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The uDig Spatial Toolbox for hydro-geomorphic analysis

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ABSTRACT: Geographical Information Systems (GIS) are now widely used in hydrology and geomorphology to automate basin, hillslope and stream network analyses. Several commercial GIS software packages are available which provide terrain analysis functionalities for hydrogeomorphology, however, these are often prohibitively expensive. JGrasstools in uDig GIS, is, instead free and Open Source. Recently, uDig was integrated with significant resources for environmental analysis. The Spatial Toolbox for uDig is a specialized toolset for topographical analysis, geomorphometry and hydrology. A large number of tools are included in the toolbox for terrain analysis, river network delineation, and basin topology characterization. They are designed to meet the research needs of academics and scientists, but it remains simple enough in operation to be used for student instruction and professional use. JGrasstools and uDig are developed in Java, which ensures their portability in all operating systems running a Java Virtual Machine. This chapter demonstrates the capabilities of the uDig Spatial Toolbox, which range from the extraction of landform parameters to more advanced DEM manipulations and hydro-geomorphological modelling.

KEYWORDS: Hydrology, geomorphology, GIS, Open Source, catchment analysis, network extraction

Introduction

Since efforts in the late 1980s (Bras *et al.*, 1986, Band 1986, 1993; Grayson *et al.*, 1991) much progress has been made in extending terrain modelling and implementing the mathematical findings of geomorphometry (e.g. Evans *et al.*, 2003) into usable tools (e.g. Wilson and Gallant, 2000, Pike, 2002, Rigon *et al.*, 2006). Furthermore, the availability of Digital Elevation Models (DEMs) has promoted the automatic derivation of river basin features by researchers and practitioners in hydrology and geomorphology.

Given that the tools available were sometimes prohibitively expensive, some researchers provided their tools as a free product (e.g. Lindsay, 2005; Wood, 2002), but, with few exceptions (e.g. Garbrecht and Martz, 1997; Mitasova and Neteler, 2004, and the suite Sextante (http://www.sextantegis.com/docs.html), they provided just the executable of their code, and did not disclose the source code. Since then, with the objective to offer open source alternatives for terrain analysis, various software has been developed. A brief overview of the main software will now be given, this is supplemented by a comparative table of algorithms implemented by each provided in Appendix A (Table A1). LandSerf is an open source tool designed to provide high quality geomorphological visualization and analysis (Wood, 2009), which includes specific tools for fractal analyses of landscape surfaces. Whitebox Geospatial Analysis Tools, formerly known as TAS, was developed with the objective of providing free and improved visualizations and spatial analyses in GIS (Lindsay, 2005). TauDEM (Terrain Analysis Using Digital Elevation Models) derives from decades of theoretical and applicative work in hydrologic DEM analysis and watershed delineation by Tarboton (e.g. Tarboton, 1997). GRASS GIS is for many purposes similar to the uDig tools presented in this chapter (e.g. Jasiewicz and Metz, 2011). GeoNet derives from recent research by Passalacqua and coworkers on filtering landscape geometries with wavelet tools (e.g. Lashermes and Foufoula-Georgiou, 2007), and on channel initiation (Passalacqua *et al.* 2010a, 2010b).

The uDig (User-friendly Desktop Internet GIS) Spatial toolbox merges the visualization and spatial analysis capabilities commonly found in raster GIS packages with an extensive list of sub-programs specifically designed for research in hydrology and geomorphology. In comparison to many of the other toolkits mentioned, the Spatial Toolbox is a real GIS toolkit (like the one in GRASS, see Table A1) with the advantages of being able to access geographical databases, transform and treat several common geographical data formats, handle and conjointly use vectorial and raster data, and generate the most common data formats in output. Additionally, while most users will find the sole availability of executable code satisfactory, only the full availability of source code internals provides researchers with complete control over the final results of their analyses. For this reasons, the uDig Spatial Toolbox was designed to provide a user-friendly, open source, well-documented, new-generation, GIS for specific applications in hydrology and geomorphology, but also effective for more generic environmental applications.

For historical reasons, the tools in the uDig Spatial Toolbox are also called JGrasstools. They are organized into four toolboxes: Raster processing (RP); Vector processing (VP); HortonMachine (HM); and Others. Most of the geomorphometry analysis tools are in the HortonMachine toolbox. This chapter will concentrate on those functionalities which are useful to geomorphological analyses contained in the HortonMachine toolbox, but will also touch on those command options that can produce vectorial features of geomorphological entities, without going into a detailed description. Table 1 lists the acronyms used in this book chapter. The Raster processing toolbox has basic tools for raster corrections and operations (that work through the Map Calculator in ArcGIS), whereas the HortonMachine has functionality that ranges from standard analysis of DEMs (such as slope, aspect, curvature) to more specific hydro-geomorphological modeling solutions, which are explained under each category. Raster processing and HortonMachine have some tools which output vectorial features, the Vector Processing toolbox provides many tools for vectorial hydro-geomorphological analysis. Table 2 presents the general functionalities of the four toolboxes.

Table 1: The list of acronyms used in this chapter.

Acronyms	
RP	Raster processing
VP	Vector processing
HM	HortonMachine
OMS	Object Modeling system
Grass	Geographical Resources & Support System
JGrass	Java Geographical Resources & Support System
uDig	User-friendly Desktop Internet GIS
TauDEM	Terrain Analysis Using Digital Elevation Models
OGC	Open GIS Consortium
PNS	Pfafstetter numbering schemes
TAS	Terrain Analysis System
JAMI	Just Another Meteorological Interpolation
NaN	Not a number

Table 2: The list of uDig spatial toolboxes and summary of their general functionalities.

Toolbox	Functionalities
1. Raster processing	Raster data correction and calculations
2. Vector processing	Wide range of Vector data analyses such as vectorizer, buffer zone, line and polygon topological analyses etc.
3. HortonMachine	From simple digital raster terrain analyses to more advanced hydro-geomorphological analyses
4. Others	Design of water supply and sewer systems for urban environments, and other tools

In the next sections, some selected raster processing and HortonMachine tools are described in detail.

In showcasing the virtues of the uDig Spatial Toolbox, the Posina River Basin has been selected as a case study to illustrate the application of some tools. The Posina River Basin is located in the north-western part of the Pre-Alps of Vicenza, between the Astico Valley and Monte Pasubio. The surface area of the basin at Stancari is 116 km^2. Geomorphologically, the basin shape is roughly circular and enclosed by a series of mountains with elevations reaching 2000 m and above (Borga *et al.*, 2000). The location and associated DEM of the Posina River Basin are shown in Figure 1.

