Region - Water Conservancy, 2024 , Volume7, Issue2
DOI: 10.32629/rwc.v7i2.3222
ISSN Online: 2630-4902

Morphometric analysis of the Ayuquila river watershed, Jalisco-Mexico

RUBÉN DARÍO GUEVARA GUTIÉRREZ[1], JOSÉ LUIS OLGUÍN LÓPE[1], OSCAR RAÚL MANCILLA VILLA[2], OSCAR ARTURO BARRETO GARCÍA[1]

1. Dep. de Ecología y Recursos Naturales del Centro Universitario de la Costa Sur de la Universidad de Guadalajara. Av. Independencia Nacional 151, Autlán de Navarro, Jalisco-México. CP 48900
2. Dep. de Producción Agrícola del Centro Universitario de la Costa Sur de la Universidad de Guadalajara. Av. Independencia Nacional 151, Autlán de Navarro, Jalisco-México. CP 48900

Abstract: The description of the morphometric characteristics of the Ayuquila river basin provides basic information for the strategic planning of natural resource management, as well as for hydrological studies. The work uses Geographic Information Systems (GIS) as a base tool that allows the analysis of the digital cartography of the National Institute of Statistics and Geography (INEGI), conforming images of the stream network, hypsometry and slopes, and manipulation of digital images. The basin, which is distributed in 21 municipalities and a surface area of 3,642.43 km^2 , is made up of 24 tributary basins, dendritic drainage and 10,288 surface streams. Based on 35 morphometric parameters, correlation models were estimated, identifying the greatest dependence on the time of concentration with respect to the length of the basin ($R^2 = 0.91$) and the proportion of elongation in relation to the area of the basin ($R^2 = 0.83$).

Key words: watershed; tributary watershed; morphometry; functional zones

---

1 Introduction

The morphometric characterization of the Ayuquila river basin and the identification of its functional zones represent an important source of information that provides the basis for strategic planning for the management of its natural resources, as well as for hydrological, social and ecological studies; in this sense, little information is available on this basin in the state of Jalisco - Mexico, an important economic source due to the primary activities that are carried out, since the most important agricultural and livestock valley of the southern coastal region of the state is located in this basin. The objective of the study is to analyze the morphometric characteristics of the watershed in relation to land use and vegetation with respect to its hydrological response and identification of degradation risk zones. The structure of the bibliographic review was carried out considering the importance of watersheds and their morphometric characterization in relation to hydrological behavior. The methods used are based on the use of Geographic Information Systems (GIS) and analysis of INEGI cartography. The results obtained indicate the relationship between watershed morphometry and the influence of land use and vegetation on hydrological behavior.

2 Bibliographic review

Watersheds as natural territories are considered appropriate units for conducting strategic planning, management, exploitation, planning and water administration processes. In a broad sense, they are considered suitable territories for carrying out the integrated management of water resources (CNA, 2009; IPICYT, 2002); as well as for the planning and execution of environmental management projects and policies (Walker et al., 2006). This natural division allows understanding the interrelationships between water resources and natural conditions (relief, soil, climate and vegetation) as well as the ways in which the population organizes itself to appropriate these resources and impact their quantity, quality and seasonality, constituting the appropriate framework for the analysis of environmental processes resulting from decisions on the use and management of natural resources (Cotler, 2004). Thus, watershed morphometry allows establishing parameters for evaluating the functioning of the hydrological system of a region, as well as the management and planning of natural resources (National Institute of Ecology, 2004).

Gleason (2014), Benavides et al. (2009), González (2004), Campos (1987), Sánchez (1987) and Linsley et al. (1984) mention that watershed studies have been established to describe the main physical characteristics of watersheds, from which their hydrological behavior is conditioned, developing various methods of calculation and representation of results, in order to conserve soil and water resources, as well as to estimate runoff (average and maximum) as a direct effect of rainfall events. Santos (2004) recognizes that from the delimitation of watersheds at smaller scales and the identification of the interactions of hydrological events on the geometry of the hydrographic basins, drainage systems can be explained and divided into components of different orders. Systems that favor the construction of morphometric parameters are related to the processes of surface runoff as a function of their environmental conditions. Cortés et al. (2002) use these parameters in the formulation of regional forest hydrological programs and in the implementation of strategies to solve forest development problems.

Vidal-Abarca et al. (1987) recognize that the morphometric study of river basins based on a hierarchy of variables that make up the fluvial network, allows systematizing the diversity of basin shapes, their typification and mapping of territorial units; based on these variables, they interpret their configurations based on parameters that are divided into linear properties of the drainage networks to interpret the water transport function, in surface characteristics or rainwater catchment area that help to interpret the dynamics of basins.

The present analysis describes the fluvial morphometry of the Ayuquila river basin, and describes the geometric properties of the surface of the system, identifying the basic components: 1) Channel system, 2) Surface properties, 3) Relief of the fluvial system and 4) Channel slope (Strahler, 1986). Related to the appearance of the landscape, the phenomena that occur are as an essential prerequisite in the application of edaphological, forestry, geological and hydrological surveys. Based on the estimated values of each morphometric parameter, the relationship between them is identified through linear models, supported by maps as an important tool in land planning (Benavides et al., 2009).

3 Study area

The Ayuquila river basin is located in the Sierra Madre del Sur province and Sierras de Jalisco and Colima subprovinces, Mexico, at geographical coordinates 19°26'43" to 20°04'31” north and 103°56'53" to 104°42'51" west, distributed in 21 municipalities of the State of Jalisco and made up of 24 tributary basins (Figure 1), with an approximate population of 115,555 inhabitants, of which the municipality of Autlán de Navarro accounts for 36% and El Grullo for 16.7% (INEGI, 2005). Within this basin are located dams of importance for the agricultural and economic development of the region (Trigomil, Tacotán and Basilio Badillo or "Las Piedras" with a capacity of 250 Mm^3, 149 Mm^3 and 145 Mm^3 respectively), which benefit 19,986 ha in the municipalities of Autlán de Navarro, El Grullo and El Limón for the benefit of 2,521 families (CNA-SARH, 1992).

