Origin of channels using digital surface models in the upper watershed of the Vinces River (Santo Domingo de los Tsáchilas, Ecuador)

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SUMMARY
The definition of the hydrographic network of a basin merits the precise location of the beginnings of the channels since this position has an important influence on the dynamics of a hydrographic basin. Geographic Information Systems (GIS) together with Digital Surface Models (DSM) allow the location and extraction of drainage networks in an automated way, however, these results often require verification in the field or in different sources of information to validate and achieve high accuracy. The objective of this research is to determine and evaluate the best threshold for locating the beginnings of channels in the upper basin of the Vinces River (province of Santo Domingo de Los Tsáchila in Ecuador) using a Digital Surface Model (DSM). The evaluation of the accuracy of the automatic models obtained was compared with the results obtained from high-resolution satellite images and field control campaigns. The main results indicate variations in both the length and the number of sections according to threshold that have an impact on the results of the work. It is very important to choose an optimal threshold to obtain the drainage network model closest to the territorial reality and from there to obtain reliable and functional data.
Keywords: Hydrographic network; Vinces River; Digital Surface Model; satellite image.

INTRODUCTION
Horton (1945), Montgomery & Dietrich (1988, 1989, 1992), Montgomery & Buffington (1993), Montgomery & Foufoula-Georgiou (1993), Dietrich & Dunne (1993), Jenson & Domingue (1988), Dietrich et al. (1992) and Willgoose et al. (1991, 1992) pointed out the importance of recognizing the beginnings of channels in the terrain to explain the processes that control their formation allowing them to be able to manage, protect and restore them, they also indicated that their location helps to understand the functioning of the basin, considering the important relationship that their location has to the hydrological response.
At present, the identification and analysis of the areas of origin of the channels has not been as valued compared to hydrogeomorphological analyses carried out in the downstream system (Gomi et al., 2002). However, several works that continue in the line of research can be included in which different methodologies, models and procedures applied to the location, analysis and management of channel sources are proposed and discussed, of which Hancock & Evans (2006), Jaeger, Montgomery & Bolton (2007), Tarolli & Dalla Fontana (2009), Henkle et al. (2011), Wilson (2012), Lindsay & Seibert (2013), Wohl (2018), and Cazzador et al. (2021).

In the present study, it began with the delimitation of the hydrographic basin, defining its drainage network in order to know precisely the location of the beginnings of its channels, considering that this is very important in determining the density of concentrated drainage and also determines the distances and return times that govern the magnitude and concentration of runoff (Senciales González, 1999; Nachtergaele et al., 2002; Charlton, 2008; Gutiérrez Elorza, 2008; Munro, 2010). For Henkle et al. (2011), the identification of the beginnings of flows in the field can be relatively visible, being represented by an abrupt break or cross-section to the ground, or be so diffuse or gradual that their identification becomes somewhat subjective and can even be confused with other geoforms, while for Montgomery & Dietrich (1988, 1989) The beginning of a channel is the site that represents the transition from slope processes to channeled hydrosedimentary processes and that its location is linked to the physical characteristics of the environment such as area, slope, lithology, vegetation, climate, land uses, etc. The complex task of carrying out the reconnaissance of each of them in the field must be considered, the difficulty of which will depend on the area and slope of the basin and access to them.

Currently, the development of Geographic Information Systems (GIS) and the evolution of satellite sensors that made it possible to create Digital Surface Models (SDM) of global scope with high accuracy and resolution have made it possible to leave behind the traditional methods of digitization of drainage networks, replacing them with more advanced methodologies (López-Vicente et al., 2014; Nikolakopoulos et al., 2015; Kok et al., 2018; Shavers & Stanislawski, 2020). The availability of new technologies for measuring the elevation of the earth's surface has addressed the absence of high-resolution data, which has led to an increase in the use of this type of tools in the performance of hydrological and hydraulic modelling studies.

