Gully Mapping On Multiple Scales Based On UAV and Satellite Data

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Zusammenfassung: Die vorgestellte Arbeit beschreibt eine Methode der Gullykartierung mittels objekt-basierter Bildanalyse auf verschiedene Maßstabsebenen. Die gewählten Maßstabsebenen sind in dieser Arbeit Luftbilddaten aus Drohnenbefliegungen und hochauflösende Satellitenbilddaten. Die Auswertung dieser beiden Maßstabsebenen erlaubt eine Verknüpfung von hoher Detailinformation für einzelne Standorte mit gröberen Kontextinformationen in einer weiteren räumlichen Umgebung einzelner Gullystandorte. Diese Verknüpfung unterstützt den Erkenntnisgewinn im Bereich der Bodenerosion und ist daher von Interesse sowohl für die Fernerkundung als auch für die Geomorphologie. Die vorgestellte Arbeit fasst die wesentlichen Punkte der kumulativen Dissertation des Hauptautors zusammen (D'OLEIRE-OLTMANNS 2014c) und verweist für etwaige Detailfragen direkt auf die jeweiligen wissenschaftlichen Publikationen.

1 Introduction

Mapping gullies as one type of soil erosion with remote sensing based methods is of great interest for many researchers in the fields of remote sensing and geomorphology. In addition to the traditional field investigations carried out in geomorphology, remotely sensed data acquired at different scales offers various possibilities to analyze a specific study site, the broader spatial context around this study site (e.g. at catchment level) and finally enables area-wide mapping of gully-affected features. Especially the application of Unmanned Aerial Systems (UAS) for the acquisition of small format aerial photographs (SFAP) is an emerging field in recent years with great potential for gully mapping. This first data source reduces the data gap between field scale and satellite scale due to its very high pixel resolution. Small changes of an individual gully within short time periods can already be identified by applying short term UAS-based monitoring.

The region around the city of Taroudannt, Morocco was chosen as study area. Located between the High Atlas and the Anti-Atlas Mountains with arid climatic conditions it is prone to soil erosion due to the combination of heavy rainfall events in short time periods and the instable soil properties. There are two main aspects opposite to each other: the dynamic agro-industry which is visible through the continuous growth and the new emerging plantations in short time periods and the continuous growth of existing gullies as well as the development of new gullies threatening the agro-industrial areas as well as the newly built settlement structures. This situation shows the importance of up-to-date information on gully development as well as the distribution on gullies in the region.

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The main goal of this research work is to develop methods for the mapping and monitoring of gullies and the detection of gully-affected areas over multiple scale levels to combine the very detailed field scale and the coarser scale level covering the surrounding environment of a single gully. As input data only optical remote sensing data (aerial photographs and satellite image) was chosen which will be photogrammetrically processed and analyzed by applying the concept of Object-Based Image Analysis (OBIA).

2 Methods

2.1 UAV-based remote sensing and photogrammetric processing

UAV-based remote sensing is a recent methodology that allows the mapping of study sites which vary in their extents from several hundreds of m^2 to several hundreds of km^2. The usual hardware setup consists of a model airplane or multi-rotor copter that is equipped with a consumer grade camera in order to acquire Small Format Aerial Photographs (SFAP). A good overview on the diversity of platforms in this field may be found in WATTS et al. (2012). In recent years, the term Unmanned Aerial Systems (UAS) has been used more frequently for describing a setup consisting of an autonomous flying platform (fixed-wing, glider or multicopter) with an installed sensor and a ground station assuring the communication with the pilot. A recent review of UAS for photogrammetry and remote sensing was published by COLOMINA & MOLINA (2014).

