# The Use of Digital Elevation Models and Orthoimages for the Determination of Riverbeds of Hydrographic Basins in the Zone of Tixtla, Guerrero

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**Key words**: Geospatial information, Digital Elevation Model, Geographic Information System, Modeling, Hydrography, Disasters.

**SUMMARY**

The National Institute of Statistics and Geography (INEGI) of Mexico aims to produce data and geospatial information, in order to provide society and the State with quality, pertinent, truthful and timely information, in order to contribute to national development. This derives by law, that the INEGI generates groups of geospatial data, whose use allows to support the decision making of national scope, such as the prevention and attention of disasters, security and civil protection, land use planning, planning and construction of buildings and infrastructure , topography, communications and transportation, and for various projects, objectives and purposes, whose purpose is to be useful for the design, implementation and evaluation of public policies for the advancement and development of the country.

Currently, with the diversity of detection technologies, processing and innovative approaches related to geospatial data, the INEGI has produced digital information of the relief and images of the national territory, these data reach their maximum potential when they are spatially related in Geographical Information Systems (GIS), to offer users and specialists a range of options in the modeling and analysis of the territory with a close approximation to reality and with the variants and advantages offered by computer technology, nowadays applied to digital topography.

Through the presentation of this work, processes with geospatial information from INEGI are disclosed to promote the concurrence and use of this for the determination of riverbeds in the zone of Tixtla, Guerrero, a place where there is a high risk due to floods due to extreme or extraordinary rainfall that occur due to the effects of climate change that we are experiencing and that result in runoff with water flows that cause effects on the population and that, through the use of relief data in Digital Elevation Models (DEM) and its use in GIS, are of great importance, not only in the combination and integration of geospatial data, but also in the ability to extract digital information regarding the riverbeds or runoffs necessary to perform hydrographic modeling; This through spatial operations used for this purpose through the use of terrain-type DEMs that allow modeling the interaction between the shape of the terrain and its water and sediment transport processes, and thereby obtain additional geospatial information to analyze the environment of this hydrographic basin in Tixtla.

Therefore, by providing elements to the specialists in charge of and responsible for civil protection and disaster prevention, having complementary information on the prevention of possible risks due to the presence of hydrometeorological phenomena that cause floods, it is possible to promote a culture of safety and self-protection in the citizens themselves, as well as moving towards better living conditions, facilitating the response capacity of the communities themselves in the presence of any disturbing phenomenon or agent that could affect the security of the population of Tixtla, Guerrero.

**RESUMEN**

El Instituto Nacional de Estadística y Geografía (INEGI) de México tiene como objetivos el producir datos e información geoespacial, con la finalidad de suministrar a la sociedad y al Estado información de calidad, pertinente, veraz y oportuna, a efecto de coadyuvar al desarrollo nacional. Esto deriva por ley, que el INEGI genere grupos de datos geoespaciales, cuya utilización permita apoyar en la toma de decisiones de alcance nacional, como la prevención y atención de desastres, seguridad y protección civil, ordenamiento territorial, planeación y construcción de edificaciones e infraestructura, topografía, comunicaciones y transportes, y para diversos proyectos, objetivos y fines, cuyo propósito es que sean útiles para el diseño, la implementación y la evaluación de políticas públicas para el avance y desarrollo del país.

Actualmente, con la diversidad de tecnologías de detección, procesamiento y enfoques innovadores relacionados con los datos geoespaciales, se ha producido en el INEGI información digital del relieve e imágenes del territorio nacional, estos datos alcanzan su potencial máximo cuando son relacionados espacialmente en Sistemas de Información Geográfica (SIG), para ofrecer a los usuarios y especialistas un abanico de opciones en el modelado y análisis del territorio con una gran aproximación a lo real y con las variantes y ventajas que ofrece la tecnología informática, hoy en día aplicada a la topografía digital.

Mediante la exposición de este trabajo se dan a conocer procesos con información geoespacial del INEGI para promover el concomimiento y el uso de esta para la determinación de cauces de cuencas hidrográficas de la zona de Tixtla, Guerrero, lugar en donde se tiene un alto riesgo por inundaciones a causa de precipitaciones extremas o extraordinarias que se presenten por los efectos del cambio climático que estamos viviendo y que derivan en escurrimientos con caudales de agua que originen afectaciones en la población y que, mediante el uso de los datos del relieve en Modelos Digitales de Elevación (MDE) y su utilización en SIG, tienen una gran importancia, no solo en la combinación e integración de datos geoespaciales, sino en la capacidad para extraer información digital referente a los cauces o escurrimientos de agua necesarios para realizar un modelado hidrográfico; esto mediante operaciones espaciales usadas para tal fin mediante el uso de los MDE de tipo terreno que permiten modelar la interacción entre la forma del terreno y sus procesos de transporte de agua y sedimentos, y con ello obtener información geoespacial adicional para analizar el entorno de esta cuenca hidrográfica en Tixtla.

