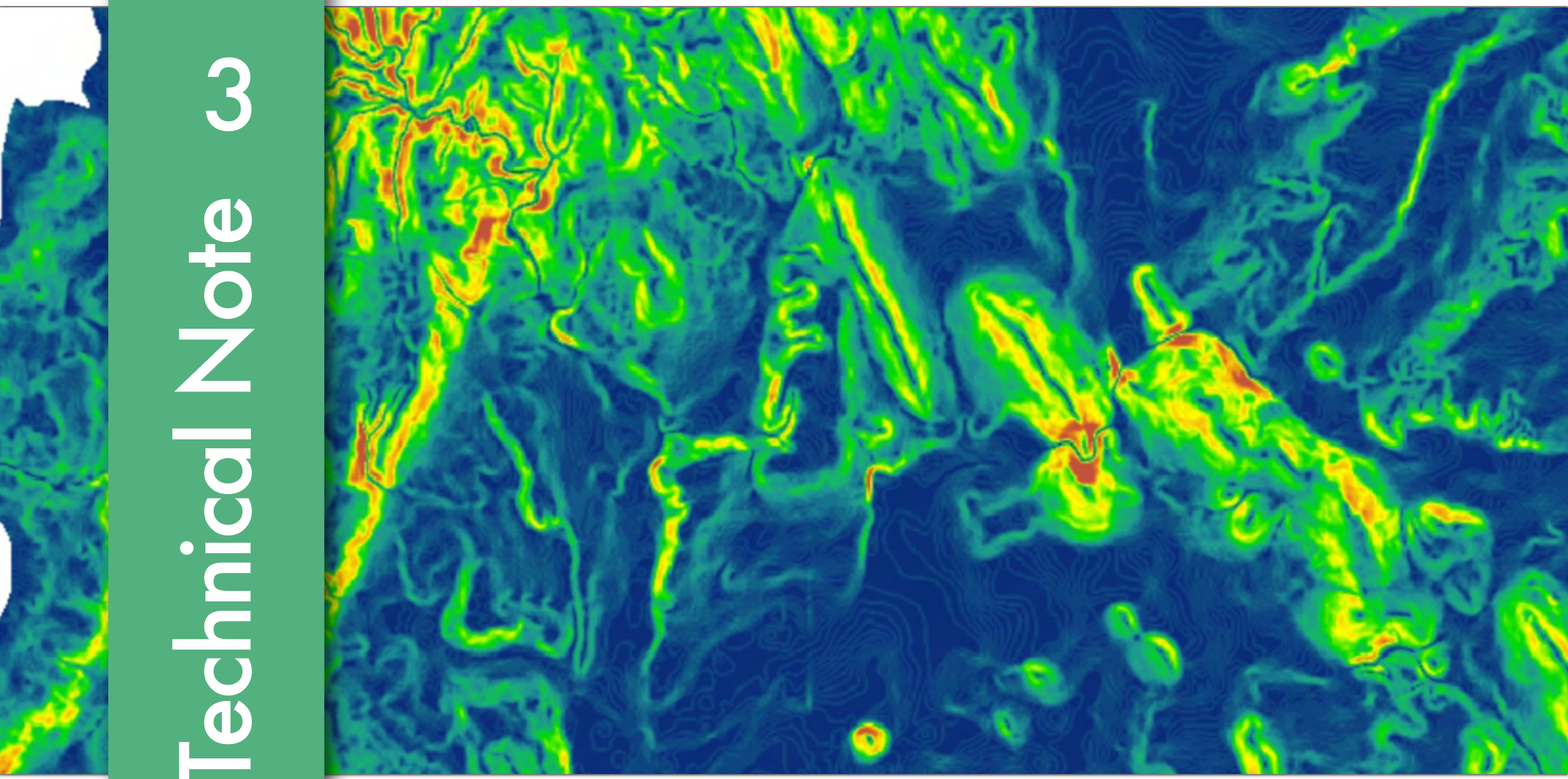
Technical Note 3



CHANNEL GRADIENT: Calculation process using GIS

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1. Concept and usefulness

The channel gradient is a fundamental parameter in the geomorphologic characterisation of river systems; however, why are people interested in studying channel gradients as a parameter of geomorphologic characterisation? Basically, because it is a reflection of the changes in the longitudinal sequence of a river through the presence of waterfalls, step pools (fasts and pools), riffle pools (rapids and pools), etc., which makes it a discriminating factor of environmental dynamics of differentiated processes, or in other words, it itself can be indicative of the river's geomorphologic movements. Also, the greater or lesser correlation of this link with other geomorphologic variables (mainly the river sinuosity -see technical note nº2 of the CIREF-) can also be indicative of geomorphologic types, although the intensity or affinity of these links is variable in function of the number of factors that interact with a specific point of the river system.

