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Morphometric characterization of the Hueyapa River microwatershed, in Guerrero, Mexico

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Abstract

The watershed is the most suitable territorial unit for the economic and social management of the ecosystem goods and services that it provides and its diagnosis must begin with its morphometric description. Cartographic and hydrological material from the National Institute of Statistics and Geography, (INEGI, for its name in Spanish), were used for its morphometric characterization. The analysis and results were obtained through Geographic Information Systems (GIS) and with ArcGis 10.3 software. It has an area of 74.88 km2 and an average slope of 31.69%. It presents a 5th order dendritic drainage pattern and main stream length of 21.84 km. It is classified as slightly flattened, from oval oblong to rectangular oblong shape, very mountainous and strongly hilly. The results will be used as the foundations for elaborating a program on territorial ordering, water balance and runoff and erosion risks in the micro watershed.

Keywords: morphometry, morphometric parameters, concentration time, hypsometric curve.

INTRODUCTION

A watershed is the most appropriate territorial unit for the economic and social management of water, forest, fauna and soil resources, among others [1, 2, 3]. Anthropogenic pressure on these territories has caused the degradation of their natural resources and it has increased the risks of natural disasters [4, 5].

The hydrographic territory of Mexico is organized into 37 Hydrological Regions (HR), subdivided into 1,471 watersheds. Three HRs, Balsas (18), Costa Grande de Guerrero (19) and Costa Chica de Guerrero (20) and 19 watersheds [6] are located in the state of Guerrero. The Balsas River and the Papagayo River Watersheds are of greater extension.

The degree of functionality in 66.0% of the watersheds along the Mexican territory is highly deteriorated; the Balsas River and the La Sabana River Watersheds are among these [2, 7], including the Papagayo River Watershed and its streams in the State of Guerrero.

The analysis of geographical areas carried out through Digital Elevation Model (DEM) and geographical and hydrological data, and these, manipulated by Geographic Information Systems (GIS), is currently the main alternative for determining the morphometric parameters of a watershed, as well as its hydrological functioning [8,9,10].

The morphometric properties of a watershed describe it physically and spatially and offer preliminary conclusions about the territory's environmental characteristics [11]. Morphometry is a quantitative method for the description and analysis of the watershed's size, shape and gradient (described in linear, area and aspects of relief) which are correlated with the possibility of water harvest, surface runoff and erosive incidence of the drainage network that integrates it [12,13].

The slope and drainage network of the watershed determine the risk of erosion, flooding by runoff and concentration at a particular point of interest [14], which must be assessed in the planning and integral management of the territory [15, 16].

Although, the Hueyapa River Microwatershed is currently integrated into the hydrological environmental services payment program (PSAH, for its name in Spanish) financed by the National Forestry Commission (CONAFOR, for its name in Spanish), there is no information on its morphometric parameters. Therefore, the aim of this research was to conduct its morphometric description in order to fulfill this lack of information.

MATERIALS AND METHODS

Study area

The study area is located between the North latitude geographic coordinates of 17° 10' 33" and 17° 17' 44" and West longitude of 99° 26' 28" and 99° 31' 12" (Figure 1). It is circumscribed within the Omitlán River Sub-watershed, of the Papagayo River Watershed, belonging to the 20 Hydrological Region in the Costa Chica de Guerrero, Mexico [17]. This micro-watershed shares territory with the municipalities of Juan R.