Por lo tanto, al proporcionar elementos a los especialistas encargados y responsables de la protección civil y de prevención de desastres, aportando información complementaria ante la prevención de posibles riesgos por la presencia de fenómenos hidrometeorológicos que causen inundaciones, se logra promover una cultura de seguridad y autoprotección en la propia ciudadanía, así como avanzar hacia mejores condiciones de vida, facilitando la capacidad de respuesta de las propias comunidades ante la presencia de cualquier fenómeno o agente perturbador que pudiera afectar la seguridad de la población de Tixtla, Guerrero.

# The Use of Digital Elevation Models and Orthoimages for the Determination of Riverbeds of Hydrographic Basins in the Zone of Tixtla, Guerrero

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## 1. DIGITAL ELEVATION MODELS (DEM)

The digital elevation models are part of the continental, insular and submarine relief data group of the National Subsystem of Geographic Information and Environment of Mexico and are a numerical data structure that contains the elevation values of land relief forms such as mountains, plains, canyons, slopes and continental shelf, pits, depressions, ridges and plateaus, as well as natural and artificial objects present in the relief, which allow modeling these geographic spaces to know aspects such as heights, depths, slopes, sections, volumes and delimitation of basins, in order to contribute to the development of Mexico and the generation of knowledge and study of the forms of relief as a determining factor of the physical environmental conditions, natural resources, infrastructure design and, where appropriate, the attention of emergencies or disasters caused by natural catastrophes.

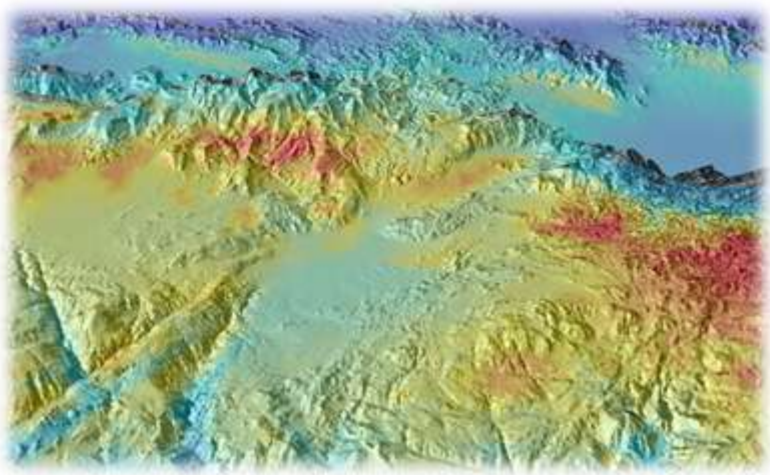


*Figure 1. Digital elevation model with hypsometry representation based on the elevation ranges contained in the model.*

Today there is the possibility of generating different types of models in which the surface and terrain models are located, the first being the numerical structure of the height values of the earth relief shapes with respect to a reference level or average sea level in which the values of the objects present on the relief are also included, such as those relating to vegetation, shipwrecks, obstructions, buildings and infrastructure. Digital terrain models are the numerical structure of the height values of terrestrial relief shapes with respect to a reference level or average sea level without considering the objects present on the relief, that is, having removed the values of natural elements and those made by Man.

There are several methods for generating digital elevation models, as well as various geographic altimeter information that can be used to produce models such as RADAR data, photogrammetric processes, LIDAR, field observations to obtain geodesic and topographical data, contours and can currently also be generated with the use of data from the processing of images captured from satellite sensors in stereoscopic mode, the latter being the one used by INEGI for most of the country, as it offers the opportunity to have information to "see" through the optical image, which when captured in stereoscopic mode will also allow to obtain altimeter data to "measure" the same geographical space and temporality of the area to be modeled.

## 2. ORTHOIMAGES

This geographic data related to the images of the territory is obtained from the photogrammetric process that is applied to optical images captured in stereoscopic mode and that it ensures that each element of the image or pixel, is in its correct geographical position, essentially corresponds to transform the central projection system of the image to an orthogonal projection, in which the displacements caused by the tilt of the camera or sensor and the relief of the terrain have been removed. It refers to a cartographic projection, so it has the geometric characteristics of a map, in addition to the pictorial quality of the photograph.

To obtain the orthoimages, INEGI performs quality control processes on the optical images to avoid that the percentage of clouds exceeds the allowed limit for each image, as well as verifying that the spatial coverage of the images completely covers the area defined in the project. Subsequently, with the support of information from field observations with GPS equipment, and the application of geodetic and topographic methods, points of known position in the terrain are obtained, known as "ground control", which is necessary to carry out the following process, the aerotriangulation, a process that aims to obtain the coordinates of various points of the terrain using photogrammetric procedures to obtain the position of the largest possible number of these support points through photogrammetric operations.

