2021, Instituto Mexicano de Tecnología del Agua

DOI: 10.24850/j-tyca-2021-02-12

Notes

Morphometric characterization of two high Andean basins of Peru using Geographic Information Systems

Caracterización morfométrica de dos cuencas altoandinas del Perú utilizando sistemas de información geográfica

Sandra del Águila[1], ORCID: https://orcid.org/0000-0001-8051-3575

Abel Mejía[2], ORCID: https://orcid.org/0000-0002-9070-3898

[1]Universidad Nacional San Cristóbal de Huamanga, Ayacucho, Perú; Universidad Nacional Agraria La Molina (UNALM), Programa de Doctorado en Recursos Hídricos, Lima, Perú, sandra.delaguila@unsch.edu.pe

[2]Universidad Nacional Agraria La Molina (UNALM), Programa de Doctorado en Recursos Hídricos, Lima, Perú, jabel@lamolina.edu.pe

Corresponding author: Sandra del Aguila, sandra.delaguila@unsch.edu.pe

Abstract

The morphometric characterization of watersheds is important because it allows to describe geomorphological processes and infer hydrological behaviors: maximum flows, soil erosion and groundwater recharge. In developing countries, studies on watershed morphometry are scarce; nevertheless, its application is substantial, especially in non-instrumented regions. A morphometric analysis was carried out evaluating the drainage characteristics of two high Andean river basins in the Junín region, Peru: The Anya river basin on the eastern side of the mountain range and the Mchique River on the western flank of the central Andes. The basins were delimited and the morphometric parameters of relief, shape and drainage were calculated, using Geographic Information Systems (GIS). Both basins are of order 3 with differentiated drainage patterns, with the Anya dendritic basin and Mchique sub dendritic with influence of structural elements given their particular elongated shape. The low values of drainage density (D_d) fix the basins as having high infiltration rates, however, they respond to their headland locations. The values of elongation (E) imply an elongated shape for Anya and more for Mchique, which indicates a lower vulnerability to flash floods and, consequently, a simpler flood management. The high topographical factor (F_t) of the basins is an indicator of steep slopes and, consequently, of greater intensity of erosive processes. The results can be the basis for hydrological and hydraulic studies, watershed management and water resources management in the area.

Keywords: Watersheds, hydrology, GIS, DEM.

Resumen

La caracterización morfométrica de cuencas hidrográficas es importante, porque permite describir procesos geomorfológicos e inferir comportamientos hidrológicos: caudales máximos, erosión del suelo y recarga de agua subterránea. En los países en desarrollo, los estudios sobre morfometría de cuencas son escasos; no obstante, su aplicación es sustancial, sobre todo en regiones no instrumentadas. Se realizó un análisis morfométrico evaluando las características de drenaje de dos cuencas de ríos altoandinos, en la región Junín, Perú: la cuenca del río Anya, en el lado oriental de la cordillera, y la del río Mchique, en el flanco occidental de los Andes centrales. Se delimitaron las cuencas y se calcularon los parámetros morfométricos de relieve, forma y drenaje, utilizando sistemas de información geográfica (SIG). Ambas cuencas son de orden 3 con patrones de drenaje diferenciados, siendo la cuenca Anya dendrítica y Mchique subdendrítica, con influencia de elementos estructurales, dada su forma alargada particular. Los valores bajos de densidad de drenaje (D_d) fijan a las cuencas como de altas tasas de infiltración, sin embargo, éstos responden a sus ubicaciones en cabeceras. Los valores de elongación (E) implican una forma alargada para Anya y más para Mchique, lo cual indica una menor vulnerabilidad a inundaciones repentinas y, consecuentemente, una gestión de avenidas más sencilla. El alto factor topográfico (F_t) de las cuencas es indicador de pendientes pronunciadas y, por consiguiente, de mayor intensidad de procesos erosivos. Los resultados pueden ser base de estudios hidrológicos e hidráulicos, manejo de cuencas y gestión de recursos hídricos en la zona.

Palabras clave: cuencas hidrográficas, hidrología, SIG, MED.

Received: 18/06/2019

Accepted: 06/07/2020

Introduction

In arid and semi-arid regions, mountain runoff can be the main source of water in the lower parts (Liniger, Weingartner, & Grosjean, 1998), with the morphological characteristics of the hydrographic basins determining their hydrological behaviors (Cruz, Gaspari, Rodriguez, Carrillo, & Telles, 2015; Vieceli *et al*., 2015).

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface (shape, dimensions of geographical features, channel network and terrain slope); therefore, it is a widely recognized principle that the morphology of the drainage basin reflects geological aspects and geomorphological processes over time (Horton, 1945; Strahler, 1964; Miller, 1953; Jardí, 1985).