Before looking further into the development of the rest of the sections that this technical note contains, two fundamental aspects should be highlighted: the concept of the gradient and the way to represent this information. In the first aspect, the concept of the gradient, understood as the inclination with respect to the horizontal, is definable according to the measuring unit that we consider:

• Gradient in sexagesimal degrees → the gradient on any point of the terrain is defined through the angle given between the normal vector to the surface in this point and the vertical vector.

• Gradient in percentage → existing connection between the altimetric or vertical variance and the planimetric or horizontal distance of two points.

• The range of values for the gradient in degrees varies between 0º (flat surface) and 90º (maximum verticality). In the case of percentages, the gradient is non-existent with a 0 value while a maximum gradient would be infinite.

• Notwithstanding, the different types of gradient data have been synthesised in three categories:

• Exceptional gradient → refers to the gradient of a specific point of the terrain, therefore, defined by a precise location. For this type of data, a higher resolution of the Digital Elevation Model (DEM, onwards), would optimize the outcome.

• Longitudinal gradient of the river → longitudinal variance on homogeneous sections. As in the previous case, a reduced pixel would favour the accuracy of the data.

• Average gradient of the basin or specific gradient → is equivalent to the average gradient of a given territory, thus, does not give a report of the river gradient sensu stricto but of the geomorphologic environment where it circulates.

2. Gradient calculation with ArcGIS 9.x®

The estimation of the gradient using G.I.S. software (Geographic Information Systems) can be carried out through different algorithms and base information (vector and/or raster). In the vector models -networks of irregular triangles, TIN- the gradient is calculated according to the maximum change index in the triangle elevation. However, most of the gradient studies are carried out through the elevation changes between cells of a DEM raster enclosed by a matrix, although this practice is not the most appropriate way to determine the gradient at river level.

The explanations and examples given in this technical note have been developed based on the commercial program ArcGIS 9.x (ESRI ArcGIS ®), although there are many other geographic operation systems that operate in a similar way1. ArcGIS 9.x obtains the gradient through an operator of low pace known as Sobel or Horn method. The process is based on a moving window of 3x3 cells (moving matrix of filtering coefficients or kernel) that travels through the DEM encompassing 8 values in each calculation, in which the problem point or the points to deduct do not intervene. For successive movements of the window, after calculating the new value of the central and unique pixel, modified in each movement, the calculations are based on the original values and not on the ones that have been filtered (see figure 1).

The Sobel operator, unlike others that also use 8 values in a calculation, weighs the 4 neighbours which are closest to those located on the diagonals. The obtainment of the gradient using this filter is resolved using the square root (√) of SA2 + SB2 in which:

SA = [(Z3 + 2Z6 + Z9) - (Z1 + 2Z4 + Z7)] / 8d
SB = [(Z1 + 2Z2 + Z3) - (Z7 + 2Z8 + Z9)] / 8d

where Z is the altimetric level and d the distance between the centres of the filtered cells.

Other G.I.S. software with widespread commercialisation like IDRISI (Dpt. of Geography of the University of Clark, USA) or ERDAS Imagine (Earth Resources Data System) obtain the gradients using algorithms of Zevenbergen & Thorne and Sharpnack & Akin, respectively. The first of these operates with the four closest altimetric values. The methodology of ERDAS Imagine is based on the calculation of the closest 8 neighbours and with the same weight for each one.

Advantages and disadvantages of the algorithm used by ArcGIS 9.x in the gradient calculation:

The fact that a very high number of points act in the filter instead of in the problem point means that there is:

- Notable smoothing effect.
- Misuse of the information of the problem point as this is not part of the calculation, a situation that can be worsened if this data coincides with a depression or a crest.

On the other hand, the method has the advantage of:

- Disguising possible timely errors of the DEM, as a high number of data intervenes in the filtering; these lose importance at the expense of the surrounding values that make up the window.

In figure 2, several G.I.S. procedures are shown for the obtainment of any of the three types of defined gradients (exceptional, specific and longitudinal). The so-called vector routine (not to be understood as TIN) is the most useful for hydro-geomorphologic studies, as it gives information which is exclusively tied to the surface occupied by the lower riverbed, whilst the raster models are much more adequate for the specific and exceptional gradients.

The following pages of this technical note are dedicated to three aspects: i) the development of the gradient with vector structures; ii) the development of the gradient with raster structures; and iii) disadvantages of the bitmap models in the calculation of the riverbed gradient.

