v. 3, n. 16, 2023

Journal of
Engineering
Research

SEDIMENTS IN THE CHACAHUA-PASTORÍA LAGOON SYSTEM, OAXACA, MEXICO

José Rafael Contreras Hinojosa
``Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias``
Campo Experimental Valles Centrales de Oaxaca
Villa de Etla, Oaxaca

Adán Hernández Hernández
``Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias``
Campo Experimental Valles Centrales de Oaxaca
Villa de Etla, Oaxaca

Rafael Guajuardo Panes
``Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias``
Campo Experimental Cotaxtla.
Cotaxtla, Veracruz

José Antonio Cueto Wong
``Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias``
Campo Experimental La Laguna.
Matamoros, Coahuila

Finlandia Barbosa Moreno
``Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias``
Campo Experimental Valles Centrales de Oaxaca
Villa de Etla, Oaxaca

Abstract: In order to assess the siltation risk of the Chacahua-Pastoria lagoon system, the Chacalapa and San Francisco rivers, tributaries of the water body, were morphometrically characterized using a 1:50,000 scale topographic map. For both rivers, their basins were delimited, the area and perimeter were determined, as well as the shape factor and circularity. The drainage network was measured and ranked, determining the drainage density and the degree of bifurcation. In the relief variables, the extreme points were determined, such as the origin and exit of the main channel, the average slope and the sinuosity index. In both rivers, suspended sediments were quantified twice a day with a DH-48 meter, while bottom sediments were evaluated with the Halley-Smith device. The results highlight that the area of the Chacalapa river basin is 108.56 km2, while that of the San Francisco river is 9% larger and elongated. For both basins the drainage pattern is dendritic, with a similar total number of channels with 83, for both rivers the average bifurcation is 3.9 with four hierarchies, passing through the coastal plain for about a third of their lengths, with low sinuosity. 83 rainfall events with 1,784.4 mm were recorded, which caused 107,577 to leave the two basins. Mm3 of water, of which 40,361mm3 correspond to the Chacalapa river. Regarding the sediments, in total they came out of the basins6,999 tons, 62% corresponding to the San Francisco River, a greater amount, in part, because it has a greater extension, corresponding to the sands, 75% of the sediments in the bottom, material that remains between marshes, prior to its arrival to the lagoons.
Keywords: erosion, granulometry, marshes, flow, sand

INTRODUCTION

The San Francisco River basin is located in Region 21 Coast of Oaxaca with code No. 2101, whichdrains an area of 624.13 square kilometers(Official Gazette of the Federation, 2013) and within this are the basins of the Chacalapa and San Francisco rivers, which discharge their waters to the Chacahua-Pastoría coastal lagoon system, located within the "Lagunas de Chacahua" National Park, a Protected Natural Area (Figure 1).

The term morphometry is applied to the shape and drainage pattern of a basin, characteristics that can be measured on maps (Gordon et al., 2004). LThe first part of the basin analysis corresponds to its delimitation, which can be done manually and through geographic information systems (Gabale and Pawar, 2015). Basin studies consider mathematical relationships to obtain values, as well as indices, derived from factors of size, shape, relief, and drainage of the basin.

In a basin there are inputs of matter, such as rain, which due to the quantity and intensity in which it occurs is transformed into kinetic energy, which can be consumed by separating and transporting soil particles. Due to the magnitude of the size of the channels to transport sediments, in basins with a high level of disturbance, values of 600 t km-2 year-1 can be had, in rivers of Asia (Zavoyanu, 1985). Based on the study of the morphometry of the basins, indices can be obtained that allow characterizing the most affected parts and therefore, promoting actions for their restoration.

In a basin three zones can be defined; The first is the production of sediments, which is located in the highest part, from where material is supplied to the channel network, either by erosion or by movement of masses, thus passing to a transfer zone. Thus, the basin can be conceptualized as a series of reservoirs, where saturated and unsaturated zones are coupled, which connect laterally and vertically through space once a rainfall occurs (McDonnell, 2003).

