been made in the availability of remote sensing technology, GIS software, and a wide range of databases, such as the National Institute of Statistics and Geography, the National Water Commission, the Mexican Institute of Water Technology, the National Meteorological Administration, and the Statistical and Geographic Information Institute of the State of Jalisco in tropical areas, it is particularly obvious that there is a lack of management plans which incorporate environmental variables, manage growth pressures and the real development needs of coastal populations.

One of the basic aspects of understanding ecosystem functions is the physical characteristics of the watershed (MartínezRamos et al., 2012; Mas, Velázquez, & Couturier, 2009). This feature is very important because it is related to their shape, which is a geometric structure projected on a horizontal plane (Llamas, 1993). This form controls the rate of water supply to the main watercourses from the source to the estuary, thus determining the potential flow and risk of floods and/or floods (Guilarte, 1978).

The purpose of this work is to describe the basin where Bahía de Navidad meets in Jalisco, Mexico, on a smaller and more accurate scale; however, this feature is only a part of its comprehensive diagnosis, because understanding the historical behavior of a series of factors, such as water quality, biochemical composition of water, and the direction of its temporary and perennial tributaries through rivers, wetlands and/or bays will help distinguish between historical geomorphic dynamics and other ecological functional processes that maintain reproductive patterns, biodiversity distribution and regional ecosystem services (MartínezRamos et al., 2012; Moberg & Rönnbäck, 2003).

2 Materials and methods

Bahía de Navidad is located in the basin: Chacala-Purificación, between the Marabasco River basin and Purificación. The territory is spatially corresponding to four cities in Halysco, of which Cihuatlán has the largest area (67.3%), followed by Cuautitlán (21.2%), La Huerta (8.4%) and finally Casimiro Castillo (3.1%).

In Bahía de Navidad, there are three small and narrow temporary ocean currents, which surround rivers with small volume and length, and immediately flow southward (due to the lack of east-west structural lines) through the bay into the Pacific Ocean. The basins of these three kinds of runoff (rivers/streams) have obvious seasonal flow, which is related to cyclonic weather. However, dry streams sometimes maintain the lowest flow throughout the year, and remain dry in winter and spring (Fig. 1). These streams rivers are rocks, organic matter soil and dry streams. They are temporary and have the nature of rainstorm. Their flow and maximum flood are related to the frequency and intensity of rainfall in Mexico's Central Pacific hurricane season.

According to the vector information of INEGI, from the letters E13b41, E13b42, E13b31 and E13b32 in the Raster format of the Mexican elevation continuum (CEM version 3.0 INEGI) with a resolution of 30 m; CE Second Edition Continuous Runoff; 1:50,000 INEGI; soil science, vector information 1:50,000; Shape, IIIGI-Jalisco Image Format and landsat satellites in the region (INEGI, 2007) and with the help of ArcView 3.1, Arc Gis 9.2, Didger 3, Surfer 8 and other professional computing software, the digital elevation model is analyzed, described and established as well as their own thematic maps, topography, hydrology, land use and vegetation, soil science. Each basin in the bay flows into the Pacific Ocean along the Parteaguas River from Punta Graham to Punta Merak in Bahía de Navidad.

Fig. 1. El Pedregal Creek at mainstream and peak flows. (Pictures taken by Judith Arciniega.)

According to these images, each of the three watersheds is defined with above technology: 1) EI-Pedregal San Patricio (EP-SP). 2) EI Organito-EI Tule (EO-ET). 3) Arroyo Seco-Barra de Navidad (AS-BN). The coverage of each vector information is reduced, and hydrological variables and indexes are calculated as part of the characterization. In addition, the change of land use is also analyzed. Rainfall records of three meteorological stations near the study area: Cihuatlán (14028), Chiflón (14048) and Apazulco (14011), are managed by SMN and La Conagua. These records and the isohyet method are used to build the precipitation curve through Kring interpolation. The following formula is uesd to calculate the average annual rainfall:

$$P = \frac{(p1a1)+(p2\ a2)+(p3\ a3)+\ldots(pn\ an)}{A} \quad o \quad P = \frac{\Sigma\ pnan}{A}$$

Where P is the average precipitation of basin P1. N=mean precipitation corresponding to the area between two isohyets.

a = area between two equidistant lines

A=total drainage area

On the other hand, the concentration time is calculated by the following equation:

$Tc = ((0.87)(Cf)^{3}/R)^{0.385}$ (Kirpich, 1940)

Where TC is the concentration time, CF=hydrologic density, R = relieve, 0.87, ^{3} and $^{0.385}$ are constants.