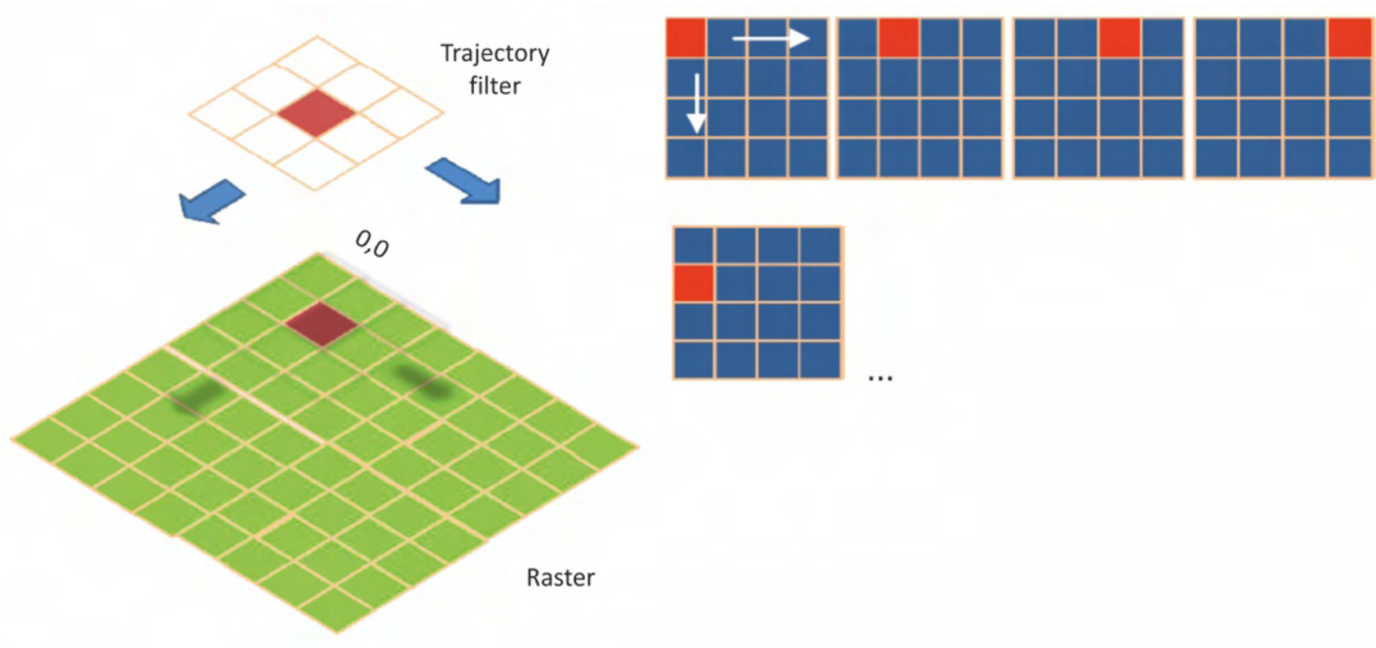

Figure 1. Simulation of the kernel trajectory on a raster.

