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MODELIZACIÓN HIDROLÓGICA PARA LA PRODUCCIÓN DE VERTIDOS EN UNA ZONA EXPERIMENTAL DE LA CUENCA DEL RÍO GUAYAS, ECUADOR.

HYDROLOGICAL MODELING FOR THE DISCHARGE PRODUCTION IN AN EXPERIMENTAL AREA OF THE GUAYAS RIVER BASIN, ECUADOR.

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ABSTRACT

Hydrological simulation is a vital issue within the comprehensive management of hydrographic basins, with estimates being an input for decision-making by territorial managers. The objective of the current study is to conduct the hydrological modeling of an experimental basin of the Guayas River, where the discharge of the Baba River will be simulated using the HEC-HMS hydrological modeler. Hereby, the morphometric and hydrological modeling of the basin was performed from a global DEM (ASTER GDEM) in an environment of Geo-graphic Information Systems (GIS) complemented with the analysis of thematic coverage of land types and uses as well as of precipitation data for the sector. The simulation of the discharge of the experimental basin determined that twenty per-cent of the precipitation that fell in the time window of analysis generated direct runoff and the residual eighty percent is attributed to abstractions. This is a condition that is given by the presence of agricultural crops corresponding to seventy percent forest masses, native forest and shrubby vegetation, as well as by the interception processes as well as water catchment systems in the urban area. The adequate results obtained in the application of the HEC - HMS model is based on the previous work of physical and hydrological characterization of the basin expressed through the physiographic structure of the basin and the valorization of the parameters that characterize the hydrological processes. This research tends to be useful for small hydrographic basins in Ecuador that play an important role in the ecosystem and lack of hydrometeorological information.

Keywords: Hydrological, HEC-HMS, Modeling, GIS, Guayas River Basin, Ecuador.

RESUMEN

La simulación hidrológica es un tema vital dentro de la gestión integral de cuencas hidrográficas, siendo las estimaciones un insumo para la toma de decisiones por parte de los administradores del territorio. El objetivo del presente estudio es realizar la modelación hidrológica de una cuenca experimental del río Guayas, donde se simulará la descarga del río Baba utilizando el modelador hidrológico HEC-HMS. Para ello se realizó la modelación morfométrica e hidrológica de la cuenca a partir de un MDE global (ASTER GDEM) en un ambiente de Sistemas de Información Geográfica (SIG) complementado con el análisis de coberturas temáticas de tipos y usos de suelo, así como de datos de precipitación para el sector. La simulación de la descarga de la cuenca experimental determinó que el veinte por ciento de la precipitación caída en la ventana de tiempo de análisis generó escurrimiento directo y el ochenta por ciento residual se atribuye a abstracciones. Esta condición está dada por la presencia de cultivos agrícolas que corresponden al setenta por ciento de las masas forestales, bosque nativo y vegetación arbustiva, así como por los procesos de intercepción y los sistemas de captación de agua en la zona urbana. Los adecuados resultados obtenidos en la aplicación del modelo HEC - HMS se basan en el trabajo previo de caracterización física e hidrológica de la cuenca expresada a través de la estructura fisiográfica de la cuenca y la valorización de los parámetros que caracterizan los procesos hidrológicos. Esta investigación tiende

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a ser útil para cuencas hidrográficas pequeñas del Ecuador que juegan un papel importante en el ecosistema y que carecen de información hidrometeorológica.

Palabras clave: Hidrológico, HEC-HMS, Modelación, SIG, Cuenca del Río Guayas, Ecuador.

INTRODUCTION

A hydrographic basin is a dynamic, natural unit that reflects close relationships between soil, water, and vegetation (Caylor et al, 2005). Its morphometric analysis and its drainage networks provide relevant hydrological information that can be applied later to the study of fluvial dynamics and processes (Gil V., Gentili J., Campo A. ,2009). In Ecuador, a country impacted by a variety of hydrometeorological hazards, the Guayas river basin presents a very important fluctuation in the hydrological flows of its territory as a consequence of the variation in precipitation determined by its two climatic seasons, the pressure for irrigation for agricultural activity, the change in land use, its important altitudinal gradient and the topographic characteristics of the terrain (Damanik-Ambarita, M. N., Boets, P., Thi, H. T. N., Forio, M. A. E., Everaert, G., Lock, K., & Goethals, P. L. (2018). The Baba River, the main drainage network of the studied basin, presents discharge variations that are related to the winter and summer periods (Hidalgo-Bastidas, J. P., & Boelens, R., 2019). Hereby, the average discharge of the years 2000 - 2012 for the months of January - April correspond to the winter months, yielding 4000 m3/sec per year while for the dry season (May to December) it is of about 200 m3/sec per year (Muñoz, 2021).