In this research work, a fixed-wing UAS (Sirius, MAVinci) was utilized for mapping purposes, assuring a stable flight also under windy conditions. This UAS was equipped with a consumer grade camera (Panasonic Lumix GF1) with a fixed focal length as the sensor to acquire the SFAPs. This workflow consists of firstly distributing Ground Control Points (GCP) over the chosen study site, secondly measuring the GCP location with a total station and thirdly carrying out the UAS mission that follows a pre-defined flight plan. The parameters of this flight plan assure an in-track overlap of at least 60% and a parallel overlap of at least 15% which are prerequisites for the subsequent photogrammetric processing. These settings avoid gaps between single photographs and complete stereoscopic coverage of the defined study site is assured. A detailed description of the workflow of SFAP acquisition is given in D'OLEIRE-OLTMANNS et al. (2012a). More information on photogrammetric principles is given in ABER et al. (2010).

This UAS setup was applied for mapping 14 selected study sites within the study area in Morocco. These study sites comprise different types of gullies: ephemeral gullies and bank gullies with different characteristics. These different study sites and gully types are described in D'OLEIRE-OLTMANNS et al. (2012a), PETER et al. (2014) and D'OLEIRE-OLTMANNS (2014). In the period from June 2010 to March 2012 multiple field campaigns with a total duration of eleven months were conducted to continuously map the chosen study sites in Morocco. About 17,500 SFAPs were acquired in total, of which selected SFAPs were analyzed.

After the SFAP acquisition a photogrammetric workflow was applied in order to generate data products. The aim of this photogrammetric processing is to transfer the 3-dimensional information from the real world to the acquired digital aerial photographs. The triangulation, i.e. assigning the measured GCP coordinate values for all three dimensions x, y and z and orientating each aerial photograph according to its respective recording angle, results in a robust image mosaic that may be refined by applying a bundle block adjustment. The photogrammetric processing was carried out in the software environment of Trimble Leica Photogrammetry Suite (LPS) and incorporated the measured Ground Control Points (GCP) as well as the acquired SFAPs. The coordinate values of the GCPs were measured with a total station (measurement precision +/-10 mm) (D'OLEIRE-OLTMANNS et al. 2012a). The chosen approach was partly connected to previous work that was carried out in the study area and assured the comparison of results from different field campaigns.

2.2 Mapping gullies with the concept of Object-Based Image Analysis (OBIA)

The approaches for mapping gullies from only optical input data relied on the concept of object-based image analysis. OBIA enables the incorporation of domain knowledge and creates a (spatial) context around the target object (LANG 2008, BLASCHKE 2010). The target objects in the context of this research work are gullies.
Data from two scale levels were analyzed: on the finer scale level gully extraction from SFAP data was conducted (D'OLEIRE-OLTMANNS et al. 2013) and on the coarser scale level the detection of gully-affected areas from only optical satellite imagery was carried out (D'OLEIRE-OLTMANNS et al. 2014). The analysis of both scale levels is described subsequently.

2.1.1 SFAP for detailed mapping

The identification of unique object features that are simultaneously spatially independent is a crucial step for the development of a (semi-)transferable rule-set for classification in OBIA. In order to extract object features that are generally applicable to optical input data for gullies, an image mosaic for a chosen study site was analyzed (D'OLEIRE-OLTMANNS et al. 2012b). The very high resolution of the input data allowed for putting the focus on the exact delineation of the gully edge. Starting with a multiresolution segmentation (MRS) the developed classification ruleset was applied. This rule-set was designed for mapping distinct landforms from different input data (D'OLEIRE-OLTMANNS et al. 2012b). As the spectral similarity between the gully and its surrounding environment was rather high, a custom feature (CF) was developed that detects the sharp border of sunlit surface and the steep gully sidewalls in the shadow cast. The validation of the classification outcome was performed against manually delineated reference data (D'OLEIRE-OLTMANNS et al. 2013).