3 Results

The delimitation of the Bahía de Navidad hydrological complex shows that a slender and irregular basin composed of three temporary tributaries covers an area of 506.27 square kilometers, and the complex is located within the coordinate range 525,812-560,908 in the east and 2'119,196-2'154,466 in the north, passing through the altitude gradient of 0 to 1,069 meters above sea level in the topographic landscape of Halysco and Kolima coastal provinces. The drainage and catchment areas are independent, forming three sub basins: Arroyo El Pedregal San Patricio (EP-SP), Arroyo El Organito El Tule (EO-ET) and Arroyo Seco Barra de Christmas (AS-BN), the last two flow into El Tule and Barra de Navidad lagoon respectively, and then into the Pacific Ocean, while EP-SP flows directly into the sea (Fig. 2).

The shape, terrain and slope will affect the runoff, because the drainage basin with higher roundness may be more or less elliptical or more compact, and the slope will also increase. The topography increases the flow velocity and shortens the concentration time. However, the combination of topography, shape and slope can adjust the behavior of upstream flow and the intensity of downstream flood at flow intersections, lagoons, and final estuaries.

Among the three basins analyzed by hydrological parameters, AS-BN stands out because of its length, scope and complexity, while EP-SP stands out, highlighting the characteristics of topography and drainage density (Table 1). AS-BN and EP-SP are similar in terrain, shape and circle, while EP-SP values are similar to EO-ET in area, length, perimeter, terrain and quality.

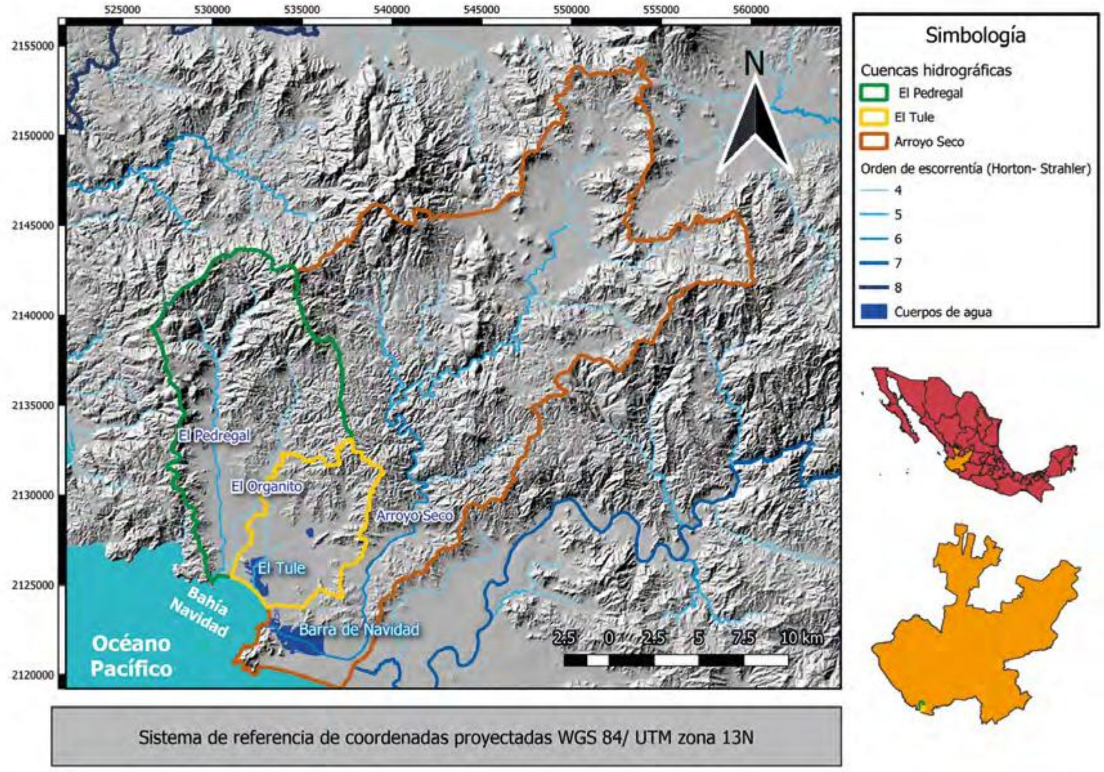

Fig. 2. Study area: Bahía de Navidad, Jalisco, Mexico.

