Applications of high-resolution images and DTMs for detailed geomorphological analysis of mountain and plain areas of NW Italy

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Abstract
Detailed analysis of Digital Terrain Models (DTMs), digital imagery, and a discussion of their various applications and derived geothematic products are presented for study areas in two different geological and geomorphological contexts of North West (NW) of Italy. In both cases it has been proposed an integrated approach for geomorphological analysis that put in evidence many advantages of using these new geomatics tools.
In the first context, digital geomorphological mapping of high altitude areas of the Aosta Valley (Gran Paradiso and Gran San Bernardo) have been carried out by using photogrammetry and remote sensing on airborne laser scanner data (LiDAR derived DTM) and orthophotos. Suitable results have been obtained for areas of difficult accessibility, with reduced costs and work time compared to traditional field techniques.
In the second geomorphological context, high-resolution images of the present topography of the high Piedmont plain (Turin, Asti and Cuneo Provinces) have been used to perform GIS mapping and analysis. Evidences of Quaternary modifications in the hydrographic network have been enhanced, suggesting new geomorphological elements for the reconstruction of the recent geodynamic history of the area.

Keywords: Geomorphology, DTMs, LiDAR, high-resolution images, Aosta Valley, Piedmont plain.

Introduction
Since almost 10 years remote sensing techniques became very popular and useful for geomorphological investigations because they open up new methods for detailed analysis of Earth surface features and new potentials for data processing. For this reason they have been applied in many kinds of geological and geomorphological contexts [Bolongaro-Cravenna et al., 2005; Seijmonsbergen et al., 2009; Anders et al., 2009; Siart, 2009]. Many
successful examples demonstrate how remote sensed data, especially LiDAR (Light Detection and Ranging) derived DTMs (Digital Terrain Models) and satellite high resolution images, can be applied for landforms analysis: they put in evidence that many geomorphological data can be rapidly and easily collected at a range of spatial scale [Drăguţ and Blaschke, 2006; Van Asselen and Seijmonsbergen, 2006; Seijmonsbergen, 2008; Cadoppi et al., 2007; Anders et al., 2009; Borgogno Mondino et al., 2009]. Furthermore remote sensed data can be a useful support for 2.5D perspective views and mapping [Teeuw, 2007; Perotti et al., 2007; Perotti et al., 2011; Sterzai et al., 2010].

Geothematic maps are synthetic ways of showing geological and geomorphological contents of an area. They can be useful both for Earth Science communication and for application in land use planning and management. As stated by the Working Group on Applied Geomorphological Mapping of the International Association of Geomorphologists, geomorphological maps are, in fact, not only important as end products of scientific researches, but also as tools for technical applications by professionals dealing with the landscape and landforms [Pain et al., 2008]. Geomatics can support regional or local geothematic mapping through the collection and interpretation of Earth’s surface landforms, materials, structures, and processes, thus enhancing natural hazards assessment and management [Giardino et al., 2012]. As an example, geomorphological maps [Goudie, 2004] of flood plains are suitable both for natural hazards studies and emergency management activities. In a similar way, geological maps of mountain regions represent an important support for developing databases and GIS (Geographic Information System) applications devoted to inventories of glacial landforms or research on natural hazards, such as landslides [Dikau et al., 1996; Giardino et al., 2004].

By analysing Earth Science literature on flood plain and mountain regions of North West (NW) of Italy, it is clear that detailed geomorphological maps and updated knowledge on Quaternary geology and recent geodynamics are key-factors for any application of geological knowledge (geotechniques, natural hazard, urban planning, ...) [Carraro et al., 2003; Alberto et al., 2008]. Nevertheless, many areas are often lacking a detailed and updated survey and/or data are not easily available for different causes (lack of time, insufficient dedicated funds, inaccessibility of the area, ...).

In the present work we propose an integrated qualitative method for using a “remote sensing” approach to geomorphological and geological studies, through the application of:

- optical analysis of aerial imagery (traditional aerial photograph and high resolution digital orthophotos);
- shaded relief maps derived from LiDAR derived DTMs, and photogrammetric DEMs from Aster and CTR.

This method has been tested in different areas characterized by different geomorphological contexts:

1) high-altitude mountain areas of the Aosta Valley, NW-Alps (Fig. 1);
2) a high-vegetated and urbanised plain area, in the central Piedmont plain, NW-Italy (Fig. 2).