As the river approaches its discharge, its slope decreases and the energy available for sediment transport is reduced, this zone is the depositional zone where the heavy material remains (Charlton, 2008). A river in equilibrium will have a well-developed hydraulic geometry in its lower part, in such a way that variations in discharge can be explained by variations in the width of the channel (Wohl, 2014).

When a particle enters the flow of water, its movement is resisted by its weight and the friction with neighboring grains. The amount of sediment transported by the river is as important as the size distribution, since the process is very different for material coarse than fine, because fine materials, such as silts and clays, are transported as suspended cargo and travel long distances, while coarse materials, which are heavier, are transported as bottom cargo (Charlton, 2008) and because of their size. , for its study there will be different forms of sampling and evaluation.

In order to assess the risk of siltation of the aforementioned body of water, a strategy was implemented to, in the first instance, allow characterizing the morphometry of the basins, quantifying and characterizing the sediments that come out of them and verifying the sediment discharge sites.

MATERIALS AND METHODS

The dominant type of geology corresponds to coarse material and according to theNational Institute of Statistic and Geography(INEGI, 2010) corresponds to intrusive igneous rocks such as granite-granodiorites 39.35%, of metamorphic rocks gneiss occupies 21.46%, while alluvial soil corresponds to 25.95% and lacustrine 6.79%. TOIn addition, superficially the presence ofsongs and rocks, product of the transport and deposit during hundreds of years by the rivers. According to García (2004), the dominant climate type in the basin is Aw, which corresponds to a warm sub-humid climate with summer rains, while the rainfall distribution is bimodal, occurring in the months of May to November, with peaks in the months of June (24%) and September (23%), with occasional torrential rains derived from hurricanes (Serrano-Altamirano et al., 2005). Land use is mainly jungle (43.51%), forest 4.50%, mangrove 3.47%, while human activity in agriculture takes care of 20.52% and cultivated pasture 17.78% (INEGI, 2010). On the slopes, maize, beans and grass are cultivated, while on the coastal plain, in addition to annual crops, there are meadows and plantations of mango, lemon and papaya.

BASIN MORPHOMETRY

The delimitation of the basins was carried out manually on the Río Grande E14D85 topographic chart, published by the National Institute of Statistics and Geography (INEGI), scale 1:50000. The area of the basin was obtained by superimposing a grid on the map and counting the number of squares involved, as well as the complement of fractions that remain within the basin, relating the total number of squares and their size to the scale of the map, while For the perimeter, the contour was measured with a curvimeter (Gordon et al., 2004). The drainage pattern was made in a comparative medium with those proposed by Gordon et al., 2004). The circularity relationship was obtained by relating the area of the basin to the area of a circle that has the same perimeter as the basin (Raghunath, 2006).thisto a line with horizontal projection between the extreme points of the channel, while the width is obtained by dividing the area by the axial length (Raghunath, 2006). The elongation ratio was obtained by relating the diameter of a circle of the same area of the basin to the maximum length of the basin (Raghunath, 2006). The compactness