2.1.2 Satellite data for area-wide mapping

For larger areas, which equals a wider spatial context (WARREN, 2002), the detection of gully-affected areas was carried out using only optical satellite imagery (D'OLEIRE-OLTMANNS et al. 2014). A defined subset of a QuickBird-2 satellite image was analyzed as input data. This representative subset comprises the different gully types (D'OLEIRE-OLTMANNS et al. 2012a; PETER et al. 2014; D'OLEIRE-OLTMANNS et al. 2014), as well as the different types of LC/LU that exist in the study area. The developed approach focused on a distinct feature extraction in contrast to a full wall-to-wall classification (D'OLEIRE-OLTMANNS et al. 2014). Detecting gully-affected areas was the main aim in order to derive a first estimation on the distribution of potential gully locations and also the extent of gully-affected areas. Therefore, the precise delineation of single gullies was not necessary.

QuickBird-2 satellite data was chosen for the analysis as this data is readily available for a large amount of people and also provides global coverage, since the mission started back in 2001. Satellite image time series have always been especially important for the investigation of gully development in the past and until today. The classification was developed as a cyclic, hierarchical approach. Initially, a coarse segmentation including the Normalized Difference Vegetation Index (NDVI) and Open-StreetMap (OSM) vector data as an additional layer generated rather large objects that were classified according to their basic land cover (LC) type. Reducing the area of interest significantly by masking out selected LC types led to the detection of gully-affected areas on a finer level (D'OLEIRE-OLTMANNS et al. 2014). The developed custom feature (CF), as described in chapter 2.1.1, was applied in combination with edge detection and further target object properties. This led to a classification rule-set that is mainly independent of location-specific spectral values (D'OLEIRE-OLTMANNS et al. 2014).

2.1.3 Soil erosion modelling

The data products derived from photogrammetric processing of SFAP (cf. 2.1.1) may be further exploited. The DSM was processed in a GIS software environment in order to calculate the total amount of eroded soil. Due to the very high per-pixel resolution the delineation of the gully edge was feasible in a 3D working environment. The creation of a cover plate that represents the original terrain height before the incision of the gully allowed the calculation of the gully volume: the height value was calculated for each pixel, summed up and multiplied with the pixel resolution. The result is an approximation of the total loss of soil material due to gully erosion (PETER et al. 2014). For the area-wide modeling of soil erosion the linkage of punctual rain simulation experiments with the SFAP data, i.e. 3-dimensional terrain data, was performed. Detailed descriptions of the experiment setup, as well as the laboratory work are provided in PETER et al. (2014) and PETER (2014). Transferring the findings from the punctual experiments to the extent of the SFAP based data led to first estimations on the geomorphological structure of the complete subcatchment of distinct gullies. General statements on the vulnerability of the study site towards erosion including estimations of the expected soil loss were possible through linking remote sensing data with the rainfall experiment results.

3 Results and Discussion

Several data products were generated based on the SFAP data. The ortho-image mosaics for selected study sites with a per-pixel resolution of 2 to 5 cm allow detailed mapping and visual interpretation of study sites (see Fig. 1).

Fig. 1: Ortho-image mosaic of one study site. The main gully already incised down to the level of the river bed.

Based on the photogrammetric processing of the SFAP data also Digital Surface Models (DSM) with very high resolution were generated. Aside of allowing a 3-D illustration of the ortho-image mosaics, the DSMs also enable quantifications of erosion rates and hydrological modelling of subcatchments (Fig. 2).

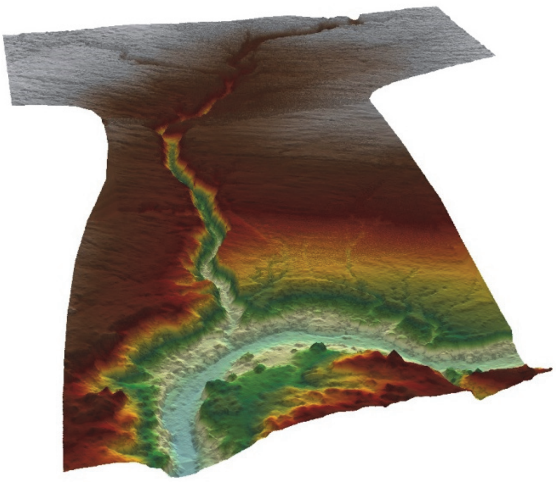

Fig. 2: Digital Surface Model (DSM) of one study site. The high resolution enables very detailed quantification of erosion rates and hydrological modelling of subcatchments.