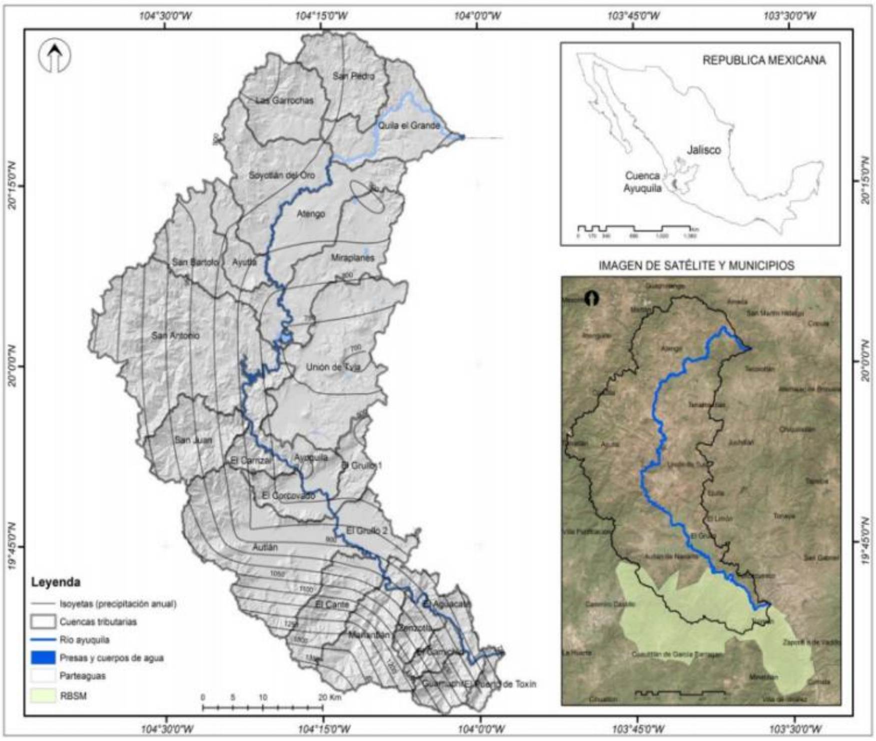


Figure 1. Location of the Ayuquila river basin

4 Methodological framework

The delimitation of the watershed was based on the main runoff through the identification of the watershed at the cartographic level using 12 digital charts at a scale of 1:50. 000 printed by the Instituto Nacional de Estadística Geografía e Informática (Autlán E13B12, El Grullo E13B13, Tapalpa E13B14, Casimiro Castillo E13B22, El Chante E13B23, Venustiano Carranza E13B24, Atenguillo F13D72, Atengo F13D73, Cocula F13D74, Ayutla F13D82, Tecolotlán F13D83 and Atemajac de Brizuela F13D84) digitized by hand in the program ATLAS GIS (V. 2.1), edited in the programs ARC GIS (V. 9.3) and IDRISI (V. 2.0) from which the morphometric parameters of the basin were estimated (Table 1). Contour lines every 20 meters were used to construct vector images with DXF extension represented as lines in the UTM-13N reference system and one meter reference unit as distance unit, as well as digital coverages (digital elevation model, slope and hydrology), with which the morphometric parameters of the basin were estimated (Table 1). These were used to analyze and define the altimetric zones from the graphic expression of their data (hypsometric curve), from which the functional zones were identified, generated from morphographic criteria (contour lines and hydrographic network) and relief (digital elevation model) and supported with spatial analysis tools of the geographic information systems (Garrido et al. , 2010). Since the hydrology of the Autlán and El Grullo tributary basins are connected to the irrigation system, the reclassification of the main stream system was performed through field verifications. Finally, the prediction and correlation models of the morphometric parameters were estimated through linear regression using as selection criteria the coefficient of determination $R^2 \geqq 0.5$ and similarity between parameters using Tukey's test (Martínez, 1988).

Table 1. Models for obtaining the physical and relief parameters of the basin

Parameter	Formula	Parameter	Formula
Number of orders	Spotlight	Average Slope	IDRISI
Average height	$hm = \frac{Ac}{Lc}$	Massiveness Coefficient	$Cm = \frac{hm}{A}$

Compactness Index	$Ic = 0.28 \frac{P}{\sqrt{A}}$	Orographic Coefficient	$Co = \frac{hm}{A} hm$
Bifurcation Ratio	$Rb = \frac{Nc}{Na + 1}$	Roughness coefficient	Rn = R Dd
Drainage Density	$Dd = \frac{Le}{A}$	Concentration Time	$Tc = 0.02 \frac{L^{1.15}}{H^{0.385}}$
Frequency of currents	$F = \frac{\sum_1^k Nu}{A}$		

hm, means height of the basin; *Ac*, area under the hypsometric curve; Lc, maximum length of the basin; Ic, compactness index; P, perimeter of the basin; Rb, bifurcation ratio; Nc, number of runoffs of given order; Na, number of runoffs of immediately higher order; Dd, Drainage density; Le, total length of channels; A, area of the basin; Cm, massiveness coefficient; Co, orographic coefficient; Rn, roughness coefficient; R, relief; Tc, time of concentration; L, length of main runoff; H, elevation differences between extreme elevations.

5 Results and discussion

The surface area of the Ayukila River basin is 3642.4 square kilometers, with 0.44% being water bodies, 0.62% being urban water use, 18.32% being livestock water use, 21.1% being agricultural water use, and 59.52% being perennial vegetation and forests (Figure 2); a proportion of this surface area is protected by the special Biosphere Reserve regime, concentrated on the southwestern slope of the lower basin, where agricultural activities are carried out in the buffer and core areas. Because of the drainage of its runoff, the basin is considered exorheic, consisting of 24 tributary basins and 10,288 streams that make up the three-dimensional elevation model.