The aerotriangulation, process physically and mathematically relates individual images and associates them with the entire project with horizontal and vertical reference. The process of digital aerotriangulation eliminates the traditional work that leads to classic errors, achieving substantial savings for the project through automated processes, then generates the orthoimage in which an image can be transformed into a projection of the terrain, the rectification corrects the existing displacements in the original image produced by the inclination of the axis of the shot. The rectified image must have the geometric characteristics of an orthogonal projection of the object captured in the image on a certain plane and at a certain scale.

Orthoimages properties allow this geographic data to offer at least the same accuracy as maps, where each pixel has a clearly determined position in the reference system. They are calibrated with respect to colors and by means of the radiometric adjustment and mosaic forming modules can be merged two or more orthoimages and produce a homogeneous color image of better quality and multitemporality. Orthoimages can adopt variable scales;raster images can be applied classification techniques to images in either color or infrared color. Multitemporal, multiscale, and multispectral properties are unique to orthoimages, they can be compared with remote sensing data to complete the interpretation process with other multispectral channels. They can be used to make calculations of surfaces, distances, displacements, among others, and that, due to their multidisciplinary nature, constitute a very useful data source for users of geographic information systems.

In INEGI, the process for the generation of orthoimages and digital elevation models through the use of stereoscopic digital images has a variety of activities that allow the production of this geospatial data of the relief and images of the territory, for which monitoring and control tools are established for the best execution of each of the processes and derive geographical products that are part of the National Statistical and Geographical Information System of Mexico.

## 3. PROJECT LOCATION

Tixtla is located in the state of Guerrero, at coordinates 17°20' and 17°43' north latitude and 99°15' to 99°28' west longitude and is part of the Central region. Its territorial limits are to the north with the municipality of Mártir de Cuilapan, to the south with the municipalities of Mochitlán and Chilpancingo de los Bravo, to the east with Zitlala and Chilapa de Álvarez and to the west with Eduardo Neri and Chilpancingo de los Bravo.

Location of Tixtla, Guerrero


Image of the Tixtla area

*Figure 2. Geographical location of Tixtla with respect to the state of Guerrero and image of the area.*

## 4. DESCRIPTION

To generate the orthoimage and obtain altimetry data for the digital elevation model of the Tixtla area, optical images were captured in stereoscopic mode, which were verified by quality control to verify that they had no more than 10% cloudiness, subsequently using geodesic control points, observed in the field with positioning equipment (GPS or GNSS) and through photogrammetric processes, the images were processed to obtain their orientation, obtaining values of orientation parameters of them in XYZ coordinates and rotation angles Kappa, Phi and Omega, this allows to obtain blocks of oriented images allowing to achieve good precisions for the generation of orthoimages and altimetry data.

Obtaining the oriented block proceeded to perform the process of orthorectification of the images in order to reduce the distortions in the image produced by the image formation geometry itself in the sensor and the curvature of the Earth's surface, for orthorectification photogrammetric processes were applied, to represent the orthogonal projection without perspective effects for this was necessary a digital model of elevation, which was obtained directly from the three-dimensional views of the oriented images (stereoscopic model), deriving as the final product of this process the digital orthoimage.

*Figure 3. Digital orthoimage generated by photogrammetric processes of Tixtla, Guerrero.*

The terrain-type digital elevation model was generated through classification and filtering processes of altimetry points derived from the photogrammetric correlation process carried out in the stage of generation of the orthorectification of the images, this classification is performed in the first instance to generate the digital surface model of the area by running an automatic classification software, to eliminate height anomalies resulting from an inadequate correlation in the images, then an interactive classification was performed where the specialist eliminated points with inconsistencies in their height value that the automatic classification process did not detect.

Once the final surface model is obtained, a computer program is executed to automatically classify the terrain, a process in which all points that correspond to infrastructure, vegetation, buildings, among others, are identified and eliminated to leave only the points that correspond to the terrain, and is complemented with an interactive process to classify those points that the automatic process did not detect efficiently. In this stage, the incorporation of information of break lines and restored water bodies with their elevation values is also carried out to intervene in the process of generating the digital terrain model with an elevation range of 1,116 to 2,006 m, which is the elevation range observed in the municipality of Tixtla; this allowed having a model closer to reality in order to detect the riverbeds or runoffs in the relief.