Self developed based on INEGI data (2007)

The hydrological networks are analyzed according to the comparison of river intensity indexes. The three networks can be compared to distinguish the differences of hydrological erosion forms, relationships and processes in each basin. Compared with the river intensity index (Table 2), AS-BN is the highest and longest basin in the three basins, with the longest perimeter and the longest concentration time and the runoff reaches Grade 6 (Table 3). However, EP-SP, which only reaches Grade 5 runoff, stands out because of its high hydrological and drainage density index, flood flow coefficient and high variability. On the other hand, EO-ET has the lowest slope, the shortest concentration time and the highest maintenance value riverbed.

Table 1. Hydrological characteristics (shape and topography) of Bahía de Navidad

Parameters	Sub basin of Bahía de Navidad		
Hydrology and geomorphology	El PedregalSan Patricio	El Organito-El Tule	Arroyo Seco-Bahía de Navidad
Area (km^2)	80.11	76.97	349.19
Length (km)	23.789	17.2	39.05
Width (km)	4.63	5.18	13.5
Perimeter (km)	61.24	52.66	139.16
Geographic description of terrain/profile	Middle front - canyon - narrow plain - sea	Lomeríos-vast plain-lagoon - sea	Highland - intermedia valley - vast plain lagoon - sea
Relief (m.s.n.m.)	0-835	0-340	0-1,069
Drainage density	3.6	2.5	2.7

Drainage mode	Dendriform	Dendriform	Dendriform
Basin type	Execute	Execute	Execute
Relief (m.s.n.m.)	0-835	0-340	0-1,069
Horton relation method	0.234	0.324	0.238
Gravelius form factor	3.37	4.48	8.94
Dense gravel	1.916	1.681	2.085
Elongation index	3.998	2.768	2.836
Cyclic factor	0.268	0.349	0.227
Slope of main channel (%)	6.208	4.966	2.022
Fournier topographic coefficient	0.320	0.292	1.031
Martonne mass coefficient	1.997	1.949	1.718
Riverbed length (km)	20.54	13.503	64.043
Average height (m)	160	150	600

Table 2. River strength of de Bahía de Navidad

Sub basin of Bahía de Navidad			
River strength parameters	El Pedregal-San Patricio	El Organito-El Tule	Arroyo Seco-Bahía de Navidad
Runoff quantity	421	251	961
Hydrologic density	5.255	3.261	2.752
Drainage density (km/river/ km/area)	3.63	2.47	2.73
Flood coefficient	4.319	2.611	2.19
Average runoff length	0.069	0.101	0.092
Channel maintenance constant	0.275	0.405	0.366
Average bifurcation value	5.557	4.275	2.106
Concentration time (h)	22.010	14.611	70.407

Note: Self developed according to INEGI data (2007).

Table 3. Horton classification of Bahía de Navidad

Microbasin	Runoff sequence	Number of segments	fractional length (km)	%Sequence number relative to segment length	Bifurcation relation
El Pedregal-San Patricio	1	346	183.34	62.92	6.784
	2	51	52.02	17.85	2.550
	3	20	32.22	11.06	6.667
	4	3	10.34	3.55	3
	5	1	13.48	4.63	1
	6	---	---	---	---

El Organito-El Tule	1	201	126.16	66.37	5.289
	2	38	40.01	21.05	3.455
	3	11	11.98	6.30	11
	4	1	11.93	6.28	1
	5	---	---	---	---
	6	---	---	---	---
Arroyo Seco-Barra de Navidad	1	764	586.59	62.14	5.026
	2	152	175.97	18.64	4.606
	3	33	73.83	7.82	3.667
	4	9	49.55	5.25	4.5
	5	2	34.13	3.62	2
	6	1	23.93	2.53	1

In addition to structural characteristics such as shape, terrain and slope, the impact of soil water vegetation trinity will also affect runoff, which has a significant impact on runoff. In this sense, there are 7 types and 10 soil subtypes in the bay, mainly Regosol, Cambisol and Fluvisol (Fig. 3). These matrixes are composed of clay, sand (in EO-ET and AS-BN) and loose pebbles (in EP-SP), as well as alluvial sequences of the above intermountain valleys, alluvial plains and valley bottoms.