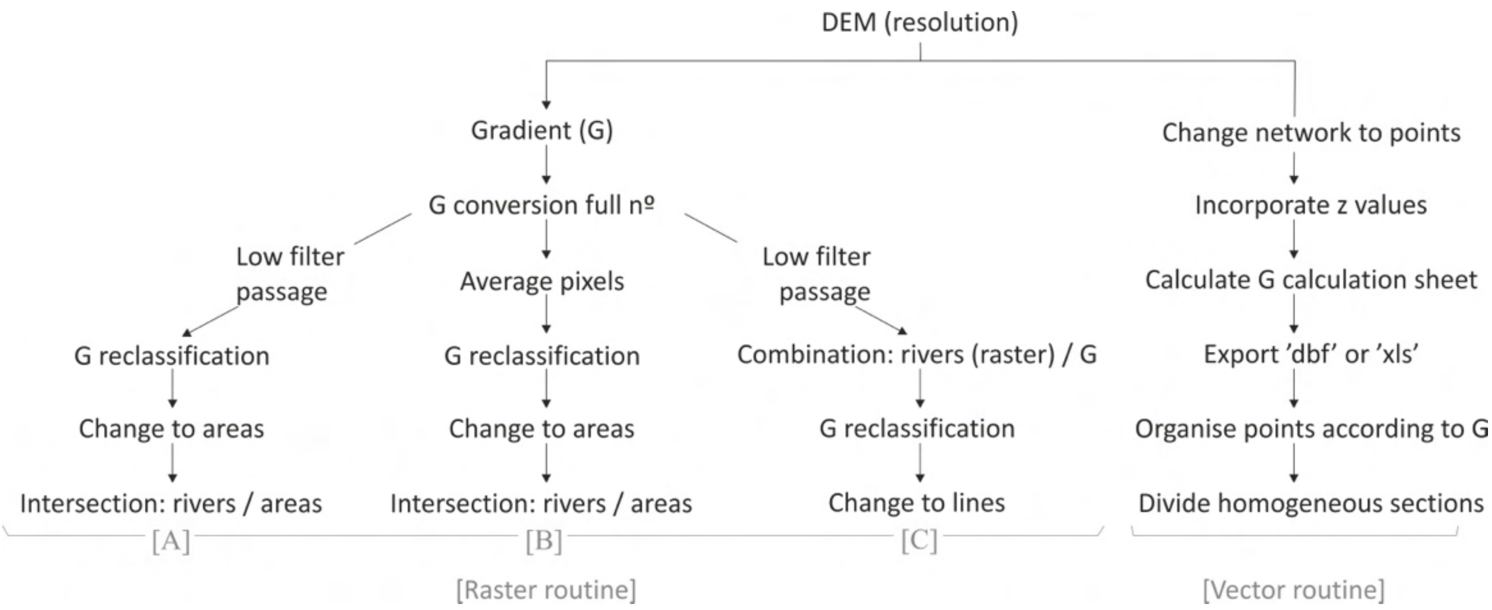

Figure 2. Work procedures for the calculation of the riverbed gradient

3. Development of the gradient with vector structures

This procedure is only valid for the calculation of the longitudinal gradient of the riverbed. Results are achieved that are as precise as the quality of the DEM. For its development, the extension of spatial ecology Hawth´s Analysis Tools ® implemented by the Department of Biological Sciences of the University of Alberta (Canada) for ArcGIS (ESRI ®) is an excellent support due to its diverse benefits.

The process starts with the breakdown of the river network at equidistant points [Hawth´s tools → Hawths tools → Animal movements → Convert paths to points (lines to points)] so that the planimetric distance is constant. The new layers of points created by each current are added to the altimetric value of the DEM at this point [3D Analyst tools → Functional surface → Surface spot || Spatial analyst tools → Extraction → Extract values to points]. The work layers (*.shp) are made up of different files, one of which is a chart (*.dbf) where all of the alphanumeric contents is stored. Each of these charts can be opened with an Excel calculation sheet to formulate the equation of the gradient in a new column known as 'G' (see figure 3).

The result is saved once again in either (*.dbf) format or (*.xls)2, both recognised by the ArcGIS 9.x. The data charts with the new stored information are sent into the program [Tools → Add XY data] to, then, represent it in the ArcMap viewfinder. The presentation of the data must be done in function of the previously defined intervals of the gradient (%) of the riverbed.

Before continuing with the process, it is necessary to create a copy of the layers river that will act as a base for the defragmentation of the gradient types. The process is a simple one and consists in cutting the copy of the lineal layer rivers -called 'Gradient'– [Split tool y Snapping ('Points_riverX')] in each gradient type change indicated according to the colour of the points and thus defined in the simbology [Rightclic → Properties → Simbology] (see mechanism in figure 3).

Note: ArcGIS 9.x does not identify the files Excel of Microsoft Office 2007 with extension (*.xlsx)