In these two contexts, data collection, analysis and interpretation have been often proved to be difficult, by using conventional field survey only; furthermore, in previous studies, geological and geomorphological mapping required long time and considerable costs, for being carried out at a large scale [Forno, 1980; Valpreda, 1984; Carraro et al., 1995; De Giusti et al., 2004; Dal Piaz et al., 2010].
Figure 1 - LiDAR Digital Terrain Model with associated shaded relief map of the Valle d’Aosta Region, NW Italy. The study areas (Gran San Bernardo and Gran Paradiso) are in the boxes (case 1).

Figure 2 - Digital Elevation Model of the Central Piedmont plain. The red box highlights the study area for case study 2 (Roero). The yellow dot line represents the western Altopiano di Poirino scarp.
Therefore, we elaborated and tested a research methodology with high potential to speed up and to increase accuracy of geomorphological mapping in difficult accessibility areas of both contexts. We focused our activities also where field data were of good quality, such as in some sectors of case study 2: the approach was tested to validate acquired data, to extrapolate local information contents to near areas and to reveal new geomorphological elements not visible or visible with difficulty in the field (cfr. Fig. 9).

**Image analysis and method**

Field and remote sensing data have been collected for the two different geomorphological contexts described above:

i) field geomorphological data and maps (where available);

ii) aerial imagery: traditional or digital;

iii) Digital Terrain Models: LiDAR DTMs (where available) and Digital Elevation Models (DEMs) from classical digital photogrammetric procedures.

Then, comparative analyses of these three kinds of products have been performed, in the perspective of elaborating a possible integrated method for geomorphological mapping. Advantages and disadvantages of using each one type of these data are synthesized in Table 1, but in general it is clear the most unlike situation is the availability of only one of these tools.

i) On the one hand, the main advantage of field survey is that observations are direct: accuracy and reliability of data are very good; both geomorphological and geological information can be recorded. On the other, field data could be not homogeneous as geographical distribution, even difficult to acquire in many areas; they require high costs and long times, and results are generally of local value only, they need to be correlated for regional interpretation.

ii) The main advantage of using aerial imagery and derived orthophotos (including traditional aerial photographs and satellite orthophotos) is related to the possible multi-scale geomorphological observations and to the possible chromatic representation of the areas where landforms are interpreted. Main disadvantages are related to the lack of direct field control of information, the high cost for images acquisition and often the limits of definition and detail of the orthophotos (cfr. Fig. 3).

iii) Advantages in using DTMs and DEMs are strictly related to their detail (Fig. 4): they are very useful for both enhancing small landforms and overviewing morphological contrasts at different scales; they allow geomorphological interpretation also in vegetated or shaded areas (Fig. 3); still, they are not sufficient to conclusive interpretation of landforms without the support of other ancillary data. Moreover, areas with detailed DTM availability are still limited.

As a result, by considering the comparative evaluation of different mapping methods and tools (field survey, aerial imagery and DEMs/DTMs; see Tab. 1), we decided to set up an integrated approach and to test it on different geomorphological contexts, with the aim to achieve better mapping products and better interpretation of recent geological/geomorphological processes with respect to the one available, either for plain or high mountain areas. Applications of the integrated method are presented below. Various tools and images are used through different steps of the research (Figs. 6-7), to obtain a unique and univocal digital map on GIS support with an associated database for each study areas of NW-Italy.
Figure 3 - Area of Mont Forchat (3010 m) in the Val Grisenche Valley (Aosta) (Case study 1): comparison between ortophoto (flight RAVA 2006) and shaded relief map derived from the LiDAR DTM (2 m). Topography in some shadow areas cannot be seen on the ortophoto, but it is clear in the DTM (1). In other cases, the DTM is not easy to interpret, while the colours in the photo can help in the interpretation of landforms, as in the case of glaciers (2), moraines (3) and rocky slopes (4).

Table 1 - Comparative evaluation (benefits and disadvantages) of different data and methods (field survey, aerial imagery and LiDAR-DTMs) for geomorphological mapping of plain and high mountain areas.

