Uncertainty in the extracted drainage network associated to the applied DEM correction method

Implementation of a new DEM correction approach

Juan Camilo Castro Gallego*, **Verónica Botero Fernández****, and **Jaime Ignacio Vélez*****
Facultad de Minas
Universidad Nacional De Colombia
Medellín, Colombia
*jccastro70@gmail.com, **vbotero@unal.edu.co, ***jivelezu@gmail.com

***Abstract*— Automated generation of drainage networks from digital elevation models (DEM) has become a popular practice due to the increment of available information. Along with the different methods proposed for the automated extraction of drainage networks, new methods to correct the DEMs have also been suggested. This paper analyses the uncertainty related to the extraction of drainage networks from several DEMs when using different correction methods, including a new approach suggested by the authors. The automated extraction of the drainage networks was made from DEMs, at different scales, corrected with three different approaches:**

1) **ArsGIS's sink filling and flow direction method (ArcGIS is a commercial GIS package from the Environmental Systems Research Institute ESRI).**
2) **Tarboton's (1997) TauDEM (methodology proposed and implemented by David Tarboton, students and collaborates in Utah State University) implemented for the free/open software MapWindow GIS in 2005 by his team and other contributors from Idaho State University.**
3) **HidroSIG 4.0 DEM processing functions (methodology proposed and implemented by the authors of this paper in the free software HidroSIG 4.0 from the Universidad Nacional de Colombia, sede Medellín). This methodology suggests a new approach based on the physical processes that take place on river networks and their geomorphological tendencies due to the work done by long term erosive processes.**

The different river networks extracted from different processed DEMs, from a mountainous tropical area in Colombia, at four different resolutions, were analyzed to determine their inherent uncertainty due to the correction and flow direction definition method used for the automated extraction.

Keywords: Uncertainty, digital elevation models (DEM), automated extraction of drainage networks, DEM processing, river networks

I. INTRODUCTION

Geographical information is scarce in developing countries like Colombia. Civil and environmental engineers, especially those who work with Hydraulic Resources, have to take as much advantage as they can from the scarce information that they can find. The recent technological development and the amount of elevation and topographic data available in many different geodata bases have made DEM an excellent tool for Hydraulic modeling. These have made it possible to extract drainage networks automatically from digital elevation models, due to the existing, inherent, relationship between hydraulics and geomorphology. With technology's rapid development, engineering software and models, have to be in constant evolution also. This is why new drainage extraction methods along with new DEM Correction methods are also constantly being suggested. This paper analyses the uncertainty related to the extraction of drainage networks from several DEMs when using different correction methods, including a new approach suggested by the authors.

II. MATERIALS AND METHODS

A. *Study Case Area*

The study case area is located in a mountainous region in the central Colombian Andes; on the eastern side of a state called Antioquia. In general the study area has highly porous topsoil composed of volcanic ash in the moderately steep areas and soils derived from igneous and metamorphic rock on the steeper areas. These soils are medium to moderately thick textured, well-drained, moderately deep and profound limited by a continuous iron oxide layer. The general morphologic traces show slight tendencies to laminar erosion. The drainage is efficient on the slopes. The dominant erosion processes are caused by diffuse runoff, furrows and small landslides. The drainage network has a dendritic pattern with moderate incisions and a intermittent existence of meandering channels. Geomorphologically the region is composed of rounded hills and vast plains along the broad-bottomed valleys.

The studied basin is located between 6°8'35.23" N and 6°12'43,19" N of latitude, and 75°24'13.21" W and 75°29'17.12" W of longitude. The stream is called Quebrada Chachafruto and its basin was traced from its pour point on the Rio DEMs Used

The DEMs used were corrected by different methods and obtained in different resolutions to observe the effect that the scale has on the results; and to get a close look on the influence of the DEM correction method when making a DEM based geomorphological analysis of a basin. The DEMs used were:

A 12.5m resolution DEM obtained by the interpolation of contour lines with the ArcGIS tool, TopoToRaster. The Contour lines were obtained from topografic information in a scale of 1:25000 bought from the IGAC (Instituto Geográfico Agustin Codazzi) and donated to the Universidad Nacional de Colombia by CORNARE (Corporación Autónoma Regional de las cuencas de los Ríos Negro y Nare) in a proyect where the Universidad Nacional de Colombia was hired to make a Digital Atlas, of their jurisdiction, for them.

1) A 30m resolution DEM downloaded freely through the internet from ASTER´s geodata base who generated DEMs through estereoscopy from satellite images.

2) A 90m resolution DEM downloaded freely from NASA´s SRTM (shuttle Radar Topography Mission), who specially modified a radar and sent it on a space shuttle to measure earth and generate one of the most complete, high resolution, geodata bases in the world.