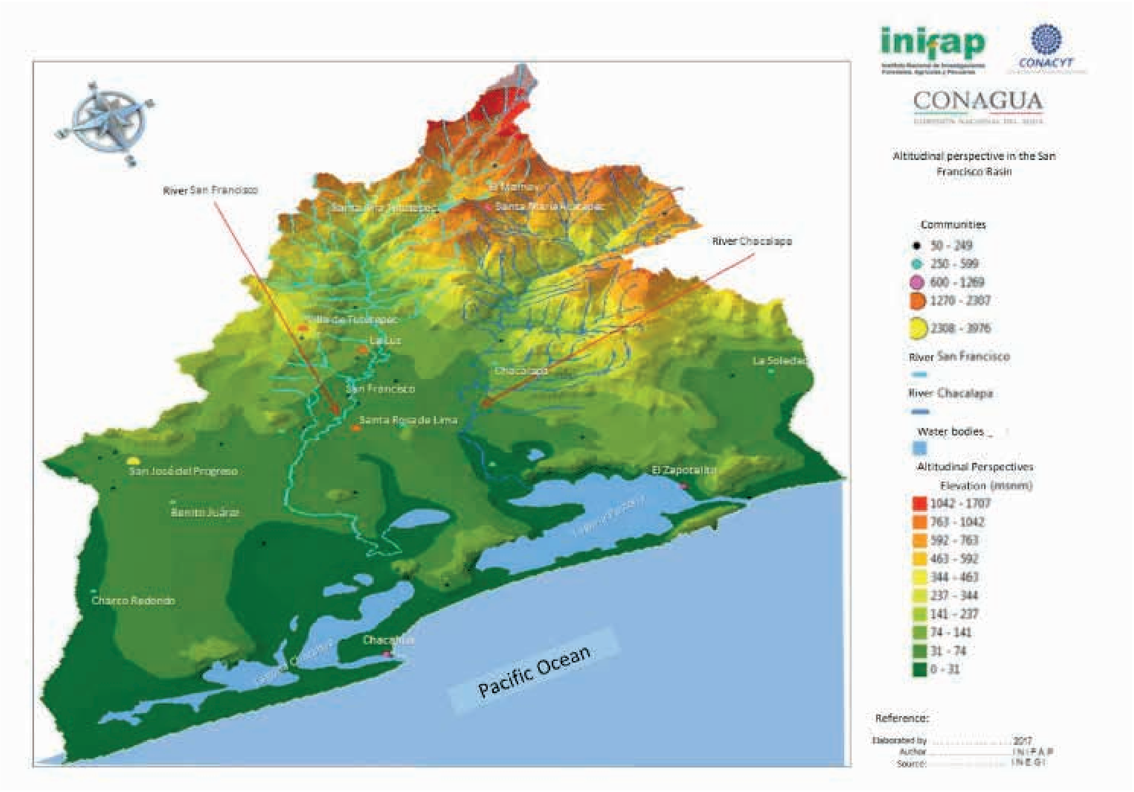

Figure 1.- The Chacahua-Pastoria lagoon system.

Variable	Chacalapa River Basin	San Francisco River Basin
Area (km2)	108.56	118.25
perimeter (km)	50.4	60.2
relative perimeter	2.15	1.96
Basin length (km)	18.5	24.5
Basin axial width (km)	5.86	4.82
drainage pattern	dendritic	dendritic
Maximum altitude of the basin (m)	900	1600
Altitude at discharge (m)	twenty	twenty
Main channel slope (%)	3.71	5.26
circularity relationship	0.53	0.41
form factor	0.34	0.19
elongation ratio	0.66	0.50
compactness coefficient	1.36	1.56
Total channels	84	83
order of the channels	1 – 4	1 - 4
First order channels	61	51
second order channels	18	12
Third-order channels	4	3
fourth-order channels	1	1
Total length of channels (km)	130.90	148.90
First order length (km)	88.95	91.75
Second order length (km)	24.35	30.00

Third order length (km)	10.05	10.00
Fourth order length (km)	7.55	17.15
Main channel length (km)	22.6	30.0
Riverbed length on the plain (km)	6.2	10.1
sinuosity index	1.20	1.25
Channel density (n/km2)	0.77	0.70
Drainage density (km/km2)	1.20	1.25
Second order bifurcation index	3.3	4.7
Third-order bifurcation index	4.5	4.0
Fourth-order bifurcation index	4.0	3.0
Average bifurcation index	3.9	3.9

Table 1. Morphometric variables for both basins.

	Chacalapa River		St Francis River	
Month	Suspension	Background	Suspension	Background
July	61,415	121,195	196,317	211,545
August	167,595	258,024	120,632	390,096
September	281,504	378,681	110.9223	220,937
October	285,901	662,300	1,354,258	282,095
November	30,592	316,026	112,554	171,899
December	8,797	78,476	51,357	128,040
Total	835,804	1,814,702	2,944,341	1,404,612

Table 2. Sediments in suspension and on the bottom (t) that left the basins.