| Retrieved datum | Type of Area | Field survey | Aerial Imagery | DTM/DEM |
|-----------------|--------------|--------------|----------------|---------|
|                 |              | Direct observation, hand sample, photograph, description, aerial visualization, chromatic representation of the area | Aerial visualization, chromatic representation of the area | Setting of topography |
| Data availability | High elevation | It depends on the accessibility of the area (generally difficult) | Good | Weak |
|                 | Hill/plain   | It depends on: accessibility of the area (generally good), and degree of urbanization | Good | Weak |

| Detail | Type of Area | Field survey | Aerial Imagery | DTM/DEM |
|--------|--------------|--------------|----------------|---------|
| High elevation | It depends on: ability of the surveyor, accessibility of the area (generally difficult) and availability of outcrops (generally good) | Good (if chromatic contrast available), it depends on quality and height of flight | It depends on quality and height of flight |
| Hill/plain | It depends on: ability of the surveyor, accessibility of the area (generally good) and availability of outcrops (generally weak) | Good (if chromatic contrast available), it depends on quality and height of flight | It depends on quality and height of flight |
Table 1 - (Continued) Comparative evaluation (benefits and disadvantages) of different data and methods (field survey, aerial imagery and LiDAR-DTMs) for geomorphological mapping of plain and high mountain areas.

| Area coverage | Type of Area | Field survey | Aerial Imagery | DTM/DEM |
|---------------|--------------|--------------|----------------|---------|
| High elevation| It depends on: ability of the surveyor, accessibility of the area (generally difficult) | Complete | Complete | |
| Hill/plain    | It depends on: accessibility and degree of urbanization | Complete | Complete | |
| Cost          | High elevation | Variable | Medium | Very good |
|               | Hill/plain    | Variable | Medium | Very good |
| Overview      | High elevation | It depends on slope aspects (generally limited) | Very good | Very good |
|               | Hill/plain    | It depends on the availability of elevated points of view (generally few) | Very good | Very good |
| Reliability   | High elevation | Very good, verified in first person | Good (if chromatic contrast available), it depends on quality and height of flight | Low, only topography description, it depends on detail |
|               | Hill/plain    | Very good, verified in first person | Good (if chromatic contrast available), it depends on quality and height of flight | Low, only topography description, it strongly depends on detail |
| Utility       | High elevation | Geomorphological mapping (landforms) and geological mapping (outcrops, structures, sedimentary bodies) | Geomorphological mapping, genetic interpretation of landforms can be inferred | Geomorphological mapping, no possible genetic interpretation of landforms |
|               | Hill/plain    | Geomorphological mapping (landforms) and geological mapping (outcrops, structures, sedimentary bodies) | Geomorphological mapping, genetic interpretation of landforms can be inferred | Geomorphological mapping, no possible genetic interpretation of landforms |

Case studies
The application of the integrated methodology to the first case study has been targeted to create a geomorphological and geomorphodynamic map of a high altitude area, for the evaluation of slope instabilities in relation to glacial and periglacial processes.
In the second case study, the application aimed to obtain a deeper knowledge of the recent geological/geomorphological evolution of the Quaternary basins and the hydrographic network of the central Piedmont plain, in relation to recent geodynamics processes.
In both cases, detailed geomorphological maps were required. The lack of updated
geomorphological data covering the whole areas and the lack of time and resources for performing detailed field mapping, suggested to use high-resolution images of different origin and resolution: traditional aerial imagery of different flights (years 1996-2000), digital orthophotos, Aosta Valley shaded relief map derived from LiDAR [Sterzai et al., 2010], 10 m DEM (interpolation from digital photogrammetric procedure) and 15 m DEM (from satellite stereo couples) for the Piedmont plain [Abrams, 2007].

The comparison, analyses and interpretation of the different images and the creation of the geomorphological maps have been supported by GIS software (ESRI, ArchMap). Other GIS applications (for example ESRI-ArcScene) have been also used to enable 3D visual representation of landforms from different sights and with different points of light.

![Figure 4 - Lacs des Seracs, at the base of the Rutor Glacier (Aosta Valley) (Case study 1). Comparison between (a) ortophoto (flight RAVA 2006) and LiDAR DTMs (b-d) with different resolution: (b) 50 m, (c) 10 m and (d) 2 m. The influence of resolution is evident: the definition of the landforms is clear only in the 2 m DTM, where also the thin morainic ridges is visible.](image)