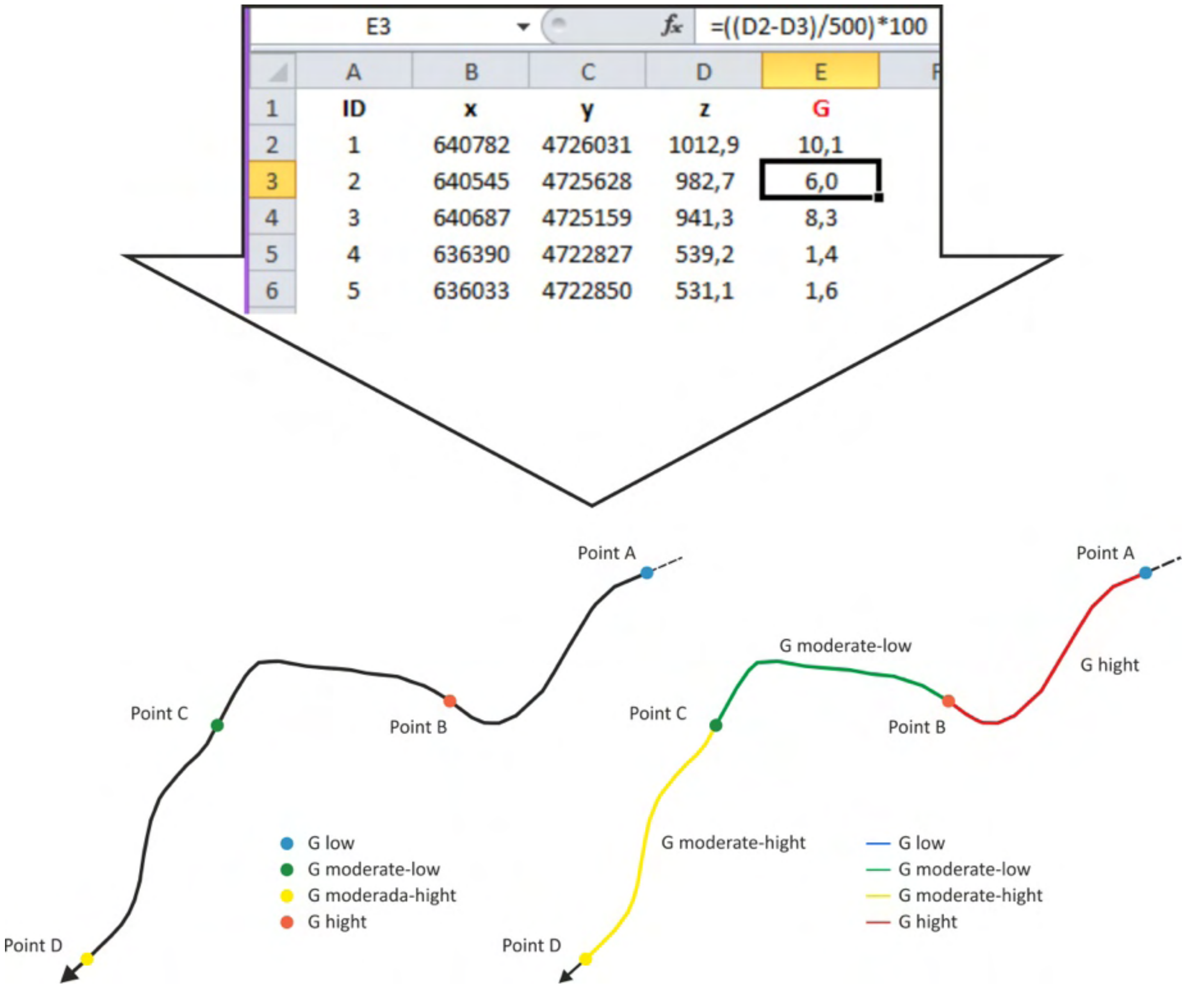

Figure 3. Obtainment of the gradient using calculation sheet Excel and instantiation of the longitudinal gradient calculation through vector models. Point D represents the gradient between this and the immediate higher point upstream (point C); point C represents the gradient between this and the immediate higher point upstream (point B), and so on.

4. Development of the gradient with raster structures

As is shown in figure 2, the obtainment of raster gradients with G.I.S. can be carried out using different procedures. Among these, the spatial resolution is an essential step with a strong imprint on the resulting grid, possibly confirming that the main obstacle for the calculation of the gradient is, above many, the pixel size of the model.

Figure 4 shows a map-raster of the gradient in percentages with a resolution of 25 m. Once this cartography has been created, it is recommendable to change the decimals to full numbers to accelerate and favour any future algebraic operations.

In the reclassifying stage (see figure 2), it is not recommendable to establish the gradient types directly from the results of the algorithm, with it being more appropriate to apply a filter of low passage beforehand to the raster layer with a kernels average of, for example, 3x3, 5x5 or 7x7 (raster routines A and C of figure 2) or transform the grid to another with average value pixels (mean) of the area of study (raster routine B, figure 2), which will help to alleviate an excessive division on gradient types. The idea is to strengthen the average component (the filter favours the peripheral pixels so the central pixel becomes more akin to these) to reduce the variability of cases and obtain a much more homogenized grid (figure 5). This implementation has particular relevance where the change frequency is high, understanding frequency as the number of changes in the values of cell per unit of distance. The aim of the filters focuses on making an image more construable or, as is this case, adjusting the grid to a classification.

This prior application of a low passage filter or average value of pixels is useful to restore the random errors that may occur in the interpolated values, as well as to reduce the spatial variability of categories (figure 5) as a preliminary step to a subsequent digital procedure.

The reclassifying exercises imply, obviously, creating sections in the river network. The degree of defragmentation will be in consonance with the size of the pixel and the number of gradient groups (types) established by the user. In this same line, during the post-classifying analysis, the average data of the number of sections, average sections and maximum section are particularly clarifying to distinguish the use of the correct filter, as they greatly reflect the response of the sectioned areas with different types of filters. The minimum section is not highly representative as it generally corresponds to those situations in which a river slightly brushes a pixel, thus acquiring its value (figure 6).

The importance that the filters acquire on the cartography of the sections of a homogeneous riverbed is clear from the fact that the non-application of these techniques results in a medium-low length of the section and a number of high sections and, inversely, the application of a filter results in that the average length of the section is higher and the number of sections are less.