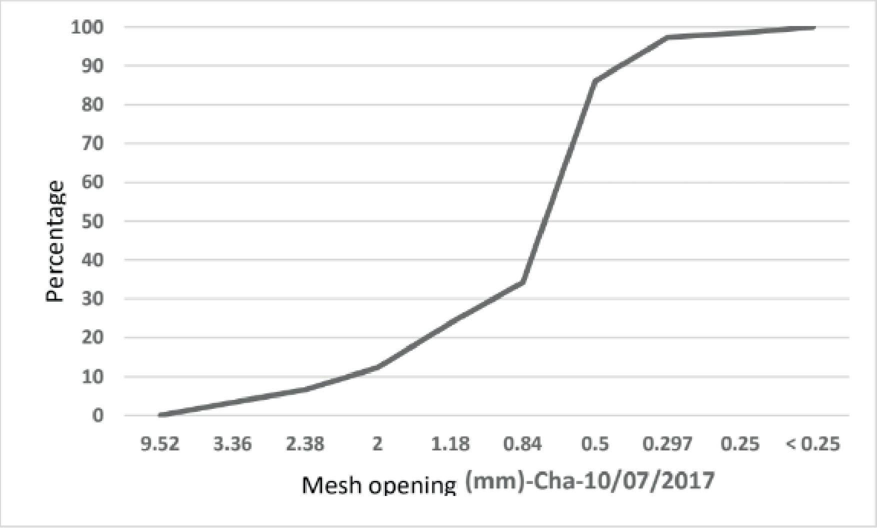

Figure 1.- Typical granulometric curve

coefficient is obtained by relating the perimeter of the basin to the circumference of a circle with an area equivalent to that of the basin (Raghunath, 2006). The number of channels was obtained by counting them. The order of the channels was made by assigning the main channel the highest value (Strahler, 1957) and the rest of the tributaries a lower order, in such a way that there is a hierarchy as they are associated with the main channel (Gordon et al., 2004).

Of all the channels, their length was measured with a curvimeter, as well as superimposing a thread and associating the distance with the scale of the map (Raghunath, 2006). The sinuosity relationship was obtained by relating the length of the main channel to the length in a straight line of the ends of the channel. The density or frequency of channels was obtained by relating the number of channels with the area of the basin, in order to obtain the number of these per square kilometer (Raghunath, 2006). The drainage density was obtained by relating the sum of the lengths of all the channels with the area of the basin (Horton, 1945). The bifurcation or fragmentation of channels of one order with the one immediately following superior was made by relating the numbers of both channels.

SEDIMENT QUANTIFICATION

During the year 2017 and under the bridges that cross the Puerto Escondido-Pinotepa Nacional highway over the rivers, the gauging units were established where the flow measurements were made. To estimate the velocity, a Flowatch brand flow meter, model FW450 (JDC Electronic, Suisse) with a resolution of 0.1 m sec-1 was used. Two daily samplings were carried out, at one sixth of the depth through three measurements, with which the average velocity was obtained. Parallel to the above, the depth of the water sheet was measured at five points with a ruler with a centimeter approximation, as well as the width of the river using a tape measure (Boiten, 2005). The average flow (m3 sec-1) was obtained by relating the width of the river (m), with the depth or height of the average level of the river (m) with the speed (m/sec),

For the measurement of suspended sediments, the DH-48 meter (Spectrum Technologies, USA) was used, to which a container was attached where the water sample with sediments is stored (Fraley, 2004). The instrument has the shape of a fish, with a nozzle with a 3 mm inlet hole where water enters isokinetically, which implies that the speed with which the water enters the implement is similar to that which passes through its sides or that which it passes through its upper or lower part and as it fills with water, the air is expelled (Davis, 2005). Two daily samplings were carried out and the quantity of sediments in suspension was obtained by letting the container settle and once the solids had settled, the excess water was extracted and these were deposited in a beaker that was placed in the oven to dry at 105 oC for a day (Vanoni,

To measure the sediments carried by the river in its lower part (bottom), the Halley-Smith gauge (Helley and Smith, 1971) was used with a square sediment capture section of 7.5 cm per side, with a total weight of 21 kg. (Fraley, 2004).