The modeling of discharges in very dynamic hydrographic basins, both due to natural and anthropic effects, this being the case of the Guayas River basin, is fundamental for decision-making within the management and use of the basin that allows the maintenance of its ecosystem and environmental services (Arce et al., 2018). At present, it is no longer enough to review the readings of the equipment that are determined by the data of the different hydrological parameters (Reyes et al, 2018). Nowadays, it is possible to advance to the simulation of data and future scenarios based on the advancement of technology in the field of applied computing, that allow the development of mathematical models for simulating high-precision values that are very similar to reality (Merkuryeva, 2015). Hydrological modeling is an important tool for the study of river basins that has spread throughout the world, mainly in developed countries (Kusre, Baruah, Bordoloi & Patra, 2010). This allows the analysis and prevention of floods, managing sufficiently realistic or foreseeable hypotheses that offer a certain degree of confidence for decision-making, whether in land use planning around rivers or to demand criteria for the design of works and infrastructures capable of supporting and functioning adequately in situations of danger due to intense rains (Moncayo, Robayo, Padilla & Toulkeridis, 2023).

There are several hydrological modelers at present, being the Hydrological Modeling System of the Hydrological Engineering Center of the US Army Corps of Engineers (Oloche, 2010) the one that was applied in the present investigation (Ogden, Downer & Meselhe, 2003). This is a program of a free computational system that is widely used internationally in the hydrological study of watersheds, being characterized by integrating a variety of options to simulate processes of precipitation - runoff and flow transit (Feldman, 2000). The HEC - HMS is a mathematical watershed modeler that contains several methods with which surface runoff, river/reservoir flow, and watershed flows can be simulated (Chu & Steinman, 2009). The HEC-HMS software uses precipitation-runoff methods to estimate direct runoff hydrographs generated by rainfall in a basin during a specified period, being a very flexible program that allows the user to select different methods for calculating losses, hydrographs, base flow, and propagation in channels. It also allows simulating hydrological processes at event level or continuously (Knebl, Yang, Hutchison & Maidment, 2005).

Geographic Information Systems (GIS) allow the integration of the different soil and topographic characteristics of hydrographic basins, being specialized computer systems that facilitate the treatment of hydrological information thanks to their ability to capture, store, manipulate, analyze, modeling and presentation of georeferenced data (Wolock, Winter, & McMahon, 2004). The contribution of the GIS can be incorporated into the decision-making process and in the planning of the territory (Llorca & Toulkeridis). Thus, the GIS constitutes an adequate instrument to respond questions related to the spatial distribution and the temporal series of the runoff within the modeling. hydrological (Estrada, 2012). The hydrological simulation of a basin with the HEC-HMS software application includes different components, such as basin model, meteorological model, control specifications and input data. The simulation calculates the rainfall-to-flow transformation in the catchment model based on the input from the weather model while the control specifications define the time period over which the simulation will run and the time interval to use. Input data components, such as time series, tables, and cell data, are required as parameters or boundary conditions in both the catchment and meteorological models (Wang, Liu & Yang).

The present study aims to perform the hydrological modeling of an experimental area of the Guayas River basin of coastal Ecuador, where the discharge of the Baba river will be simulated using the HEC-HMS hydrological modeler. The hydrological modeling will require the determination of the basin model, which covers the delimitation of the experimental area or specific hydrographic basin of study where its soil, morphometric, topographic, use and land cover characteristics will be resolved. The meteorological model that includes precipitation data and the control specifications where the modeler is parameterized according to the time interval to be modeled.

The time period used for the present work covered a temporal window of thirteen years, from January 2003 to December 2016, a period in which pluviometric and flow data from stations in the area of influence of the study basin were considered.

METHODOLOGY

THE BASIN MODEL.