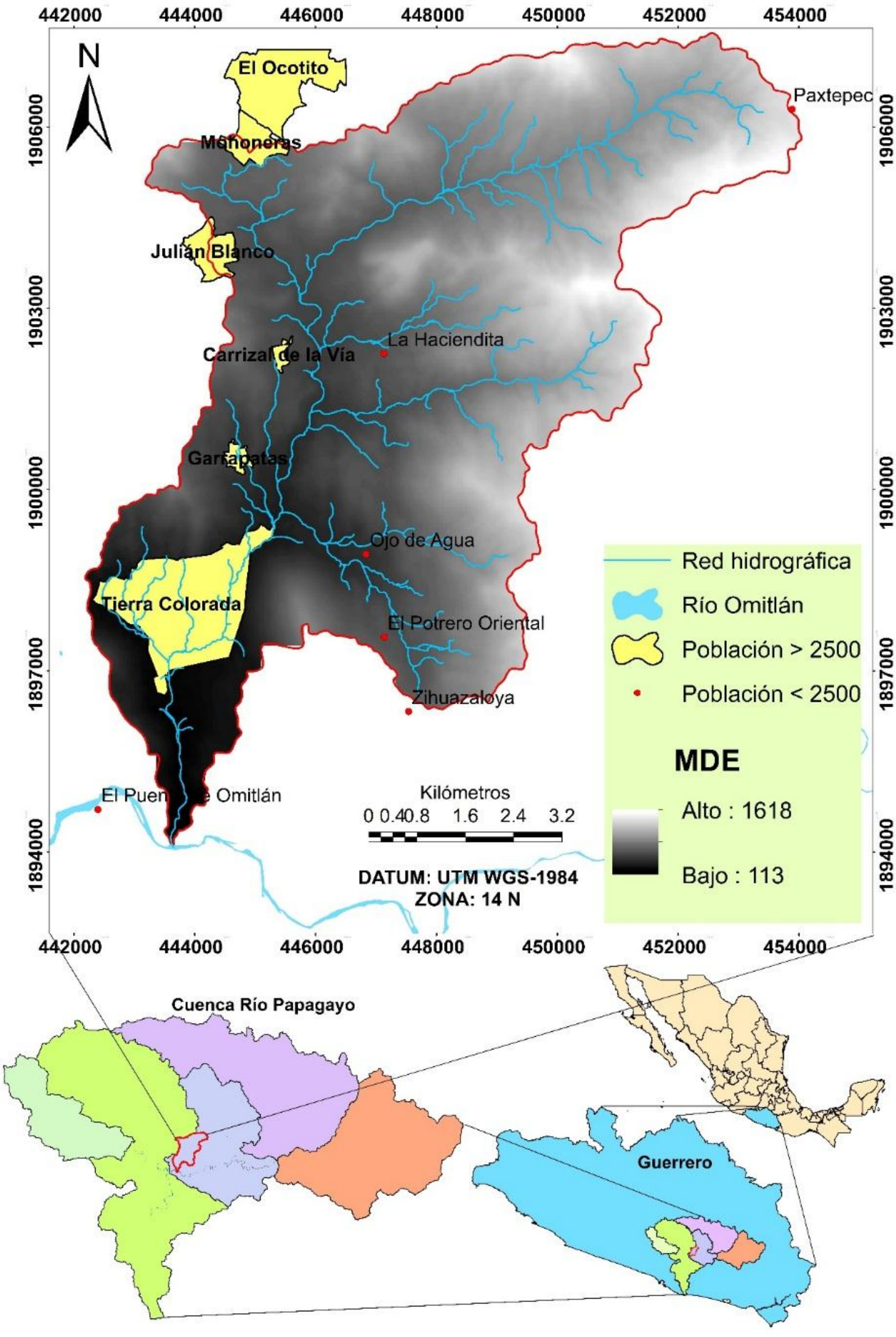

Figure 1. Study area

Escudero and Chilpancingo de Los Bravo in the State of Guerrero, with a total population of 17 463 inhabitants from eleven communities, out of which outstand Tierra Colorada, with 11 540 inhabitants, followed by Julián Blanco and Mohoneras with 1 955 and 1 777 inhabitants, respectively [18].

The main land uses are agricultural, forestry and urban. The forest area is covered by vegetation of medium subcaducifolia and low deciduous forest, *Quercus* and Pinus-Quercus forests; sub-humid warm climate with rains in summer, annual temperature average of 24° C and the precipitation fluctuates between 1,300 to 2,000 mm per year, with summer rainfall.

METHODOLOGY

The delimitation of the micro watershed was carried out through Geographic Information Systems (GIS) incorporating cartographic and topographic information from the National Institute of Statistics and Geography (INEGI, for its name in Spanish) [19]. The digital elevation model (DEM) was generated by using E14C38 and E14C48 toposheet level curves, both at scale 1: 50 000, managed with the 3D Analyst tool of ArcGis10.3 software. The slope map was generated from the DEM and its classification was made based on the Hernández proposal [20].

The hydrological network and the water streams order were extracted from vectorial data of the Hydrological Network of the watershed RH20E (Papagayo River) and sub-watershed RH20Eb (Omitlán River), edition 2.0, scale 1: 50000 (INEGI, 2010), manipulated with the Hydrology tool of the Spatial Analyst Tools module of the ArcGis10.3 software (ArcGIS Pro version 1.3 application). The streams' order was classified by using the Strahler technique [21].