Today, the morphometric characterization of the hydrographic basins is carried out with a Geographic Information System (GIS), either manually or automatically, and they are ideal for being dynamic in the visualization and processing of the quantification of the topographic attributes of a basin (Medeiros *et al*., 2019; Kabite & Gessesse, 2018; Rai, Mohan, Mishra, Ahmad, & Mishra, 2017). Studies have shown that data on morphometric parameters and river discharges from drainage basins in developing countries are scarce or very inadequate when they exist (Oruonye, Ezekiel, Atiku, Baba& Musa, 2015) In the rivers of Peru, there are few studies from the hydro geomorphological perspective (García & Otto, 2015).

The Anya and Mchique river basins are located in the central Andes of Peru and are important because their runoff contributes to the discharges of the Mantaro River that allows 35 % of the generation of the country's electricity service (Córdova, 2015). These basins are of small dimensions, high slopes, with probabilities of activation of mass removal processes, for which reason it was proposed to know the relief features in depth through a quantitative analysis for comparative purposes.

In this work, the objective was to characterize and analyze the morphometry of the Anya and Mchique basins through the calculation of their geomorphological parameters to explain their hydrological responses.

Materials and methods

Study area

2021, Instituto Mexicano de Tecnología del Agua

The Anya and Mchique river basins belong to the central high Andes of Peru. Geographically, the Anya river basin is located on the left bank of the Mantaro river between 11.89°S and 11.98° Latitude and 75.21°W and 75.28°W Longitude and the Mchique river basin, on the right bank of the Mantaro river between 11.86°S and 11.97°S Latitude and 75.45°W and 75.38°W Longitude (Figure 1).