In the definition of drainage networks, the Digital Surface Model (DSM) only considers the height variable, so it is necessary to verify in the field or in different data sources the models obtained to achieve the greatest precision of the start and development of the networks. The upper basin of the Vinces River, due to its very typical physical conditions, there are numerous factors that intervene in the formation of a channel and in many cases make it difficult to recognize, therefore, the premise of this study is to determine and evaluate the optimal threshold for locating the beginnings of the channels of the upper basin of the Vinces River (province of Santo Domingo de Los Tsáchilas) through the use of an MDS complemented with several evaluation methodologies that will allow evaluating and determining the optimal model according to the reality studied for its subsequent application to water hazard studies.

MATERIALS AND METHODS

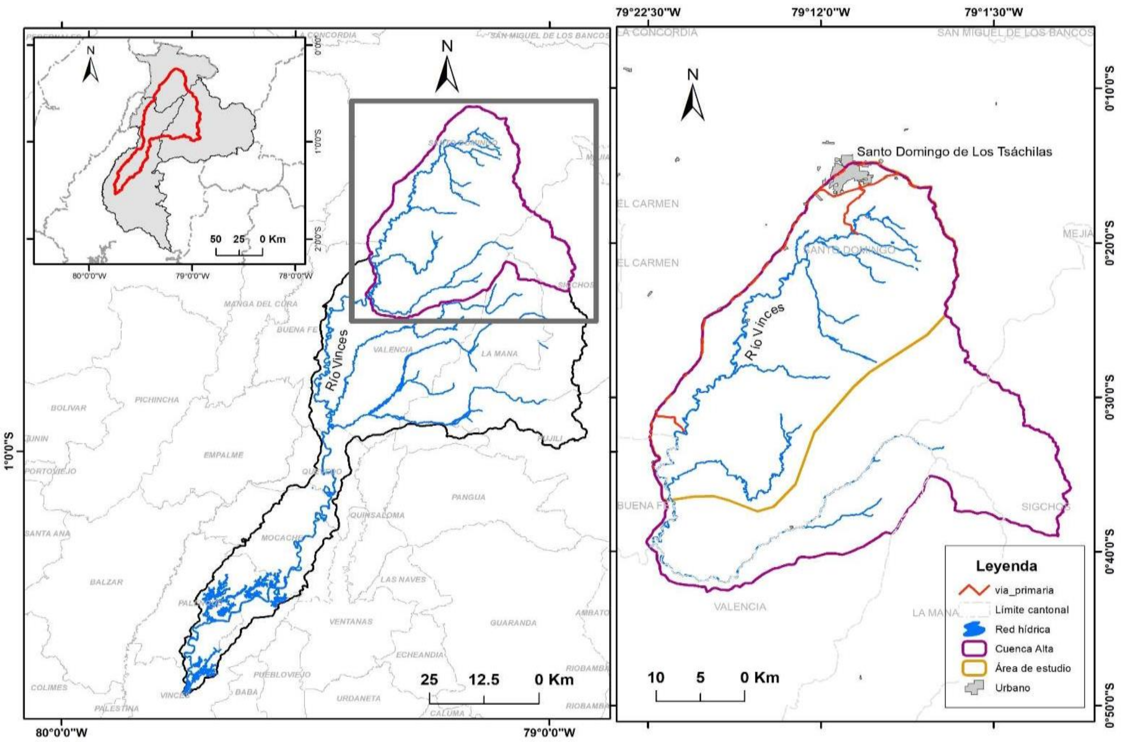
Study Area

The Vinces River basin is located from the northeastern sector to the center of the Guayas River basin, extending for 4,268 km². It takes its name from the river that crosses it, the same that takes different names depending on the canton through which it crosses, so we have that at the height of the Quevedo canton it is known as the Quevedo river, then in the Mocache canton it is called the Mocache river and finally when it crosses the palenque and vinces cantons it is identified as the Vinces river (Muñoz, 2021). It should be noted that the Quevedo River is formed from the convergence of three rivers: Baba, Lulo and San Pablo (Figure 1).