The measurement was carried out in the middle part of the width of the river, the meter was placed perpendicular to the direction of the flow on the bed for approximately 20 minutes and all the organic and inorganic material that was dragged or in saltation was captured in the mesh, the which was emptied into a plastic bag and later put to dry. Manually and using tweezers, the organic material that due to its size was susceptible to being extracted from the sample was extracted, such as twigs, segments of leaves and roots, as well as seeds, which were weighed and thus also quantify the organic sediments that were present. come out of the basin.

Once the sample was dry, it was passed through a group of sieves with a mesh opening of 9.52, 3.36, 2.3, 2.0, 1.7, 1.18, 0.84, 0.50, 0.297 and 0.25 mm and the amount of inorganic material that was retained in the sample was weighed. these (McCarty et al., 2016). The amounts of sediment retained on each sieve were converted into percentages by relating them to the total and plotted on a cumulative granulometric curve.

RESULTS AND DISCUSSION

Table 1 presents the results of the morphometric analysis, the areaof the basin for the Chacalapa River is 108.56 km2 and 118.25 km2 for the San Francisco River, the latter being 9% larger.

The perimeter of both basins indicates 50.4 km for the Chacalapa River, while for the San Francisco River it was 60.2 km, or 8% greater. The length of the San Francisco river basin was 24.5 km, 6.0 km longer than that of the Chacalapa river, while the axial width of the Chacalapa river basin is greater by one kilometer, with 5.86, which indicates that this basin is shorter but wider.

For both basins, the drainage pattern is dendritic, which implies that the discharge is mainly from a smaller channel to a larger one. There is a marked difference in altitude above sea level where the runoff originates; for the San Francisco River it is 1,600 m, while for the Chacalapa River it is 900 m. The discharge zone for both basins is in the coastal plain, approximately 20 meters above sea level, in a wetland. This height difference and the length of the main channel generate an average slope of 3.71% and 5.26%, for the Chacalapa and San Francisco rivers, respectively.

The circularity ratio values were 0.53 for the Chacalapa river basin, while for the San Francisco river basin it was 0.41. This indicates that the Chacalapa river basin is closer to roundness than the San Francisco river basin, partly because the latter is longer. The shape factor values for both rivers were 0.34 for the Chacalapa River, while for the San Francisco River it was 0.19. This indicates that the Chacalapa river basin is 2.9 times longer than it is wide, while for the San Francisco river this proportion is 5.08 times. The elongation ratio for the Chacalapa river basin was 0.66, while for the San Francisco river basin it was 0.50.According to Strahler (1957) elongation values generally range from 0.6 to 1.0. Values close to 1.0 are for areas of low slope, while values from 0.6 to 0.8 are associated with areas of high relief.

The fragmentation or bifurcation of channels considers the degree of integration between channels of different order (Asfaw and Workineh, 2019) and the results, for both, were 3.9. Sukristiyanti et al. (2018) indicates that values less than five are considered low and that the geological structure does not affect the drainage pattern.According to Giusti and Schneider (1965)this value oscillates close to two, in relatively flat basins up to three or four in mountainous or highly dissected basins, the highest values correspond to a higher drainage density and therefore to having shorter times for the discharge to reach the outlet of the basin.

The average distribution of the number of channels per basin area was 0.77 and 0.70 per square kilometer, for the Chacalapa and San Francisco rivers, respectively, while, due to their length, the values were 1.20 and 1.25 km/km2, it is worth noting that for the Chacalapa river, 61% of the channels were of the first order, covering 72% of the total length, while for the San Francisco river, 61% were of the first order and covering 61% of the total length.

Regarding the quantification of sediments, the results highlight that 83 rain events were recorded for a total of 1,784.4 mm that promoted 107,577 to leave the two basins. Mm3 of water, of which 40,361mm3 correspond to the Chacalapa river, while thesan francisco river are67,216mm3. Regarding the sediments, in total they came out of the basins6,999 tons, 64% corresponding to the San Francisco River, a greater quantity, in part, due to its greater extension (Table 2).