**Case study 1 – Mountains areas in the Aosta Valley**

**Geomorphological context**

The examined areas are among the most elevated mountains of the Western Italian Alps: 1) the Gran San Bernardo (2960 m) and 2) the Gran Paradiso Massif (4061 m). From the geological point of view, they are part of two different structural complexes: the Upper Pennidic Zone, constituted of micaschist, gneiss and metagranites and the Piedmont Zone,
formed by schists and metabasites [De Giusti et al., 2004]. The structural setting of the area is characterised by post-collisional brittle tectonics, whose role in the control of the morphodynamic evolution of the mountain relief has been underestimated for a long time. The recent CARG (geological and geomorphological mapping of Italy, 1:50000 in scale), and IFFI 2001 – 2010 (Landslide Inventory of Italy) projects, also thanks to the use of remote sensing (mainly satellite and radar images) have evidenced the importance of tectonics as conditioning factor of geomorphological setting [Ratto et al., 2009; Dal Piaz et al., 2010; Martinotti et al., 2011]. From the geomorphological point of view, the two mountain areas are characterised by steep slopes, developed from about 2000 to 4000 m high, and locally covered by glaciers. At lower elevations, gentler slopes are covered by thick vegetation, and the bottom of main valleys are connected to the slopes by 20°-30°-steep surfaces. The main slopes and valleys are characterised by Pleistocene glacial landforms, glacier modelling still being active at the highest elevations. Large slope instabilities affect both superficial covers and deeper rock masses by means of Deep-Seated Gravitational Slope Deformations (DSGSD). Fluvial dynamic plays an important geomorphic role along valley bottoms or torrential incisions.

Object of the study and method
In the framework of previous studies on natural instabilities in the Aosta Valley [Bonetto and Gianotti, 1998; Giardino and Ratto, 2007; Ratto et al., 2007], the Gran San Bernardo and the Gran Paradiso areas have been analysed and mapped, with a focus on Quaternary landforms and deposits. In order to acquire a better understanding of the area and enhance mapping products, an integrated geomorphological analysis has been set up, including GIS and remote sensing techniques (Figs. 5 and 6).
Figure 6 - Flowchart of the different investigation approaches and methods adopted to create geomorphological maps. An integrated method is suggested for better results.

The process consisted in the following consequential work phases:
- traditional photo-interpretation of aerial photographs (photo RAVA- Autonomous Region of Aosta Valley, flight date 20-11-1991, 1:20.000 scale) to identify major landforms of the area with the support of topographical basis (A in Fig. 7);
- comparison with satellite images associated with LiDAR DTM (2 m pixel and 0.60 m elevation accuracy) of the surveyed area, to better define limits of major landforms, and to identify smaller landforms (A in Fig. 7);
- genetic interpretation of landforms and definition of the boundaries between the different geological bodies based on their morphology and environmental context (e.g. alluvial, glacial, landslides deposits);
- GIS mapping (by ArcMap software, ESRI) of the observed landforms (linear elements) and sedimentary bodies (polygons) (B in Fig. 7);
- comparison with previous digital maps from detailed studies (e.g. landslides and rock glaciers, from the Aosta Valley Inventory and the IFFI Project 2001-2010; [Giardino and Ratto, 2007];
- description of polygons and lines within a GIS database associated with corresponding...
symbols to the map legend (cfr. Fig. 7);
- superposition of the two shapefiles (lines and polygons) as to produce different layouts of the map in different scales (C in Fig. 7).

Figure 7 - Flowchart of the method applied for case study 1, in the area of Glacier de Breuil and Glacier de Monchair, Gran Paradiso massif (Aosta Valley).
Results

All the geomorphological data and maps have been elaborated in a GIS system. From the cross-referencing and extrapolation of collected data, a detailed geological and geomorphological map has been produced with an associated 1:10,000 symbol-based legend (Fig. 6). Over 5,800 polygons and 4,200 lines has been mapped. In the associated database each polygon is associated to a representative code of the genetic facies and each line is associated to the name of the geomorphological linear element. The digital map produced in this work and the correlated database are used as a base for applied studies for slope stability analysis, planning activities and for any further detailed field study of the areas. In particular, our geographical system represents a digital multi-scale geological map that can be easily superposed to other digital thematic maps describing other controlling factors of stability, such as: slope map, structural map, soil use map, climatic maps, etc.

This integrated method has proved to be particularly effective in the following situations:

a) High altitudes areas (above 3,000 m), not easily accessible for field surveys. Here, high resolution images and DTMs allowed to carry out detailed geomorphological mapping in shorter times and easier ways than by traditional field techniques.

b) Thick vegetated, wooded or shadowed areas, where landforms are not easily recognisable, neither by field survey nor by traditional aerial photointerpretation. In this particular case, the use of LiDAR was very useful for eliminating “noises” associated with those elements, therefore allowing clearer visual representation of topography.

c) Small dimension landforms (less than 10 m²), weakly visible with aerial photographs or images. Even in this case, the LiDAR DTM associated to shaded relief map allowed a good visualisation of landforms, as well as a detailed mapping.

d) Multitemporal analysis of geological and geomorphologic elements. The possibility of easily superimposing geo-referenced images of different kind and period allowed identification of changes of landforms and/or superficial deposits (e.g. rock-glacier, landslides, glacial deposits brought to light following the reduction of glaciers) during recent times.

