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Detection of gullies in Fort Riley military installation using LiDAR derived high resolution DEM

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ABSTRACT

Intensive use of military vehicles in military installations create conditions favorable for gully formation. Gullies impede the access of vehicle, restrict the continuation of training, and lead to significant damage to vehicle and risk the life of soldiers. Therefore, it is critical to correctly identify the locations of gullies for continuous training mission. In this study, Fort Riley (FR) military installation was chosen as the study area. LiDAR derived 1 m resolution digital elevation model (DEM) acquired on 2010 was used to map the gullies. A procedure that measures local topographic position, i.e., difference from mean elevation (DFME) along with its integration to the land surface having high surface curvature values was employed. Two high spatial resolution WorldView-2 images of 2010 and field gully data collected in 2010 were utilized for accuracy assessment. Results showed that: (1) A total of 237 small and 166 large gullies were detected and most of them dominated the central west and northwest parts of the installation; (2) Based on the visual interpretation in the WorldView-2 images, there was no statistically significant difference between the detected and observed numbers of gullies; (3) Gullies measured in the field were well detected with an overall accuracy of 78%.

1. Introduction

Military training activities such as field maneuver, mechanized maneuver, combat vehicle operations, live firing, and mortar and artillery firing have been continuously taking place in Fort Riley (FR) and other military installations in the United States. The training activities directly degrade land condition through the removal of vegetation cover and top soil, landscape fragmentation, soil compaction and erosion, and gully forming (Althoff et al., 2006, 2007; Ayers, 1994; Buck et al., 2011; Dale et al., 2002; Harmon and Doe, 2001; Milchunas et al., 1999; Singer et al., 2012; Wang et al., 2007, 2014). The impacts of training activities in military lands vary depending on the types, intensity and frequency of the training, and the use of different kinds of vehicles (Howard et al., 2011; Li et al., 2007; Liu et al., 2007; Shoop et al., 2008; Wang et al., 2014). Among the training activities, using wheeled vehicles and tracked off-road tanks makes direct contact with the ground surface and creates ruts and rills. The ruts and rills, without immediate restoration, will develop into runoff channels and eventually turns into gullies (Önal et al., 2016). Gullies not only significantly degrade the land condition, but also impede the access and fast moving of vehicles such as tanks (Önal et al., 2016). Such gullies can damage the vehicles and impose significant economic loss, and also greatly risk the life of soldiers.

Accurately locating gullies and quantifying their dimensions are critical for sustainable training mission and Army combat readiness. The conventional field method of measuring gullies using differential global positioning system (GPS), tapes, and total stations is time consuming, inefficient and costly. On the other hand, remote sensing images at multiple spatial, spectral and temporal resolutions provide the potential to derive the information of gul-

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lies over large areas, which is affordable, efficient and reliable. Remote sensing data have also been extensively used in military installations to map land disturbance (Wang et al., 2014). Furthermore, the availability of high spatial resolution images has made it possible to accurately model the land degradation. However, mapping gullies is still challenging as the military installation landscapes with gullies do not necessarily exhibit particular spectral signatures. According to Baruch and Filin (2011), unlike buildings and trees that provide distinct spectral signatures, gullies are embedded within terrains and therefore, unlikely to show unique spectral signals. The existence of vegetation surrounding gullies impedes their identification, and their widths and depths are also difficult to accurately measure (Baruch and Filin, 2011). Additionally, optical images are not useful for deriving the information of gullies. There is also a lack of effective methods for assessment and monitoring of gullies based on optical sensors (Marzolff and Poesen, 2009).

Detection of gullies in a military installation can be conducted using Light Detection and Ranging (LiDAR) data. One of the major advantages for using LiDAR data is the capability to estimate elevation and corresponding spatial variability by acquiring spatially dense point cloud data over a time period (Woolard and Colby, 2002). Several approaches based on LiDAR derived DEM have been developed and used to assess gullies and their subsequent erosion process (Baruch and Filin, 2011; Betts and DeRose, 1999; James et al., 2006; Leyland and Darby, 2008).

Baruch and Filin (2011) conducted a study to detect gullies in the alluvial fans of western Dead Sea coastal planes using LiDAR and multi-scale data through an optimization driven model. Mason et al. (2006) used a technique with LiDAR data for channel network extraction. Castillo et al. (2012) evaluated the use of different methods for the quantification of gully erosion using LiDAR data, 3D photo-reconstruction and total station, and found that 3D methods are superior to 2D methods for obtaining cross-sectional data. Based on LiDAR derived DEMs, James et al. (2006) used a profile extractor (a function in ESRI ArcView 3.3) to extract gully cross section under forest canopy in upper piedmont, South Carolina.