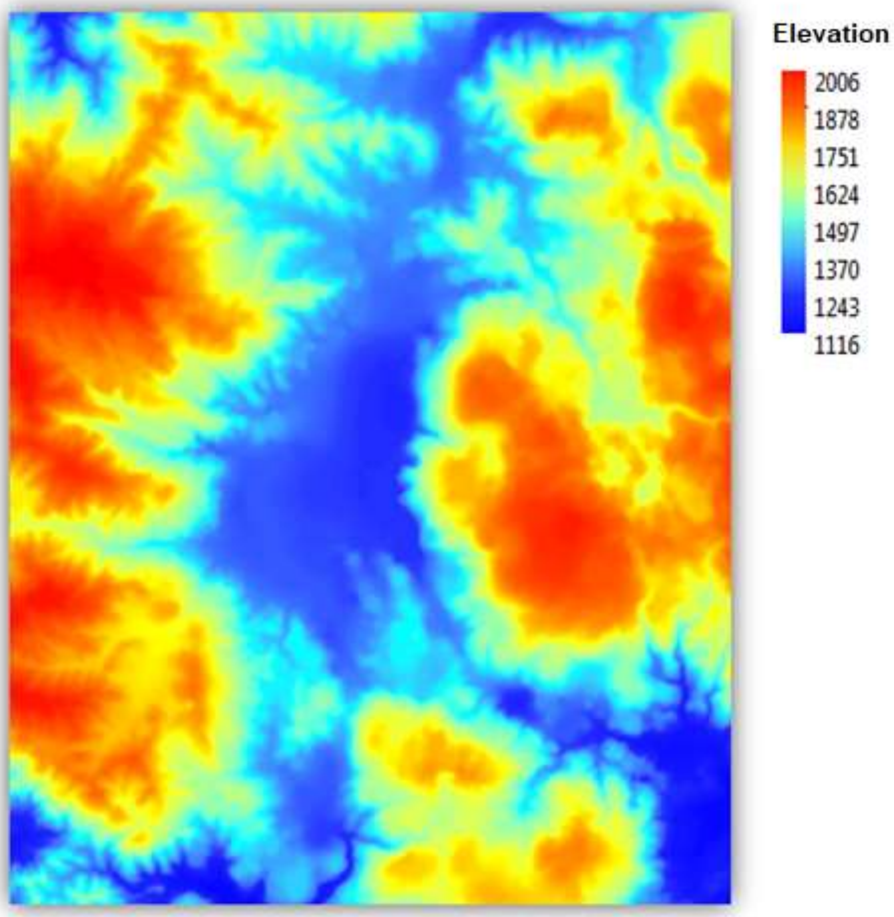



*Figure 4. Digital terrain-type elevation model generated by classification of altimetry points in the area of Tixtla, Guerrero.*

Having generated the orthoimage and the digital terrain model, the first exercise that was carried out as part of the identification of hydrological riverbeds or runoffs in the Tixtla area, was through the use of a Geographic Information System (GIS) placing the background orthoimage in which each of the runoffs were identified and digitized, obtaining a first runoff network for the area covered by the orthoimages produced and for the entire watershed of the area.

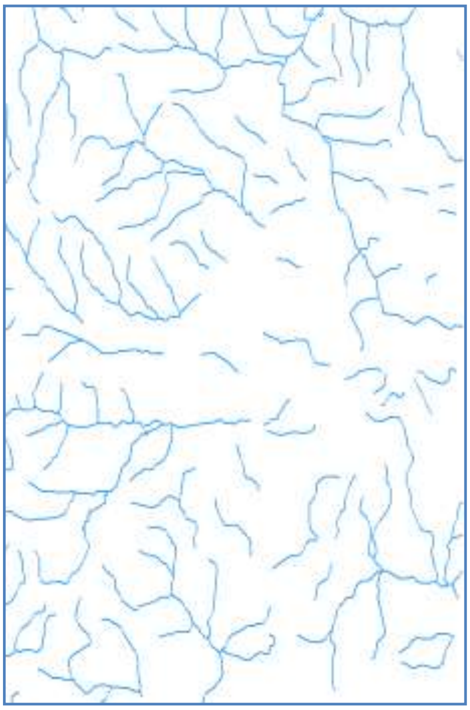


*Figure 5. In the image on the left the orthoimage with the riverbeds of rivers and digitized streams both overlapping in the GIS. In the image on the right the result obtained from the riverbeds near the town of Tixtla*

By conducting a second exercise using the digital terrain model derived from the classification of altimetry points and applying the procedure designed in INEGI to generate riverbeds or streams of water semi-automatically, it was possible to derive a second network, this due to the ease of the procedure of auxiliary of the elevation values of the digital model to model the interaction between terrain shape's and its water flow processes for delineate an characterize it the tributaries that form the watershed.

The basis for the process of generating riverbeds from the model is to define the flow directions that the waterways would have from the value of each pixel in the digital model of the terrain, where the flow direction is determined by the direction of the steepest descent, or the maximum drop, from each pixel of the model. The accumulated flow is then calculated as the cumulative weight of all pixels or cells flowing in each downstream slope pixel in an output raster file, which will give rise to the runoff or waterway in the relief, as cells with a high flow accumulation will be areas of concentrated flow and can be useful for identifying streams and rivers.

Taking into account the processing, the digital terrain-type elevation model was carried out to obtain the river and stream channels in the Tixtla area, resulting a network consisting of 999 segments considering a flow accumulation parameter of 800 cells, this means that it will take all pixels that have more than 800 cells flowing towards them.