The basin model is a component that defines the hydrological elements of the system. In the present case it is limited to sub-basins and delivery points at the catchment site, which is where the watershed was closed. Once the elements of the water network have been defined, the information for each basin is entered. Specifically, the loss estimation method is defined in order of execution, the rainfall-flow transformation method, and the base flow determination method. Then we proceed with the entry of the parameters that correspond to the sections of currents depending on the selected method. In this case, the modified Soil Conservation System (SCS) curve number method was selected for the separation of rainfall and runoff calculation, and the unit hydrograph method was used for the transformation of runoff into discharge (Wang, Liu, Yang, 2012).

WEATHER MODEL.

Before defining the meteorological model, the precipitation and evaporation data are entered, in this case it corresponds to the precipitation increments obtained from the average hyetogram for each month. An evaporometric tank coefficient of 0.7 was taken for the calculations of water losses by evaporation. Once the hyetograms and evaporations for each month were introduced, the meteorological model was defined, which consists of determining the rain to apply with its respective evaporation and the period in which it will be applied (Andersen, Foster & Pratt, 1999).

CONTROL SPECIFICATIONS.

In the control specifications, as also realized in previous models, it is assigned a name, (arbitrary) dates, rain times and defined intervals. With a certain basin model and with a selected meteorological model, the model can already be run for different time intervals or with different increments. Finally, the previous components are marked, the basin model, the meteorological model, and the desired control specifications, then the program is executed to perform calculations and to generate results. Collection of basic information are used to the unit hydrograph method for the transformation of runoff into discharge (Huang, Cheng, Wen & Lee, 2008).

All the cartographic, hydrological, hydrographic, physical, and geographic information required by the HEC - HMS model was collected, which, once compiled and analyzed, became the basic information from which the other calculations were derived.

MORPHOMETRIC CALCULATIONS AND OF THE HYDROLOGICAL CURVE NUMBER (CN).

It was necessary to calculate the morphometric parameters such as area (A), length of the main channel (Lcp), average slope of the main channel (Scp), concentration time (Te), delay time (Tlag), hydrological curve number (CN) (Pal et al., 2012; Nidhi et al., 2017; Masoud, 2016). For the calculation of the CN by sub-basins, the thematic maps of current land use and soil type were used, which were crossed in ArcMap to obtain a thematic map that provided polygons of the same type of soil and cover. Subsequently, a characterization of the soils present in each sub-basin1 was conducted, with which information on slope, texture and natural drainage was obtained for each of the polygons. With this information, a
soil hydrological group was assigned to each of the polygons. Finally, with the information on the coverage and hydrological group of soils of each polygon and by using tables of specific content, the CN value was calculated for each one of them, which was weighted with respect to the total area of the basin.

MODEL CALIBRATION.

For the calibration of the present work, two annual rainfall series were used within the total series. total series. In both cases, the identification of the parameters for the calibration was performed manually by the trial and error method. Subsequently, it was checked automatically using the Objective Function included in the Optimization tool of the HEC-HMS software.

In order to enter the observed flow data into the HEC-HMS model and comply with the calibration and validation tests, the gauging measured at the Quevedo Baba station was used, which has a series of measurements from January 2003 to December 2016 corresponding to daily observations; this information was provided by INAMHI and sent via e-mail upon request.

STUDY AREA

The present investigation was developed in the Guayas River basin in western, coastal Ecuador. There are extends between the parallels 00º 14' S, 02º 27' S and the meridians 78º 36' W, 80º 36' W, covering partial or total territories of eight of the twenty-four Ecuadorian provinces, being Guayas, Los Ríos, Manabí, Santo Domingo de los Tsáchilas, Cotopaxi, Bolívar, Chimborazo, and Cañar (CISPDR, 2015). In turn, the provinces of Guayas and Los Ríos together represent 48% of the surface of the basin and 72% of its population. The total area covers approximately 32,219 km2 (Fig. 1).

In the northern sector of the Guayas River basin, an experimental area corresponding to a micro-watershed was delimited that was located in the province of Los Ríos at the centroid of latitude 1° 1'47.18"S and longitude 79°26'39.81"W, the same that was delimited from the use of surface analysis tools in the raster GIS (Fig. 2).