The calculation and analysis of the micro watershed's morphometric parameters and indices were based on the methodology of several authors [8, 9, 13, 15, 16, 22, 23], whose formulas and results are presented in Table 2.

RESULTS AND DISCUSSION

Area and slope

The Hueyapa River Micro Watershed covers an area of 74.885 km², a perimeter of 52.96 km; with a maximum length and width of 16.22 km and 7.89 km, respectively. Due to its dimensions, it is considered as a small micro watershed [24].

Its altitude varies from 113 to 1618 meters above sea level, with an average slope of 31.69%. Out of its 7 488.55 ha, only 23% corresponds to flat to moderately undulating terrain (of urban and agricultural use), while 77% are undulating to sharply steep terrains (forest and grazing land use) (Figures 2 and 3).

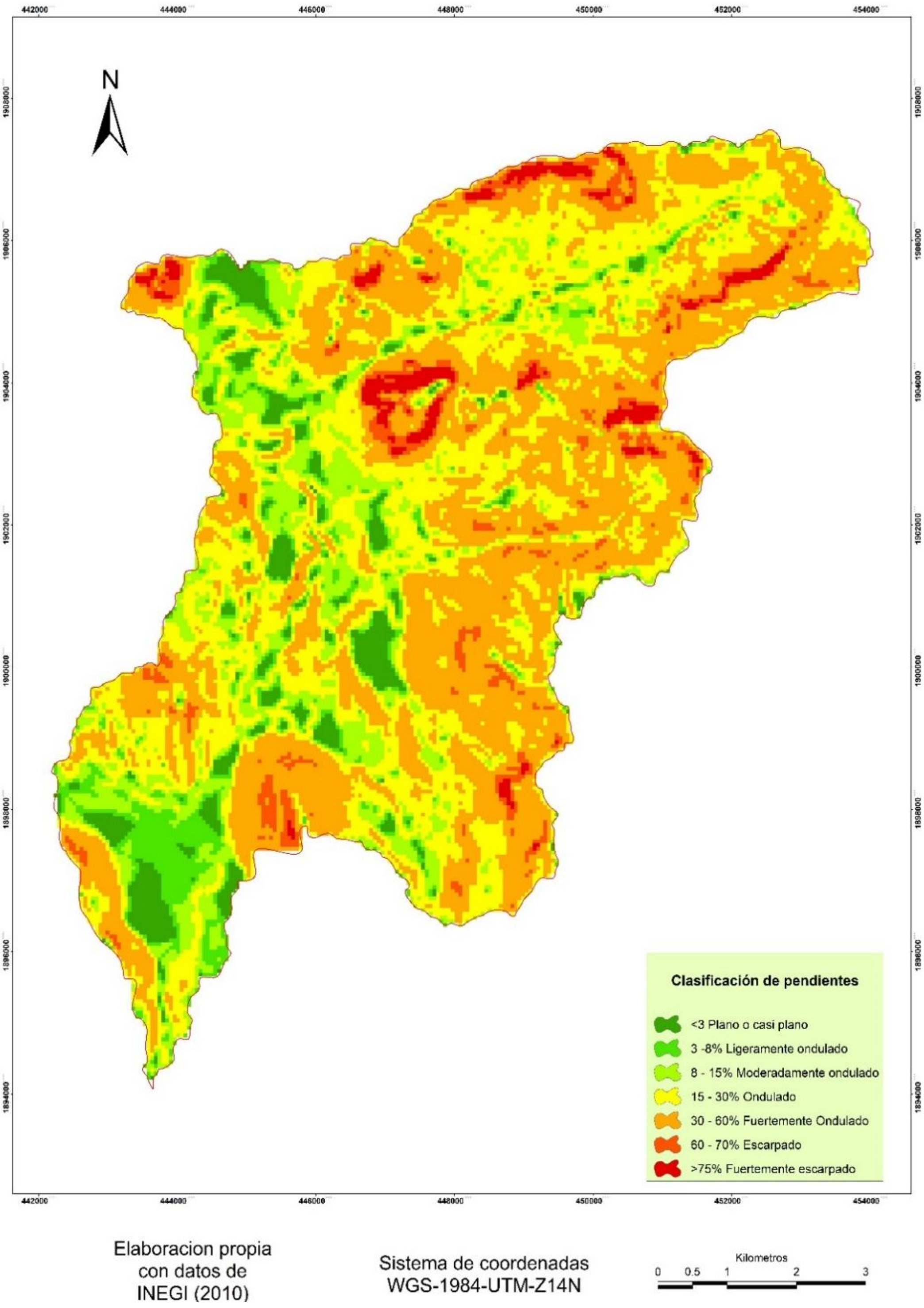

Figure 2. Map of the Hueyapa River Micro Watershed slopes

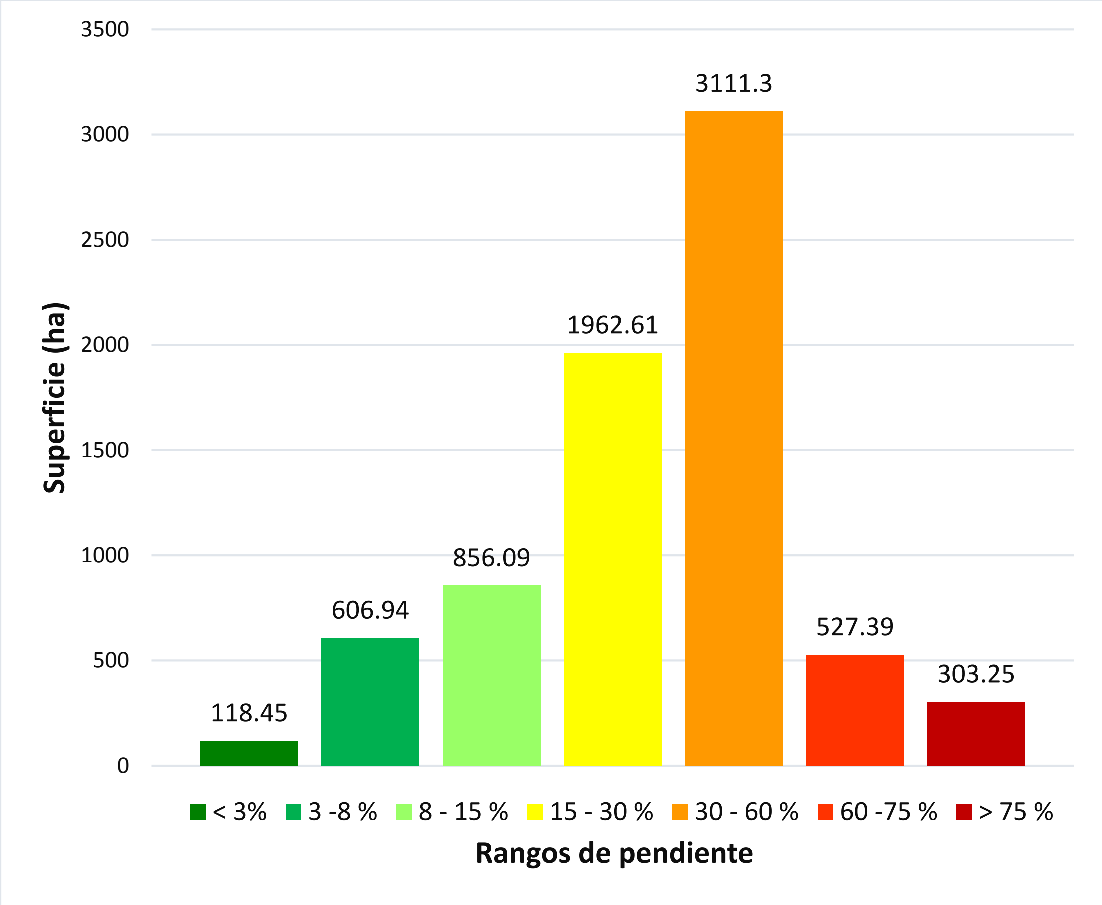

Figure 3. Surface distribution based on the slope ranges

Drainage parameters

The main stream of the micro watershed covers a length of 21.84 km and its direct length of 14.97 km, which flows into the Omitlán Sub-watershed (RH20b), has an initial limit of 113 and a final level of 1,301 masl, with a slope average of 5.44%; while the slope of the general drainage network is higher than this (12.81%). The main stream´s coefficient of hydraulic sinuosity (1.46) is characteristic of a transitional runoff [25].