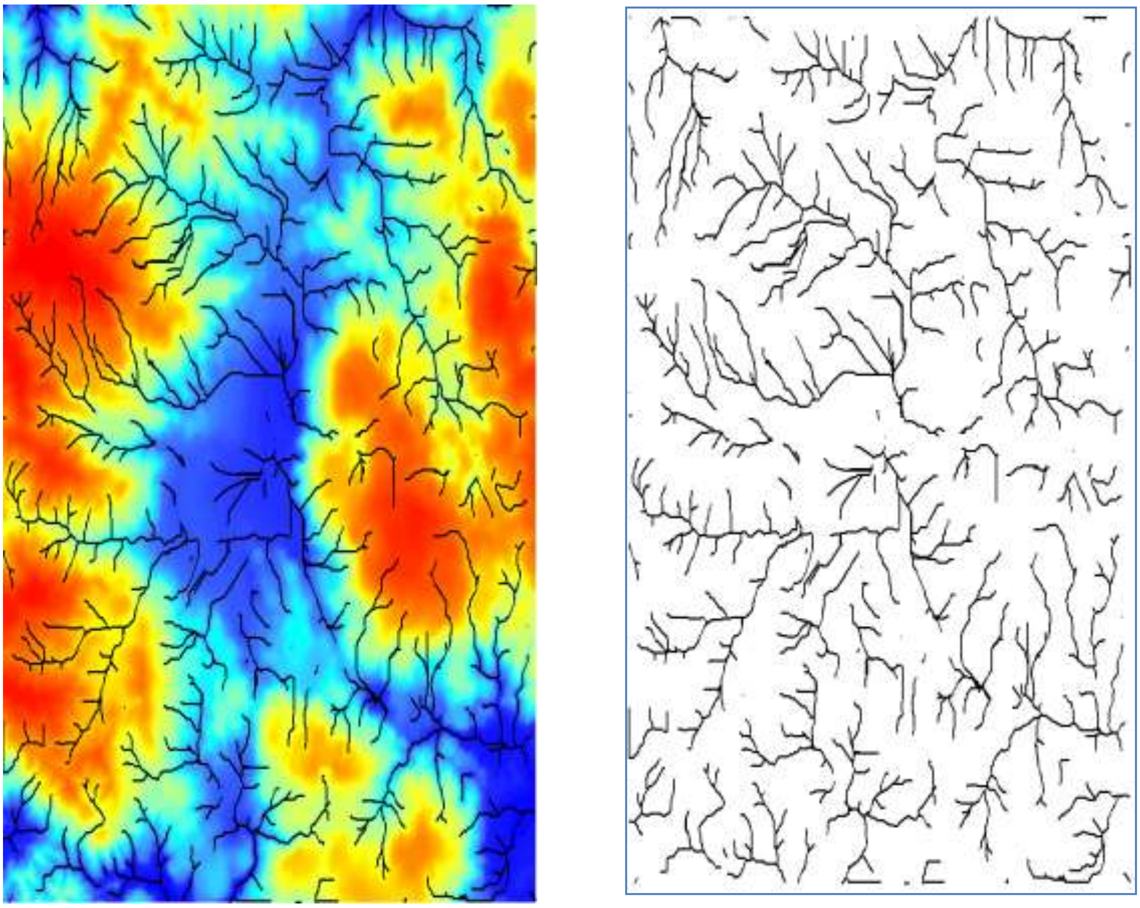
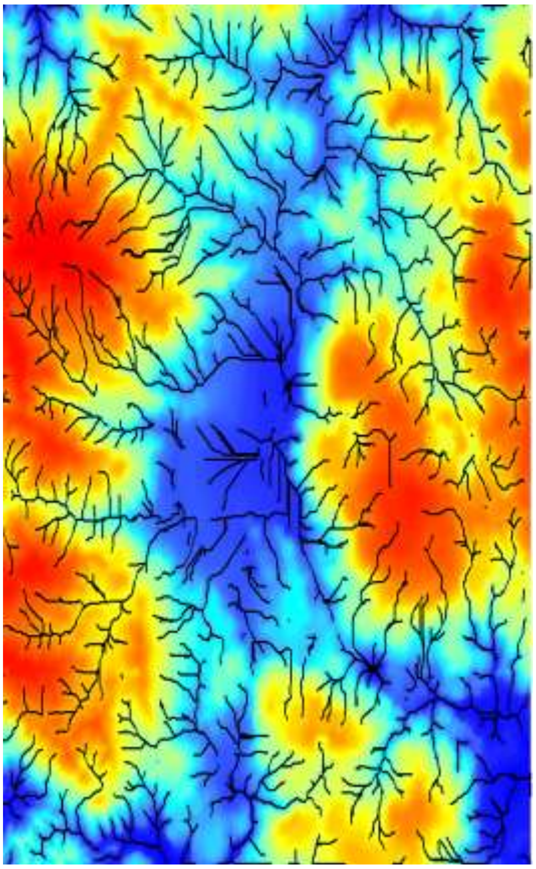
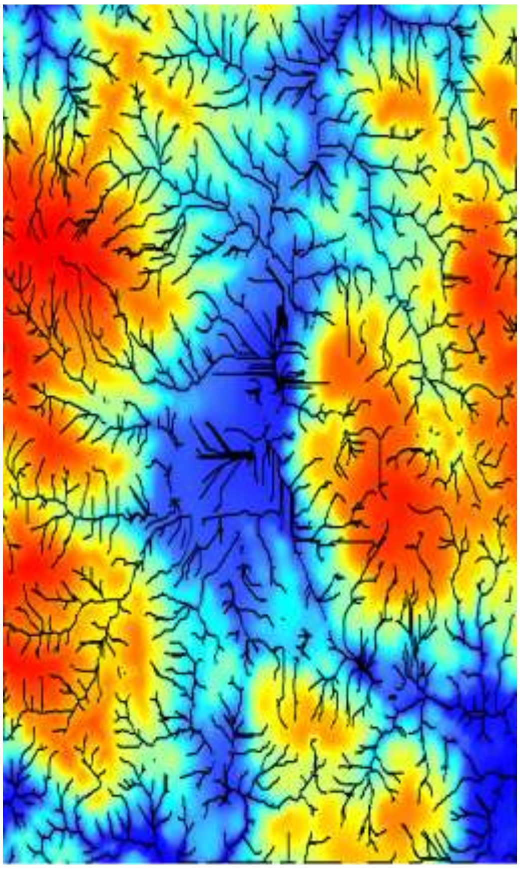