The granulometry of the sediment in the bottom followed a trend in the shape of an elongated "S" at its ends, dominating the coarse particles, on average 3.5% were particles smaller than 0.25 mm, which corresponds to fine and very fine sand, silt and clay. ; 21% was gravel and 75% sand (Figure 2).

Following the route of the rivers towards their discharges, it was found that there is no "open sky" discharge towards the lagoon system. The Chacalapa river is stopped by sand obstacles in a mangrove swamp, forming swampy areas with the presence of hydromorphic soils, dominating the presence of the "Botoncillo" mangrove (*Conocarpus erectus*) (Agraz-Hernández et al., 2006) in arboreal form, with specimens up to 20 cm in diameter at breast height.

On the other hand, the main channel of the San Francisco River is completely silted up and covered with vegetation, in such a way that the runoff fragments into small channels, until it reaches a mangrove swamp.

After these points, where the configuration of the rivers is completely lost, before reaching the runoff to the lagoons, an area of marshes continues, to finally reach where the bodies of water begin, in whose contour the presence of the "Red" mangrove dominates. " (*Rhizophora mangrove*) (Agraz-Hernández et al., 2006).

Due to the obstacles that stop the continuity of runoff, a large amount of energy is needed to move the water through the small channels in the marshes, due to the resistance of the flow, such as the friction between the water and the limits of the channels (flanks) and the bottom (Charlton, 2008). For this to occur, water velocities of 0.15 m sec-1 (Miller, 1970) are required for fine sand particles to rise, become suspended and continue in the flow, an action that can sometimes take several cycles (Gyr and Hoyer, 2006).

It was observable that after rain events, the entry of sediments into bodies of water is from an infinite number of places, through the mangrove swamp, observable through the turbidity of the water and, above all, by the movement of organic material in suspension, mainly in the Pastoría lagoon.

CONCLUSIONS

By studying the morphometry of the basins, no major differences were observed in the parameters evaluated between the two. It is noteworthy that the San Francisco river basin is larger and longer, while the Chacalapa river basin is more similar to a circle, which in the first instance would facilitate the discharge of large avenues. Based on the foregoing and what has been quantified, it is noteworthy that the amount of sediments that comes out of the basins is in greater quantity through the San Francisco River, due to its larger basin size and steeper drainage slope.

Due to the fact that close to a third part of the transit of both rivers is made in the coastal plain, therefore, this route allows to cushion the turbulent flow that could appear and that the sediments stop. The foregoing is relevant since there are no large avenues that free the discharge zone, it is considered that, due to the accumulation of sediments, the extension of the wetland will increase over time.

Due to the geological origin of the parent material, this is manifested in the size of the sediments that come out of the basins, most of which correspond to the sands, however, there is no risk of the coarse material entering the bodies. of water, due, among other things, to its own weight and due to obstacles, such as sand deposits and marshes.

THANKS

The results are part of the project "Biophysical characterization and hydrodynamic study and sediment transport at the basin level of the Chacahua-Pastoría lagoon system", financed by INIFAP and the CONAGUA-CONACYT Sector Fund.

REFERENCES

Agraz-Hernández, C. M.; Noriega-Trejo, R.; López-Portillo, J.; Flores-Verdugo, F. J. y Jiménez-Zacarías, J. J. Guía de Campo. Identificación de los Manglares en México. Universidad Autónoma de Campeche. Centro EPOMEX. Comisión Federal de Electricidad. Comisión Nacional Forestal. Instituto de Ecología, A.C. CEDESU. Instituto de Ciencias del Mar y Limnología-UNAM. Campeche, Camp. 2006.

Boiten, W. Hydrometry. The Netherlands: Taylor & Francis. 2005.

Charlton, R. Fundamentals of Fluvial Geomorphology. New York: Routledge. 2008.

Davis, B. E. A guide to the proper selection and use of federally approved sediment and water-quality samplers. United States Geological Survey Open-File Report 2005-1087. Vicksbur, M.S. 2005.