The water streams have a dendritic drainage pattern of 5th order (Figure 4). This number of order or greater than 5, is related altogether, with the presence of structural controls of the relief and greater possibility of erosion [15], as it was observed in the landslides in the steepest slope and shallow soils area of the micro watershed, throughout Tropical Storm Manuel, in the year 2013.

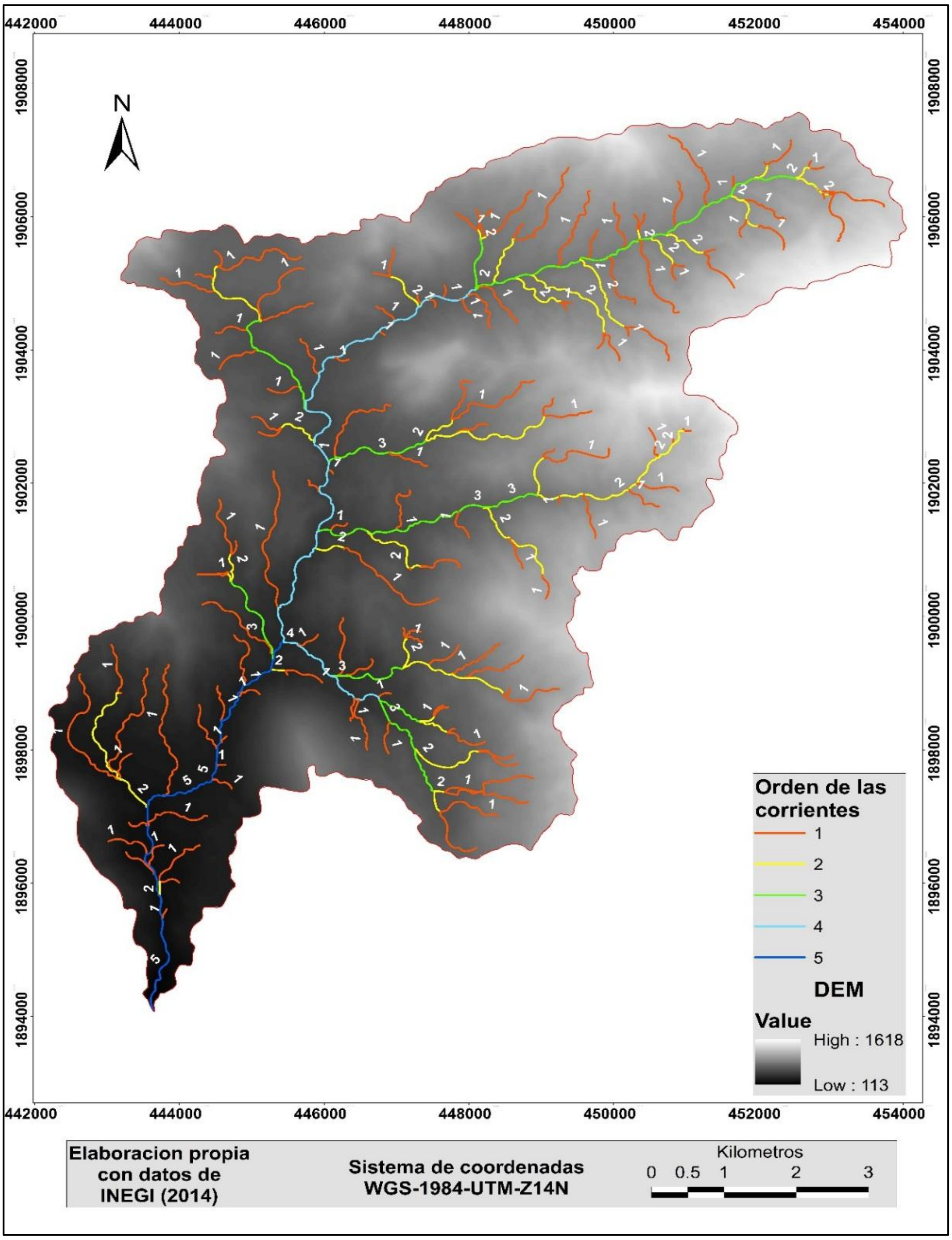

Figure 4. Order of the drainage network of the Hueyapa River Micro Watershed

There were 165 first-order and 72 second-order streams, mostly distributed at an altitude higher than 640 meters above sea level. At lower altitudes, higher order streams were distributed, with a decreasing number and length of streams [10]. The high weighted mean bifurcation ratio (3.06) (Table 1), indicates a homogeneous geological configuration and that the drainage pattern has not been affected by structural alterations [26], besides the water extends in all the orders of the streams, allowing greater harvest opportunity [16].