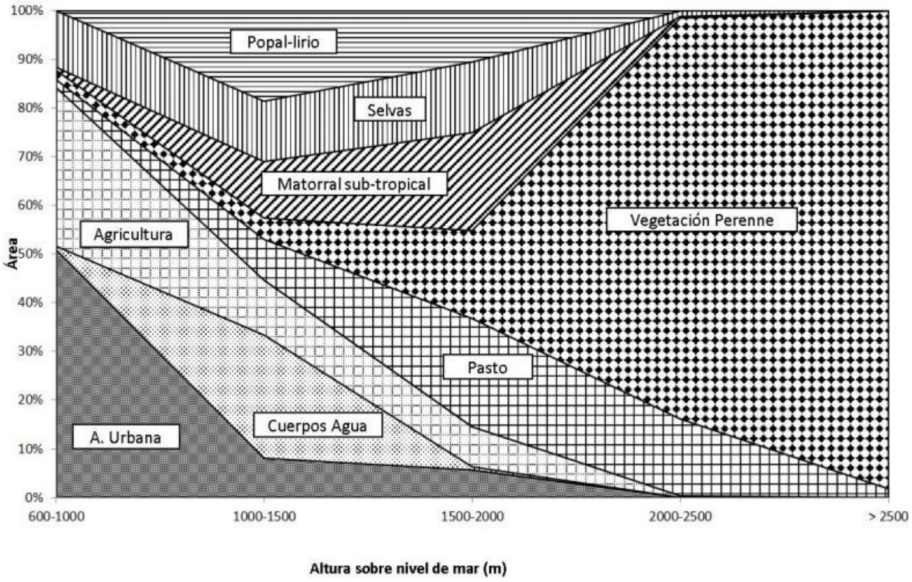


Figure 2. Land use distribution based on altitudinal ranges

The estimated length of the basin is 8,893.58 km and stream order 7, which shows the energy produced within the system (Pozo and Elosegi, 2009). The values of drainage density 2.44, stream frequency 2.82 and bifurcation ratio 3.58 indicate that the energy and efficiency of the hydrological network favors drainage and runoff capture, as well as its erosive potential (INE-SEMARNAT- PLADEYRA, 2003), which added to the low massiveness coefficient (0.02) reflecting environment characteristic of mountain areas with erodible soils, strong slopes mainly in the middle and upper basin, with a rapid hydrological response (Linsley et al., 1984; Gleason, 2014), influenced by the dendritic and sub dendritic drainage model, conformed by a main stream and irregular terrain slopes (Sanchez, 2008) predominance of orders

1 and 2 forming gullies or gullies constituted of igneous rocks (extrusive and intrusive, basalt and tuff) and alluvial soils (Guerra, 1980; Strahler, 1986; INE, 2004). These characteristics are associated with the size of the basin and soil type, condition the response and velocity of runoff (Gleason, 2014), which defines the expansion capacity of the drainage network and its bifurcation ratio (Doffo and González, 2005). In consideration of the bifurcation ratio, Sánchez (1991) mentions that this parameter determines the speed of flood waves and thus the degree of danger of the basin, based on the estimate made for the Ayuquila river basin, Gleason (2014) states that this corresponds to a highly dissected basin with a rapid response to storms (proportional in relation to the slope and runoff) of permeable soils that are not very resistant to erosion.

In reference to the shape and size gradients of the basin, Vidal-Abarca et al. (1987) comment that these respond to topographic factors, relief and substrate typology, with the Ayuquila river basin having an elongated (rectangular) shape representative of mountainous sectors with depressed and flat areas. Doffo and González (2005) comment that the shape of the basin is closely related to the shapes of the stream network and its degree of expansion, which allows inferences to be made about the state of equilibrium of the network. Based on the shape index (0.52), the elongation ratio (0.79) and the compactness index (1.75), the watershed is considered to have an oval-oblong shape, a main river length of 21.8 km and an average slope of 22%, with a time of concentration greater than 120 minutes, which reduces the risk of flooding, without affecting the runoff hydrograph and peak flow rates (Linsley et al.. 1984), favoring a diffuse hydrological response depending on the direct channels and the dimensions of the tributary basins along the path of the main runoff (González, 2004). In areas of gauging (middle and lower basin), the surface area is reduced and the hydrographs vary over time (Welcomme, 1980), reaching values of over 582.9 Mm^3 of average volume, which is concentrated in the middle basin, rapidly leaving the lower basin due to its narrow and elongated shape. This increases the danger of flooding due to the increased slope ranges (30 % and > 45 %) and the distance between the points of the watershed with respect to the central axis, which affects the runoff concentration time (Sánchez, 1987). Based on the results, it is assumed that the flow dominates the channel flow over the slope flow, which results in a shorter response time to the growth of the hydrograph (peak time).

Campos (1987) and Becerra (1999) recognize that this effect is increased due to the basin's average slope (63.5%), average height (1,507.14 meters) and relief ratio (82.9), a response regulated by the Trigomil dam located in the middle basin within the municipality of Unión de Tula and modified by the different land use coverages and changes in land use patterns, deforestation, soil type and climate. In this sense, Linsley et al. (1984) established that the increase in floods is conditioned by the vegetation structure in interaction with the resistant and permeable lithological conformation that favors the infiltration of rainfall by reducing the effect of the kinetic energy of surface runoff, which is integrated into the fluvial network. However, it is considered that the average slope of the watershed is a parameter that provides the characterization of the relief, which is closely related to the erosive phenomenon of the soil, infiltration, surface runoff and soil moisture; as the slope of the watershed increases in its origin, the possibility of increased flooding and fluvial erosion persists in depositional areas of the middle and lower watershed. Slesak et al. (2015) note the increase in the process of soil erosion on slopes due to timber extraction and the application of soil preparation techniques.

The Ayuquila river basin is divided into western slopes (VW) with an altitudinal range of 988 to 2,385 m and a surface area of 2,251.8 km^2 and eastern slope (VE) of 1,087 to 1,889 m with a surface area of 1,390.6 km^2 . Based on this altitudinal range, the greatest climatic and ecological variation is observed in the VW (Ruíz et al., 2002; Martínez and Castillo, 1996). The orientation of each relief imposes the direction of the fluvial network with a high degree of channel hierarchy (higher than 4) and respective runoff numbers of 6,891 and 3,397; the branching of the drainage network for VW is 5,916.234 km and 2,977.349 km in VE, with drainage density higher than 2, narrow and scarce length, values that conform a continental type hydrological morphology. Doffo and González (2005) recognize that this morphology is influenced by the structure and lithology of the terrain since 80% of the basin is made up of igneous rocks, conditions that in the middle and upper basin tend to reduce rapid flooding but not in the lower basin since it is characterized by its narrow shape, low branching and hierarchical drainage. Based on the topographic chart (1:50,000) published by the National Institute of Statistics and Geography (INEGI), more than 95% of the watercourses are intermittent or temporary.