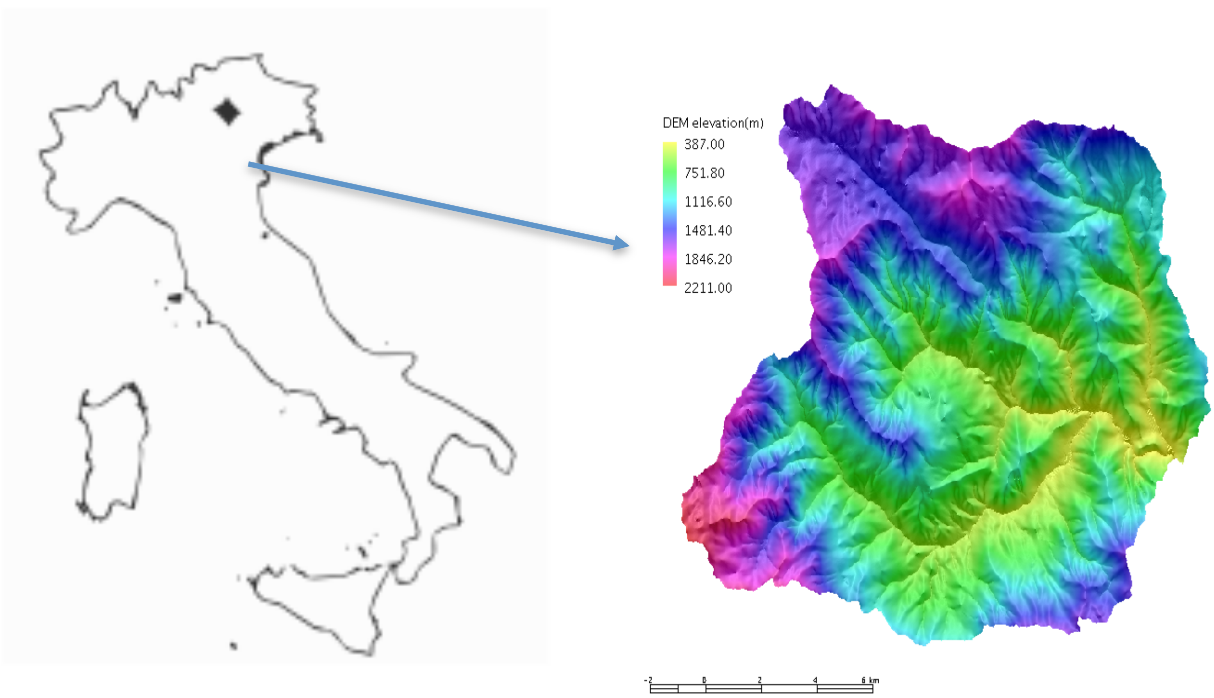

Figure 1: The location and the DEM of Posina river basin, the case study.

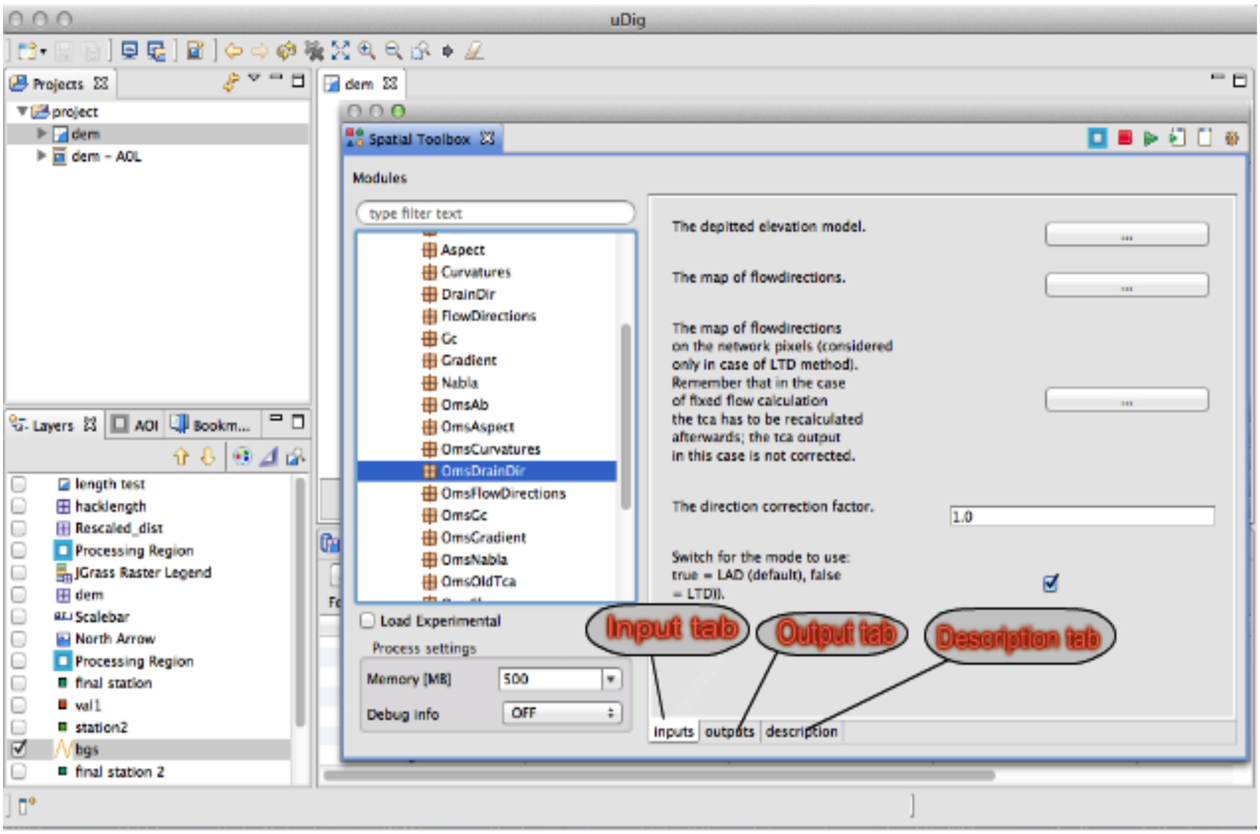

Figure 2: uDig GIS interface with spatial toolbox overlay and the three tabs: inputs, outputs and descriptions tabs at the bottom of the toolbox.

Raster Processing

The **Raster Processing toolbox** contains a set of tools for the preparation of topographic data for hydro-geomorphological applications. Figure 2 shows the typical appearance of the uDig Spatial Toolbox. When the Spatial Toolbox is open, for any tool, there are three tabs that serve to input and the output variables. The third tab contains the help associated with the selected the tool, with a short explanation of what the tool does. Raster processing toolbox contains tools for the quick manipulation of raster maps (the relevant tools are listed in Table 3). For all the tools listed in Table 3, which are useful for modifying and improving DEMs and provide input data for geomorphological and hydrological analyses, information can be found in the Help of the toolbox package.

There are about 30 tools under the RP toolbox that can be implemented. However, there is not the scope to explain all of them here, therefore a little more detail will be provided about a selection of the more interesting tools within the RP toolbox.

Among the list of tools presented in Table 3, a very useful one for advanced raster map manipulation is the raster calculator

(**MapCalc**), which allows complex calculations involving numerical and logical functions. With Mapcalc one can perform the most common mathematical operation on a map, modify map’s values, combine maps, multiply, divide one map by another map (i.e. the values contained in one map for the corresponding values of another map), select part of a map, and so on.

Ranglookup, **Rastercorrector**, and **Rasterconverter** provide summary statistics of raster maps. The **Rangelookup** tool is particularly important as it identifies the raster data included between user-defined range values.

RasterSummary tool is useful as it provides basic summary statistics (such as the minimum, maximum, mean, standard deviation, histogram, and the NaN value) of the raster map.

Table 3: Some of the tools available in the Raster Processing toolbox of uDig.