Furthermore, the “negative aspects” of this method are related to the reliability of the interpretations, being conditioned by the availability of field data that in high elevation areas are not easily achievable. Moreover, very detailed (< 5 m) digital images and DTMs are also needed for obtaining a map of about 1:20,000 scale, but the coverage of these images is still limited to small areas. Fortunately in the case of the Aosta Valley the coverage is almost complete for all the region.

Case study 2 – The middle River Tanaro plain

Geomorphological context

The examined area includes part of the central Piedmont plain and the Roero Hills. It is drained by the middle-lower part of the Tanaro River, (tributary of the Po River) locally flowing from the town of Bra to Asti; the area is bounded by the Turin Hill to the North, by the Poirino Plateau to the West, by the Langhe and Monferrato Hills to the East and by the highplain of the southern Piedmont basin to the South (Fig. 2).

From the geological point of view, the area is mainly composed by marine sands, clays and marls, locally characterised by a large amount of fossil contents (Pliocene age, “Astian” and “Piacentian” lithological facies) and by fluvial deposits (Pleistocene and Holocene)
Geological studies in the area have been mainly addressed to sedimentological characters of Pliocene formations. However, less is known about Quaternary geology and geomorphology: most of the studies of the area concerns fluvial dynamics and the evolution of drainage network referring to the fluvial diversion of the River Tanaro that occurred near the town of Bra during the upper Pleistocene [Castiglioni, 1934; Castiglioni, 1979; Carraro and Valpreda, 1991; Carraro et al., 1995; Lucchesi, 2002] (point 2 in Fig. 8).

From the geomorphological point of view, the studied area, even if apparently flat, is rather complex. The River Tanaro plain is 1-2 km wide, gently dipping towards NE and bounded by low hills characterised by the drainage network of the river Borbore, the main North tributary of the Tanaro in the studied area.

Between Bra and Buttigliera d’Asti, a 50-100 m high scarp (yellow dot line in Figure 2) outlines the eastern edge of the Poirino Plateau, a relic of an old plain modelled by an ancient setting of the River Po (palaeo-Po in Fig. 8) [Forno, 1980]. The plateau divides two areas with different drainage direction, respectively to the Est and to the West (Fig. 2).

From the structural point of view, the area is located at the southern end of the Rio Freddo Deformation Zone (ZDRF), between the T. Traversola deformation zone (FT) to the East [Piana and Polino, 1994; Dela Pierre et al., 2003; Boano et al., 1998] and the so-called “Asti syncline” to the North [Serv. Geol. It., 1970a] (Fig. 8). More recent studies [Mosca et al., 2009; Vigna et al., 2010] evidenced high complexity of the geological structure and of the geodynamic activity in the area.

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**Study object and method**

Based on the results of previous studies on Quaternary geology and evolutionary stages of the hydrographic network of Central Piedmont [Carraro et al., 1982; Carraro and Valpreda,
1991; Valpreda, 1984; Forno, 1980; Lucchesi, 2000] we planned a geomorphological use of various available geomatic products (aerial photographs, satellite images, DEMs). In particular, we tried to evidence the “topographic anomalies” (such as isolated hills, scarps, elongated ridges) and the significant geomorphological elements (watershed, elbows, meanders) for the reconstruction of the present-day and past drainage networks related to the important deviation phenomena of two ancient watercourses during the upper Pleistocene (namely, palaeo-Po and palaeo-Tanaro in Fig. 8).

Unfortunately, in this area, LiDAR DTMs is not yet available from the Regional Cartographic Service (the complete DTMs will be available for the end of 2012 – 5m grid cell size with 0.6 m vertical accuracy). Looking for alternative data to perform better geomorphological analysis, we evaluated the 30 m ASTER satellite DEM [Bitelli, 2007], and the 10 m interpolated DEM from Technical Regional Vectorial Map. Our choice was the second product because our goal is a better definition of landforms (Fig. 4). For this purpose it seemed fundamental the use of 10m DEM derived, enhanced by appropriate colour processing. Different altimetric classes of 10 m range have been defined for better visualisation of altitudinal belts, from 150 to 430 m elevation. Even if the available DEM had a 10 m as pixel, the relative accuracy allows the main scarps and incisions and the isolated reliefs to be easily highlighted (Fig. 9).