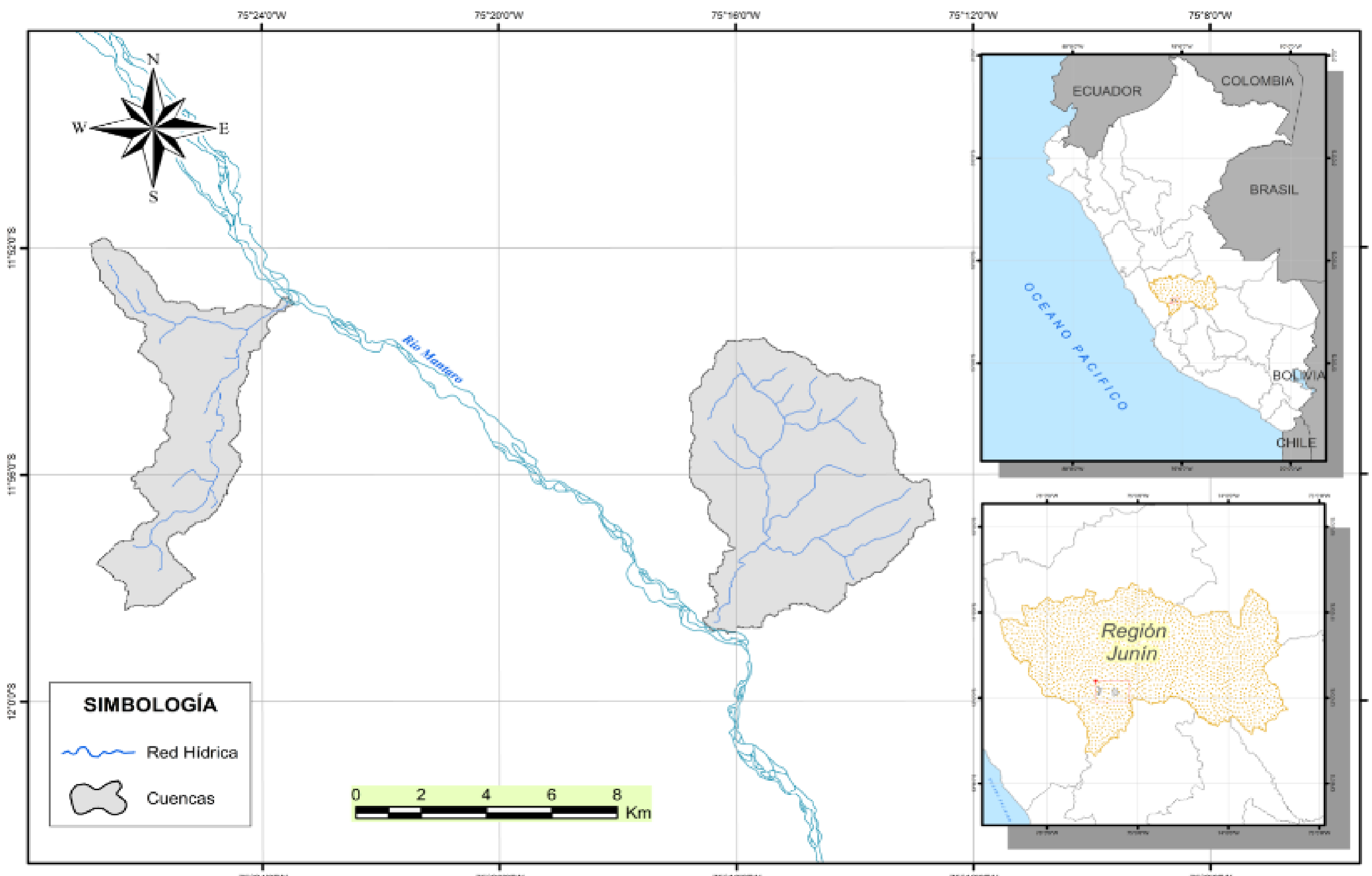

Figure 1. Location map of the Anya (right) and Mchique basins (left).

The study area includes heights between 3 000 and 4 400 masl, its climate is temperate cold, with an annual average temperature of 10.5 °C. The multi-year accumulated precipitation is 800 mm/year, with maximum precipitations in the months of January, February and March, decreasing sharply in April until reaching its minimum values in June.

In the Anya and Mchique basins, the areas of extensive rainfed agriculture for self-consumption are 40 % and 51 %, with representative crops of the area: potatoes, corn, barley, beans, ullucos and oats. In addition, 29 % and 40 % correspond to the Andean creeping grassland of mountains and 13.6 % and 9 % to scrub. Anya, unlike Mchique, has eucalyptus forest plantations in 12 % of the area of its basin.

Data source and processing

Base cartographic information was selected (topographic charts from the National Geographic Institute - IGN and a map of rivers from the National Water Authority - ANA). The platform https://vertex.daac.asf.alaska.edu/ was accessed remotely to download the ALOS PALSAR Digital Terrain Elevation Model (DEM), with 12.5 m spatial resolution and acquisition code AP_23821_FBD_F6940_RT1. The DEM was trimmed adjusting it to the study area and the automatic process of delimitation of the basins was carried out with the ArcToolbox / Spatial Analyst Tools / Hydrology option of the ArcMap 10.5 program (Figure 2). Next, the basic parameters (area, perimeter, width, elevations, order and length of the currents) of each basin were calculated separately. Finally, based on the parameters calculated with the Arc Map 10.5 program in the previous step and using the equations in Table 1, the elongation, elongation, shape factor, compactness coefficient, bifurcation ratio and drain density were calculated.