Raster Processing Tools	Functionalities
BobTheBuilder	Builds human artifacts (such as dams) on a raster map
CutOut	Raster masking and cutout with some threshold
KernelDensity	Estimates the kernel density
MapCalc	Performs map algebra on raster map
Mosaic & ImageMosaicCreator	Patches rasters and creates mosaics of shapefiles for images
PointRasterizer & LineRasterizer	Rasterizes vectorial point and line features respectively
CannyEdgedetector	Performs edge detection operations
Profile	Creates profiles over raster maps
RangeLookUp	Reclassifies and assigns values of maps for a given ranges of raster values
RasterConverter	Converts rasters from one format to another
RasterCorrector	Corrects some raster values
RasterDiff	Calculates the difference between two rasters
RasterReprojector	Re-projects maps
RasterResolutionResampler	Resamples the raster map coverage
RasterSummary	Calculates the summary statistics of a raster map
RasterVectorIntersector	Analyzes raster maps within a polygon vector (intersection)

A group of tools for rasterizing vector data includes **BobTheBuilder**, **PointVectorizer** and **LineVectorizer**. **BobTheBuilder** rasterizes human artifacts, such as dams and buildings, which could be useful to include in the raster maps. **PointVectorizer** and **LineVectorizer** rasterize point and line features, such as measurement stations and river channels respectively.

Finally, **SurfaceInterpolator** is useful for interpolating landscape data (such as elevation and temperature), from point measurement to the whole study area. Two surface interpolation algorithms are incorporated in this tool: the Thin Plate Spline (TPS) Interpolator and the Inverse Weight Distance (IWD) Interpolator (e.g. Goovaerts 2000). These methods can be applied to create Digital Terrain Models (DTM) from a set of GPS points or digitized maps, as well as models of other continuous environmental variables, for instance, surface temperature.

HortonMachine Functionality in Geomorphometry

The **HortonMachine toolbox** is organized into seven broad categories of commands: DEM manipulation; Geomorphology indices; Network related analysis; Hydro-geomorphology model tools; Basin related tools; Hillslope related attribute tools; and spatial statistics tools. Each of these will now be outlined in turn, and Tables 4 and 5 present the selection of tools useful for hydro-geomorphological applications.

DEM manipulation toolbox

The **DEM manipulation** tools contain subprograms used for preparing DEMs for analysis. These subprograms include routines to remove flats, spikes, and depressions from DEMs (**pitfiller**), to extract streams (**ExtractNetwork**), to extract sub-

Table 4: Some of the tools for DEM manipulations, geomorphology, hydro-geomorphology and statistics available in the HortonMachine toolbox (for hydro-geomorphological terminology, please refer at http://www.physicalgeography.net/glossary.html).

HortonMachine Tools	Functionalities
1. DEM Manipulations	e.g. Moore *et al.*, 1991; Palacios-Velez *et al.*, 1986; Rigon *et al.*, 2006
ExtractBasin	Extracts a basin by using the flow direction map
Markoutlets	Marks the outlets of a basin on the drainage direction map
Pitfiller	Fills the depression points of the DEM
SplitSubbasins	Labels the sub-basins of a basin using stream ordering
Wateroutlet	Extracts the watershed for a defined outlet
2. Geomorphology tools	e.g Orlandini *et al.*, 2003; Tarboton, 1997; Mitasova and Neteler, 2004; Moore *et al.*, 1991; Garbrecht and Martz, 1997.
Aspect, slope, Gradient, curvature	Calculate aspect, slope, gradient and curvature type of the map respectively
FlowDirections, DrainDir, LeastCostFlowDirections	Calculate the D8 method drainage direction, drainage directions minimizing the deviation from the real flow, and least cost method drainage directions respectively
Tca, Gc	Calculate contributing areas and topographic classes, respectively
3. Hydro-geomorphology	
Hillshade	Calculates the shadows of the DEM
Skyview	Calculates the skyview factor of the DEM
Insolation	Estimates the amount of shortwave radiation on a surface for a given of time
4. Statistics	
Cb	Calculates the histogram and the statistical moments of a set of data from a map with respect to another map
SumDownStream	Calculates the sum values of a map from upstream to downstream following the flowdirections
Jami	An interpolation method
Variogram,	Calculates the experimental semivariogram
Kriging	Implements the ordinary kriging interpolation algorithm

basins (**ExtractBasin**, **SplitSubbasins**), and to find the basin outlets (**Wateroutlet**). Depression filling is perhaps the most widely implemented algorithm for depression removal and is found in all the terrain analysis tools (e.g. TauDEM - Tarboton,1997; Rivix - Peckham, 2009; TAS - Lindsay, 2005; GRASS - Jasiewicz and Metz, 2011). JGrasstools uses the algorithm presented by Bras *et al.* (1986).

Geomorphology toolbox

The **Geomorphology** toolbox contains tools for calculation of slopes, curvatures, drainage directions and contributing areas, among many others. One of the simplest geomorphological attributes maps is the aspect map, a map that shows which side a slope is directed, this can be calculated using the **Aspect** tool from the DEM (Figure 3).

Terrain attributes are based on local neighbourhoods and reflect a simple application of the differential geometry of curves on surfaces (Peckham and Jordan, 2007). Algorithms involving upslope or downslope calculations (i.e. those within the basic topographic attributes and network related measures tools) rely on the steepest descent (or ‘D8’) flow-routing algorithm (O’Callaghan and Mark, 1984) because of the need for unique, non-diverging flowpaths. Two other algorithms involving analysis of neighbourhoods are implemented in uDig because using the ”pure” D8 method for the drainage direction estimation causes deviation from the “real” flow direction identified by the gradients. The first algorithm implemented according to Orlandini *et al.* (2003) is the D8-LAD (least angular deviation), which minimizes the total angular deviation. The second algorithm, D8-LTD (least transversal deviation), minimizes the total deviation length of the flow going downstream. uDig (through the uDig Spatial toolbox) is currently the only GIS that contains these algorithms.

A third algorithm available is the multiple flow directions algorithm, first implemented by Fairfield and Leymarie (1991). This is used mainly for comparison, since this effect is barely found in nature (e.g. Orlandini *et al.* 2012), and D8-LAD and D8-LTD recover very precisely the real drainage directions. Gradient calculation (**Gradient, Slope**) is another standard tool present in all modern toolboxes.

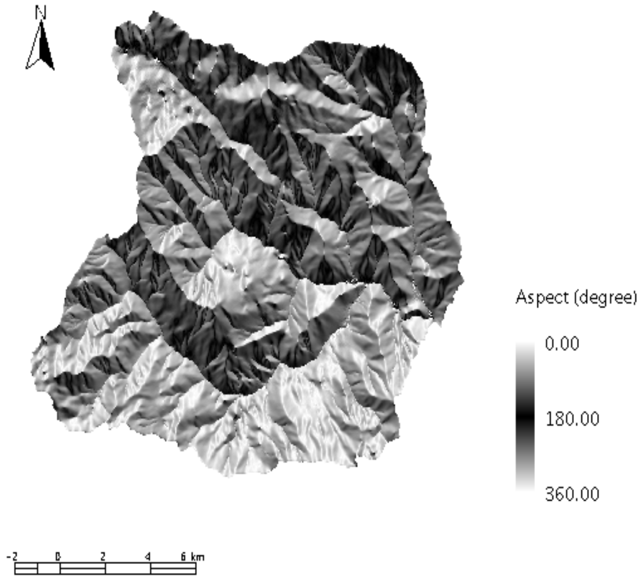

Figure 3: Aspect map of the Posina river basin, with enhanced visualization using the style editor tools in uDig GIS.