The SFAP data was analyzed to detect single gullies and the QuickBird-2 satellite image was analyzed to detect gully-affected areas over a larger region. In both cases the accuracy was checked against a manual delineated reference data set.
The detection of single gullies based on the SFAP data led to an overall detection rate of 67% (see also D'OLEIRE-OLTMANNS et al. 2013). Main challenges are similar geomorphological structures that appear in the close surrounding to the main gully. These linear structures are hard to differentiate based on remote sensing rules.
The detection of gully-affected areas based on the QuickBird-2 satellite image yielded in satisfying results considering that erosive landforms lack a sharp border (see Fig. 3).

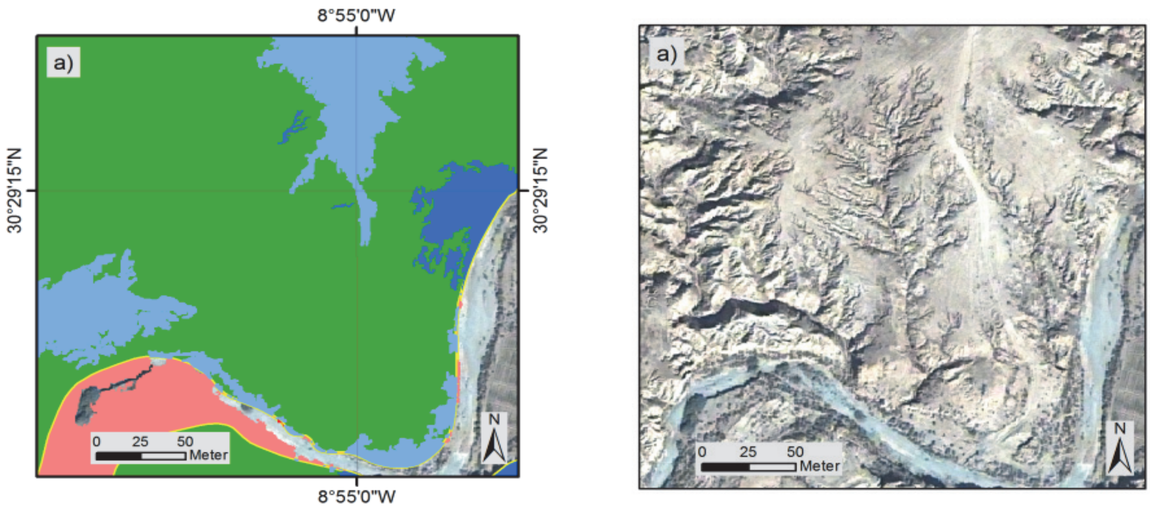

Fig. 3: Subset with several gullies (left). Classification results of the OBIA approach illustrated according to the different error types (right). Green represents true positives and the bluish and redish areas illustrate different classification mistakes.

Manually delineating a reference data set requires a certain expertise and still remains arguable. The overall classification accuracy (true positives) reached a value of 62%. The error of commission reached a value of 16%. These values were derived from a traditional accuracy assessment approach. However, the detection of gully-affected areas led to results that enable the identification of gullies on a coarser scale level which is important for a general statement of the distribution of gullies in a wider extent (see D'OLEIRE-OLTMANNS 2014).
Overall this work contributes to the field of landform mapping and especially to remote sensing and geomorphology. The ongoing discussion on landform borders and the translation of landform features into classification rules will be topic of many future discussions as the smooth transition zones from erosive landforms are still not yet defined finally.

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