The average slopes of hillside are 27% for VW and 14% in VE, more than 50% of the cross sections are represented by values higher than 20%, a basic and limiting parameter to establish strategies to solve problems of deterioration risks and degradation effects, accelerated by the inappropriate management of non-renewable natural resources. This use is distributed in different altitudes and slope ranges but mainly in ranges from 0 to 15 % (95 128 ha), from 15 to 30 % predominantly forests (34, 642 ha) and from 30 % to >45 % perennial vegetation (60 457 ha) (Figure 3); The latter ranges correspond to the headwaters of the basin, where rainfall is highest, and rivers are born and flow down steep slopes, helping to regulate and distribute water, and the greatest pressure on forests due to deforestation is registered. Jardel (1992) recognized that the main impact of agriculture is below 2000 m.a.s.l.; the CIGA- UNAM (2012) identified that in the period 1995 to 2010 the Ayuquila river basin lost more than 30,000 ha of lowland forests and more than 11 thousand hectares of forest, with the respective increase in pastures and agriculture. This process, according to Faminow (1998), accelerates soil degradation by more than 12.3 million hectares worldwide. This change in land use and hillside agriculture has led to the deforestation of more than 600,000 hectares per year, an area considered the most susceptible to erosion due to the length and slope of the terrain (Lal, 2000). Quiñones and Dal Pozzo (2005) identified increased degradation risks on slopes greater than 50%. Factors, that interact with vegetation characteristics and impermeable lithology, reduce soil infiltration and increase the friction of surface runoff, thereby increasing the occurrence of higher erosion rates (Gómez-Pompa and Burley, 1991). According to Vidal-Abarca et al. (1987), the relationship between land use and morphometric typology is inversely proportional in relation to the conservation and exploitation of resources with respect to small units of abrupt relief and permanent watercourses, where more than 80% of forest relicts are preserved.

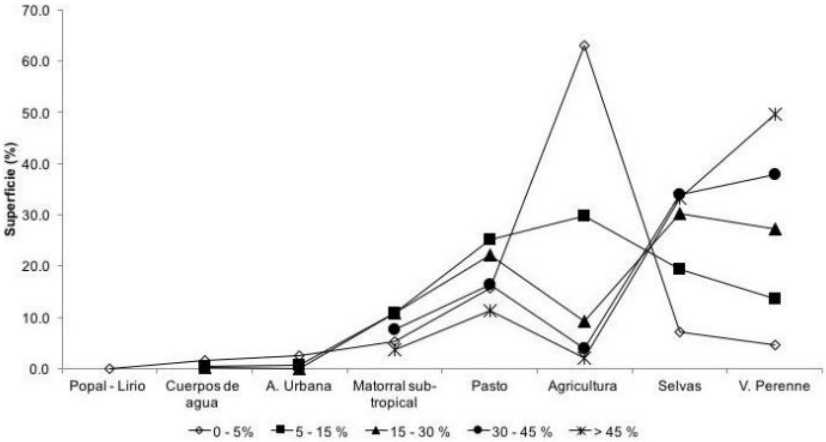


Figure 3. Distribution of land use based on slope ranges

With the hypsometry and average slope values, it is reaffirmed that the basin is representative of mountainous areas or hill headwaters in most of the surface (middle and upper basin), as well as catchment areas where surface streams are born, which, due to their morphological conditions, are more fragile hydrologically (García et al., 2003). The values allow us to know the variations of the curves because they present more than one inflection point (Campos, 1987) and are related to tectonic or lithological controls (Racca, 2007). The longitudinal profile of the basin (Figure 4) represents an irregular relief dominated by slopes greater than 15%, in which two stages of development can be distinguished. The first is a stage of equilibrium identified between 1,550 and 2,860 m.a.s.l. (53% of the surface area), considered a foothill basin, with a tendency to be an eroded or valley basin, dominated by perennial vegetation and, to a lesser extent, by clearings for livestock and small areas of subsistence agriculture. The second stage is identified as a geologically young or in equilibrium basin, located between 648 and 1,550 m.a.s.l. (47% of the surface area) where agricultural activity predominates, and subtropical scrubland increases from 1,500 m to 2,000 m.

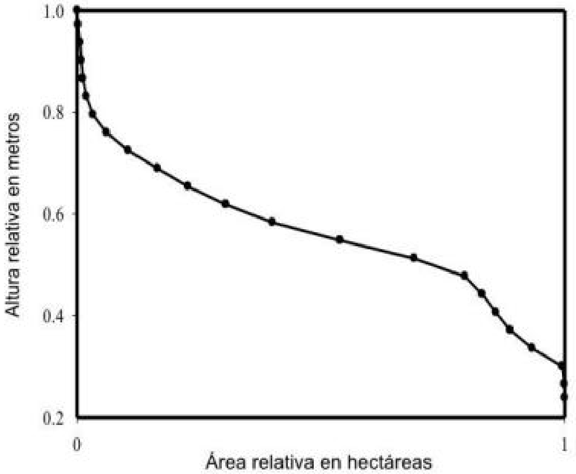


Figure 4. Representative hypsometric curve of the geologic cycle

One of the proposals for the delimitation and study of watersheds is established by Garrido et al. (2010), from which three functional zones were identified in the Ayuquila river basin (Figure 6). The upper watershed (border zone) is an area of 143,852.24 ha (39.4%) with an altimetric proportion above sea level of 1600 to 2880 m. The hydrology is characterized by a predominance of first and second order streams that show evidence of fluvial-erosive processes associated with steep slopes and greater forest cover; however, there are areas with a low slope range, which are frequently deforested. The middle basin (transition area) is distributed over an area of 200,411.08 ha (54.8%) with an altitudinal range of 1,000 to 1,600 m.a.s.l., and predominant slopes of 15 to 50% in more than 60% of the area. Its drainage system is mostly integrated by second to fourth order dissections; in this zone there is the largest deposition area corresponding to agricultural production zones (valley of the municipalities of Autlán de Navarro, El Grullo and El Limón). Finally, the lower basin is distributed over 21,238.32 ha, considered the outlet area of the drainage system, altimetrically it is the lowest portion composed of flood plains (670 to 1000 m.a.s.l.), including the fluvial terraces and ordinary beds, characterized by being narrow at the mouth, but due to its topographic irregularity it has high energy flows with scarce deposition areas (Figure 5).

In the search for models that explain the associations between parameters and differences between tributary basins, 14 morphometric parameters were correlated, considering only those that reflected an $R^2 \geq 0.50$. Seven of them were identified as being dependent on more than one parameter, with the elongation ratio standing out as dependent on eight of the 14 and time of concentration dependent on six (Table 2). The parameters most frequently correlated to others are the area $R^2 = 0.93$ in reference to runoff length; number of runoffs $R^2 = 0.98$ in relation to runoff length; the massiveness coefficient with $R^2 = 0.97$ with respect to the orographic coefficient and main runoff length $R^2 = 0.71$ in relation to watershed length.

