Catena 76 (2009) 97–106

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

LiDAR-derived slopes for headwater channel network analysis

Alessandro Vianello [a,*], Marco Cavalli [b], Paolo Tarolli [a]

[a] *Department of Land and Agroforest Environments, University of Padova, Agripolis, viale dell'Università 16, 35020 Legnaro (PD), Italy*
[b] *CNR-IRPI, Corso Stati Uniti 4, 35127 Padova, Italy*

ARTICLE INFO

Article history:
Received 16 May 2008
Received in revised form 23 September 2008
Accepted 27 September 2008

Keywords:
Channel slope
Channel morphology
Colluvial and alluvial channels
High resolution DTM
LiDAR

ABSTRACT

Slope is one of the most important distinguishing features for channel morphology. Variations in the computation of slope from a digital elevation model can affect a wide range of hydrogeomorphically derived applications. We compare different methods for computing channel slope using LiDAR-derived digital terrain models (DTMs) with varying resolutions. We chose a headwater basin of the Eastern Italian Alps, characterized by a dense ephemeral colluvial network and a main alluvial channel as our study area. The identified alluvial morphologies are characteristic of steep mountain streams, namely, cascades and step pools. Field surveys were carried out along the main channel and in some small tributaries. Results indicate that a single method for slope calculation cannot estimate channel slope at the hydrographic network scale. The differential geometry approach for slope calculation tends to overestimate field-surveyed channel slope values for all the DTM resolutions (1, 2, 5 m). When a trigonometric approach for slope calculation is applied, 2 and 5 m DTM resolutions give more consistent results. Nevertheless, a reliable channel slope can be derived from a DTM with an appropriate resolution by choosing a suitable method only after considering the channel width.

1. Introduction

Airborne Laser Swath Mapping (ALSM) technology, also known as Light Detection And Ranging (LiDAR), provides high-resolution topographic data that can contribute significantly to a better land surface representation (Ackerman, 1999; Kraus and Pfeifer, 2001; Briese, 2004). A valuable characteristic of this technology, which has many advantages over traditional topographic survey techniques, is the capability to derive a high-resolution Digital Terrain Model (DTM) from ground LiDAR data obtained by filtering vegetation points (Slatton et al., 2007).

LiDAR-generated DTMs improve base map information such as slope and drainage density, and they represent a useful remotely sensed approach for surveying the morphology of a large study area. These capabilities represent a great improvement in the analysis of surface morphology since much relevant information can be derived from them. This also facilitates topographic, hydrologic, and ecologic modeling.

Several studies have reported applications of LiDAR data in mountain areas. Mckean and Roering (2004) and Glenn et al. (2006) characterized and differentiated landslide morphology and activity by slope, curvature and roughness index analyses. Tarolli and Tarboton (2006) used LiDAR-derived DTMs for shallow landslides modelling. Storesund and Minear (2006) analyzed river geomorphology and river restoration by LiDAR data. Staley et al. (2006) used LiDAR-derived topographic attributes (profile curvature and surface gradient) at a fine resolution to differentiate deposition zones on debris-flow fans. With regard to the application of LiDAR techniques in recognizing small ephemeral channels, James et al. (2007) showed the capability of LiDAR data in identifying and mapping gullies and headwater streams, even under forest cover. Frankel and Dolan (2007) combined quantitative measures of surface roughness obtained from LiDAR data with classic methods of geomorphology and sedimentology to characterize and differentiate alluvial fan surfaces with different relative ages. Lashermes et al. (2007) used the wavelet theory of signal processing to objectively extract valley and channel networks by calculating landform curvature from 1 m DTMs. Cavalli et al. (2008) used the surface roughness index to recognize channel bed morphology in a headwater alpine basin by differentiating step pools from riffle pool reaches. Smart et al. (2004) demonstrated the suitability of a portable hand-held laser scanner for obtaining accurate Digital Terrain Models of alluvial channels. Otherwise, a terrestrial laser scanner can be applied at the restricted scales of individual test areas in channel beds.

In mountain landscapes, the local and systematic downstream spatial organization of channel forms is controlled by the geomorphic processes that are directly connected to the drainage network (e.g., Church, 1992; Montgomery and Buffington, 1997). Understanding the different geomorphic processes and channel characteristics is a fundamental problem of landscape evolution, aquatic ecology, conservation biology, and river restoration. Consequently, the ability to predict the spatial variation of channel morphology would be valuable for a wide range of applications.

* Corresponding author. Tel.: +39 049 8272700; fax: +39 049 8272686.
E-mail address: alessandro.vianello@unipd.it (A. Vianello).

0341-8162/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.catena.2008.09.012

One of the most important distinguishing features for channel morphology classification is the channel bed slope (Montgomery and Buffington, 1997). Local slope changes along the network influence, for the same drainage area, the lateral channel adaptation (width) and define those reaches with higher (great stream power or energy reaches prone to erosion) or lower transport capacity (Brummer and Montgomery, 2003). They therefore affect the local morphology and local coarsening, especially in headwater channels (Vianello and D'Agostino, 2007).