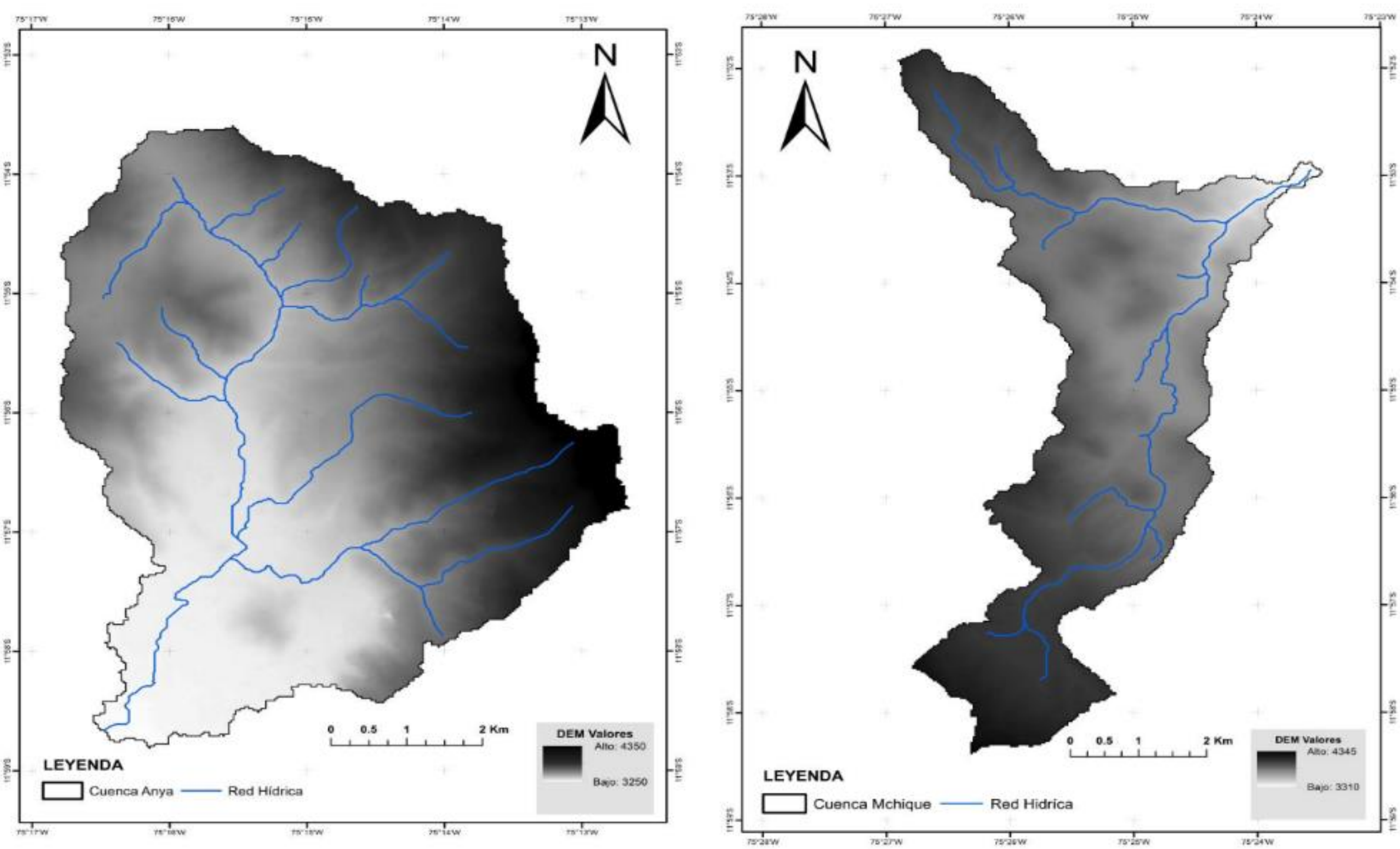

Figure 2. Digital Elevation Models (DEM) of the Anya and Mchique basins.

Table 1. Equations for the calculation of morphometric parameters in basins.

Parameter	Symbol	Formula/Definition	Unit
Geometry of the basin			
Area	A	Measured on the GIS map	km²
Area of the rectangle equivalent to the basin	*Ar*	$\mathrm{A_r} = \mathrm{La_{max}}$	km²
Equivalent rectangle larger side	*Lmay*	$Lmay = \sqrt{A}(\frac{K_c}{1.12} + \sqrt{(\frac{K_c}{1.12})^2 - 1}$	km
Equivalent rectangle minor side	*Lmen*	$Lmen = \sqrt{A}(\frac{K_c}{1.12} - \sqrt{(\frac{K_c}{1.12})^2 - 1}$	km
Perimeter	*P*	Measured on the GIS map	km
Length	*L*	Measured on the GIS map	km
Average width	*a*	$\mathrm{a = A/L}$	km
Maximum width	*amax*	Measured on the GIS map, perpendicular to the length of the basin	km
Diameter	*D*	$D = \sqrt{\frac{4A}{\pi}}$	km
Perimeter of a circle equal to the area of the basin	*Pc*	$Pc = \pi\sqrt{\frac{4A}{\pi}}$	km
Gradient and relief shape of the basin			
Minimum altitude	*h*	Reading contour lines of the topographic chart	masl

Maximum altitude	H	Reading contour lines of the topographic chart	masl
Average altitude	H_m	GIS estimate	masl
Maximum relief	R_m	$R_m = H - h$	masl
Relief radius	R	$R = R_m/L$	masl/km
Relative relief	R_r	$R_r = R_m/P$	_
Average slope (Alvord Criterion)	P_m	P_m = D x L_{total} contour lines/A	%
Altitude of the source of the main channel	H_{nac}	Reading contour lines of the map	masl
Altitude of the main channel drain	h_{des}	Reading contour lines of the map	masl
Altitude of the main channel at its origin as a higher order channel	H_{com}	Reading contour lines of the map	masl
Average slope of the longitudinal profile of the main channel from the spring to the mouth	P_{cpm}	Reading contour lines of the map	m/m
Maximum relief of the main channel	R_{mcp}	$R_{mcp} = H_{nac} - h_{des}$	masl
Topographic factor	F_t	$Ft = \mathrm{Rmcp}\sqrt{\mathrm{Pcpm}}$	_
Hypsometric integral	IH	$IH = (H_m - h)/(H-h)$	_
Massiveness coefficient	C_m	$C_m = H_m / A$	m/km^2
Orographic coefficient	C_o	$C_o = (H_m \text{ in km})^2 / A$	_
Roughness number	NR	$NR = RmA^{-0.5}$	_
Basin shape			