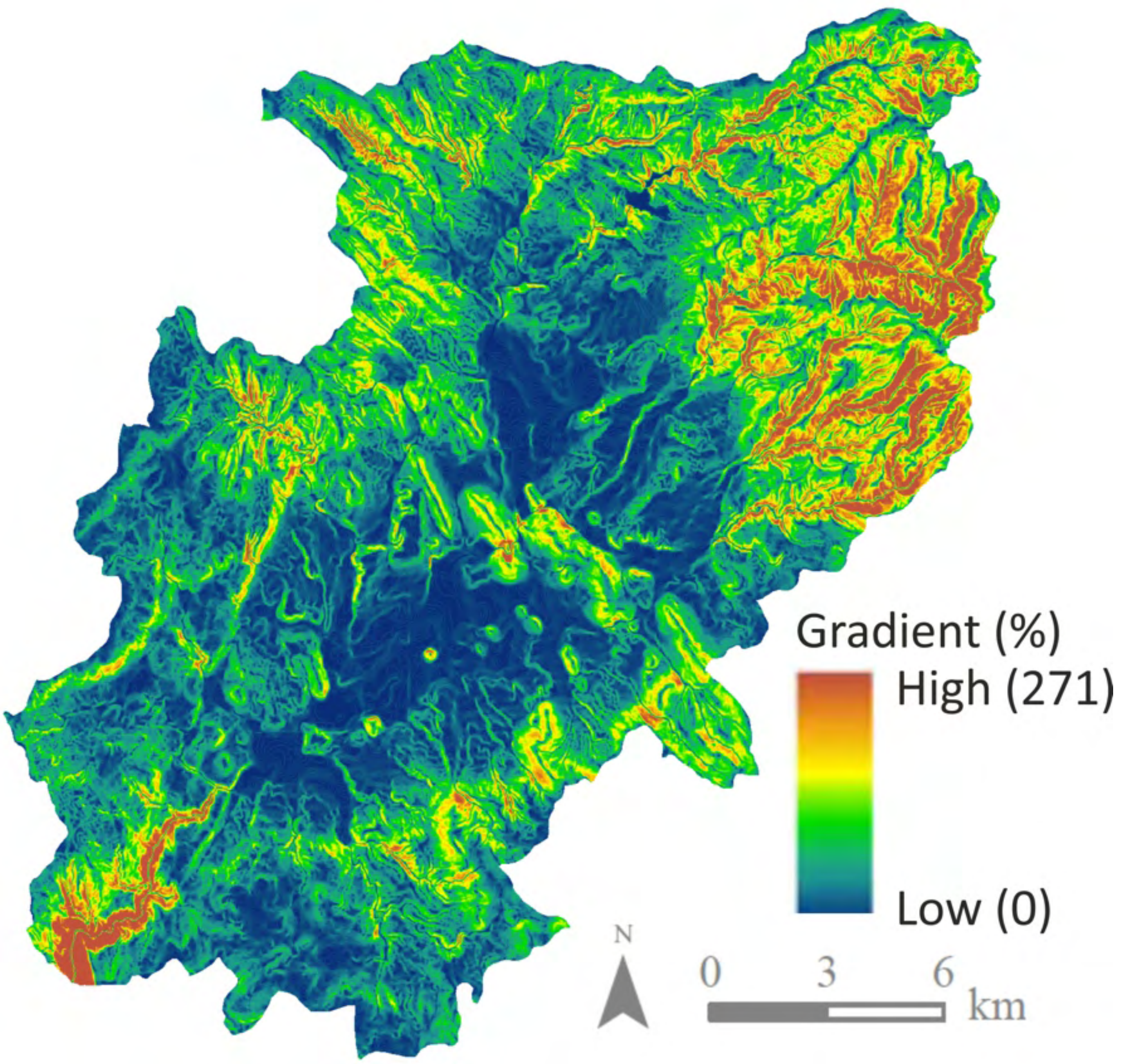

Figure 4. Gradients in percentages (%) of a hydro-graphic basin.