The methodology presented in the current study aims to provide guidance on how both the data management phase with GIS was developed, as well as the application of the HEC-HMS model to simulate the discharge of the Quevedo River. The methodology can be divided into four main tasks, being (1) obtaining the geographic information and location of the studied basin (2) DEM processing, watershed delineation, morphometric characteristics, and terrain processing (3) importing the data processing to HEC-HMS and finally (4) model simulations. To run the hydrological simulation model, the global ASTER GDEM digital terrain elevation model (DEM) (METI & NASA, 2022) was used, as well as precipitation meteorological data from the Pichilingue station provided by the National Institute of Meteorology and Hydrology (INAMHI), with a land use coverage at a scale of 1:100,000 prepared in 2015 by SENPLADES - MAGAP (MAGAP, 2015) as well as soil texture coverage at a scale of 1:25,000 from the pedological map prepared in 2020 by MAGAP.

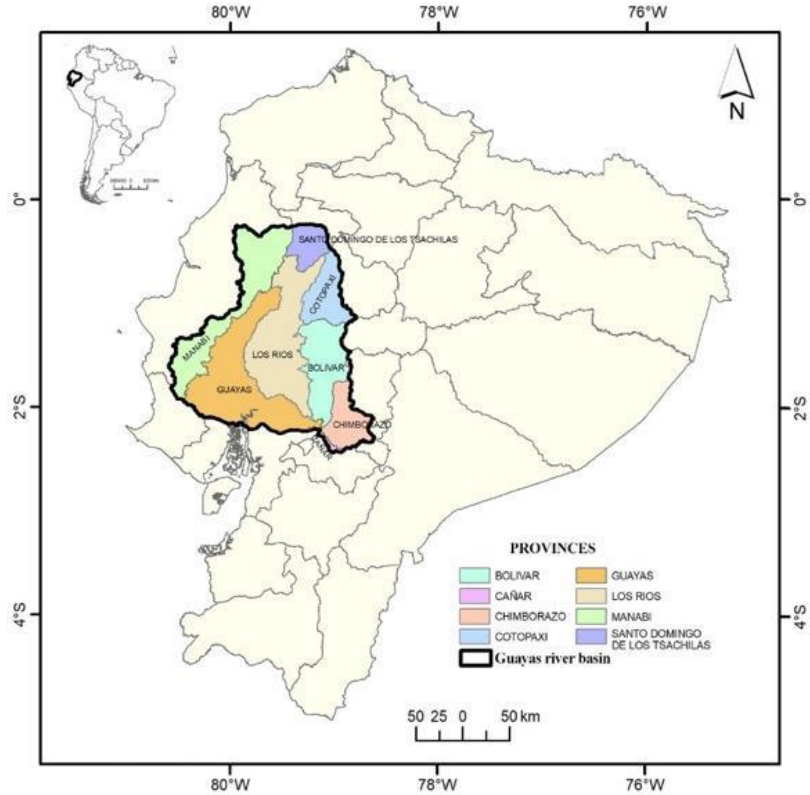

Figure 1. Guayas river basin. Source: Own elaboration.