Orientation of the basin	_	Direction with respect to the geographic north. It is measured on the map	°
Elongation	*E*	$E = 1.129\frac{A^{0.5}}{L}$	_
Compactness coefficient	K_c	$K_c = 0.28\frac{P}{\sqrt{A}}$	_
Elongation index	I_a	$Ia = \frac{L}{a_{max}}$	_
Homogeneity index	I_h	$I_h = A/A_r$	_
Shape factor	F_f	$Ff = \frac{A}{Lcp^2}$	_
Caquot lengthening	A_c	$Ac = \frac{L}{A^{0.5}}$	_
Elongation radius	R_e	$R_e = D/L$	_
Circularity radius	*RC*	$RC = \frac{4\pi A}{P^2}$	_
Shape index	*IF*	$IF = P/2\pi A$	_
Index between the length and the area of the basin	*ICo*	$ICo = D/A$	_
Shape coefficient	C_f	$C_f = am/L$ am = average width of the basin = a	_
Roundness coefficient	C_r	$Cr = \frac{\pi L^2}{4A}$	_
Drainage network extension			
Main channel length	L_{cp}	Measured on the GIS map	km
Major order of the main river	_	From the GIS map	_
Straight length start and end of main channel	L_{vm}	Measured on the GIS map	km
Sinuosity index	S_t	$S_t = L_{cp}/L_{vm}$	_

Total length of drainage network streams	L_{tc}	$L_{tc} = \sum L_c$ L_c = length of all drainage network currents Measured on the GIS map	km
Drain density	D_d	$D_d = L_{tc}/A$	km/km^2
Drainage pattern	–	Interpretation of the arrangement of the currents that make up the drainage network on the map	–
Channel maintenance coefficient	C_{mc}	$C_{mc} = \frac{A}{L_{tc}}$	km^2/km
Average extent of surface runoff	E_m	$E_m = A/(4L_{tc})$	km

The hypsometric curve of the basins was represented, which is a double axis curve where the ordinate represents the altitude level in masl (with an equidistance of 200 m) and the abscissa is the area above or below a level (%), as established by Strahler (1964). This curve is important because it provides us with information about the stages of the landscape and the erosion processes that occur in the basin (Cruz *et al*., 2015). Concentration time (T_c) was calculated as the average value obtained from empirical formulas developed for different conditions.

Results and discussion

2021, Instituto Mexicano de Tecnología del Agua

The surfaces of the Anya and Mchique basins are 48.03 km^2 and 28.55 km^2; its perimeters are 31.59 km and 39.33 km, with the Mchique basin having the largest perimeter. Anya's orientation is to the southwest and Mchique is oriented to the northeast. The equivalent rectangle of the Anya basin has sides of 4.11 km and 11.68 km and those of Mchique 1.58 km and 18.08 km, which gives us an idea of the longitudinal extension of Mchique. The mean heights are 3 700 masl and 3 831.42 masl in Anya and Mchique, with the mean slopes (P_m) of the basins equal to 20.9 % and 15.8 %, which correspond to strongly rugged reliefs (P_m > 15 %) typical of the Andes, which they influence the speed of surface runoff (Pérez, 1979). On the one hand, with respect to the hypsometric curve and its shape, it is inferred that the Anya basin is in a stage of maturity and equilibrium, representing an average erosive activity (type B curve). On the other hand, the Mchique basin is young, reflecting great erosive power and high activity potential (type A curve). The median altitudes are 3 600 masl and 3 800 masl for Anya and Mchique, respectively.

As for the relief, the maximum values of each of the Anya and Mchique basins are 1 080 m and 932 m and the main channel of their rivers are 273.23 m and 728.52 m, the mass coefficients (C_m) are 77.04 m/km^2 and 134.20 m/km^2, the orographic coefficients are 0.29 and 0.51 and the Melton roughness numbers (*NR*) were 155.84 and 174.43. The relief radius (*R*), defined as the ratio of the maximum relief of the basin between the length of the basin were 120 masl/km in Anya and 83.44 masl/km in Mchique (Table 2). Relief significantly influences the speed of erosive processes in a basin as it determines the direction and intensity of the movement of water and sediment (Schumm, 1977). The results reflect that the Mchique River basin has the highest values of the massiveness coefficient (C_m), orographic coefficient and Melton roughness number (NR) respectively, however, in both cases, the values obtained are typical of the Andes mountains and they represent steep areas, with very rugged reliefs and high erosive potential. The relief radius is greater in the Anya basin due to its greater topographic difference and shorter basin length than Mchique.

Table 2. Results of calculation of morphometric parameters in the Anya and Mchique basins.