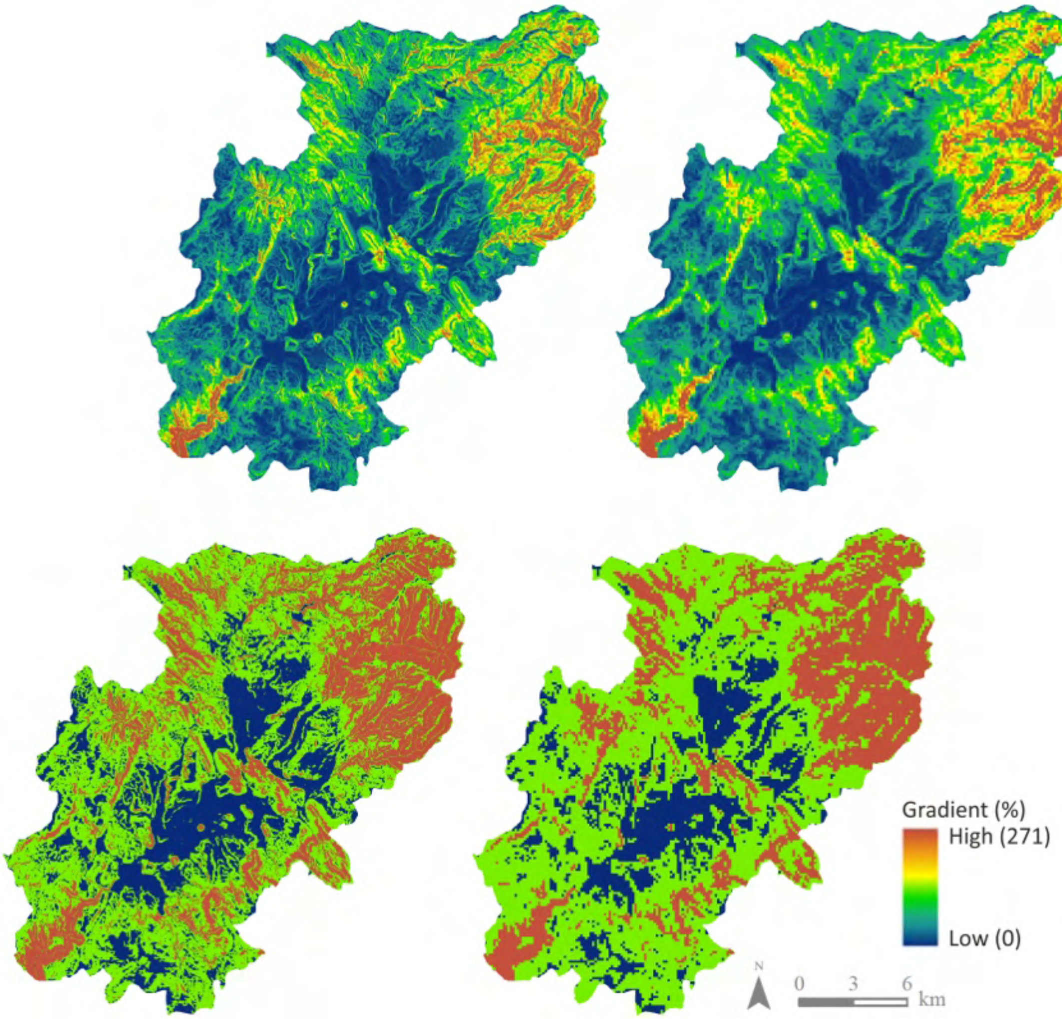

Figure 5. Gradient in percentages without a filter (upper left.); filtered gradient with a low passage filter 7x7 (upper right); gradient without a filter reclassified to three categories of gradient (lower left); filtered gradient with a low passage filter 7x7 and reclassified to three categories of gradient.

5. Disadvantages in bitmap models in the calculation of the riverbed gradient

The resolution of the DEM mainly has 3 types of problems to determine the gradient at the level of the riverbed: i) the less resolution the DEM has, the less exact will the calculation of the gradient be; ii) in narrow valleys, gorges, canyons, etc. a gradient value higher than the real value is given (figure 7); iii) sections of the riverbed in leguminous ground may appear due to the effect that the filters imply, underestimating or overestimating the value of a specific point in function of the value of the points included in the filter window. The result is, consequently, a network with many inaccuracies (noise): discontinuities, phenomena in leguminous ground, sudden cuts...

In figure 6, an example is shown of how, in a section of the river of a scarce 180 m, the program divides the network before the filtering in 10 sections, some of which are only of 2 or 3 m. However, with a low filter of 3x3, this entire section is reduced to one single spot and, therefore, to one single type of gradient or section. The course of the river is also an intractable setback, as there are many occasions in which, as has already been stated, they slightly brush the pixels of different gradient-type, thus creating a small section. This problem cannot be solved automatically, although the possibilities of suffering from this after the filtration is notably reduced.

Generally speaking, a 'zoning error' can be seen on the raster gradient maps, that is, there is a striking contrast between areas where the deviation of the gradient, with respect to the correct value, is elevated -mountain areas-, by others of plausible accuracy -flat