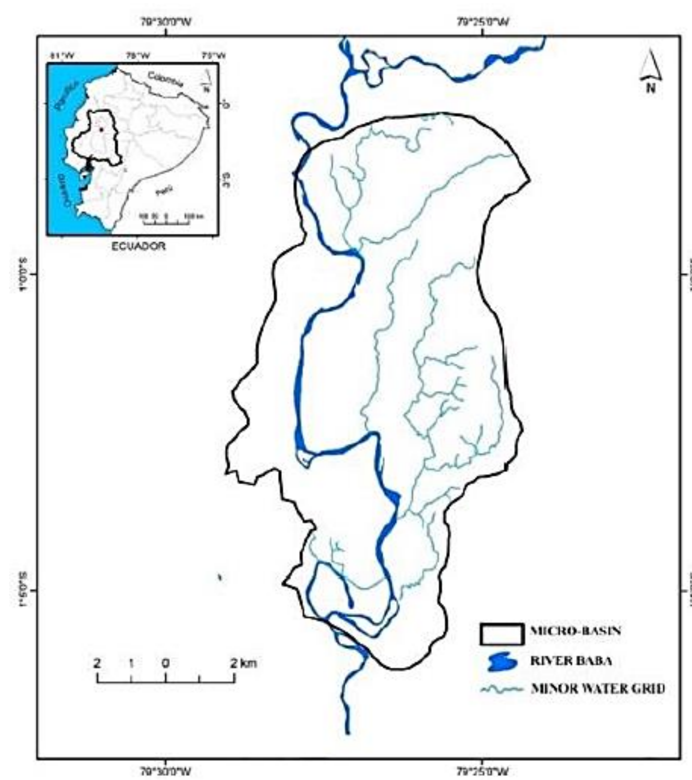

Figure 2. Area of the experimental basin. Source: Own elaboration.

RESULTS

The physical model of the basin uses as input a digital elevation model (DEM) of global extent, ASTER GDEM, which was delimited by the GIS ArcMap 10.4.1 software with the Spatial Analyst Tools and the "Hydrology" toolbox (Fig. 3) allowing the delineation of the drainage network patterns of the basin (Ceconi, Allasia, Bernardi, Fensterseifer, 2018).

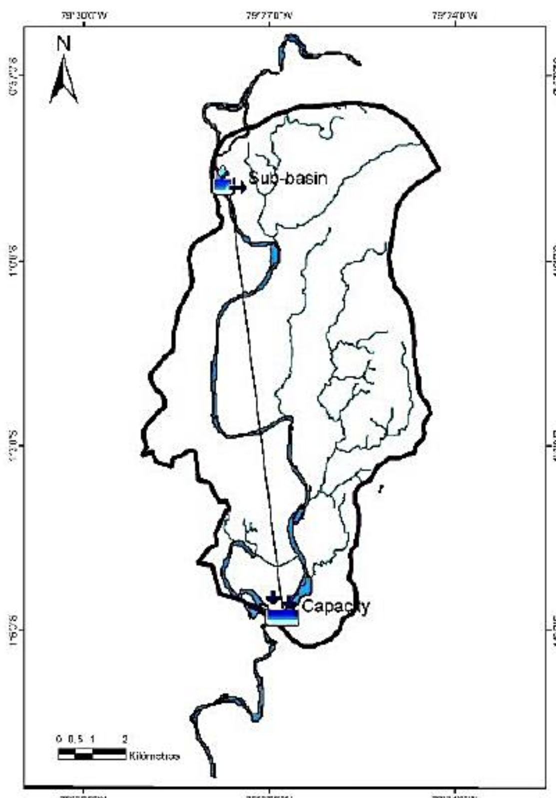

Figure 3. From the sub-basin towards capacity. Source: Own elaboration

Figures 4 a, 4 b, 4 c and 4d illustrate the altitude, slope, soil texture and land use coverage of the sample basin. However, the components of the model work based on simple mathematical relationships that try to represent the processes involved in the generation and circulation of runoff hydrographs such as losses, transformation of excess rainfall into outflow from the basin, addition of base discharge and circulation of the hydrograph through the channel (López et al., 2012) The HEC-HMS hydrological modeler, as illustrated Fig. 5, uses four vital components for discharge simulation, these being the model basin, meteorological model, control specifications and time series data.

Table 1 lists the morphometric parameters of the experimental basin obtained from the DEM modeling (ASTER GDEM).

Parameters	UNIT (km.)
Area (km)	91.43
Perimeter (km)	46.81
Length of the main course (km)	20.02
Alt max (m)	111
Alt min (m)	35
Pending main course (km)	0.3796
Height difference (m)	76
Circle diameter (km)	7.32909
Distance from the environment (km)	2.09

Table 1. Morphometric parameters of the experimental basin. Source: Own elaboration.

The effective precipitation is the fraction of the total precipitation that is transformed into direct runoff, the rest of the precipitation is considered as losses. As the HEC-HMS has different methods for the calculation of the losses, for the present investigation we applied the method of the SCS Soil Conservation Service, or also called the CN curve number, for having information on the use and type of soil with an appropriate scale. It should be noted that this method was developed by the US Department of Agriculture to estimate losses in a rain or downpour event (Mockus, 1969). The curve number varies in the range from 0 to 100 and depends on factors that influence runoff generation in the basin, such as hydrological type of soil (Hydrological group-Drainage capacity), land use and management, soil surface condition and its moisture condition.