Parameter	**Unit**	**Magnitude**	
		Anya	**Mchique**
Geometry of the basin			
Area	km^2	48.03	28.55
Area of the rectangle equivalent to the basin	km^2	48.00	28.57
Equivalent rectangle larger side	km	11.68	18.08
Equivalent rectangle minor side	km	4.11	1.58
Length	km	9.00	11.17
Average width	km	5.34	2.56
Maximum width	km	7.77	2.84
Diameter	km	7.82	6.03
Perimeter of a circle equal to the area of the basin	km	24.57	18.94
Gradient and relief shape of the basin			

Minimum altitude	masl	3 240	3 308
Maximum altitude	masl	4 320	4 240
Average altitude	masl	3 700	3 831.4
Maximum relief	masl	1 080	932
Relief radius	masl/km	120	83.44
Relative relief	_	3.8	2.1
Average slope (Alvord Criterion)	%	20.9	15.8
Altitude of the source of the main channel	masl	3 529.2	4 064
Altitude of the main channel drain	masl	3 256	3 335.5
Altitude of the main channel at its origin as a higher order channel	masl	3 298	3 424
Average slope of the longitudinal profile of the main channel from the spring to the mouth	m/m	0.03	0.06
Maximum relief of the main channel	masl	273.23	728.52
Topographic factor	_	43.2	178.45
Hypsometric integral	_	0.43	0.56
Massiveness coefficient	m/km^2	77.04	134.2
Orographic coefficient	_	0.29	0.51
Roughness number	_	155.84	174.43
Basin shape			
Orientation of the basin	°	19° SW	28°NE
Elongation	_	0.87	0.54
Compactness coefficient	_	1.28	2.06
Elongation index	_	1.16	3.93

Homogeneity index	_	1.001	0.999
Shape factor	_	0.38	0.2
Caquot lengthening	_	1.3	2.09
Elongation radius	_	0.87	0.54
Circularity radius	_	0.6	0.23
Shape index	_	0.1	0.22
Index between the length and the area of the basin	_	0.16	0.21
Shape coefficient	_	0.59	0.23
Roundness coefficient	_	1.32	3.43
Drainage network extension			
Main channel length	km	11.3	12
Major order of the main river	_	3	3
Straight length start and end of main channel	km	9.3	10.3
Sinuosity index	_	1.22	1.17
Total length of drainage network streams	km	41.12	25.56
Drain density	km/km^2	0.86	0.9
Drainage pattern	_	Dendritic	Sub-dendritic
Channel maintenance coefficient	km^2/km	1.17	1.12
Average extent of surface runoff	km	0.29	0.28

With respect to the longitudinal profiles of the Anya and Mchique rivers, average slopes were obtained are 3 % and 6 % and main stream lengths equal to 11.3 km and 12 km, noting that the Anya river has a bed made up of 03 zones: one high zone (with steeper slopes in the mountain areas), medium and low (coinciding with the valley). The Mchique river develops from a rocky massif, with a swampy zone in the middle of its route and its slope shows abrupt changes due to lithological and structural control, even very close to its confluence with the Mantaro river. With respect to the bed of the Anya and Mchique rivers, they show some differences: The Anya river has a slightly rocky and partially vegetated bed, being winding in the lower part; the Mchique river is not winding and has a rocky bed throughout its trajectory (Grados, 2012), so it presents hauling more dangerous materials.

The compactness coefficients K_c of the Anya and Mchique basins are 1.28 and 2.06, which means that the shape of the Anya basin is more similar to a circle (K_c = 1) and the Mchique basin is more elongated. Regarding the form factor (F_f), which is the quotient between the area of the basin and the square of the length of the basin, 0.38 and 0.20 result, suggesting different shapes than that of a circle of F_f = 0.7854, and that the Anya and Mchique basins are oblong, the Mchique basin being much more elongated than the Anya basin. The elongated shape is less susceptible to flooding in situations of extreme precipitation, but the possibility of rain covering the entire extension, including tributary rivers, is also low as the flood hits the main river at various points (Medeiros *et al*., 2019).

The radius of circularity (R_c) is influenced by the length and frequency of the currents, geological structure, land cover, climate and slope of the basin (Waikar & Nilawar, 2014). High values of the circularity radius indicate a maturity stage of the topography (Rai *et al*., 2017). In this case, the radii of circularity are 0.60 and 0.23 for Anya and Mchique, which are low values and are indicative that the topography is in formation (youth) in both basins, with Mchique being younger than Anya.

The radius of elongation (R_e) is the diameter of a circle of area equal to the drainage area of the basin divided by the maximum length of the basin. It has values that vary between 0.6 and 1.0 in a wide range of climates and geology. When $R_e < 0.88$ it is considered elongated and is usually associated with steep reliefs and slopes (Strahler, 1964; cited by Kabite & Gessese, 2018). R_e of 0.87 and 0.54 was obtained, which means that the Anya basin is oblong oval and the Mchique basin has greater elongation.