Table 5: Some of the tools available in the ***Network sub*** *toolbox and their general functionalities.*

HortonMachine Network tools	Functionalities
ExtractNetwork	Extracts the raster network from DEM (Orlandini *et al.* 2012; Montgomery and Dietrich, 1988, 1989)
HackLength	Calculates the distance of each pixel to the divides going upstream along the flow directions (Rigon *et al.*, 1996)
NetDiff	Calculates the difference between the value of a quantity in two network points with different numbering
Netnumbering	Assigns identification (id) numbers to the network links
NetworkAttributesBuilder	Extracts the network as a shapefile and adds networks attributes to it some (Rodriguez-Iturbe and Rinaldo., 1997; Rigon *et al.*, 1996)
DistanceToOutlet	Calculates the planar projection of the distance of each pixel to the outlet (D’Odorico and Rigon, 2003)
NetShape2Flow	Transforms the network shapefile to a flow raster map

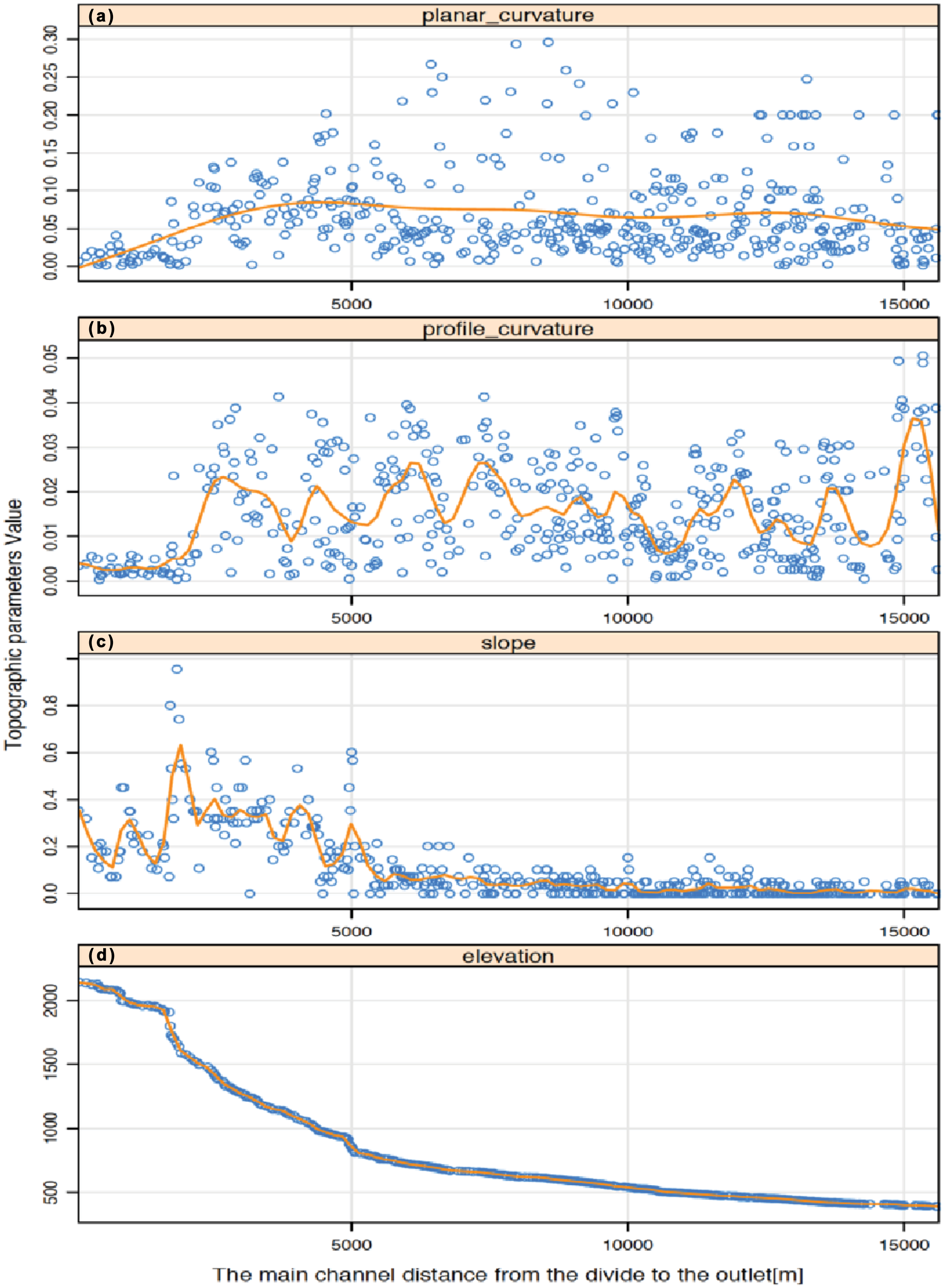

Figure 4: The topographic parameters: (a) planar curvature, (b) profile curvature, (c) slope and, (d) elevation, in the main stream of case study basin of Posina.

The classification of topographic sites into three different classes of curvature is another important tool (**Tc**, **Gc**). Longitudinal (or profile), normal and planar curvatures for each pixel are helpful to estimate the deviation of the gradient vector. Profile curvature measures the topographic curvature (i.e. the gradient deviation) along a flow line following the steepest descent path, and planform curvature measures the curvature of contour lines on topographic maps. Detailed description of different landform curvatures is found, for instance, in Tarolli *et al.* (2012). In combination with some other general tools, provided by the uDig Spatial Toolbox, these tools can provide the information shown in Figure 4 (see also complementary material at http://abouthydrology.blogspot.it/2014/05/the-udig-spatial-toolbox-paper.html). Figure 4 shows the elevation, slope and curvatures along the main stream of the Posina. Two knickpoints are particularly evident in the elevation plot, which reflect changes of gradient and curvature. The curvatures, in turn, are both positive starting after the first knickpoint, as expected, and identifying the presence of convergent-convex sites typical of a valley, and of channel geomorphology.

Network toolbox

The main tasks available in the **Network toolbox** in uDig are related to watershed extraction, various basin morphometric analyses, stream network extraction and analysis. These are presented in Table 5. The stream network extraction tool uses three alternative approaches: total contributing area threshold; slope-area threshold; and, curvature based. The first, and most common, method of extracting a channel is by setting some threshold on the total contributing area (**Tca**), representing the total area of upslope cells. Cells with a total contributing area greater than a given threshold area are considered to be flow channel, since Tca is considered a surrogate of discharge (O'Callaghan and Mark 1984).

In addition to the contributing-area threshold method, a slope-area threshold method based on work by Montgomery and Dietrich (1992) and a curvature based stream delineation method (Tarboton and Armes, 2001) have been implemented in the stream network extraction tool. Furthermore, stream network analysis includes utilities to order channel streams (using Hack and Horton-Strahler ordering schemes, e.g. Rodriguez-Iturbe and Rinaldo, 1997). From this ordering, it is possible to derive statistics associated to the network, to estimate Shreve's magnitude, and to measure link-average slopes and lengths and from them estimate, for instance, Horton laws (e.g. number and length of channels per Horton order, bifurcation ratio, and length ratio; see Rodriguez-Iturbe and Rinaldo, 1997).

The **HackStream** tool provides the channel ordering based on Hack's stream enumeration (Rigon *et al.*, 1996). In Hack's ordering, the main channel of the network is assigned the order 1, the channels that flow into it are assigned the order of 2, and the branches that flow into channels of order 2 are assigned the order of 3, and so on.