Table 1. Number of streams and their bifurcation in the Hueyapa River Micro Watershed

No. of order	Nu	Ls	Als	br	Nsi	(br*Nsi)	
1	165	90.96	0.55				**Weighted mean bifurcation ratio**
2	72	30.41	0.42	2.29	237	542.73	
3	32	13.29	0.42	2.25	104	234.00	
4	3	1.02	0.34	10.67	35	373.45	
5	1	21.84	21.84	3.00	4	12.00	
Total	**273**	**157.52**			**380**	**1 162.18**	**3.06**

Nu: number of streams of order *u,* Ls: total length of streams of order *u* (km), Als: average length of streams of order *u* (km), br: bifurcation ratio, Nsi: number of order *u* streams involved in the ratio.

The total number of streams (ephemeral, intermittent and perennial) was 273 with a cumulative total length of 157.51 km. The frequency of streams was 3.65 runoff km^{-2} and a drainage density of 2.10 km km^{-2} that shows good drainage [12], which is typical of regions with permeable subsurface material; although the relief of this micro watershed is rugged, it has a good vegetation cover, which favors a greater capacity to infiltrate groundwater [27].

The length of overland flow low (*lo*=0.24), the moderate drainage texture (*Td*=5.15), the high roughness number (*Nr*=3.17) and the high infiltration number (*If*=7.67) are indicators of a high relief, a moderate infiltration capacity, coupled with a good drainage density, indicate low possibility of runoff and a high possibility of groundwater recharge [16].

Hypsometric curve and hypsometric integral

At the same time, the hypsometric curve reveals that 50% of the lowest surface area of the micro watershed is located at less than 850 masl, with a low steep slope. Twenty percent is located at an altitude higher than 1200 masl and 10% above 1300 masl, observing very steep slopes at the head of the micro watershed (Figure 5a).

In relation to the dimensionless hypsometric curve (Figure 5b) that expresses the evolutionary potential of the watershed, Gaspari [11] defines it as a watershed in the phase of equilibrium or maturity, concordant with the hypsometric ratio of 1.24.

Likewise, the value of the hypsometric integral (*IH*=0.54) reveals that the Hueyapa River Micro Watershed is in transit between a young watershed and a watershed in equilibrium, where the erosive process is stabilizing [9].

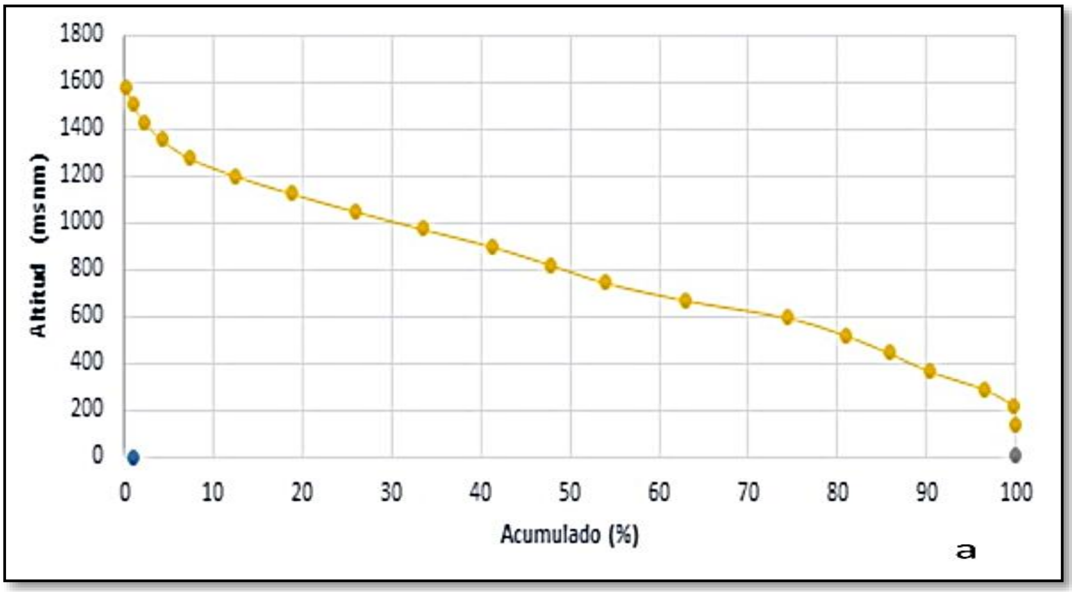

Figure 5. Hypsometric curve (a) and dimensionless hypsometric curve (b) of the Hueyapa River Micro Watershed