Diario Oficial de la Federación. Acuerdo por el que se actualiza la disponibilidad media anual de las aguas superficiales en las cuencas hidrológicas Río San Francisco, Río Grande, Río Manialtepec, Río Colotepec 1, Río Colotepec 2, Río Cozoaltepec 1, Río Cozoaltepec 2, Río Tonameca 1, Río Tonameca 2, Río Copalita 1, Río Copalita 2, Río Coyula, Río Zimatán 1, Río Zimatán 2, Río Ayuta 1, Río Ayuta 2, Río Astata 1, Río Astata 2 y Río Mazatán, mismas que forman parte de la región hidrológica número 21 Costa de Oaxaca. 12 de abril del 2013. Recuperado el 3 de enero de 2023, de https://www.dof.gob.mx/nota_detalle.php?codigo=5295784&fecha=12/04/2013&print=true

García, E. 2004. Modificaciones al Sistema de Clasificación Climática de Köppen. Serie Libros No. 6. México, D.F.: Universidad Nacional Autónoma de México. 2004.

Fraley, L. Methods of measuring fluvial sediment. Baltimore County: University of Maryland. 2004.

Gabale, S. M. y Pawar, N. R. Quantitative morphometric analysis of AmbilOdha (Rivulet) In Pune, Maharashtra, India. Journal of Environmental Science, Toxicology and Food Technology, 9 (7), 41-48. 2015.

Giusti, V. E. y Schneider, W. J. The distribution of branches in river networks. Geological Survey Professional Paper No. 422-G. Washington, D.C. 1965.

Gordon, N. D.; McMahon, T. A.; Finlayson, B. L.; Gippel, C. J. y Nathan, R. J. Stream Hydrology: An Introduction for Ecologists. (2ª ed.). England: John Wiley and Sons. 2004.

Helley, E. J. y Smith, W. Development and calibration of a pressure-difference bed load sampler. U.S. Geological Survey Open File Report, Washington, D.C. 1971.

Horton, R. E. Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. Bulletin of the Geological Society of America 56:275-370. 1945.

Instituto Nacional de Estadística y Geografía (INEGI). Compendio de Información Geográfica Municipal 2010. Villa de Tututepec de Melchor Ocampo. Oaxaca. Recuperado el 10 de diciembre de 2022, de https://www.inegi.org.mx/contenidos/app/mexicocifras/datos_geograficos/20/20334.pdf. 2010.

McCarty, L .B.; Hubbard Jr., L. R. y Quisenberry, V. Applied Soil Physical Properties, Drainage, and Irrigation Strategies. New York: Springer. 2016.

McDonell, J. J. 2003. Where does water go when it rains? Moving beyond the variable source area concept of rainfall-runoff response. Hydrological Processes, 17: 1869-1875. 2003.

Miller, H. Methods and results of river terracing. En G. H. Dury (Ed.), Rivers and River Terraces (pp:19-35). Great Britain: Macmillan. 1970.

Raghunath, H. M. 2006. Hydrology. Principles-Analysis-Design. New Delhi: New Age International Publishers. 2006.

Serrano-Altamirano, V.; Silva-Serna, M. M.; Cano-García, M. A.; Medina-García, G y Ruiz-Corral, A. Estadísticas climatológicas básicas del Estado de Oaxaca. Santo Domingo Barrio Bajo, Etla, Oax.: Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias. 2005.

Strahler, A. N. Quantitative Analysis of Watershed Geomorphology. Transactions of the American Geophysical Union 38(6):913-920. 1957.

Sukristiyanti, S.; Maria, R. y Lestiana, H. Watershed-based morphomeetric analysis: a review. IOP Conference Series: Earth and Environmental Science, 118. 012028. 2018. doi: 10.1088/1755-1315/118/1/012020

Vanoni, V. A. 2006. Sedimentation Engineering. American Society of Civil Engineers. Manuals and Reports on Engineering Practice No. 54. Reston, Va. 2006.

Wohl, E. 2014. Rivers in the Landscape. United Kingdom: Wiley Blackwell. 2014.

Zavoianu, I. Morphometry of Drainage Basins. Develompments in Water Science 20. Amsterdam: Elsevier. 1985.