The Vinces River, the main drainage network of the basin, presents variations in flows that are related to the winter and summer periods, as can be seen in Figure 2: the average flow of the years 2000 - 2012 for the months of January - April corresponding to the winter months is 4000 m^3/sec per year, while for the dry months between May and December it is 200 m^3/sec per year.

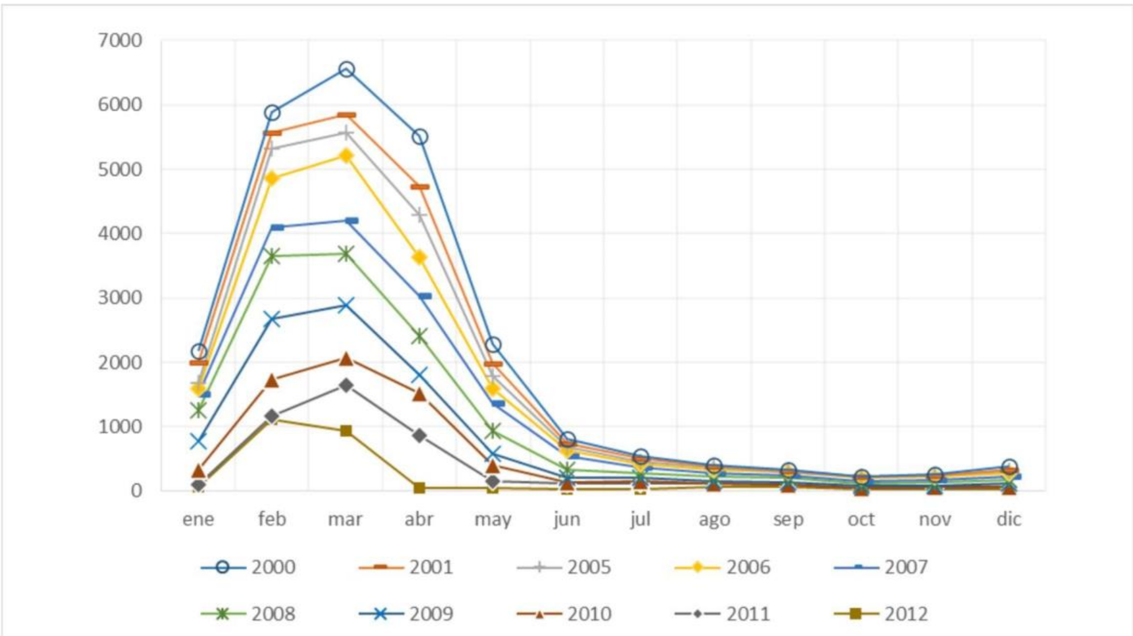
The characteristic lithology of the study area in 72% are coarse-grained volcanic sandstones, breccias, tuffs, hyaloblastites, volcanic siltstones, microgabbros-diabases, sub-porphyritic basalts, lavas in pads and scarce calcarenites and pyroclasts and surface alteration kaolin (MAGAP, 2020) that are part of the Macuchi formation of volcanic origin with loam-sandy textures on its surface and at depth. The riverbeds in the area are full for most of the year.

Figure 1. Study Area



Source: Prepared by the authors on the basis of the 1:50,000 (IGM) charts - INEC

Figure 2. Average flows (m^3/s) year 2000-2012 Vinces basin



Source: Prepared by the author based on INHAMI, 2016

To meet the proposed objective, the beginnings of the channels of the La Ventana stream were visually identified in satellite images extracted from Google Earth Pro® from 2022 previously georeferenced (scale 1:2,000). In order to corroborate this visualization, some of these points were verified in the field. The points were displayed in a vector layer in the ArcGIS® software and were used as guides for the location of the beginnings of channels in the automatic extraction of the hydrographic network.