The drainage network contains short-distance channels and streams and intermittent regimes in large percentages (51.9 % Anya and 47.4 % Mchique) with total stream lengths of 41.12 km and 25.56 km in Anya and Mchique respectively. Horton (1945) introduced Drainage Density (D_d) as an important indicator of linear scale of landform elements and erosion of stream topography, which is obtained from the ratio of the length of total streams (km) between the basin area (km^2). Drainage density is an indicator of the drainage efficiency of the basins and varies from 0.5 km/km^2 in poorly drained basins and 3.5 km/km^2 or more, for well-drained basins (Mejía, 2012). The D_d of the Anya and Mchique basins are 0.86 km/km^2 and 0.95 km/km^2, corresponding to a low density due to the short length of their channels and little extension of their drainage basins. In larger basins, the low drainage density leads to inferring a coarse drainage texture, while the high drainage density leads to a fine drainage texture, high runoff, and an erosion potential of the basin area (Kabite & Gessesse, 2018). Both basins have an order 3 hydro geomorphological system, with dendritic drainage patterns in Anya and sub dendritic in Mchique: the hydrologically dendritic drainage pattern reflects homogeneity in texture of the subsoil strata and the sub dendritic pattern, structural control (Banerjee, Singh, & Pratap, 2017).

The small areas of these basins imply short concentration times, in which the entire area contributes to surface runoff, with hydrographs expected to be of pronounced peaks and short duration, that is, in the presence of a storm of considerable extension, the entire basin is activated and contributes water, reaching the expense of balance. The results of the concentration times (T_c) of the Anya and Mchique basins are 3.20 and 2.21 hours, obtained from the average of the considered equations; the higher value in Anya is due to its 3 % lower slope compared to 6 % of Mchique, despite having a shorter length of its main current of 11.3 km with respect to Mchique which is 12.0 km (Table 3).

Table 3. Concentration times in hours of the Anya and Mchique basins.

Concentrations times (hr)	**Equation**	**Anya basin**	**Mchique basin**
Giandiotti	$T_c = \frac{4\sqrt{A} + 1.5L}{25.3\sqrt{S\,L}}$	3.49	1.82
Kirpich	$Tc = 0.06628\left[\frac{L^{0.77}}{S^{0.385}}\right]$	1.84	1.32
California (U.S.B.R.)	$Tc = \left[\frac{0.87075L^3}{H}\right]^{0.385}$	1.84	1.32
Bransby - Williams	$T_c = 14.6\,L\,A^{-0.1}\,S^{-0.2}/60$	3.98	3.66
Passini	$T_c = \frac{\left[0.108\,(A\,L)^{1/3}\right]}{S^{0.5}}$	5.86	3.07

Pérez	$T_c = \dfrac{L}{72\left(\frac{H}{L}\right)^{0.6}}$	1.52	0.90
Témez	$T_c = 0.3\left[\dfrac{L}{S^{0.25}}\right]^{0.76}$	3.89	3.38
Standard deviation		0.95	0.29
Variance		0.91	0.09
Maximum		5.86	3.66
Minimum		1.52	0.90
Final average		**3.20**	**2.21**

Conclusions

Basin morphometric analysis is the basis of hydrological studies as part of water resources studies. The use of geographic information systems, specifically Arc GIS and computational techniques, allow obtaining results for a quick understanding of the physical dynamics of the drainage network of hydrographic basins, in this case of the Anya and Mchique rivers, tributaries of the Mantaro river in Junín - Peru.

The basins studied have mountainous landscapes with steep slopes, in which, through morphometric analysis, it is concluded that their erosive capacities are accentuated by their slopes, rather than by their compactness and elongation indexes; its carrying and material transport capacities, due to the structural composition of the bed of its rivers. From the identified parameters, it is inferred that in both basins there is a risk of floods, moderate in Anya and low in Mchique, there being hydrological similarity between both basins.

The information reported in this study can serve others of a hydrological and hydraulic nature; for example, in runoff generation models, in addition, using the hydraulic similarity theory, it is possible to apply the results obtained by transferring small-scale models to large-scale prototypes to make the necessary comparisons.

Acknowledgments

The authors express our gratitude to the San Cristóbal de Huamanga University and the Doctoral Program in Water Resources of the National Agrarian University La Molina for allowing us to carry out teaching and research work.

References

Banerjee, A., Singh, P., & Pratap, K. (2017). Morphometric evaluation of Swarnrekha watershed, Madhya Pradesh, India: An integrated GIS-based approach. *Journal Applied Water Science*, 7, 1807. Recovered from https://doi.org/10.1007/s13201-015-0354-3.