Slope can be measured in the field, but it can also be derived by remotely sensed applications using Digital Terrain Models (DTMs). DTM resolution has been shown to affect a wide range of hydro-geomorphically derived applications (Jenson, 1991; Panuska et al., 1991; Quinn et al., 1991; Zhang and Montgomery, 1994; Dietrich and Montgomery, 1998; Wilson and Gallant, 2000; Schoorl et al., 2000; McMaster, 2002; Claessens et al., 2005; Tarolli and Tarboton, 2006; Wechsler, 2007). One of the most sensitive DTM-derived attributes to grid cell size is the parameter slope (Claessens et al., 2005; Tarolli and Tarboton, 2006). Warren et al. (2004) found that not only the DTM resolution but also the adopted algorithms may affect the calculation of the slope. Several algorithms for slope calculation are available in the scientific community. Most of these are based on computing slope locally for each cell on the DTM from data within a 3×3 cell moving window (Burrough and McDonnel, 1998).

Skidmore (1989) reviewed six methods of estimating slope and concluded that both the second-order, finite-difference algorithm (Zevenbergen and Thorne, 1987) and the third order finite difference method (Horn, 1981) are the better algorithms to derive slope from a DTM. Jones (1998) analyzed eight algorithms for computing slope and found the same results. The slope algorithm developed by Horn (1981)

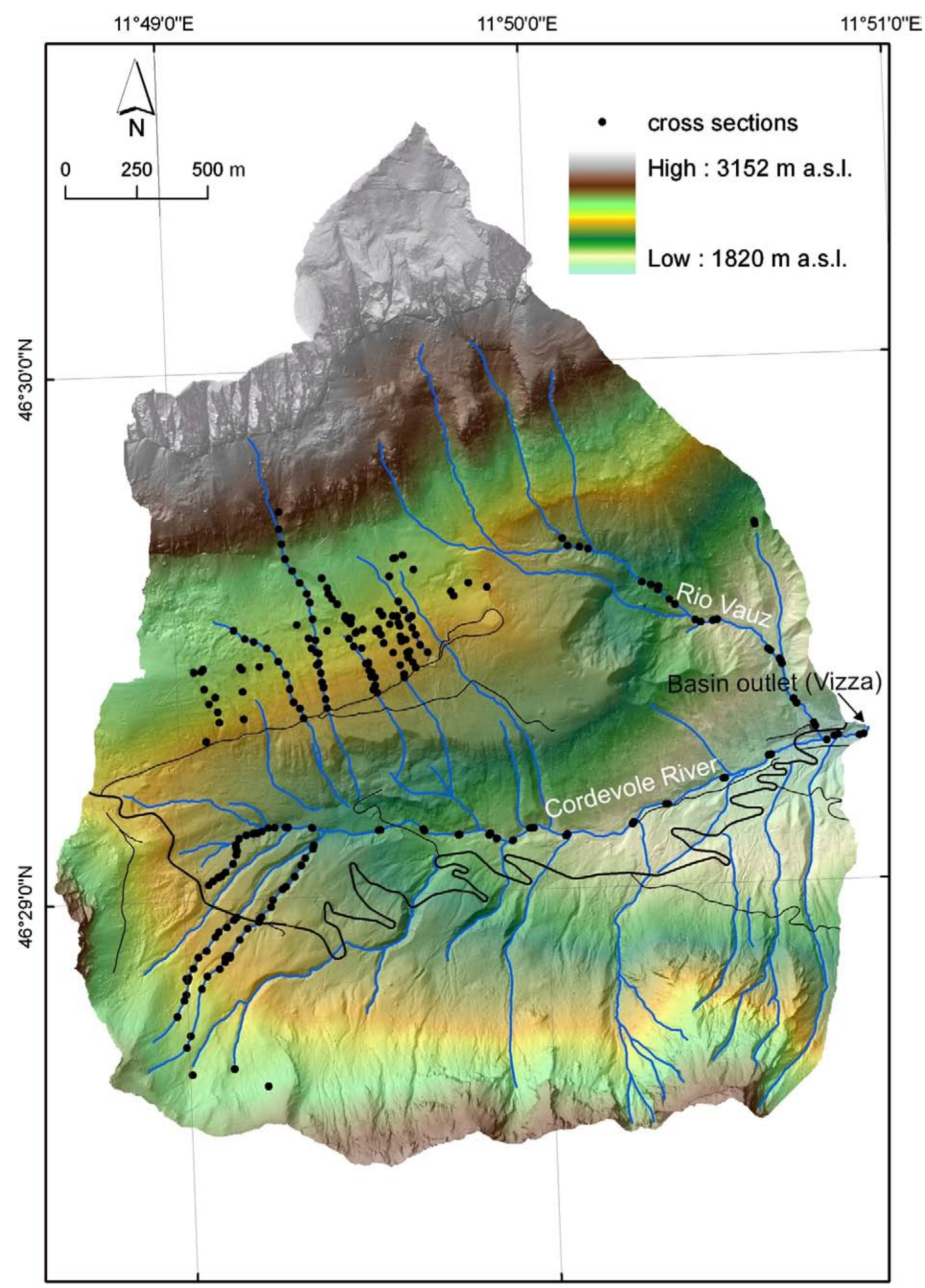

Fig. 1. Cordevole basin at Vizza. Geography and location map; cross sections (black points) are displayed along the hydrographic network. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)