The most common and popular method of channel classification is according to the Horton-Strahler ordering scheme (Horton, 1945; Strahler, 1957), which is implemented in the **NetworkAttributesBuilder** tool: the network is divided into links that connect either two tributary junctions (internal links) or a tributary junction and a channel source point (external links: Rigon *et al.*, 1996). This ordering system assigns order 1 to the source; and when two or more streams of the same order, n, meet they form a stream of order, n+1. When two streams of different orders, n and m with n > m, meet the order of the channel they form remains with the order of the greater of the two, n. The **NetworkAttributesBuilder** produces not only the raster enumeration, but also the vectorial features of the stream ordering.

Another method for labeling channel links and associated hillslope is the so-called Pfafstetter coding method (e.g. Verdin and Verdin, 1999). It provides the topographical connectivity between channels and hillslopes. The technical description of the Pfafstetter numbering schemes (PNS) as implemented in the **Pfaf** tool is given by Formetta *et al.* 2013a. The generalization of this coding system, implemented in the uDig Spatial Toolbox, can also take account of the presence of dams and irrigation channels. The **Pfaf** tool produces a shapefile (i.e. a vectorial feature) that contains, besides the enumeration itself (as shown in Figure 5), the associated properties, such as the starting and ending point of a link, the elevation drop and other properties.

Hillslope toolbox

The **Hillslope** toolbox contents are presented in Table 6. They include tools for the classification of hillslope points into categories derived from information about curvatures, tools for evaluating distances of hillslope points to streams, and tools for calculating statistics of any quantity in a hillslope (Ghesla and Rigon, 2006). In addition to the estimation of pixels curvature, based on the longitudinal (profile) and transversal curvatures mentioned before, the topographic class (Tc) tool subdivides the sites of a basin in different topographic classes. The program has two outputs: the more detailed nine topographic classes (Parsons, 1988) and an aggregated topographic classification with three fundamental classes. Figure 6 is a visual comparison of an example of detailed nine and aggregated three topographic class maps of Posina river basin.

Planar curvature represents the degree of divergence or convergence perpendicular to the flow direction, and profile curvature shows convexity or concavity along the flow direction. By combining these two main curvatures, the topographic class (Tc) tool identifies 9 classes, which are three planar type sites (parallel–planar, divergent-planar convergent-planar sites), three convex type sites (parallel-convex, divergent-convex and convergent-convex sites), and three concave type sites (divergent-concave, parallel-concave and convergent-concave sites). These attributes can be summarized into three fundamentals classes (concave, convex and planar sites). The graphical depiction of the curvature classification of hillslopes is shown in Figure 7.

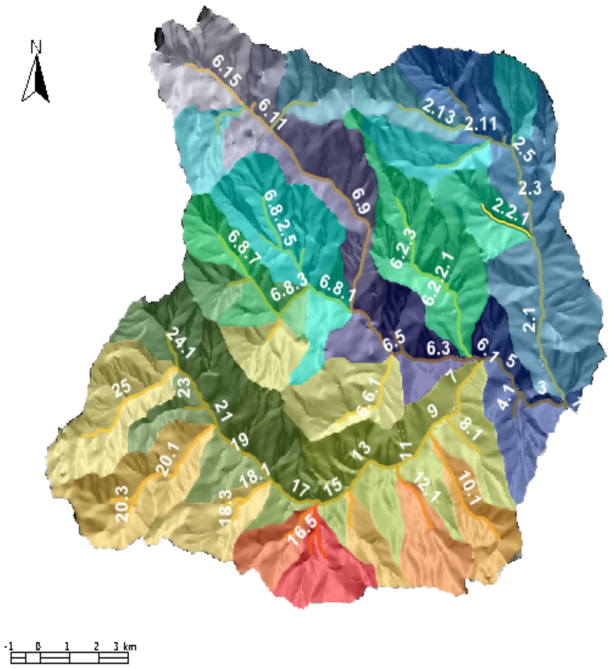

Figure 5: The pfafstetter enumeration scheme for the Posina river basin, as implemented in uDig GIS spatial toolbox for channel networks and hillslopes.

Table 6: The list of tools in Hillslope and Basin sub toolbox and their general functionalities.

HortonMachine tools	Functionalities
Hillslope toolbox	e.g. Parsons, 1988; Rodriguez-Iturbe and Rinaldo., 1997
H2CA	Estimates some attributes of hillslopes associated to a common channel network.
H2cd	Calculates hillslope distance from river network
Tc	Subdivides hillslopes into topographic classes
Basin toolbox	e.g. Rigon *et al.* 2011; D'Odorico and Rigon, 2003
BasinShape	Creates sub-basin shape file following the netnumbering tool
RescaledDistance	Calculates the rescaled distance of each pixel from the outlet
TopIndex	Calculates the topographic index of each sites

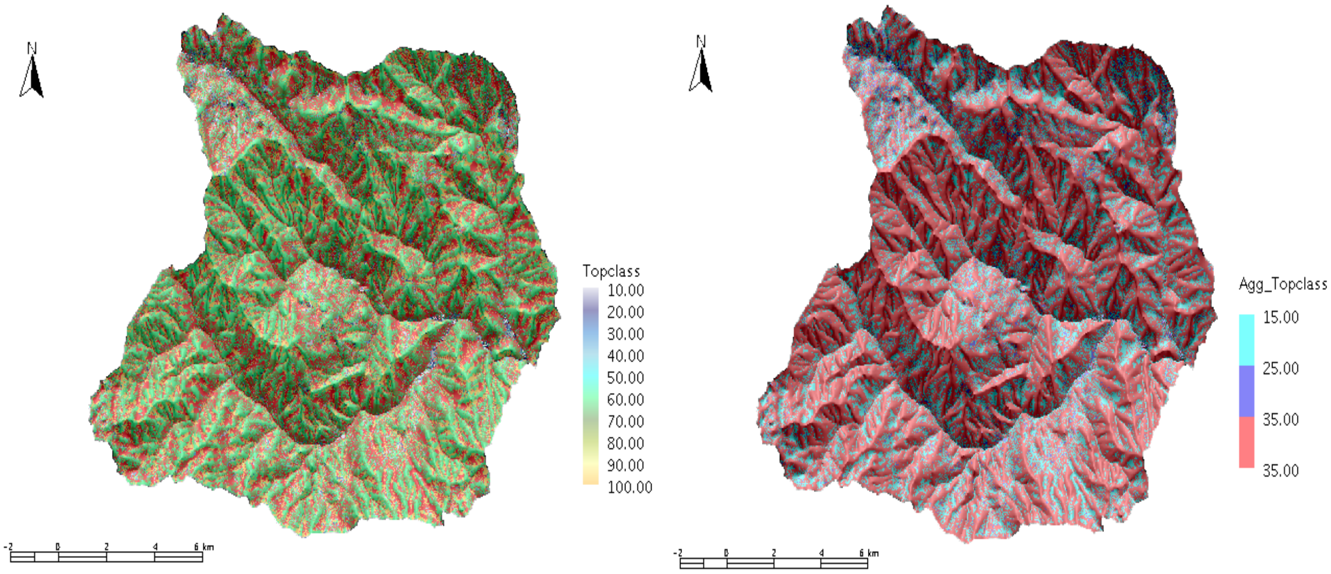

Figure 6: Hillslope topographic classes map of the Posina river basin. The first map (left) shows the nine hillslope classes based on topographic curvature (planar-planar sites (10), convex-planar sites (20), concave-planar sites (30), planar-convex sites (40), convex-convex sites (50), concave-convex sites (60), planar-concave sites (70), convex-concave sites (80), and concave-concave sites (90)). The second map (right) shows the three principal topographic classes (concave sites (15), planar sites (25), and convex sites (35)) of the basin.