B. Methodologies used in the Different DEMs

Three different correction methods were used on the DEMs. It is important to have in mind that each one of the DEM has a different resolution and was obtained from different sources, this was made on purpose by the authors to observe the results of each of the methods without having to depend on a definite resolution or DEM generation method. The three different methodologies used were the following:

1) ArsGIS´s sink filling and flow direction definition method (ArcGIS is a commercial GIS package from the Environmental Systems Research Institute ESRI).

2) Tarboton´s (1997) TauDEM (methodology proposed and implemented by David Tarboton, students and collaborates in Utah State University) used the application implemented for the free/open software MapWindow GIS in 2005 by his team and other contributors from Idaho State University.

3) HidroSIG 4.0 DEM processing functions (methodology proposed and implemented by the authors of this paper in the free software HidroSIG 4.0 from the Universidad Nacional de Colombia, sede Medellín). This methodology suggests a new approach based on the physical processes that take place on river networks and their geomorphological tendencies due to the work done by long term erosive processes.

C. A General Overview of the suggested DEM Correction Approach (HidroSIG 4.0)

The methodology proposed and implemented by the authors of this paper in the free software HidroSIG 4.0 tries to put together the existing, inherent, relationship between geomorphology and hydrology by paying special attention to the geomorphological traces left by streams that have carved their natural channels through long term erosive processes.

The Methodology uses as inputs the DEM, a geological structure map and an erodability map (with values taken from USLE´s erodability factors; the erodability map can also be used to calculate stream heads based on power thresholds) in raster format if available, if the erodability map is not available then the application uses a mid erosion, constant value, for all of the pixels. The methodology works with flow direction maps extracted by the deterministic 8 methodology (O´Callaghan y Mark, 1984) and the infinite deterministic neighbours methodology (Tarboton, 1997), leaving the sinks and flat zones without a definite direction to be determined afterwards through the suggested sink correction method or the flat zone flow direction definition method.

1) Flow Direction Definition Method for Flat Zones

Before briefly describing the direction definition method it is important to establish some common working grounds.

Let:

Pl be all of the pixels that have a same elevation as the flat zone and that have no definite direction because their slope is equal to 0.

b1, b2, b3…,bn be the nearest neighbors to Pl with flow towards Pl

bmax be the pixel, that belongs to b1, b2, b3…,bn, and that has the greatest accumulation value.

Another important thing to have in mind before describing the method is that flat zones are geomorphologically possible, the method suggests not to correct or change these zones but to associate a flow direction to each of the pixels that has not received a flow direction because of its slope.

When observing still water on a flat surface, if the water reaches a pour point then the water table´s longitudinal profile changes, generating a small hydraulic head that leads the water, as much as possible, towards that pour point. If the soil beneath that pour point is erodible, and depending on the discharge, then small amounts of soil might be eroded. This generates a slight change in the water table which translates into a slight increase on the discharge. This increment in the discharge might also augment the erosion process generating a positive feedback on the discharge and the erosion.

The application begins by emulating the flow inertia process (described afterwards) for b1,2,3…n extending the flow for a certain length that depends on the accumulation associated discharge. Afterwards it looks for all of the possible pour points neighbors to Pl and emulates a retrogressive erosion process based on the erodablity map, until bmax is reached. The retrogressive erosion process emulates the physical phenomenon by progressively diminishing the elevation of each of each of the pixels who are reached by the retrogressive erosion process. Then the application compares which of the pour points would take less effort during the erosion process and denotes that point as the flat zone´s pour point. After having a definite pour point the application repeats the retrogressive erosion process for that pixel until it gets to b_{max}. The retrogressive erosion process allows calculating new slopes which at the same time assigns flow directions to the pixels. This way it is possible to start at b_{max}, follow the flow direction map and end up again at the pour point. This flow path through the flow direction map from b_{max} to the flat zone´s pour point is designated as a principal channel. The original pixel elevations are restored for Pl except for the pixels that are part of the newly formed principal channel. Afterwards flow directions are recalculated for Pl and if there are pixels which have not received a flow directions then the retrogressive erosion process is repeated starting from the principal channel until it reaches the next highest accumulation in b1,2,3...n. The process is then repeated: the new channel is added to the principal channel, the flat zone's elevations are restored except for the pixels which belong to principal channels and flow directions are then recalculated. The process takes place until all of the pixels inside the flat zone have a definite flow direction. This generates a much more accurate drainage network because it effectively aggregates the network and concentrates the flow lines in flat zones which has always been a problem when extracting drainage networks from DEMs. When all of the pixels inside the flat zone have a definite flow direction the elevation of the pixels inside the flat zone are brought back to their original values.