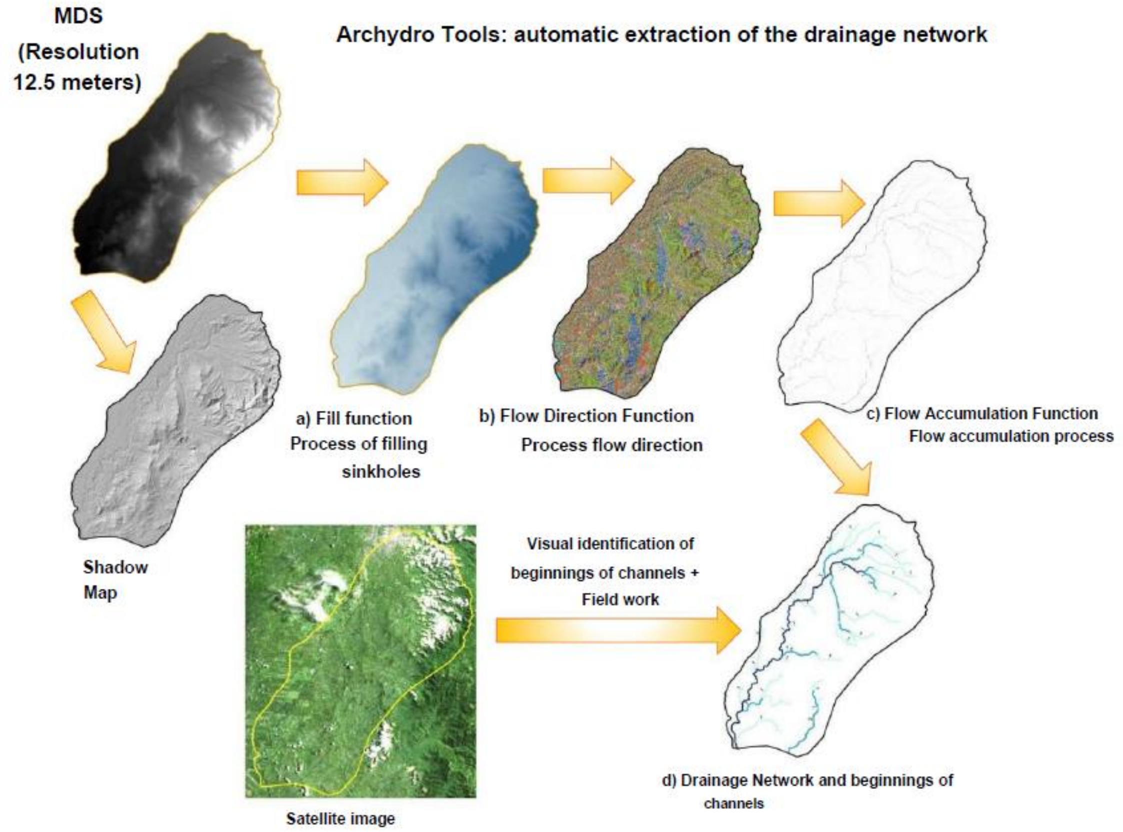
Automatic extraction of the drainage network was carried out using ArcGIS® Arc Hydro tools and processes (sump filling, flow direction, flow accumulation, flow definition) and was based on the MDS that comes from the Japanese Alos Palsar satellite of 12.50 x 12.50 meters. To evaluate the optimal threshold or number of cells in the definition of the flow according to reality, different thresholds (1,000, 500, 300 and 150 pixels) were used as a test, the results of which were compared with the layer of the beginnings of the hydrographic network identified in the satellite images.

RESULT AND DISCUSSION

Determination of optimal threshold and generation of drainage network

Figure 3 presents the stages and the schematization of the results to define the channels derived from the use of Arc Hydro tools of ArcGIS®. First, the fill tool (Figure 3 a) was applied to the MDS to obtain a correct matrix. In this way, artificial depressions, holes or any other type of error that behaves as a barrier to the fluidity of the course are eliminated. (Ngula et al., 2019). Then, through the "flow direction" command (Figure 3b), a runoff direction pattern was created from each cell to its highest downhill slope. The model applied for this process was the D8, which considers a single pixel and incorporates its eight neighboring pixels, that is, its 8 valid output directions, and was selected because it is the most widely used procedure for automatic flow extraction (Maidment, 2002; Li et al., 2020). Through its analysis, it is possible to determine the direction of the descent with the greatest slope; when it recognizes it, the output cell is encoded with the value that that address represents (Ariza-Villaverde et al., 2013; Nikolakopoulos et al., 2015).