Although LiDAR derived DEMs have been used in the study of gullies, to our knowledge, there have been no published reports that used LiDAR derived DEMs to detect gullies for military installations. Furthermore, it is also critical to test whether or not LiDAR derived DEMs are applicable with accuracy requirements met to detect gullies that are caused by military training activities. The objective of this study is to assess the application of a LiDAR derived DEM to identify and quantify gullies in Fort Riley (FR) Military Installation through the validation with high spatial resolution WorldView-2 and field data. Quantifying the gullies in each training area of FR is critical for the land managers for decision-making of land restoration, training scheduling, and rotation of training activities.

2. Study area

FR Military Installation located at 39°15′N and 96°50′W was chosen for this study. FR was established in 1853 as a military deploying station (Althoff et al., 2009a; Singer et al., 2012) and covers parts of Clay, Geary and Riley counties of Kansas, USA (Fig. 1a). Two major expansions of the area took place: one in 1940 (12,960 ha) and the other in 1966 (20,250 ha) respectively for the purpose of education and training of the infantry (Singer et al., 2012). Currently FR installation consists of 41,154 ha, and of which approximately 69.2% (28,725 ha) is used for training purpose and the rest 30.8% (12,429 ha) is occupied by cantonment areas where offices, base houses, and vehicle maintenance are located. The land for training is divided into live fire areas (gunnery ranges, small arms, and impact area) and training areas for maneuvers. The impact area lies on the central east part of the installation where all access is restricted (Fig. 1d). There is a total of 103 training areas where maneuvers and combat operations take place.

FR is characterized by a tall grass prairie landscape and dominated by grassland (32,200 ha), shrub land (6000 ha), and woodland (1600 ha) (Althoff et al., 2005; Bailey, 1976) (Fig. 1c). Its elevation ranges from 314 to 420 m above mean sea level with the highest elevation located along a north-south axis through the center of the installation and decreasing towards the southwest (Fig. 1b). The climate of FR is characterized by hot summers and cold, dry winters with an average mean monthly temperature of 26.6 °C in July and −2.7 °C in January (Althoff et al., 2007). The average annual precipitation is 83.5 cm and most of which (approximately 75%) occurs during the growing season (Hayden, 1998).

The geology of FR is comparatively simple, corresponding with the topography, and developed within the limits of the reservation, with the exception of some Quaternary deposits (Hay, 1896). There is a prominent feature that the increase in number of deposits westward leads to the increment of elevation in that direction. There is also a dip along the west to the northwest for the whole region. Slight depression exists toward the stream valleys, indicating small synclines as the basis of the original drainage. The topography is characterized by the great fluvial system and the features of the three-river system (Republican, Smoky Hill, and Kansas river) formed by Republican Valley and Smoky Hill Valley (Hay, 1896). The ruggedness of FR is attributed to pre-Glacial erosion and the modification leading to Glacial and post-Glacial deposits (Hay, 1896). Military training activities such as field maneuvers, combat vehicle operations, live-fire exercise, mortar, artillery and tank firing exercises, small arms fire, etc., have been taking place in FR for several decades, fragmenting the landscape, disturbing vegetation and soil, increasing soil erosion and impacting the characteristics of the ecosystem (Singer et al., 2012; Wang et al., 2007, 2014).

3. Datasets and methods

3.1. LiDAR derived DEM

LiDAR data for FR were collected from March 18, 2010 through March 30, 2010 with a Leica ALS-50II MPIA aerial LiDAR sensor system. The LiDAR data had 1.4 m (4.6 ft.) point spacing and a vertical accuracy of 0.08 to 0.24 m depending on flat and rugged areas to support the generation of 0.61 m (2 ft.) contours. The field survey for collecting the LiDAR data was conducted by combining 21 primary control points and 60 LiDAR check points that included various types of ground cover such as tall grass, short grass, gravel, and trees. From the LiDAR data, a DEM was derived using ArcGIS from the bare earth (.las files) with 1 m spatial resolution (Fig. 1b). The LiDAR surface project specification of RMSE was less than 15 cm with an overall RMSE of 10 cm at the confidence level of 95% (USACE, 2010).

3.2. Gully field data collection

The field data of gullies were collected in 2010 by Kansas State University and FR installation integrated training area management (ITAM) staff. Gullies larger than 1 m width and greater than 0.5 m depth were measured at their widest and deepest points using field tapes and the locations were recorded with the Trimble GeoXT GeoExplorer® 2005 Series GPS unit with ±3 m maximum error (Fig. 1d). The standard width of a channel to be considered as a gully was set to be 1 m or greater based on "military gap", a