*Figure 6. Digital terrain model and derived riverbeds with a flow accumulation parameter of 800 cells and their result.*

Subsequently, other processing was performed considering different flow accumulation parameters for 400, 200, 100 cells, the results of which were as follows:



Digital terrain model and derived riverbeds with a flow accumulation parameter of 400 cells resulting in a network consisting of 1,919 segments.



Digital terrain model and derived riverbeds with a flow accumulation parameter of 200 cells resulting in a network consisting of 3,937 segments.

*Figure 7. Results obtained from the processing of the digital terrain model and the derived riverbeds by changing the value of the flow accumulation parameter.*

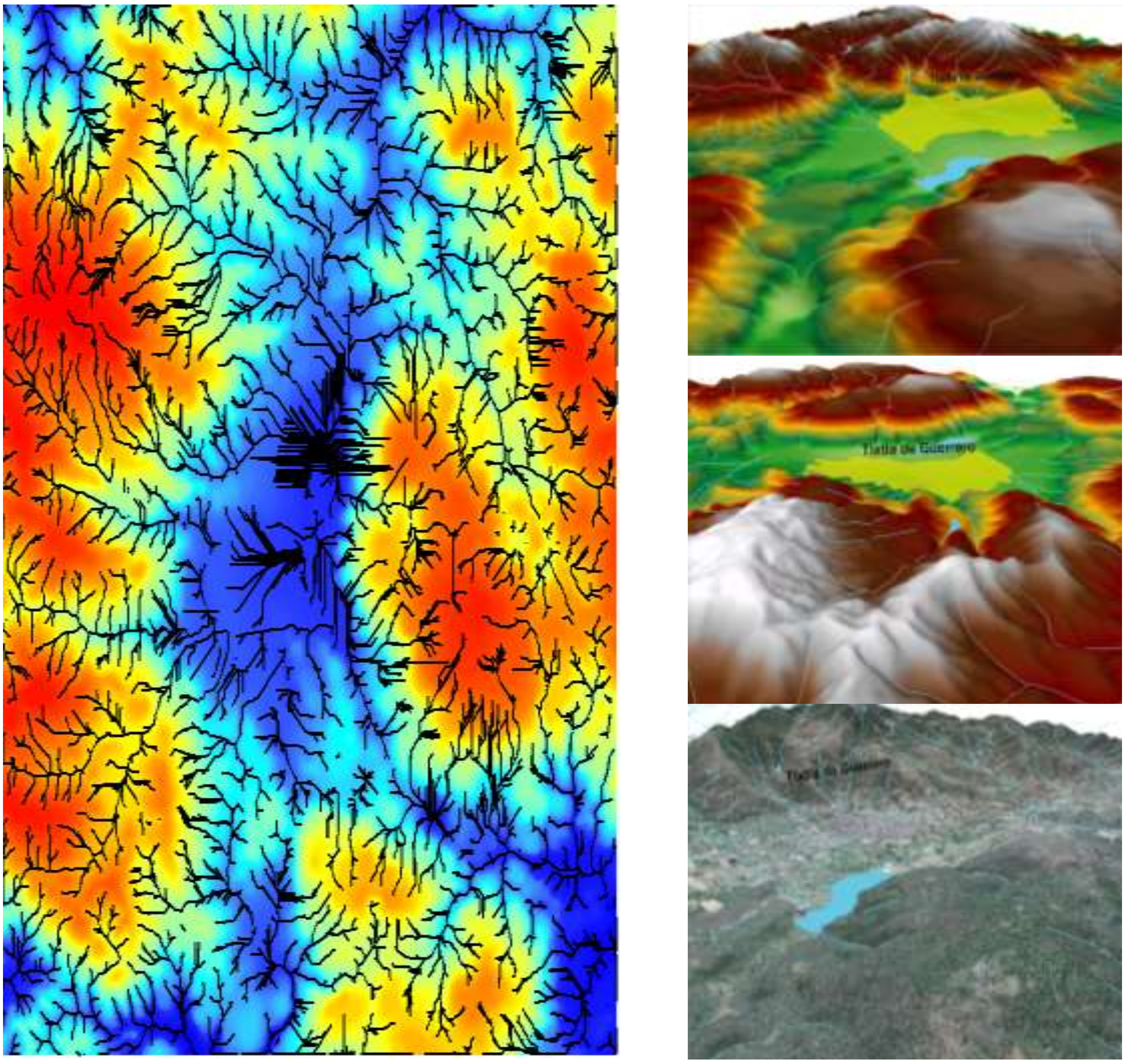


*Figure 8. Digital terrain model and derived riverbeds with a flow accumulation parameter of 100 cells and its result of 8,544 segments that make up the network. On the right is the digital 3D elevation and orthoimage model with the geographical location of the town of Tixtla.*

Once the results of the riverbeds derived from the digital terrain model have been obtained, it is possible to use some methods to determine the main riverbed or identify what would be the largest flow contribution in the hydrographic network from the tributaries that join it by the links that join it, for example, the methods proposed by Strahler (1957) and Shreve (1966), or simply using a more specialized spatial analysis of GIS.