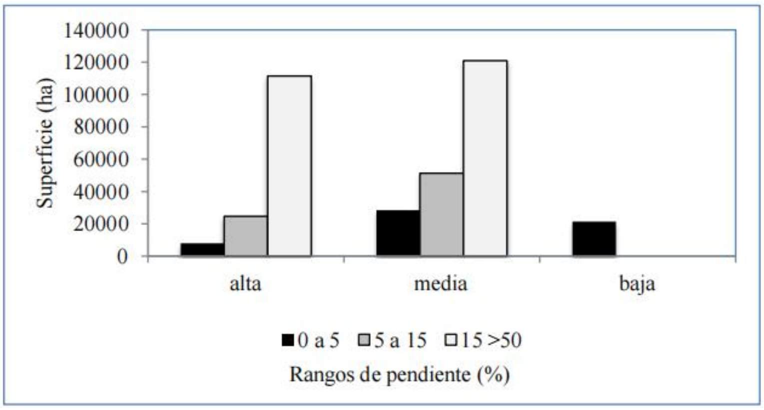


Figure 5. Distribution of slope ranges by functional zone

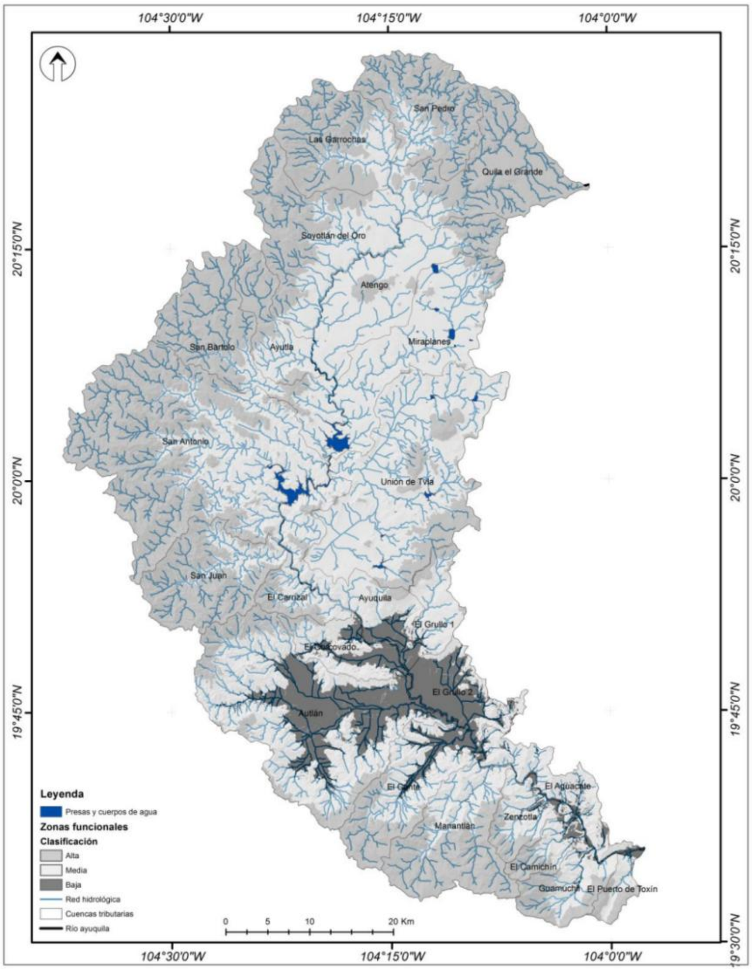


Figure 6. Functional zones of the Ayuquila river basin

Table 2. Correlation models of morphometric parameters

Dependent variable	Independent Variable	Model	R^2
Length of runoff	Number of runoffs	Y = 1,2425 X - 31,761	0,98
	Area	Y = 0,359 X - 18,501	0,93
	Basin length	Y = 0,0153 X + 11,435	0,57
Elongation ratio	Form index	Y = 1,3649X - 0,5571	0,98
Orographic coefficient	Massiveness coefficient	Y = 0,6259X + 0,0006	0,97

Number of runoffs	Area	Y = 0,2811X + 31,283	0,90
Runoff length ratio	Orographic coefficient	Y = 5,4246 X – 5,4232	0,63
	Massiveness coefficient	Y = 3,0448 X – 3,0436	0,87
Circularity ratio	Compactness index	Y = -0,3301X + 0,926	0,88
Drainage density	Hydrologic density	Y = 1,4603X – 0,7527	0,71
Basin slope	Length of runoff	Y =-8,2752 X –237,3	0,69
	Number of runoffs	Y = 10,257 X – 324,8	0,67
	Massiveness coefficient	Y = - 0,0003 X + 0,041	0,58
	Length of main runoff	Y = 0,268 X + 2,0938	0,54
Hydrologic density	Constant channel maintenance	Y = -6,661X + 5,5515	0,54
Elongation ratio	Area	Y=-0,0002X+0,6174	0,83
	Perimeter	Y=0,0008X+0,6449	0,82
	Massiveness coefficient	Y=1,8614X+0,5528	0,75
	Runoff length ratio	Y=0,1241X+0,9325	0,71
	Length of runoff	Y=-9002X+5617,7	0,71
	Number of runoffs	Y=-11059X+6874,8	0,68
	Length of main runoff	Y=-311,18X+203,6	0,62
	Orographic coefficient	Y=0,7671X-0,4187	0,59
Concentration time	Basin length	Y=-0,1353X+3,2827	0,91
	Perimeter	Y=0,611X+10,97	0,75
	Length of main runoff	Y=0,2105X+0,269	0,67
	Relief ratio	Y=-1,0265X+187,74	0,66
	Elongation ratio	Y=-0,0005X+0,6369	0,65
	Area	Y=1,9227X+-44,68	0,54
Basin length	Perimeter	Y=4,2952X-0,0094	0,75
	Length of main runoff	Y=1,535X-4,4739	0,71
	Elongation ratio	Y=-0,0038X+0,6482	0,68
	Area	Y=14,637X-98,592	0,63
	Number of runoffs	Y=45,956x-357,38	0,55
Relief ratio	Basin length	Y=0,4631X+7,0167	0,71
	Length of runoff	Y=7,7669X-17,404	0,59
	Number of runoffs	Y=25,253X-121,38	0,55
	Area	Y=20,08X-66,802	0,55

The differences observed between mean values and the increase in standard deviation suggest differences between morphological parameters of the tributary basins (Table 3), a response that is confirmed in the ANOVA (Table 4).