Córdova, M. (2015). *Estimación de caudales medios naturalizados en la cuenca del río Mantaro mediante el método de regionalización estadística* (tesis para optar el título de Ingeniero Civil), Pontificia

Universidad Católica del Perú. Lima, Perú. Recovered from http://tesis.pucp.edu.pe/repositorio/handle/20.500.12404/6273

Cruz, B., Gaspari, F. J., Rodriguez, A. M., Carrillo, F. M., & Telles, J. (2015). Análisis morfométrico de la cuenca hidrográfica del río Cuale, Jalisco, México. *Revista Investigación y Ciencia de la Universidad Autónoma de Aguascalientes*, (64), 26-34. Recovered from http://www.redalyc.org/pdf/674/67441039004.pdf

García, E., & Otto, M. (2015). Caracterización ecohidrológica de humedales alto andinos usando imágenes de satélite multitemporales en la cabecera de cuenca del río Santa, Ancash, Perú. *Ecología Aplicada*, 14, 115-125.

Grados, D. (2012). *Estudio de avenidas en las cuencas del Anya y Mchique, departamento de Junín, Perú (Período 2011-2012)* (tesis para optar el título de Ingeniero Agrícola), Universidad Nacional Agraria La Molina, Lima, Perú.

Horton, R. E. (1945). Erosional development streams and their drainage basins: Hidrophysical approach to quantitative morphology. *Geological Society of America Bulletin*, 56, 275-280.

Jardí, M. (1985). Forma de una cuenca de drenaje. Análisis de las variables morfométricas que nos la definen. *Revista de Geografía*, (19), 41-68.

Kabite, G., & Gessesse, B. (2018). Hydro-geomorphological characterization of Dhidhessa River Basin, Etiopia. *International Soil and Water Conservation Research Journal*, 6(2), 175-183. Recovered from https://doi.org/10.1016/j.iswcr.2018.02.003

Liniger, H., Weingartner, R., & Grosjean, M. (1998). *Mountains of the World: Water towers for the 21st Century*. Berne, Switzerlad: Centre for Development and Environment.

Medeiros, F., Lima, J., Silva, R., Pereira, S., Freitas, A., Lima, A., Lima, L., Silva, J. L., & Monte, A. (2019). Analysis of morphometric variables of river Espinharas hydrographic sub-basin using geographic information system. *Journal of Experimental Agriculture International*, 31(6), 1-18. Recovered from https://doi.org/10.9734/jeai/2019/v31i63008

Mejía, A. (2012). *Hidrología aplicada*. Lima, Perú: Universidad Nacional Agraria La Molina.

Miller, V. C. (1953). *A quantitative geomorphic study of drainage in the Clinch Mountain area, Virginia and Tennessee. Office of Naval Research, Geography Branch, Project NR 389-042, Technical Report, 3*. Columbia, USA: Columbia University.

Oruonye, E. D., Ezekiel, B. B, Atiku, H. G., Baba, E., & Musa, N. I. (2015). Drainage basin morphometric parameters of river Lamurde: Implication for hydrologic and geomorphic processes. *Journal of Agriculture and Ecology Research International*, 5(2), 1-11. DOI: 10.9734/JAERI/2016/22149

Pérez, J. (1979). *Fundamentos del ciclo hidrológico*. Caracas, Venezuela: Universidad Central de Venezuela, Facultad de Ingeniería, Departamento de Meteorología e Hidrología.

Rai, P. K., Mohan, K., Mishra, S., Ahmad, A., & Mishra, V. A. (2017). A GIS-based approach in drainage morphometric analysis of Kanhar

River Basin, India. *Journal Applied Water Science*, 7, 217. Recovered from https://doi.org/10.1007/s13201-014-0238-y

Schumm, A. (1977). *The fluvial system*. New York, USA: John Wiley & Sons.

Strahler, A. N. (1964). Quantitative geomorphology of drainage basins and channel networks. In: Chow, V. T. (ed.). *Handbook of applied hydrology* (pp. 439-476). New York, USA: McGraw- Hill.

Vieceli, N., Bortolin, T. A., Abritta-Mendes, L., Bacarim, G., Cemin, G., & Schneider, V. E. (2015). Morphometric evaluation of watersheds in Caxias do Sul City, Brazil, using SRTM (DEM) data and GIS. *Environmental Earth Sciences*, 73(9), 5677-5685. Recovered from https://doi.org/10.1007/s12665-014-3823-3

Waikar, M. L., & Nilawar, A. P. (2014). Morphometric analysis of a drainage basin using Geographical Information System: A case study. *International Journal of Multidisciplinary and Current Research*, (2), 179-184. Recovered from http://ijmcr.com/wp-content/uploads/2014/02/Paper32179-184.pdf