For example, if we take the Shreve method all links on the network should be considered, that is, all external links are assigned an order of 1. For all inner links of the Shreve method, orders are additives. Therefore, the intersection of two first-order links creates a second-order link, the intersection of a first-order link, and a second-order link creates a third-order link, and the intersection of a second-order, third-order link creates a fourth-order link and so on.

Because orders are additives, method numbers are known as magnitudes instead of orders. The magnitude of a link in the Shreve method is the number of tributary or riverbeds above and therefore it is possible to identify the main riverbed with the largest set of waterways.

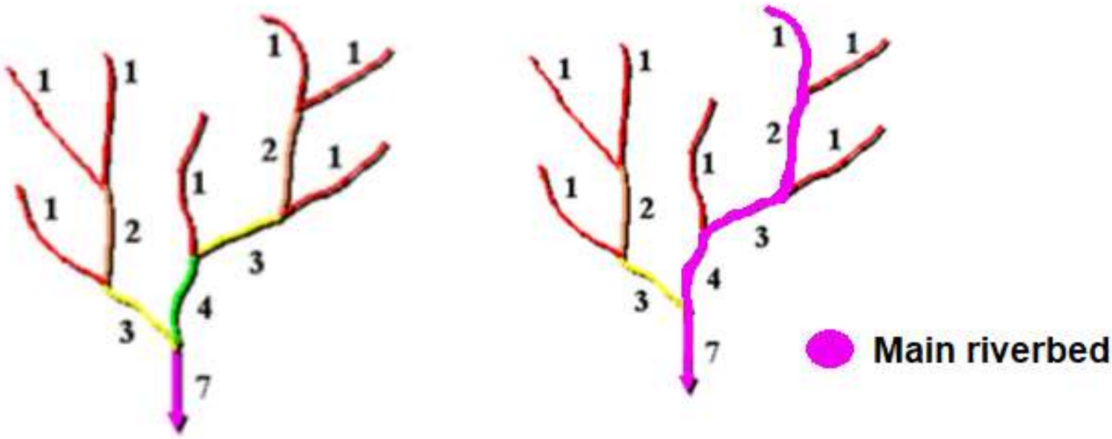



*Figure 9. Example of calculating the main riverbed using the Shreve method.*

With this method it is possible to define the main riverbed that in theory is the one that carries the greatest contribution of water or flow carried in its waterway and that in the end, could mean a potential flood risk for the town of Tixtla, since the spatially estimated water flows, are abnormally high and that, exceptionally, registers a stretch of a current that constitutes higher than usual surface water flows, which, in overcoming its confinement, overflows, temporarily occupying lands that are not usually submerged.

These extraordinary water flows in this town of Tixtla could have their origin in natural factors linked to precipitation, due to exceptional meteorological conditions that imply a very rapid increase in surface currents or watercourses, and in human factors (not linked to precipitation), where they can occur due to the failure of dam structures and river dams, deforestation and inadequate land use practices, as well as the expansion of extensively populated areas and irregular settlements.