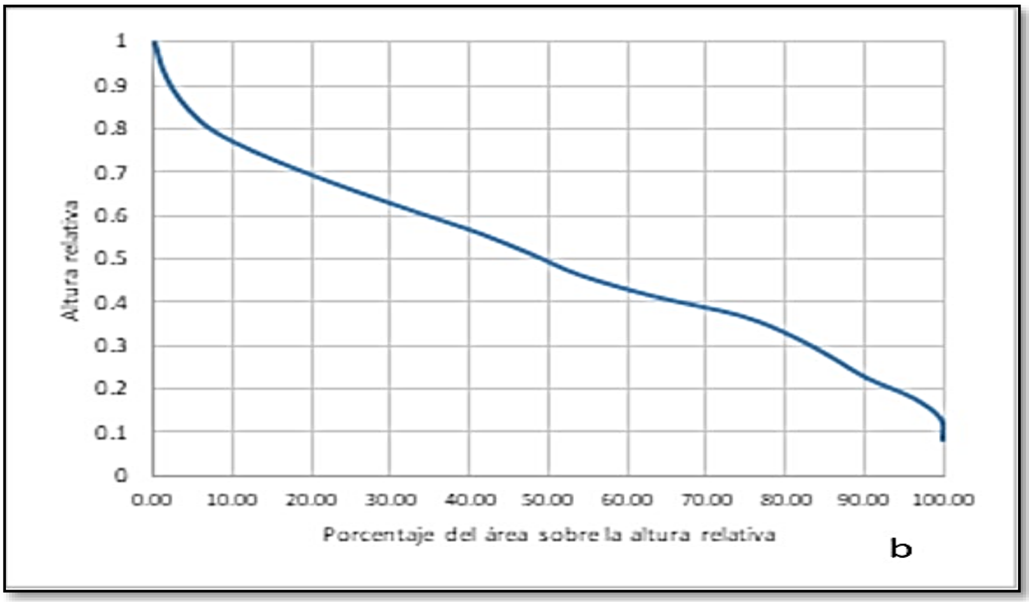

Figure 5. Hypsometric curve (a) and dimensionless hypsometric curve (b) of the Hueyapa River Micro Watershed

Longitudinal and transversal profile

The longitudinal profile of the main stream is 21.84 km, starting from its mouth in the Omitlán River, where the lower and middle part of the course of the stream presents a low erosive power; however, at kilometer 15 the slope increases, accentuating in the last two kilometers, so that in this section of the river it is more prone to increase its erosive power [11], but it is attenuated by the presence of abundant rocks and a slope covered with shrubby and riparian arboreal vegetation.

In the transversal profile of the widest part of the micro watershed (7.89 km), the main stream crosses approximately half of the micro watershed. To the extreme West, there are plains destined to agricultural activities and to the East, there are small areas of agricultural use, most of them are areas of forest use, and the micro watershed shows an altitudinal difference of approximately 500 meters.

Morphometric indices

The morphometric parameters, calculated and obtained directly from the GIS, are summarized in Table 2.

Table 2. Calculating formulas and morphometric parameters results of the Hueyapa River Micro Watershed.

Morphometric parameter	Formula	Calculated value	Bibliographic references
Stream frequency	$Fc = \frac{Tns}{A}$	3.65	[28]
Drainage density	$Dd = \frac{Tls}{A}$	2.10	[28]
Length of overland flow	$lo = \frac{1}{2Dd}$	0.24	[28]
Drainage texture	$Td = \frac{Tns}{P}$	5.15	[28]
Infiltration number	$If = Dd * Fc$	7.67	[30]
Slope of the main stream	$Pcp = \left(\frac{\Delta l}{Lms}\right) * 100$	5.44	[31]
Form Factor	$Ff = \frac{A}{L^2}$	0.28	[28]
Compactness coefficient	$Kc = 0.2821 * \left(\frac{P}{\sqrt{A}}\right)$	1.73	[28]
Circulatory ratio	$Fc = 4 * \pi * \frac{A}{P^2}$	0.34	[32]
Elongation ratio	$Re = \left(\frac{2}{L}\right) * \sqrt{\frac{A}{\pi}}$	0.60	[31]
Elongation index	$Ia = \frac{L}{a}$	2.06	[22]
Massivity coefficient	$Km = \frac{Hm}{A}$	12.39	[22]
Relief (km)	$R = Hmax - h$	1.51	[33]