Table 3. Descriptive statistics of morphometric parameters of the 24 tributary watershed

Parameters	Media	Desv. Std	Error Std.	Median	25%	75%	Bias	Kurtosis
Area	151,768	117,009	23,884	141,416	68,942	180,834	1,626	2,615

Altitude	1507,135	263,97	53,883	1548,819	1394,482	1703,749	-0,888	0,22
Ind. Comp.	1,76	0,316	0,0644	1,687	1,578	1,831	1,072	1,041
N° esc.	428,667	393,837	80,392	330,000	170,000	519,000	2, 166	6,034
Long. Esc.	370,566	313,543	64,002	296,231	164,383	438,643	2,093	5,095
Long. Esc. Ppal.	21,781	11,525	2,353	19,908	11,053	29,571	0,543	-0,538
Long. Esc. Medio	0,949	0,244	0,0499	0,892	0,803	1,006	2,561	8,285
Den. Drenaje	2,365	0,483	0,0986	2,412	2,022	2,696	-0,0258	-0,238
Den. Hidrológica	2,659	0,844	0, 172	2,554	2,082	3,117	0,469	-0,356
Rel. Bif.	3,586	0,466	0,095	3,55	3,33	3,857	0,226	-0,348
Orden	4,542	0,833	0, 17	4,50	4,00	5,00	0,103	-0,371
Pend. Med.	22,036	11,84	2,417	20,992	12,19	33,244	0,426	-0,916
Rel. Elong.	0,789	0,196	0,0399	0,772	0,633	0,919	0,683	-0,43
Prop. Relieve	82,854	56,475	11,528	59,215	46,53	97,844	1,264	-0,0494
Coef. Mas.	0,0158	0,0141	0,00288	0,01	0,01	0,02	1,737	3,294
Coef. Orog.	0,0285	0,0294	0,00601	0,02	0,01	0,035	1,907	2,579
Num. Rug.	2876,003	1435,739	293,069	2265,553	1801,831	3846,271	0,575	-0,974
Long. Cca.	17,104	6,331	1,292	16,513	12,175	22,1	0,182	-0,893
Concentration time	102,172	44,664	9,117	97,289	71,081	141,703	0,152	-0,971

The differences between pairs were compared using Tukey multiple comparisons ($\alpha = 0.05$), observing differences between some parameters and similarities between others; consequently, it is established that in the first group there is no influence on the numerical increase, and in the second group there is a numerical influence between parameters (Table 5). For example, Díaz Delgado et al. (1999) and González (2004) identified the influence of the elongated shape of the basin and the basin surface on the runoff concentration time and on the intensity of the maximum flows towards the outlet of the basin.

Table 4. Application of ANOVA of morphometric parameters

Source of Variation	DF	SS	MS	F	P
Between Groups	18	222166426,4	12342579,24	97,564	<0,001
Residual	437	55283583,29	126507,056		
Total	455	277450009,7			

6 Conclusion

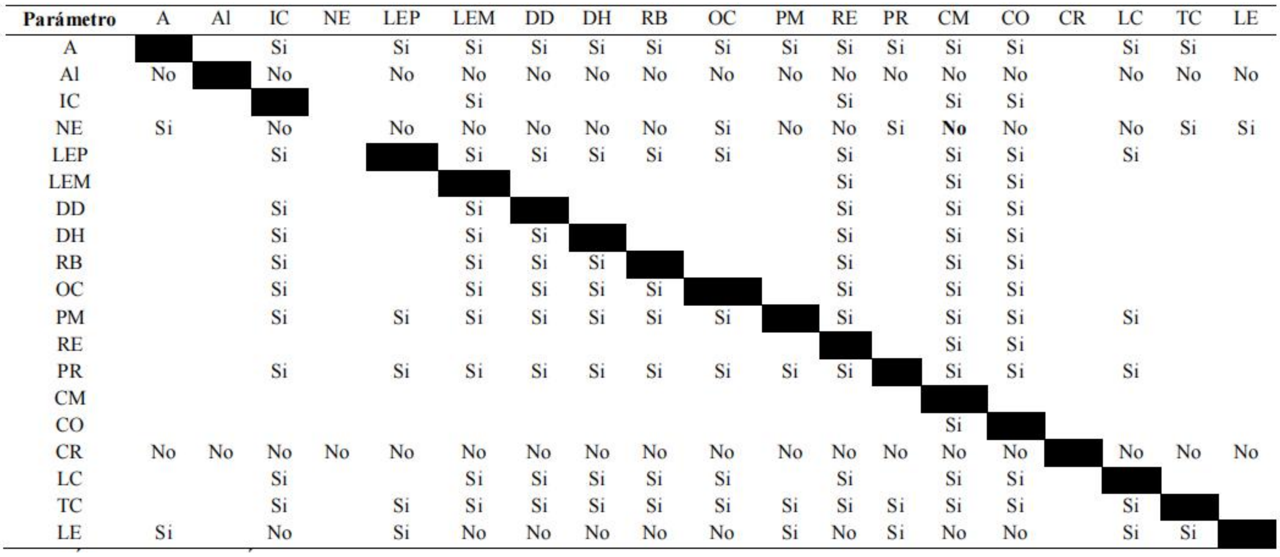
The morphometric analysis of the watershed as a natural unit of study makes it possible to establish evaluation criteria that facilitate the understanding of its functioning and have an impact on the planning, management and use of its resources, serving as a basis for the integrated analysis of watersheds.

The morphological conformation of the natural system is considered to be altered by a complex political-social apparatus that at the municipal level influences the modification of land use and vegetation cover, which has repercussions on the dynamics of the energy captured in the fluvial network. This response is conditioned by the physical-topographical characteristics of the basin, but specifically by its morphometric properties (catchment surface, shape, average slope, relief and the conformation of the hydrological network, mainly its direct channels) and the dimensions of tributary basins to the main runoff, thus conditioning the speed and volume of surface flows, in addition to the hydraulic dams located therein.

Considering the functional zones of the basin, it is considered that the high slopes that dominate the upper and middle zones are characterized in their longitudinal profile as being in a stage of equilibrium, with a tendency in the lower part towards a valley basin. These zones present important mountain ranges that register constant changes in land use (mainly agricultural) and vegetation, manifested in different altitudinal and slope gradients that favor the speed of surface flows, the increase of the erosive process and sediment deposition in the lower zone.