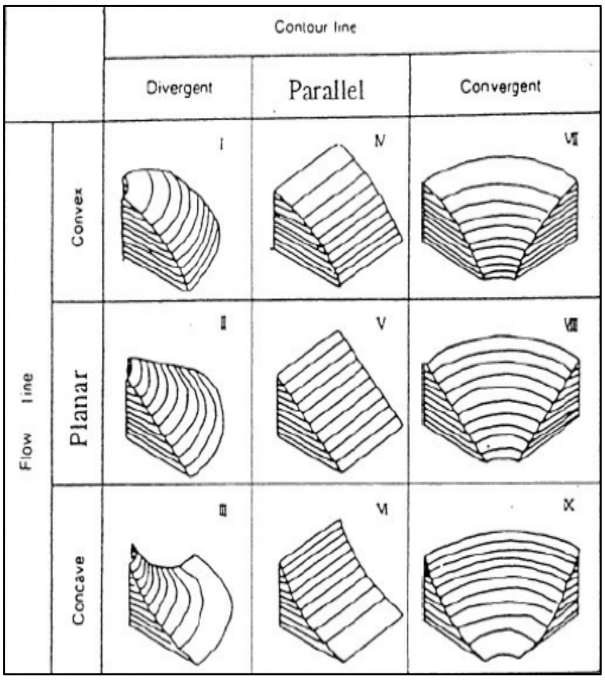

Figure 7: The subdivision of the hillslope sites according to their curvature (after Parsons, 1988).

In general terms, divergent-convex landforms are associated with the dominance of hillslope processes, while convergent-concave landforms are associated with valley-dominated erosion (e.g. Tarolli and Dalla Fontana, 2009). Mapping these divergent and convergent sites is essential for the geomorphological and hydrological analyses of a basin, the local divergence and convergence roughly identifying convex zones as hillslope zones, the concave zones as valleys, which are subject to different processes (as also enlighten by Figure 4).

Other tools from this toolbox were used, for instance, to produce the calculations in D'Odorico and Rigon (2003) to evaluate the distance of any point in a hillslope to a channel. The hillslope to channel distance (**H2cd**) calculates the distance of each point on the hillslope to the channel network following the steepest descent (see Figure 8).

H2CA calculates the distance a drop of water released (or rained) in any point in a hillslope takes to arrive into a channel. **H2CA** plus **H2Cd** is the total length from any point in a basin to the basin outlet. It is useful to separate these tools so as to associate to each of them a different residence time, as was done by Rinaldo *et al.* (1995).

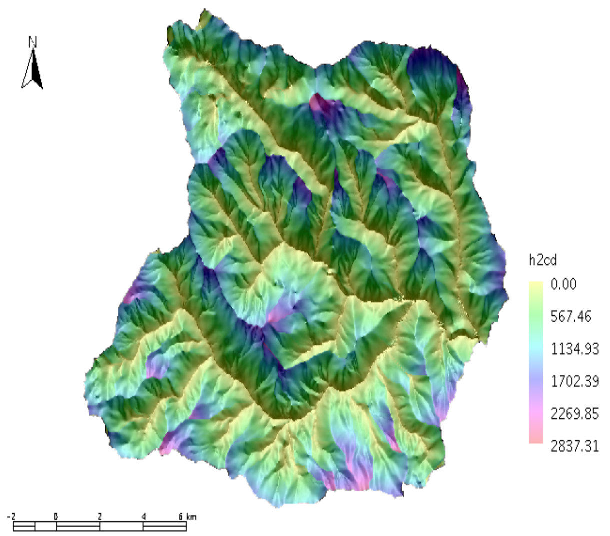

Figure 8: The map of the distance of each hillslope pixel to the channel (h2cd) in the Posina basin.

Figure 9, shows the distribution of distances from any point in a hillslope to channel versus the distance of the hillslope to the outlet. The figure was obtained after a little manipulation of the data (produced by the tool) made with R (http://www.r-project.org, please see the complimentary material). It clearly shows that the mean hillslope lengths of the Posina catchment are increasing downstream. The command **Drainage Density** (which equals the total network length per contributing area) can be used to obtain the homonymic quantity. Historically the two quantities, H2CA and drainage density were thought to be inversely proportional (e.g. Rodriguez-Iturbe and Rinaldo, 1997), and the second was often used to infer the first because easier to estimate from maps.

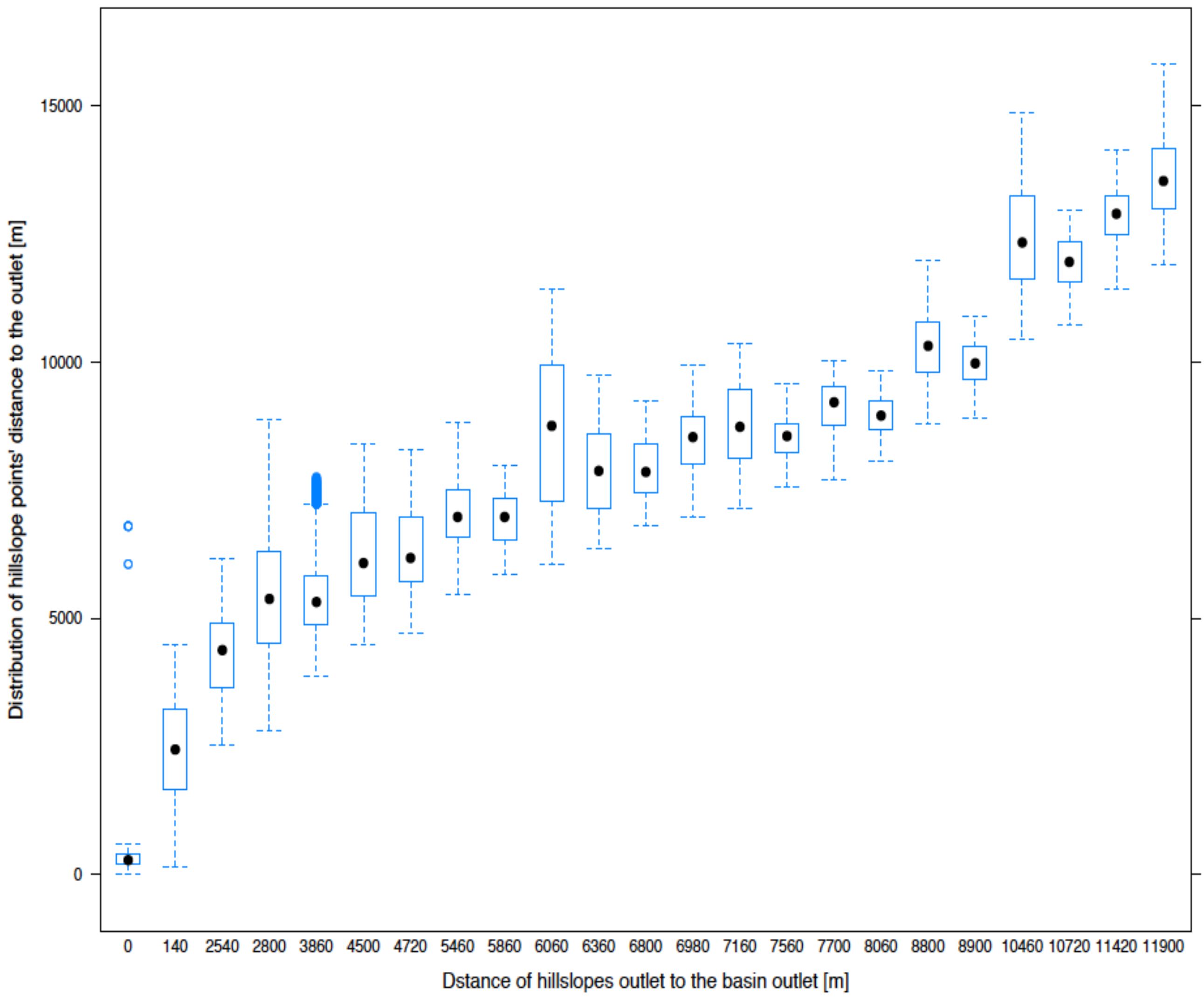

Figure 9: The distribution of hillslope pixel distance to the outlet versus the mean hillslope distance.