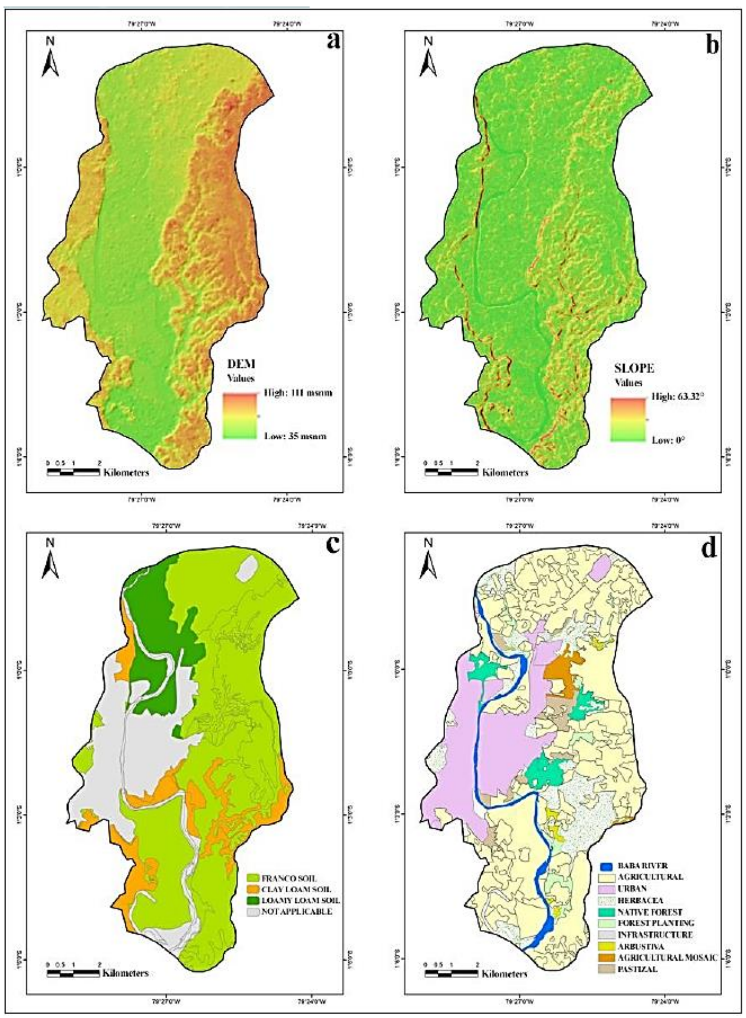

Figure 4. Altitude, slope, texture, and land use of the experimental basin. Source: Own elaboration.

Figure 5. Components of the HEC - HMS hydrological modeler. Source: Own elaboration.

In Fig. 6 the hyetogram of the flow simulation is presented, demonstrating in the upper part in red tone that begins with infiltration and then gives way to runoff. In addition, it can be noted that the precipitation in the experimental basin presents its peak at 06:00 and then begins to drop to its minimum level.

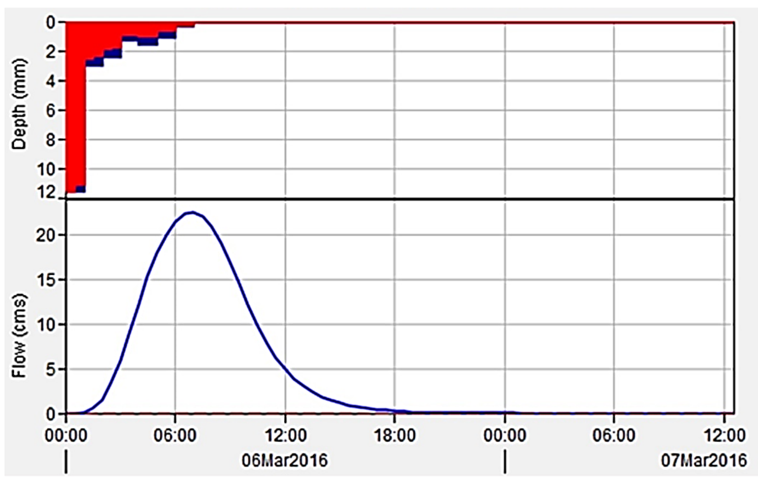

Figure 6. Hyetogram of the experimental basin. Source: Own elaboration.