The drainage network is represented by its high degree of hierarchy and dendritic and subdendritic branching, which influences the hydrological response of the basin, but is conditioned by the permeable material that makes up the soil, the forested vegetation cover in the upper zone and the agricultural and livestock activity in the middle and lower basin, mainly.

Table 5. Multiple comparison between morphometric parameters through Tukey ($\alpha = 0.05$)



Parámetro	A	Al	IC	NE	LEP	LEM	DD	DH	RB	OC	PM	RE	PR	CM	CO	CR	LC	TC	LE
A	■		Si		Si	Si	Si	Si	Si	Si	Si	Si	Si	Si	Si		Si	Si	
Al	No	■	No		No	No	No	No	No	No	No	No	No	No	No		No	No	No
IC			■			Si						Si		Si	Si				
NE	Si		No		No	No	No	No	No	Si	No	No	Si	**No**	No		No	Si	Si
LEP			Si		■	Si	Si	Si	Si	Si		Si		Si	Si		Si		
LEM						■						Si		Si	Si				
DD			Si			Si	■					Si		Si	Si				
DH			Si			Si	Si	■				Si		Si	Si				
RB			Si			Si	Si	Si	■			Si		Si	Si				
OC			Si			Si	Si	Si	Si	■		Si		Si	Si				
PM			Si		Si	Si	Si	Si	Si	Si	■	Si		Si	Si		Si		
RE												■		Si	Si				
PR			Si		Si	Si	Si	Si	Si	Si	Si	Si	■	Si	Si		Si		
CM														■					
CO														Si	■				
CR	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	■	No	No	No
LC			Si			Si	Si	Si	Si	Si		Si		Si	Si		■		
TC			Si		Si	Si	Si	Si	Si	Si	Si	Si	Si	Si	Si		Si	■	
LE	Si		No		Si	No	No	No	No	No	Si	No	Si	No	No		Si	Si	■

A=Area, A=Altitude, IC=Compactness Index, NE=Number of runoffs, LEP=Length of Main Runoff, LEM=Length of Mean Runoff, DD=Drainage Density, DH=Hydrologic Density, RB=Bifurcation Ratio, OC=Order of Streams, PM=Mean Slope, RE=Elongation Ratioo, PR=Relief Proportion, CM=Massiveness Coefficient, CO=Orographic Coefficient, CR=Roughness Coefficient, LC=Length of Catchment, TC=Time of Concentration, LE=Length of Runoff.

Conflicts of interest

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

References

[1] Becerra, M.A. (1999): Escorrentía, erosión y Conservación de suelos. Universidad Autónoma Chapingo. México,. 361 p.

[2] Benavides, M.V., Tarlé, P.T.C. y Galbiatti, J.A. (2009): Caracterizacióny clasificación de la red hidrológica de la cuenca del río Bobo, departamento de Nariño - Colombia, Ingeniería e Investigación, Vol. 29 No. 3, Diciembre, pp. 97-101.

[3] Campos, A.D.F. (1987): Procesos del ciclo hidrológico. Cap ítulo 2 Geomorfología de la Cuenca. Volumen 1 1ra. Reimpresión. Tomo ½. Universidad Autónoma de San Luis Potosí, 29p

[4] CIGA - UNAM. (2012): Análisis de cambio de cobertura yuso del suelo, escenario de referencia de carbono y diseño preliminar del mecanismo de Monitoreo, Reporte y Verificación en los diez municipios de la Junta Intermunicipal del Río Ayuquila, Jalisco. Informe final. Centro de Investigación Geográfica Ambiental (CIGA), Universidad Nacional

Autónoma de México (UNAM), Universidad de Guadalajara (UdeG), pp.13-14. [Consulta: 10-12-2017]. Disponible en: https://es.scribd.com/document/211806847/InformeFinal-JIRA-May10- 12#from_embed

[5] CNA. (2009): Cuencas hidrográficas. El concepto de cuenca hidrográfica, Sistema de consulta de cuencas de cuencas hidrográficas en México 2009. [Consulta: 09-05-2010]. Disponible en: http://www.agua.org.mx/index.php?option =com_content&view=category&id=46&Itemid=75.

[6] CNA-SARH. (1992): Presa Trigomil, General Ramón Corona Madrigal. Grupo Editorial Códice S.A. de C.V. Talleres de Edita S.A. de C.V. 27p.

[7] Cortés, H., Medina, R., Gómez, A., Wruck, D., Viramontes, D., Palma, G., Aguayo, A., Rivera, M., Olvera, M.D., & Yáñez, M., (2002): Formulación de los Programas Regionales Hidrológico-Forestales de la Regiones IV Balsas y VIII Lerma- Santiago-Pacifico, Anuario del Instituto Mexicano de Tecnología del Agua, IMTA. 7p.

[8] Cotler, H. (2004): Manejo Integral de cuencas en México: estudios y reflexiones para orientar la política ambiental, Secretaría del Medio Ambiente y Recursos Naturales, Instituto Nacional de Ecología, Primera Edición. 267p.

[9] Díaz-Delgado, C., Mamadou-Bâ, K., Iturbe-Posadas, A., Esther, M. V., Reyna-Sáenz, F. (1999): Estimación de las características fisiográficas de una cuenca con la ayuda de SIG y MDET: caso del curso Alto del río Lerma, Estado de México. Ciencias Eergo Sum, (6), (2), pp. 123-134.

[10] Doffo, N. y González, B.G. (2005): Caracterización morfométrica de la cuenca alta del arroyo las Lajas, Córdova: un análisis estadístico. Revista de la Asociación Geológica Argentina, 60 (1), pp. 16-22.

[11] Faminow, M.D. (1998): Cattle, deforestation and development in the Amazon: An economic, agronomic and enviromental perspectiva. CAB International Wallingtord, U.K.

[12] García, C.I., Martínez, O.A., Vidriales, C.H.G. (2003): Balance Hídrico de la Cuenca del Río Pixquiac, Delimitación de Zonas Prioritarias y Evaluación de los Mecanismos Existentes para el Pago de Servicios Ambientales Hidr ológicos en la cuenca del Río Pixquiac Veracruz, México, Documento técnico, Proyecto NCMA3-08-03. [Consulta:06-12-2017]. Disponib en: https://www.researchgate.net/publication/333292361_Balance_hidrico_preliminar_de_la_microcuenca _del_Rio_Pixquiac

[13] Garrido, A., Pérez, D.J.L., Enríquez, G.C. (2010): Delimitación de zonas funcionales de las cuencas hidrográficas de México. En Las cuencas hidrográficas de México, diagnóstico y priorización. Cotler A.H. (Coord.). Primera Edición. Pluralia Ediciones e Impresiones S.A. de C.V. Méx. D.F., pp. 14-17.