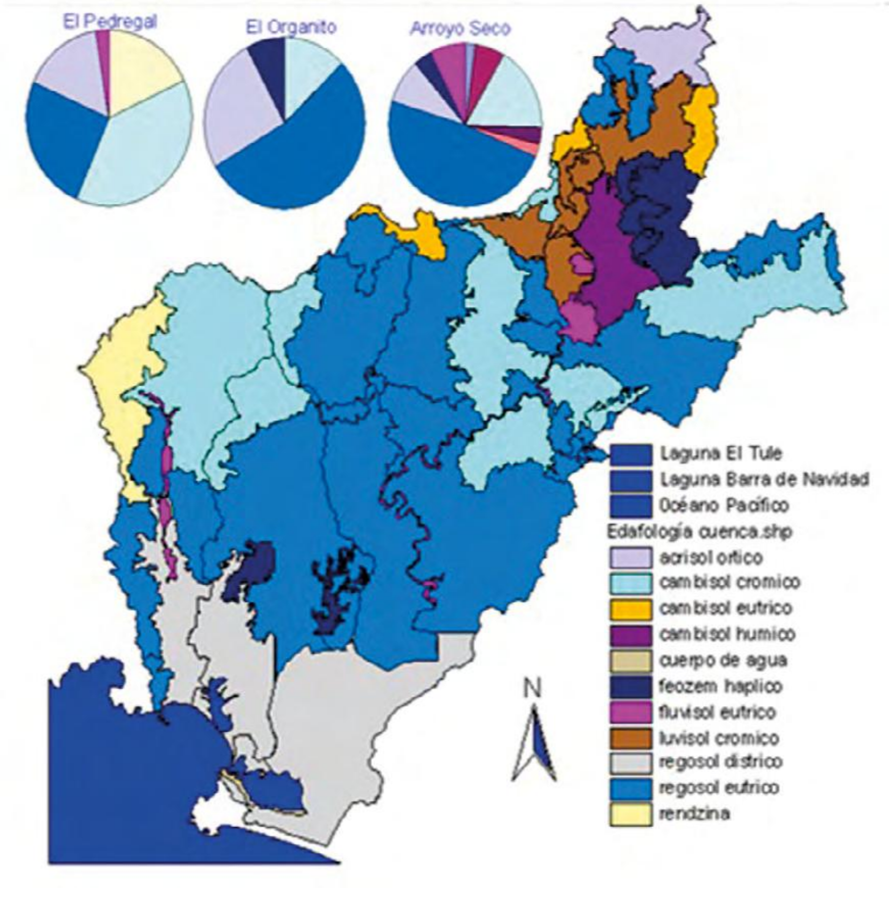

Fig. 3. Soil science map, spatial distribution, type of Bahía de Navidad flooring
According to INEGI data (2007).

The fluvisol is limited to the sediments in narrow streaks of stream channels flowing along the coastal plain, which accounts for more than 45% of the territory, while the other types are located in the upper part of the basin. The area with a slope of more than 10%, Lomerios, Montes and the foot of the mountain, accounts for more than 55% of the area. The main texture is sandy to silty Franco type, in which coarse sand, medium sand and fine to very fine silty sand components dominate. It indicates the river source of raw materials and the impact of wind activity, because they are located on<10% slopes in the landscape, making them highly erosive. In relation to its size, the basin of the type and use of vegetation is Arroyo Seco-Barra de Navidad (AS-BN), with 9 associations and uses, followed by 5 in El Organito-El Tule (EO-ET) and 4 in El Pedregal-San Patricio (EP-SP), with the smallest diversity and the largest use area (Fig. 4).

Through the analysis of historical precipitation records of stations near the basin, four contour lines crossing the elevation gradient are established. The annual average values of EP-SP, EO-ET and AS-BN slopes are 708.3 mm, 639.87 mm, 620.65 mm and 734.35 mm respectively (Fig. 5).