## 5. CONCLUSION

It is possible to obtain efficient and varied results with the use of digital elevation models in the definition of the riverbeds of a hydrographic watershed, with the feasibility of having variants in the number of segments or tributaries and see the scopes they may have as to the number of runoffs that may be part of a hydrographic network and that in turn allow the user to apply them for different purposes and as support information, for example, considering the hydrographic network and the digital elevation model it is possible to perform 3D modeling of the Tixtla area in order to identify main riverbeds based on the branches or tributaries that form the main riverbed.

In a Geographic Information System it is possible to overlay the orthoimage, the digital elevation model and the hydrographic network derived from the model itself to make a comparison between the riverbeds by means of a dynamic modeling that allows us to recognize critical points in the area, derived from the location and number of maximum branches and lengths thereof, however, the analysis carried out with the terrain-type digital elevation model yields more results in drains, which makes it possible to identify cases that are not observed with the orthoimage itself and thus perform risk analysis or modeling. It should be mentioned that the number of riverbeds obtained semi-automatically depends on the resolution of the digital lifting model, since the higher resolution and accuracy of the model causes are obtained with better precision for use in risk analysis.

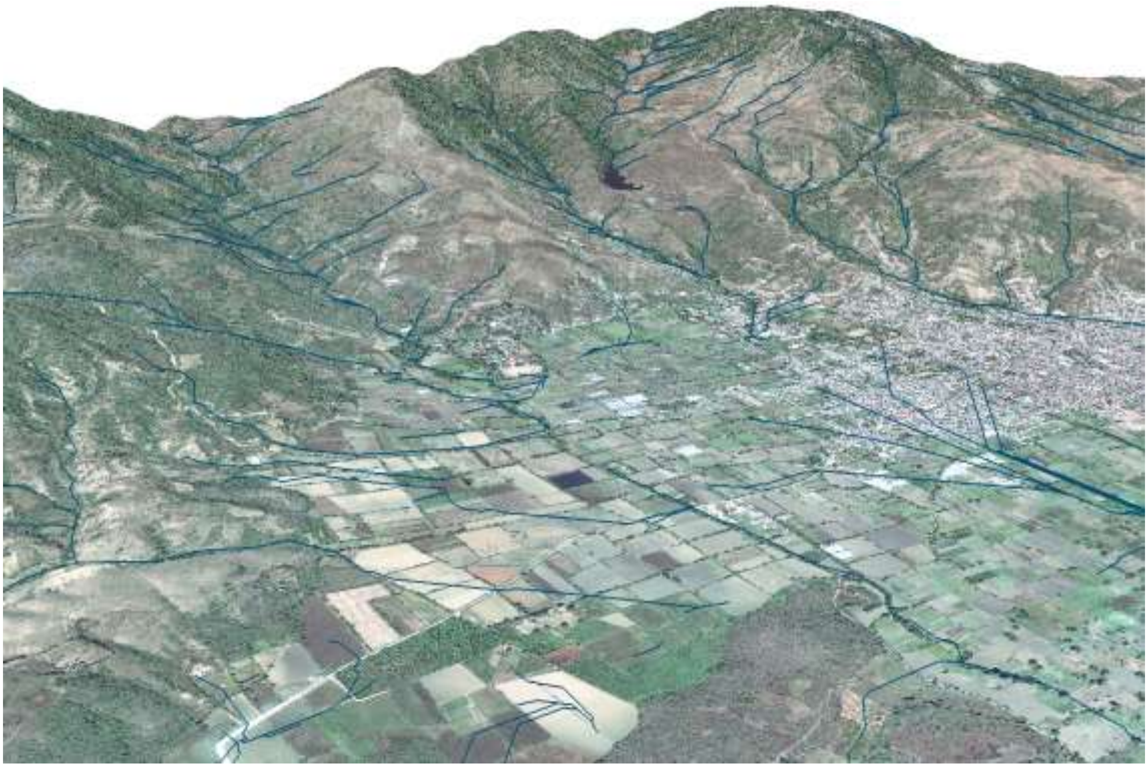


*Figure 10. 3D modeling in a GIS showing the orthoimage and network of riverbeds generated from the digital terrain-type elevation model with a flow accumulation parameter of 100 cells and its result of 8,544 segments in the Tixtla area.*

Therefore, this method of generating geographic information from waterways or water runoffs from digital elevation models provides information on geospatial elements complementary to specialists in charge and responsible for civil protection and disaster prevention, in the face of the prevention of potential risks from the presence of hydrometeorological or anthropic phenomena that cause flooding , thus promoting a culture of security and self-protection in the citizenship itself, as well as moving towards better living conditions, facilitating the responsiveness of the communities themselves to the presence of any phenomenon or disruptive agent that could affect the safety of the population of Tixtla, Guerrero.

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## BIOGRAPHICAL NOTES

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