[14] Gleason, E.J.A. (2014): Sistemas de agua sustentables en las ciudades. Editorial Trillas S.A. de C.V. México, D.F. 1^a . Edición. Impreso en México, pp. 47-53.

[15] Gómez-Pompa, A. y Burley, F.W. (1991): "The management of natural tropical forest", en: Gómez-Pompa, A, T. C. Withmore y M. Hadley (eds.), Rain forest regeneration and management, UNESCO-The Phathernon Publishing Group, pp. 3-18.

[16] González, de M.A.I. (2004): Análisis morfométrico de la cuenca y la red de drenaje del río Zadorra y sus fuentes aplicado a la peligrosidad de crecidas. Boletín de la A.G.E. No. 38, pp. 311-320.

[17] Guerra, P.F. (1980): Fotogeología. Configuraciones Naturales de Drenaje. 1ra Edición. Universidad Autónoma de México, pp. 206-255.

[18] INEGI. (2005): Base de datos Iter. 2005 II Conteo de Población y Vivienda, INEGI 2005, México. Disponible para World Wide Web:

[19] INE-SEMARNAT- PLADEYRA. (2003): Paisajes hidrológicos y balance hídrico de la cuenca Lerma Chapala, México.

[20] Instituto Nacional de Ecología -INE- (2004): Análisis morfométrico de cuencas: caso de estudio del Parque Nacional Pico de Tancítaro. Dirección General de Investigación de Ordenamiento Ecológico y Conservación de Ecosistemas. Estudio Contratado a: Fuentes J.J.J. 47p.

[21] IPICYT. (2002): Reportes del Instituto Potosino de Investigación Científicay Tecnológica, A.C. Primer Foro Ambiental y Manejo de Recursos Naturales Renovables. Manejo y Conservación de la Cuenca del Río Ayuquila. Volumen 1, Numero 1. Noviembre 2002,pp. 118-125.

[22] Jardel, P.E.J. (Coord.). (1992): Estratega para la conservación de la Reserva de la Biosfera Sierra de Manantlán. Editorial Universidad de Guadalajara, Guadalajara, Jal. 315p.

[23] Lal, R. (2000): Integrated watershed management in the global ecosystem. Edited by Rattan Lal. Soil and Water Conservation Society. New York: CRC Press.

[24] Linsley, R.K.Jr., Kohler, M.A., y Paulhus, J.L.H. (1984): Hidrología para ingenieros. Segunda edición. Edit. McGraw-Hill, S.A. de C.V. Impreso en México, pp. 211-357.

[25] Martínez, C.A., y Castillo, R.F. (1996): Estacionalidad pluviométrica en Galicia: Comportamiento, representatividad espacial y mecanismos asociados. GEOGRAPHICALIA, 33, pp. 127-145.

[26] Martínez, G.A.(1988): Diseños experimentales. Métodos y elementos de teoría. Editorial Trillas. S. A. de C. V. Primera edición, pp. 128–138.

[27] Pozo, J. y Elosegi, A. (2009): El marco físico: La cuenca. Capítulo 3. Conceptos y técnicas en ecología fluvial. Primera edición. Fundación BBVA.[Consulta:03-09-2017]. Disponible en https://w3.grupobbva.com/TLFU/dat/cap_03.pdf.

[28] Quiñónez,E. y Dal Pozzo, F. (2005): Influencia del cálculo del factor topográfico e la distribución espacial del riesgo de degradación de los suelos por erosión hídrica en el Estado de Mérida, Venezuela, GeoFocus (Artículos), N°5, ISSN 1578-5157, pp. 204-218.

[29] Racca, J.M.G. (2007): Análisis hipsométrico, frecuencia altimétricay pendientes medias apartir de modelos digitales del terreno. Boletín del Instituto de Fisiografía y Geología 77(1-2): 31-38. Rosario. ISSN 1666-115X. 8 p.

[30] Ruiz, C.J.A., Pimienta, B.E., Zañudo, H.J. (2002): Regionestérmicas óptimas y marginales para el cultivo de Agave tequilana en el estado de Jalisco. Agrociencia, vol. 36, núm. 1. Texcoco, México, pp. 41-53.

[31] Sánchez, K.G.Y. (2008): Patrón de drenaje, Universidad Nacional Federico Villareal, Facultad de Ingeniería Geográfica, 2008, 26 págs., [Consulta: 20-05-2010]. Disponible en: http://www.scribd.com/doc/5581866/PATRONES-DE-DRENAJE

[32] Sánchez, T. (1991): "Estudio morfoclimático del Cabeçó d´Or." Universidad de Alicante. España. 69 p.

[33] Sánchez, V.A. (1987): Conceptos Elementales de Hidrología Forestal Agua, Suelo y Vegetación. La cuenca hidrográfica. Editorial División de Ciencias Forestales. Primera Edición. Volumen 1. Universidad Autónoma de Chapingo, pp. 57-97.

[34] Santos, R.F. (2004): Planejamento Ambiental, São Paulo., Oficina de Textos, pp.71-135.

[35] Slesak, R.A., Schoenholtz, S.H., Evans, D. (2015): Hillslope erosion two and three years wildfire, skyline salvage logging, and preparation in southern Oregon, USA. Forest Ecology and Management. 342 (2015) 1-7.[Consulta: 10-04-2018]. Disponible en: www.elsevier.com/locate/foreco.

[36] Strahler, A.N. (1986): *Geografíafísica*. Ediciones Omega, S.A. Barcelona, España. 765p.

[37] Vidal-Abarca, M.R., Montes, C., Suárez, M.L. y Ramírez-Díaz, L. (1987): Caracterización morfométrica de la cuenca del río Segura: Estudio cuan titativo de las formas de las subcuencas. *Papeles de Geografía (Física)* N°. 12,pp. 19-31.

[38] Walker, J., Dowling, T.,y Veitch, S. (2006): An assessment of catchment condition in Australia, Ecological Indicator, Volume 6, Issue 1, January 2006,pp. 205-214.

[39] Welcomme, R.L. (1980): Cuencas fluviales. FAO, Doc, 1980 Téc. Pesca, (202): 62p. [Consulta: 10-11-2017]. Disponible en:http://www.fao.org/docrep/003/X6853S/X6853S00.htm.