Basin toolbox

The **Basin toolbox** in the HortonMachine toolbox contains models to estimate basin-wide characteristics (shown in Table 6). They include, among others, methods to evaluate the width function (e.g. Rigon *et al.* 2011; D'Odorico and Rigon, 2003) and the rescaled width function (**RescaledDistance**; Rinaldo *et al.*, 1995), and topographic index (**TopIndex**) which is commonly used to quantify topographic control on hydrological processes which accumulate soil moisture (Beven and Kirkby, 1979). This has been criticised as a model for deriving maps of soil (see Barling *et al.*, 1994; Lanni *et al.*, 2012), however, the topographic index still remains a useful visualisation of the process of saturation, which can serve as a first approximation to understand which points saturate first (e.g. Crave and Gascuel-Odoux, 1997; Hjerdt *et al.* 2004). The rescaled distance is the distance of each pixel from the outlet measured along the drainage directions, weighted by the ratio of the water velocity in channels and on the hillslope. If the ratio of velocities is taken equal to one, the normal planar projection of the distances to outlet for any point in a basin is obtained.

The topographic index classifies the basin based on its ability to generate surface flow, according to Beven and Kirkby (1979). As is known, sites with a higher topographic index tend to become saturated before sites with a lower topographic index. The map showing the topographic index and the rescaled distances for each pixel of the study basin is shown in Figure 10. **BasinShape** is a tool which creates feature collections of sub-basins extracted by the netnumbering tool. It is useful for extracting important information form each sub-basin, such as area, perimeter, max elevation, minimum elevation, mean elevation etc.

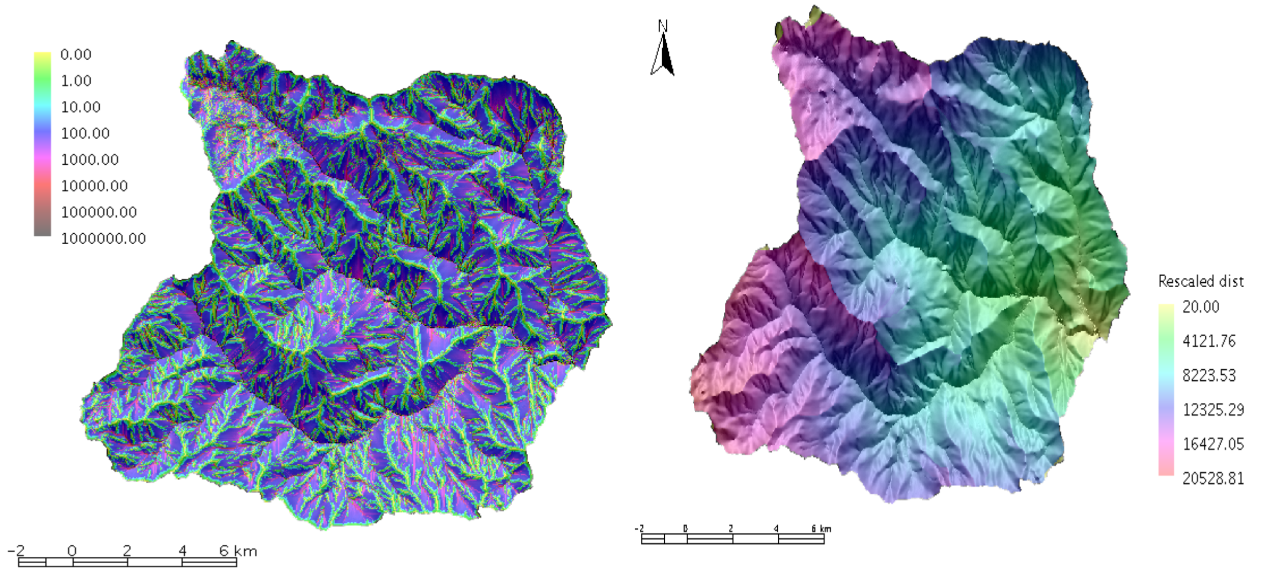

Figure 10: The map of the topographic index (left) and the rescaled distance (right) for the Posina river basin.

Statistics toolbox

In addition to the terrain analysis functionalities described above, the spatial toolbox also incorporates statistical tools (presented in Table 4). Among these, there are tools for both deterministic and geostatistic interpolation algorithms. These include Just Another Meteo Interpolator (JAMI) and kriging interpolation tools. JAMI is a robust approach of interpolating different meteorological data presented in Formetta (2013). The geostatistical technique implemented in the statistical toolbox is kriging. At the moment, the ordinary kriging algorithm (Goovaerts 1997, 2000) is the one implemented in the toolbox. If input data are provided as time series, the **kriging** runs over all the time steps, estimating a different semivariogram model, and the parameters

used for kriging interpolation, for each time step.
The kriging tool provides both point (non-regular grid) and regular raster grid outputs. Figure 11 and 12 are examples of grid and point interpolations obtained using exponential semivariogram model fitting. Figure 11 is a scatter plot comparing measured and interpolated hourly meteorological data (temperature).

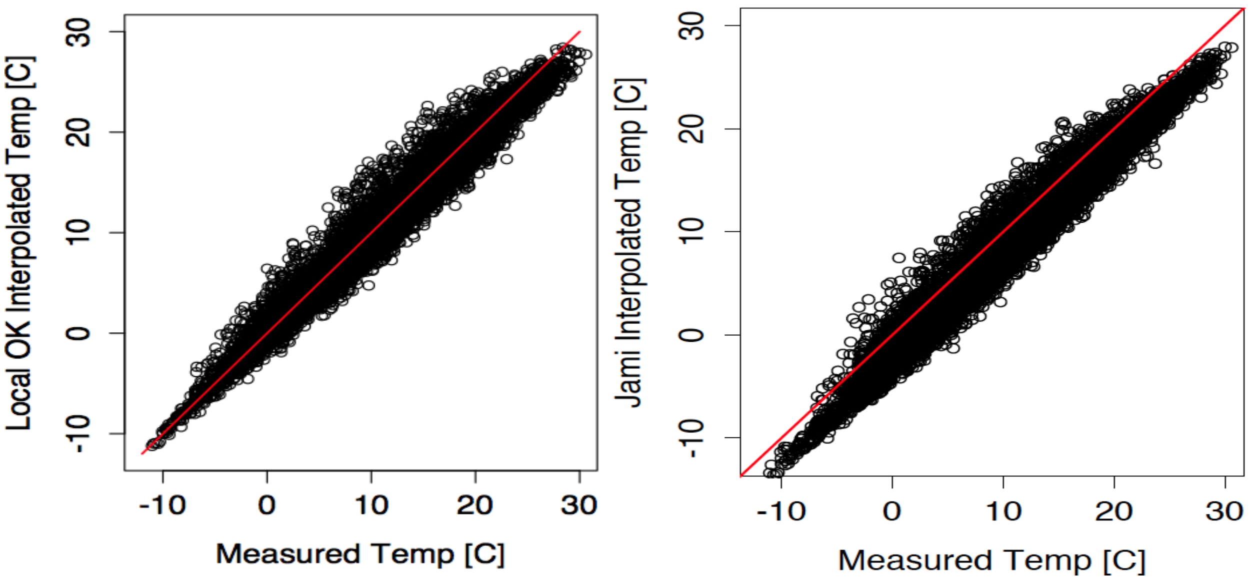

Figure 11: Scatter plot of measured and ordinary kriging interpolated (left: with R2 = 0.78) and JAMI interpolated (right: with R2 = 0.74) hourly temperature for one year (1995), in one of the measurement station in Posina river basin.