2) Sink Correction Method

The sink correction method offers the option of manually correcting a designated sink or sinks with areas greater than a certain threshold. This way if the sink correction is not accurate the user can define the sinks pour point helped by any other information that the user might have. It also gives the opportunity of determining automatically the pour points of all sinks, for the present paper all of the pour points where calculated automatically. This helps the user to be aware of the possible mistakes that can be easily made by believing blindly on automated models. The automated sink correction method begins by finding the sinks pour point. This is made by looking for the nearby saddles that may lead downstream from the sink and analyzing their behavior to decide which of the saddles is the best options. After finding all possible saddle points the application looks for faults in the geological structures map. If a fault passes through a saddle point then that point is determined as the pour point. If there is no geological structures map or no fault passes through a saddle point, then the flow direction map is followed from each saddle point until a pixel with lower elevation than the sink is found. Here several parameters like the topographic index, and the stream power are calculated for the end pixels in each of the different flow paths. The flow path that shows a greater geomorphological evidence of a channel and which has closer values to the theoretical tendencies of streams, is chosen as the pour flow path that the water should follow. Afterwards if there is more than one saddle associated to the chosen pour path then another optimization algorithm is used to find the saddle pour pixel with the lower elevation and which is closest to the sink. This methodology gives gemorphological coherence to the DEM and the river network.

After finding the sink's pour point another optimization algorithm determines whether it is better to correct the sink by filling it or by incising through the saddle's flow path. The algorithm works with different weight factors for each of the processes having in mind that normally the DEM generation method is, sometimes, more likely to fall in certain kinds of errors, either tending to assign higher elevations to the pixels as it happens when the DEMs are made from remote sensing, or being likely to commit both types of errors when interpolating from contour maps. The resulting map is then treated as if it was a flat zone.

3) Bifurcation Correction Method

The first method tried for correcting bifurcations is the Inertial Flow method (described afterwards) if the inertial flow method is not able to associate a flow direction to the pixel then the Flow Direction map obtained by the Infinite Deterministic neighbors is used to see if there is any statistical tendency in the complete map that would suggest a possible direction for the pixel. This helps to guarantee the geomorphological coherence because it allows to take decision which is consistent with the general tendencies of the map.

4) Inertial Flow

If c is the pixel for which the inertial flow is required and b1, b2, b3...,bn are c's nearest neighbors with flow towards c; then the inertial flow method consists on finding the greatest flow accumulation in bi with i=1,2,3...n, let this pixel be called bmax. If the direction associated to bmax is a suitable direction for c then c is given bmax's direction; if not, then the inertial flow is not an option and another method must be tried. This method tries to give hydrological coherence to the direction definition methods because it resembles the physical processes that take place in the channel networks having in mind that the strong geomorphologic carving is done by hydrologic (crecidas) and, normally, the power of the main stream during these events is much higher than those of the secondary arriving streams.

TABLE I. GEOMORPHOLOGICAL PARAMETERS

Basin's area (Km^2)	34,585
Horton/Strahler's order	6
Number of channel heads	313
Total Channel Length (Km)	165,7
Principal Channel Length (Km)	13,16
Drainage density (Km^{-1})	4,79
Basin's highest elevation (m)	2738,4
Elevation at basin's pour point	2088,4
Basin's average slope (%)	22,2
Basin's perimeter (Km)	41,76

III. EVALUATION STRATEGY

The evaluation of the different extracted river networks was made by measuring several geomorphological parameters in the previously mentioned basin in each of the different DEM resolutions. Each of the parameters was measured with the HidroSIG 4.0 morphological report tool. After obtaining the parameters they were compared with the values obtained from a geomorphological analysis made from cartography maps, satellite images and a 5 m resolution DEM. The geomorphological parameters and the values measured for the, Chachafruto's basin, used to evaluate the different drainage networks associated to the DEM correction methods are listed in Table 1.