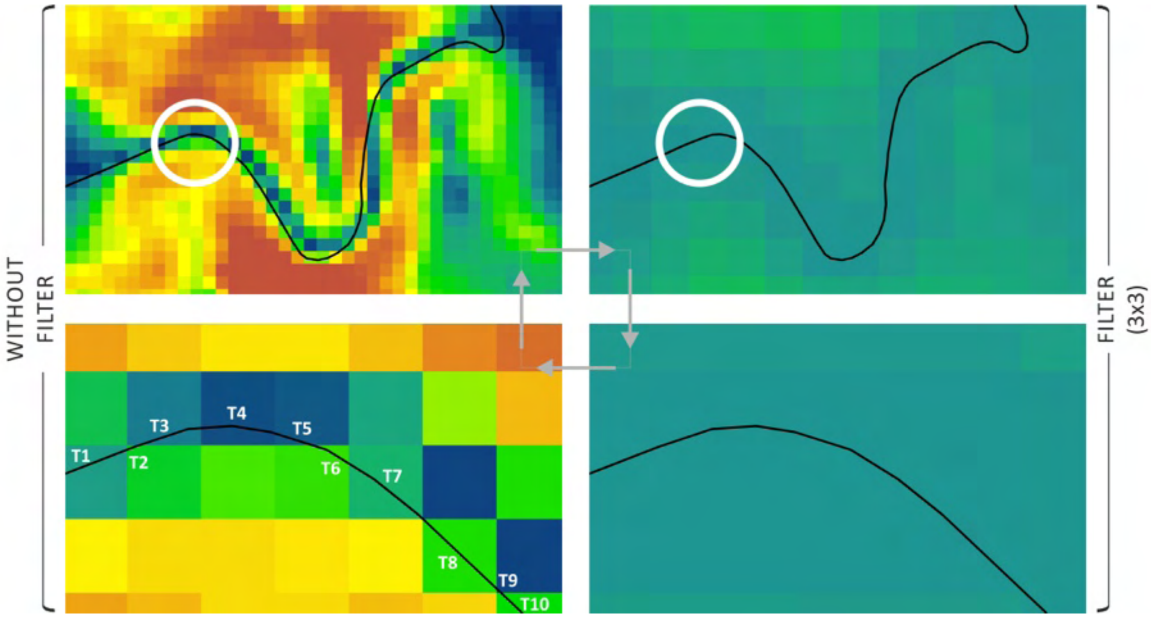

Figure 6. Images of a section of the basin: without filtration (left) and with low passage filter 3x3 (right). In the lower images, the number of sections drawn by the G.I.S. before (left) and after (right) the application of the filter is shown in a section of 180 m and with a pixel size of 25 m.

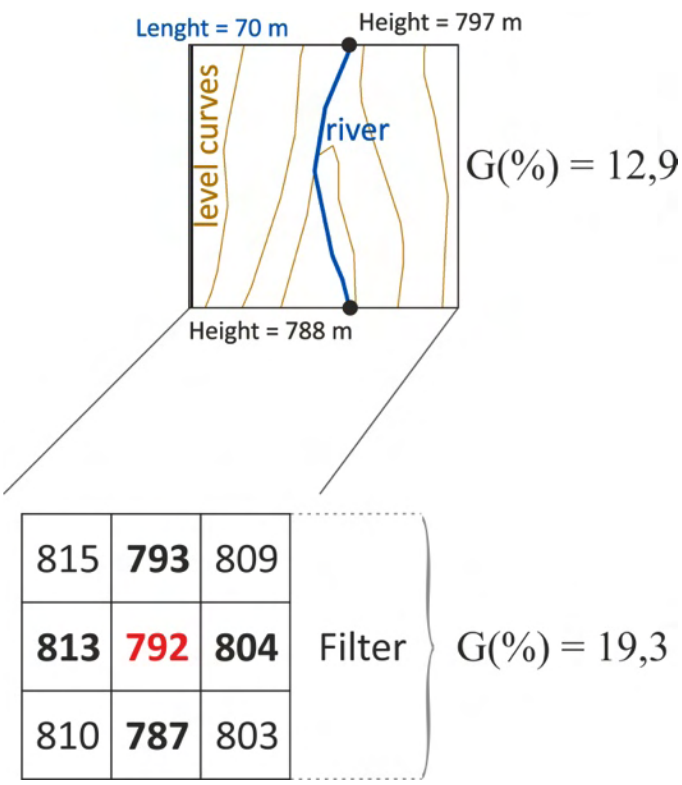

Figure 7. Calculation of the gradient procedure with Sobel type filters.

areas-. In the case of the sectors of plain areas, the precision is higher, as the heterogeneity of the altimetric values is low. On the contrary, in points of higher verticality, it is common the gradient of the riverbed differs highly from reality because, in the calculations, the watershed gradients are taken into account, which are much higher than the gradient of the riverbed.

Some conclusions of interest:

- In the current supply of G.I.S. products, there is no record (according to the authors knowledge) of any tool that has the entire modus operandi implemented for a reliable calculation of the longitudinal gradient or at riverbed level.
- The technical method proposed has the advantage of offering good results, elementary base materials and easy handling.
- The technical method proposed has the additional problem that it brings together different tools, extensions and even software, with the inconvenience that this may assume in terms of formats, installations, licenses or digital compatibility.
- The efficiency of the results will always be dependent on the quality of the digital model of elevations.
- The obtainment of the gradient of a riverbed with raster models has a high risk of generating overestimated gradients, mainly in areas of strong verticality. This is caused by the calculation matrix mixing a high amount of territory, which is very coarse with respect to the possible real gradient of the riverbed.

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