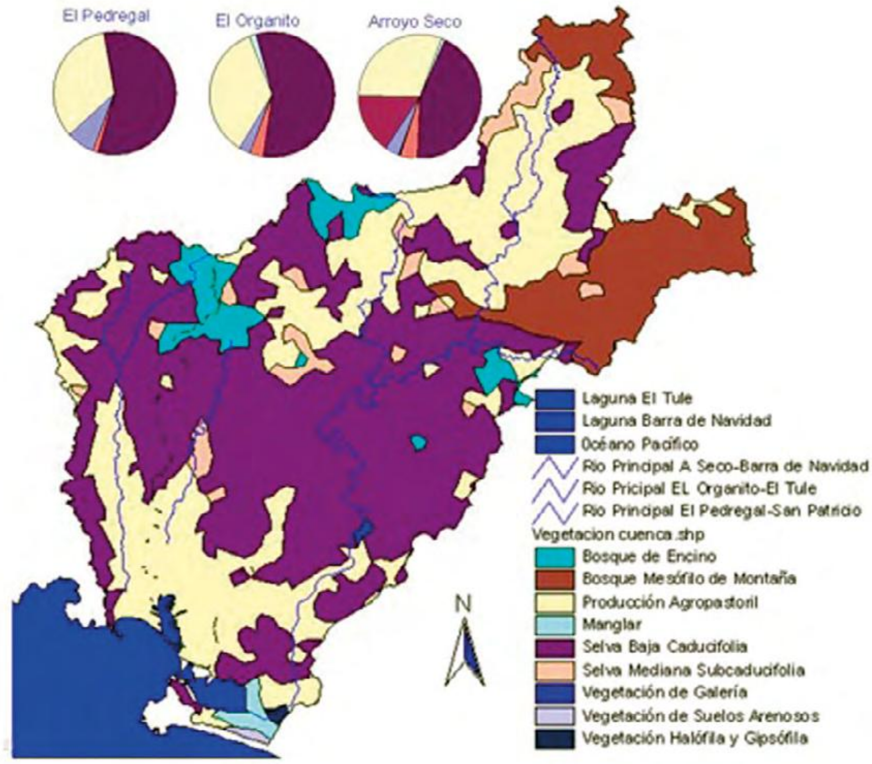

Fig. 4. Botanical society and land use map of Bahía de Navidad.
Self developed based on INEGI data (2007).

4 Discussion

The three sub basins analyzed constitute a marginal coastal basin with marine volcanic sedimentary characteristics, whose origin can be traced back to the Upper Jurassic Period. It is composed of upper Cretaceous granite, where there are important pyroclastic fan, swamp and lagoon environments, and late Holocene coastal zone (Bandi, Kostoglodov, Hurtado-Díaz, & Mena, 1999; CETENAL-INEGI, 1981; Ferrari-Pedraglio, Morán-Zenteno, & González-Torres, 2007; Méndez Linares, López Portillo, Hernández Santana, Ortiz Pérez, & Oropeza Orozco, 2007). This structure accounts for 45% of the coastal plain (river fan) and 55% of the high relief surface with a slope of more than 14% (mountain foot, Lomerios and enclosed environment). Because of this topographical structure, the soil in the upper part of the basin is very thin (3-40cm), so it is more vulnerable to erosion, alluviation and landslide, transportation, river bed siltation and water body siltation. But in the plain (river delta), according to its age and nature, the deeper soil is dominant (Gonzalez-Vazquez, Silva, Mendoza, & Delgadillo-Calzadilla, 2014; Maderey-Rascón, 1990; Méndez Linares et al., 2007; Trucíos-Caciano, Estrada-Ávalos, Cerano-Paredes, & Rivera-González, 2011).

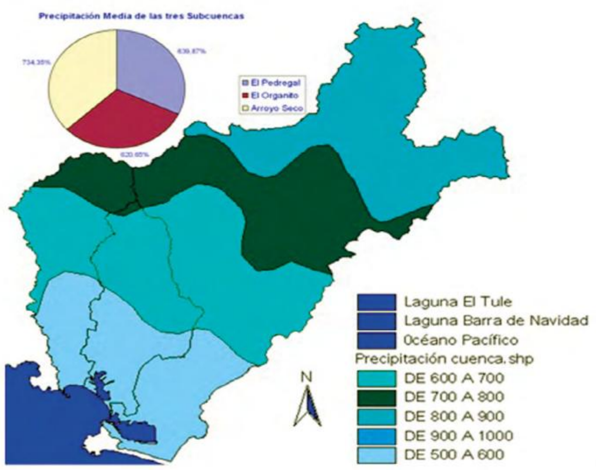

Fig. 5. Rainfall distribution in the basin of Bahía de Navidad.
Self developed based on INEGI data (2007).