Morphometric parameter	**Formula**	**Calculated value**	**Bibliographic references**
Relief ratio	$Rr = \frac{R}{L}$	0.09	[31]
Ruggedness number	$Nr = R * Dd$	3.17	[29]
Hypsometric Integral	$IH = \left(\frac{Hm - h}{Hmax - h}\right)$	0.54	[34]

Where:

A: area of the micro watershed

P: perimeter of the micro watershed

L: Length of the micro watershed

a: width of the micro watershed

Hm: average elevation

$Hmax$: maximum elevation

h: minimum elevation

Nts: total number of streams

Lts: total length of streams

Nu: number of streams of order u

Nu+1: total number of streams of the next order or higher

Δl: unevenness between the highest and lowest point of the main stream

Lms: length of the main stream

Form factor

The Hueyapa River Micro Watershed (*Ff*= 0.28) is slightly flattened. This means a moderately delayed reaction between the time of precipitation and the main flood at the mouth [13], concordant with the Kirpich concentration time of 2.17 hours, classified as slow [22]. This allows successful managing of a possible eviction in populated areas with flood risk [23].

Compactness coefficient

The compactness coefficient was 1.69, so it does not represent a latent danger for its inhabitants, since an index higher than unity, allows concentrating moderate volumes of runoff water on its surface [35]. In addition, the low value in this index is related to greater elongation and less soil loss due to erosion [23].

On the contrary, Esquivel-Arriaga *et al.* [35] assert that a steeply hilly slope and a very mountainous massivity coefficient would have a direct influence on the runoff and infiltration processes and their duration. Therefore, when comparing the Hueyapa River Micro Watershed with the Cuale River Watershed, located in the State of Jalisco, and which has similar morphometric indices, Cruz *et al.* [15] assert that, before an unusual meteorological phenomenon, there would be a rapid contribution of surface runoff that would induce a strong impact in the lower part of the micro watershed.

Circularity factor, elongation ratio and elongation index

The circularity factor is associated with geological factors, slope and vegetation cover.

The *Fc* (0.34) indicates scarce circularity of the micro watershed and it is associated with a watershed with high relief (*R*=1.51 km), low infiltration rate [13], steep slope (31.69%) and a very mountainous mass coefficient (*Km*=12.39). However, the infiltration rate can be improved by the good tree cover in the upper part of the micro watershed. Both *Re* (0.60) and *Ia* (2.06) classify the Hueyapa River Micro Watershed as elongated to moderately elongated [23].

Relief ratio

The *Rr* practical application is related to the sediment loss estimation. As this index decreases, the infiltration capacity increases and the sediment loss decreases due to erosion. With an *Rr* of 0.09 the soil loss would be approximately 3.5% [31]. The high value of *Rr* is associated with the steep and mountainous slope of the micro watershed [8, 36].

However, the altitudinal difference (*R*=1.51 km) of the micro watershed allows observing varied forest ecosystems. At altitudes less than 650 meters above sea level, there is low deciduous forest and medium subcaducifolia vegetation; at 650 meters above sea level and above (70%), the transition forest begins between the medium forest and the oak forest. From 800 meters above sea level, the pine-oak forest extends, which represents 48% of the surface of the micro watershed and it is dominated by P. *oocarpa* Schiede and six *Quercus* species.

CONCLUSIONS

The Hueyapa River Micro Watershed is small, very mountainous and strongly hilly, moderately long and with a concentration time of slow eviction; it shows an evolutionary stage in equilibrium, with dendritic water network of 5 order.

The results will serve as the foundations to elaborate a territorial ecological ordering plan and the study of the hydric balance that would come to potentialize water resources planning schemes through the prioritization of water recharge sites in order to obtain a permanent water harvest for its function as a micro watershed inserted in the PSAH of the CONAFOR, as well as to prevent risks of flooding by possible adverse meteorological phenomena in the population of Tierra Colorada, Guerrero, Mexico, settled in the lower part of the main river bank.

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