Figure 9 - DTM of Piedmont (10 meter) (Case study 2), with different colours for different elevation ranges, on which some significant elements of the hydrographic network and of the topography are mapped.

In particular, we focused on the identification of landforms related to present-day and ancient rivers with the following method:
- digital interpretation of stereoscopic aerial images (flight “Flood 2000” of the Piedmont Region) for the identification of landforms related to fluvial dynamic, particular topographical elements or anomalies (ex. relicts of meanders, watersheds, knee points);
- map on a GIS system (ESRI, ArchMap) of the observed elements and their description within an associated data-base;
- overlap on a GIS platform of the landforms to the DTM with altimetric classes;
- identification of landforms interested by recent morphotectonic deformation. For
example, meanders actually developed at higher elevation than the actual river landforms are indicative of an uplift occurred in the period of time since their formation; their present distribution and elevation can be compared with the base-level of the present drainage (Fig.10).

**Figure 10** - DEM (10m) processed with different colours for different elevation ranges of the hilly area of Guarene (CN) and of the plain of River Tanaro and Borbore draining from Alba to Asti. The paths of the relict of meander are draped on DEM. They were recognized by aerial photographs (flight 2000 flood, of the Piedmont Region: meanders of ancient drainage pattern related to the palaeo-Tanaro are in black and meanders related to the present hydrographic pattern are in blue.

**Results**

The methodology provided a preliminary but essential geomorphological framework of a vast area of the central Piedmont plain, that has allowed to identify key-areas for addressing future detailed field activities. In particular the performed analysis showed detailed evidences of the hydrographic network, its areal distribution and a new identification of topographical anomalies, useful for a better interpretation of ancient hydrographic networks that drained the area. Some macro-areas with similar geomorphological features has been identified: this elements can be useful for verifying differential geodynamic activity. By using high resolution images, the landforms overview in a wide area is possible, and this, in turn, allows altimetric correlation of the geomorphological elements on a regional scale. In an area where elevations are moderate, slopes are gentle and landforms lack of great evidence, a detailed DTM is a fundamental instrument for topographical considerations. Unfortunately, the limited detail of the present DEM available (10 m) only permits to give
evidence to large geomorphological elements. However, the aid of some localised detailed field data allowed to compare landforms on digital images with landforms observed also on the field, and then to extrapolate their interpretation to areas not yet covered by geomorphological maps. In future studies, the topographical anomalies identified with this method could be compared with geological maps of deep structural elements and eventually with maps of recent deformation derived from interferometric data (i.e. inSAR-technique) or GNSS (Global Navigation Satellite System) monitoring, in order to:
- verify if superficial geomorphological elements correspond to particular deep geological structures;
- verify if deep geological structures could have been affected by recent geodynamics;
- identify areas of intense geodynamics activity during the Quaternary, and possibly, of related seismic activity.

Conclusions
A combination of geomatics and geomorphological techniques has been applied for the study of two areas of NW-Italy: a high-altitude mountain area (Aosta Valley) and a plain area (central Piedmont).
The application of digital images and high-resolution DTMs associated with GIS systems in geomorphologic analysis and the evaluation of results allow to emphasize some potentials of the above-mentioned method, either for data processing and interpretation:
  a) very quick visualization of geological elements and landforms at different scales and from different points of view (easy framework, from overview to details);
  b) possibility of displaying/hiding/overlapping different thematic layers (e.g. topography, symbols, hydrography, ...);
  c) individualization of topographic elements not visible through traditional aerial photo interpretation or even on the ground, for several reasons (vegetation cover, difficulty of access, lack of time, ...) and their enhancement in map representation by means of shaded relief map and appropriate colour processing;
  d) very detailed mapping of the objects of interest (points, lines, areas) and at the same time, their immediate georeferencing in a coordinate system in space;
  e) rapidity of the mapping activity for large areas, for a limited waste of financial and human resources;
  f) creation of an associated database with alphanumeric information concerning geomorphological elements comparable with future analysis.
As a result, high-resolution images and DTMs have to be considered of fundamental importance for detailed and regional geomorphological studies. They proved not only to be an important complementary tool to field activities for optimizing time and dedicated resources, but also for the enhancements of interpretation and scientific results. However, the geomatics approach should not be considered exhaustive, a complete geomorphological study and analysis being necessarily supplemented by field surveys.

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