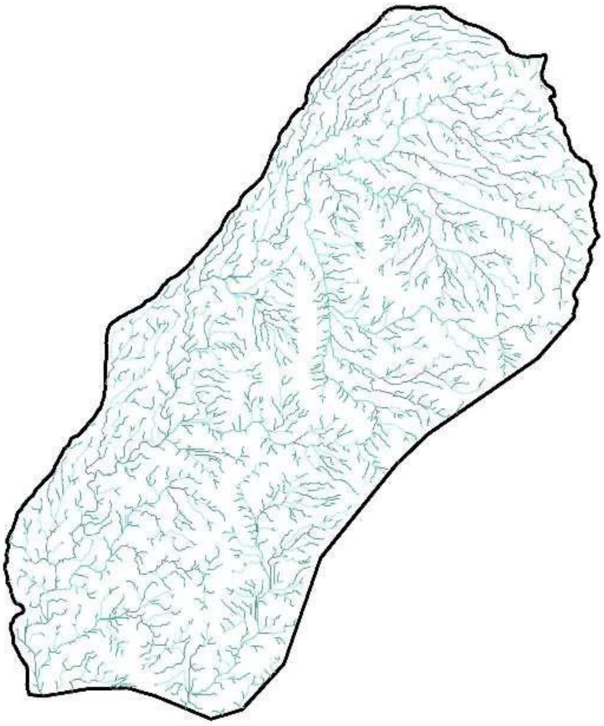
Figure 3. Stages and schematization of the methodology and processes applied to the determination of channel beginnings in the upper basin of the Vinces River



Using the "Flow Accumulation" tool (Figure 3c) the amount of water flowing within each cell from all downward-slope cells in the output raster was calculated. Here you can see the accumulated volume of the draining cells, that is, the cells are draining to a specific point identifying the main course and its tributaries. The thresholds associated with the number of cells or area that are taken into account for the generation and the density of the flow (number of branches) were defined. A very high value will result in the generation of a few major flows, while a very low value will generate a large number of extremely small flows (Nikolakopoulos et al., 2015). To obtain the different drainage networks, thresholds of 1,000, 500, 300 and 150 pixels were used. The selection of the threshold is associated with a certain area in km² from which a channel is defined, for example, in the particular case of the threshold of 1000 pixels, the points that receive flow from an area of at least 0.156 km² are considered as channel beginnings.

Once the drainage network for each model was obtained and hierarchical, the results were compared and validated. In the first measure, a visual verification was made with the points identified as the beginnings of channels in the satellite images extracted from Google Earth Pro®. In the latter source, 50 channel starts were located, of which 45 coincided with those extracted automatically through the MDS (Figure 4). The system identified networks that are not consistent with reality and this may be due to the fact that the MDS considers only the height variable and assumes that all drainage lines are channels when in reality other variables such as slope, lithology and its structure, vegetation, among others (Nikolakopoulos et al., 2015).