On the other hand, the distribution of natural vegetation in the basin follows a general altitude gradient, and the relics of mesozoic mountains and oak forests can be seen in the coldest highlands. While deciduous low forests are developed in flat areas with good drainage and poor soil (Gonzalez-Vazquez et al., 2014).

Agricultural irrigation land is located in the coastal alluvial plain, while mangroves are developed in dry streams and the delta fan of the Cihuatlán River, bordering the Bahía de Navidad lagoon along the transition zone, and coastal areas are surrounded by dune vegetation (Holland, Mariscal-Romero, DavidsonArnott, & Cardille, 2011; Méndez Linares et al., 2007).

Due to its temporary nature, the floods in the three streams flowing into Navi Dade Bay are the result of significant runoff generated by very heavy rainfall, with daily rainfall ranging from 150 to 300 mm and/or lasting to these volumes (Pardo-Gómez & Rodríguez-López, 2014). The relationship between rainfall intensity duration and growth amplitude is direct, which has an impact on the characteristics of the basin (Pardo-Gómez & Rodríguez-López, 2014). It has a slope of more than 10% in more than 55% of the territory. Shallow soil types, such as soil and cambisol, are fine in texture, and clay, shallow and low in organic carbon, are distributed on a wide surface. Because of these characteristics, the United States Department of Agriculture (USDA) believes that they have slow infiltration and high runoff potential. In addition, due to the drastic change of land use, the degradation of original vegetation in different degrees will weaken and/or increase the flood in varying degrees, resulting in floods, landslides and collapse. (Pardo-Gómez & Rodríguez-López, 2014; Richter, 1999).

In this regard, it is believed that water erosion in Mexico is one of the most serious environmental problems affecting the land. Because according to the geomorphology, 65 per cent of the national territory has a slope of more than 10 per cent (Trucíos-Caciano et al., 2011). For the special conditions of the study basin, the storm runoff in summer and early autumn is estimated to be between 500 and 10,000 Mg of sediment per square kilometer per year. These volumes are among the highest erosion values in Mexico (Maderey-Rascón, 1990). The precipitation of the basin is distributed according to the elevation gradient of 4 dry streams and 3 isohyets of El Pedregal and El Organito, and the annual average cumulative amount is 708.3 mm mainly from July to October. The average values for each watershed El Pedregal-San

Patricio, El Organito-El Tule and Arroyo Seco-Barra de Navidad are 639.87, 620.65 and 734.35 mm, respectively. The annual average water volume is also estimated to be 53.61, 51.24 and 253 mm^3 for the same watershed, which corresponds to the average runoff of the main stream of 500 to 1000 mm, respectively (Jiménez & MadereyRascón, 1990). These hydrometeorological phenomena are the main mechanisms in the formation, growth and geomorphological changes of alluvial fans where the Gulf city area is located (Gonzalez-Vazquez et al., 2014).

According to the length and gradient, AS-BN has a higher terrain, with a lower average riverbed gradient, which is relatively lower than other riverbed gradients. Due to the lower bifurcation level, the maximum concentration time is 70h, so its risk is buffered. However, EP-SP with 1020 reliefs, 5.0 bifurcation levels and 22 hours of concentration time is a combination that makes it highly dangerous. The EO-ET with height of 840 and 6.2 is defined as a medium characteristic, although its risk increases due to its shortest concentration time (14 hours). In contrast, the calculated river shape and strength parameters are different from each other. They are similar to AS-BN and EP-SP in terms of terrain, shape and circle, and the latter is similar to EO-ET in terms of area, length, perimeter, terrain and quality. On the other hand, they are different from the concentration time, and EP-SP stands out because of its high drainage density.

5 Conclusion

This descriptive study or hydrological characteristics enable people to learn more about some of the operational processes of the hydrological complex known as Bahía de Navidad. The three sub basins constituting the complex can be considered as a single hydrological unit, although they have different specific characteristics due to their connection at the plain level. Due to its morphology and hydrological combination, the El Pedregal-San Patricio Basin (EP-SP) has the highest risk, and its flow is directly received in the urban area of San Patricio-Melaque before being discharged into the Pacific Ocean. The danger of EL Organito-El Tule (EO-ET) is low, but its ecological stability is crucial, and it provides water ecological conditions for El Tule lagoon. On the other hand, Arroyo Seco-Barra de Navidad (AS-BN) is the largest, most extensive and most complex river, which determines the very important ecological process of the whole bay, especially the Barra de Navidad.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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