IV. RESULTS AND DISCUSSION

The results observed are presented in Tables II, III and IV. They show what can be seen when looking at the drainage

TABLE II. RESULTS FOR HIDROSIG

	HidroSIG					
Resolution	12.5 m		30 m		90 m	
Errors are all in percents	Value	Error	Value	Error	Value	Error
Basin's area	35.69	-3.2	34.12	1.3	36.15	-4.5
Horton/Strahler's order	6	0	6	0	5	16.6
Number of channel heads	321	-2.56	305	2.5	293	6.3
Total Channel Length	164.7	0.6	162.3	2.0	168.4	-1.6
Principal Channel Length	12.7	3.5	12.4	5.7	12.6	4.2
Drainage density	4.6	3.7	4.8	0.7	4.6	4.5
Basin's highest elevatio n	2739	-0.02	2740	-0.06	2740	-0.06
Elevation at basin	2089	-0.03	2090	-0.08	2090	-0.08
Basin's average slope	23.4	-5.4	21.3	4.0	19.7	11.2
Basin's perimeter	41.9	-0.3	39.2	6.1	38.3	8.2

TABLE III. RESULTS FOR MAPWINDOW

	MapWindow					
Resolution	12.5 m		30 m		90 m	
Errors are all in percents	Value	Error	Value	Error	Value	Error
Basin's area	32.39	6.3	34.20	1.1	34.307	0.8
Horton/Strahler's order	8	-33.3	7	-16.7	6	0.0
Number of channel heads	382	-22.0	371	-18.5	343	-9.6
Total Channel Length	176.4	-6.5	173.2	-4.5	178.1	-7.5
Principal Channel Length	12.83	2.5	12.2	7.3	12.542	4.7
Drainage density	5.4	-13.7	5.1	-5.7	4.9	-2.3
Basin's highest elevation	2737.7	0.0	2723	0.6	2732	0.2
Elevation at basin	2088.3	0.0	2092	-0.2	2090	-0.1
Basin's average slope	21.3	4.1	16	27.9	15.4	30.6
Basin's perimeter	40.325	3.4	38.133	8.7	36.303	13.1

TABLE IV. RESULTS FOR ARCGIS

	ArcGIS					
Resolution	12.5 m		30 m		90 m	
Errors are all in percents	Value	Error	Value	Error	Value	Error
Basin's area	32.38	6.4	33.12	4.2	36.2	-4.7
Horton/Strahler's order	9	-50.0	9	-50.0	8	-33.3
Number of channel heads	396	-26.5	373	-19.2	332	-6.1
Total Channel Length	174.5	-5.3	176.2	-6.3	183.5	-10.7
Principal Channel Length	12.7	3.5	12.5	5.0	12.3	6.5
Drainage density	5.4	-12.5	5.3	-11.0	5.1	-5.8
Basin's highest elevation	2739.3	0.0	2738.5	0.0	2738.8	0.0
Elevation at basin	2088.3	0.0	2089.6	-0.1	2089.6	-0.1
Basin's average slope	21.4	3.6	15.2	31.5	20.1	9.5
Basin's perimeter	39.85	4.6	37.90	9.2	36.80	11.9

network maps. HidroSIG's method for making geomorphologicaly coherent networks prevents the creation of a great number of channel heads that do not represent reality in an accurate way this is show by the high values of the errors for number of channel heads and on the network's Horton/Strahler's order. When looking at the basin's the DEM correction method doesn't and the resolution don't seem to have a great influence on the parameter; but when you look at the distance values like channel lengths and basin's perimeter you see that the resolution plays an important role. Probably the most affected parameter by the resolution was the basin's average slope. Other parameters that seem to be greatly influenced by the DEM correction method are the ones that measure channel lengths. This is partly due to the incapability of most DEM correction methods of effectively concentrate channels in flat zones. This is why most of the networks extracted by different DEM processing tools show a great amount of parallel channels which increases the total channel length.

V. CONCLUSIONS

In conclusion the DEM correction method and the resolution play an important role in finding the geomorphological parameters normally needed for hydrological studies. It is also important to have in mind that there is a certain scale at which it is not necessary to work with a higher resolution because it only produces delays in the DEM processing and the results do not justify the time.

REFERENCES

Tarboton, D.G. (1997). A new method for the determination of ow directions and upslope areas in grid digital elevation models. *Water Resources Research*. 33, 309-319.

O_Callaghan, J.F. and Mark, D.M. (1984). The extraction of drainage networks from digital elevation data. *Computer Vision, Graphics, and Image Processing*. 28(3), 323-344.

Pitlick, J. (1994). Relation between peak flows, precipitation, and physiography of five mountainous regions in the western USA, *Journal of Hydrology*. 158, 219–240.

McArthur, D.S. and Hope, A.S. (1993). A physiographic streamflow model for small Sierra Nevada basins. *Yearbook of the Association of Pacific Coast Geographers*, (pp. 66–75), Corvallis, Ore, USA: Oregon State University Press.

Ramirez Osorio, J. M. (2002). *Extracci_on autom_atica de redes de drenaje a partir de modelos digitales de terreno*. Thesis for Civil Engineering. Universidad Nacional De Colombia, Sede Medellín, Facultad de Minas. Escuela de Ingeniría civil.