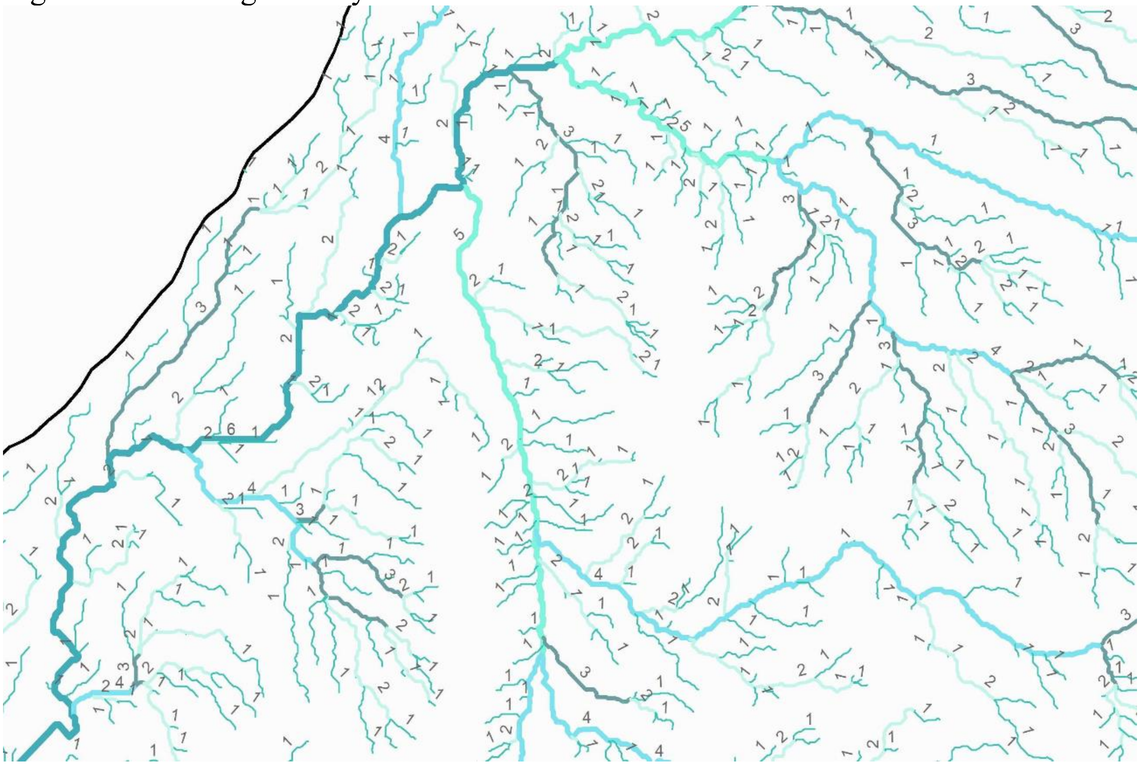
Figure 4. Location of channel beginnings and definition of drainage network according to threshold



In the box in Figure 5 it can be seen that the drainage network that was obtained through the threshold of 1000 pixels is the one that comes closest to reality and is consistent with the location of the beginnings of channels determined by observing satellite and field images. On the other hand, in the drainage network obtained through the threshold of 150 pixels, the river courses begin on average about 300 meters downstream from the beginnings identified in the satellite image. The lower the threshold selected to extract the drainage network, the beginnings of channels were obtained less close to their location in the basin.

To obtain the lengths of the sections of each drainage network, the Stream Link tool was used, which allowed each flow segmentation raster to be vectorized and converted into a layer of continuous drainage lines divided into orders. The total length extracted from the channels varied in a range between 129.9 (150 pixels) and 63.14 kilometers (1000 pixels) (Figure 5).

Figure 5. Length of drainage networks in square kilometers and determination of order 1 segments according to analyzed thresholds



The vectorization of the model derived from the 150-pixel threshold did not allow to obtain a coherence in both the quantities and the lengths of the river courses according to their orders, which may be due to the level of detail derived from the large number of pixels used.

CONCLUSIONS AND RECOMMENDATIONS

This study consisted of the application of a methodology for the automatic extraction of the drainage network of the upper basin of the Vinces River in the province of Santo Domingo de Los Tsáchilas through the use of an MDS with special importance of the location of the beginning of the channels. The importance of choosing an optimal threshold to obtain the drainage model that is most in line with reality and from which valid and concrete data can be extracted for use in the future calculation of morphometric indices of the basin was verified.

Through the analysis and comparison of results obtained from different data sources and verification methodologies, it was possible to establish that although, for the particular case of the study area, the threshold of 1000 pixels was optimal in the approximation of the beginnings of channels to reality. The network obtained through the threshold of 150 pixels is the model from which less precise data were obtained. Therefore, it is concluded that the use of a certain threshold will depend on the objective of the work required.

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