DISCUSSION

In the Yumbo river basin, Valle del Cauca in Colombia, a 0.89 correlation coefficient was obtained with the average data from the Pasoancho hydrological station and the estimated values in the modeling (Escobar et al., 2007), which indicates a high approximation to the real data, determining that the quality of the modeling results depends on the degree of reliability of the information used for the model. In the estimation of discharges for the Toachi river basin located in the upper part of the northeast of the Guayas River basin (Tapia, 2012) determined that the validation results are acceptable where the distribution of the flood is represented in a very approximate way to reality, being the peaks and the minimum flows represented in the modeling. The adequate results obtained in the application of the HEC - HMS model in the Arga river basin in Pamplona, Spain in the last 10 years, validate the previous work of physical and hydrological characterization of the basin expressed through the physiographic structure of the basin and the assignment of values to the different parameters that characterize hydrological processes (López et al., 2012).

The modeling of the digital elevation model (DEM) of global origin (ASTER GDEM)

together with the use of the land and the hydrological groups allowed to determine the Curve Number
(CN) of the experimental area, to later be used in the HEC-HMS hydrological model and obtain the simulated discharge and the outlet hydrographs of the experimental basin. The conceptual model of the unitary basin is sufficient to carry out the modeling of small basins with a certain scarcity of information, homogeneity of physical-geographical and climatic characteristics, in order to obtain information on flows that allow decision making within the framework of the integrated management of water resources, risk theory and mitigation of adverse effects in the territory. However, the unitary basin is sufficient for modeling small basins that present scarcity of information, homogeneity of physical-geographical and climatic characteristics (Heredia et al., 2021). The application of the Integral Hydrometeorological Scheme for HEC-HMS allows the reduction of drawbacks in the management of hydrometeorological information (Nadeem et al., 2022).

Applying the methodology based on the HEC-HMS hydrologic modeler allowed obtaining results that presented an acceptable adjustment when compared to the values observed at the Pasoancho hydrometric station (Escobar et al., 2007). In many cases there is a lack of flow rates of the main sources and their tributaries, either average or minimum maximums and for different time intervals. It is in these cases that continuous hydrological modeling is presented as a good alternative to generate the flow rates of the sources at specific points, based on basic information such as rainfall series, type and land use, as well as the morphological characterization of the basin (Naranjo y Duque, 2004). The Faculty of Engineering of the Universidad Francisco de Paula Santander in Cúcuta presented the geomorphological modeling of the El Guamal and La Morena micro-watersheds using geographic information systems (GIS), specifically Digital Elevation Models (DEM); this modeling was carried out with the use of the HECGeoHMS extension loaded in Arc View GIS 3.2 software (Caicedo y García, 2004). Nonetheless, the geospatial interface module HEC-GEO-HMS (Geospatial Hydrologic Modelling System Extension), developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers as an extension of the ARCGIS GIS, allows the generation of watershed characterization information and hydrologic input parameters for the HEC-HMS model (Doan, 2003).

CONCLUSION

The processing of a cartographic model for the Baba River basin in the northern sector of the province of Los Ríos with the support of GIS gave way to the creation of a complete georeferenced cartographic base of the area whose thematic axes were the topography, drainage network, soil texture and current land use, in this way it was possible to carry out the hydrological simulation of the flow of the study area.

The applied methodology adequately responds to the central objective of this study, the SCS Curve Number method is applicable for basins smaller than 250 km2, the CN curve number is the most sensitive parameter in hydrological modeling, so Its estimation must be as accurate as possible based on soil thematic cartography of an appropriate scale, since its variation has a great effect on the value of the simulated discharge.

Furthermore, from the sensitivity analysis, the curve number and the lag time were determined as sensitive parameters. Hereby, the results obtained establish that of the total precipitation fallen in the basin, twenty percent generates direct runoff, and the rest is attributed to abstractions, a condition given by the presence of agricultural crops corresponding to seventy percent forest masses, native forest and vegetation, shrubland, as well as interception processes, surface storage, evaporation, evapotranspiration, and water collection systems in urban areas.

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