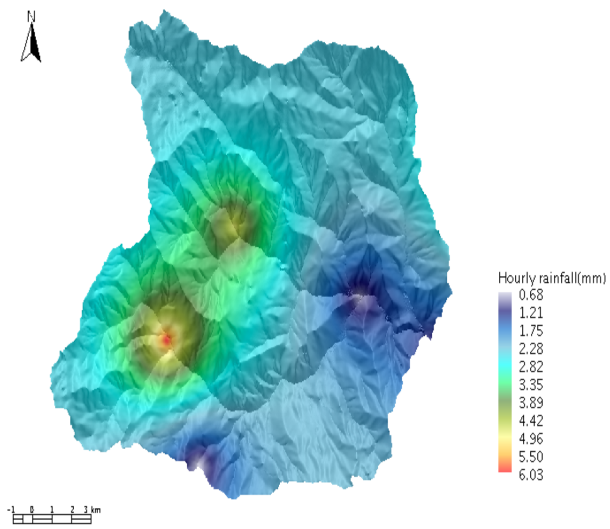

Figure 12: The grid-based rainfall interpolation using Ordinary kriging for the Posina basin at time step 1994-01-01 01:00 hour.

Further characteristics of the Spatial Toolbox

The geomorphological tools described in the previous sections are made even more effective by the general characteristics that the Spatial Toolbox inherits from uDig, which are summarize briefly below.

Visualization

The graphical user interface (GUI) of the Spatial Toolbox allows multiple images to be displayed simultaneously with transparency effects, facilitating the visual inspection of multiple terrain attributes. Displayed images can also be combined with shaded-relief images to enhance visualization of terrain. In these 'composite-relief models', variations in colour correspond to the displayed attribute and tonal variations correspond to hill shading. Vector data may be overlaid onto raster images to enhance data visualization and interpretation. Spatial Toolbox is distributed with a standard set of colour palettes, which have been set as the default. Nonetheless, users can eventually create custom palettes for specific purposes using the **Palette manager**

Importing and exporting data

DEMs are the main input data to Spatial toolbox, but the program can utilize many other types of spatial data, including satellite imagery. Raster import / export functions include read and write ArcView raster formats, GRASS images, Surfer grids, Autodesk .dwg and device independent bitmaps. The program can also read all the supported raster data included in the GDAL (http://www.gdal.org) library and the Shuttle Radar Topography Mission (SRTM) data (http://www.ppp.org). JGrasstools in Spatial toolbox reads and writes shapefiles, GRASS ASCII and native (supported since the GRASS 5.0) vector file formats, and delimited XYZ vector point files. Graphical output (i.e. displayed images with vector overlays) can be saved as MS-Windows bitmap (.wbmb), jpg, jpeg, and Portable Network Graphics files (.png), which can be read by most graphical packages and several word-processing programs.

Program development and availability

The spatial toolbox was originally developed as JGrass, and is now available as a collection of different tools (jGrasstools). The capabilities of the program have extended considerably in the past few years. The Spatial toolbox operates under Microsoft Window, Linux and Mac OsX platforms. Hardware requirements vary depending on the size of DEM or image being processed, but the standard requirements are 512MB RAM.

Spatial toolbox latest source code is also available for download at: https://code.google.com/p/jgrasstools/.

Program development is ongoing (the stable version is uDig 1.4.0 and jgrasstools0.7.7). The Hydrologis team has made a wiki page (http://code.google.com/p/jgrasstools/) in which the evolution of the software is tracked and documented. A mailing list for users and developers is available at jgrasstools@googlegroups.com and the authors welcome comments and feedback. The Spatial toolbox is maintained by the authors of the paper.

Complementary material that explains how the Figures in the paper were generated can be found at: http://abouthydrology.blogspot.it/2014/05/the-udig-spatial-toolbox-paper.html

Concluding remarks

The uDig Spatial toolbox is a powerful, research-grade environmental modeling environment. The main tools have been described in this chapter, however many more tools are available, particularly an advanced Hydrological model called JGrass-NewAGE modelling system (Formetta *et al.* 2011, 2013b, 2014), complete sub-models for estimating rainfall-runoff, radiation, evapotranspiration, snow water equivalent, landslide models like SHALSTAB (Montgomery and Dietrich, 1994), and CISLAM (Lanni *et al.*, 2012) peak flow modelling (Rigon *et al.*, 2011).

Tools in JGrasstools are ideal for both research and student instruction due to ease of use and free availability. Therefore, we believe, the uDig Spatial toolbox is suited to be used in research and education in physical geography, hydrology, geomorphology, climatology, environmental science and watershed modelling.

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Appendix A

Table A1: Comparison of some selected open, free GIS software for hydro-geomorphological analysis.

	TauDEM	**LandSerf**	**GeoNet**	**Whitebox Geospatial Analysis tools**	**GRASS**	**uDig Spatial Toolbox**
Surface parameters and topographic feature extraction	Slope, aspect, curvature, topographic	Slope, aspect, curvature	Slope, curvature, landform features	Slope, aspect, curvature	Slope, aspect, curvature, landforms	Slope, aspect, curvature, sky view
Flow Direction	D∞, D8	D8	D∞, D8	D∞, D8, FD8	D8, MFD	D8, D8-LAD, D8-LTD
Channal delineation	tca, area-slope, area at concave	tca	Yes	tca	tca, slope-area method	tca, slope-area, concave sites
Enumerate networks	-	-	Horton, Strahler	Horton-Strahler stream order	Horton, Strahler, Shreve, pfafsttater	Horton, Strahler, Hack, netnumber, pfafstatter
Delineation of basin and subbasin	Yes	Yes	Yes	Yes	Yes	Yes
Data Interpolation algorithms	Thiessen polygon	Yes	x	Nearest neighbour	Yes	JAMI, Kriging
Flow distances	Yes	Yes	Yes	Yes	Yes	Yes
Raster calculator and Raster summary	Yes	Yes	Yes	Yes	Yes	Yes
Topographic index	Yes	-	-	Yes	Yes	Yes
Vector analysis capability	Yes	Yes	Yes	Yes	Buffer, polygonizer, clip, merge, reshape	Buffer, polygonizer, clip, merge, reshape
Map layer visualisation	Yes	Yes	Yes	Hillshade layer	3D vector map, Voxel	Aspect, 3D
Raster and vector transformation	Yes	Yes	Yes	Yes	Yes	Yes
Surface interpolator	IDW, TIN, splines	Cressman interpolation	Yes	IDW, nearest neighbour	IDW, nearest neighbour	IDW, Delaunay triangulation, Thin Plate Spline