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Monitoring soil erosion in the Souss basin, Morocco, with a multiscale object-based remote sensing approach using UAV and satellite data

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Abstract: This article presents a multiscale approach for detecting and monitoring soil erosion phenomena (i.e. gully erosion) in the agro-industrial area around the city of Taroudannt, Souss basin, Morocco. The study area is characterized as semi-arid with an annual average precipitation of 200 mm. Water scarcity, high population dynamics and changing land use towards huge areas of irrigation farming present numerous threats to sustainability. The agro-industry produces citrus fruits and vegetables in monocropping, mainly for the European market. Badland areas strongly affected by gully erosion border the agricultural areas as well as residential areas. To counteract the significant loss of land, land-leveling measures are attempted to create space for plantations and greenhouses. In order to develop sustainable approaches to limit gully growth the detection and monitoring of gully systems is fundamental. Specific gully sites are monitored with unmanned aerial vehicle (UAV) taking small-format aerial photographs (SFAP). This enables extremely high-resolution analysis (SFAP resolution: 2-10 cm) of the actual size of the gully channels as well as a detailed continued surveillance of their growth. Transferring the methodology on a larger scale using Quickbird satellite data (resolution: 60 cm) leads to the possibility of a large-scale analysis of the whole area around the city of Taroudannt (Area extent: ca. 350 km²). The results will then reveal possible relationships of gully growth and agro-industrial management and may even illustrate further interdependencies. The main objective is the identification of areas with high gully-erosion risk due to non-sustainable land use and the development of mitigation strategies for the study area.

Keywords: soil erosion; land-use change; object-based classification; remote sensing; multiscale; UAV; SFAP.

1. Introduction

The conservation of natural resources is considered to be a core need for establishing sustainability not only with respect to environmental management, but also regarding the social and economic dimension. In this context, land degradation and particularly soil erosion is a serious threat to the natural resource soil. In semi-arid regions, the loss of soil by gully erosion is considered to be, at different spatial and time scales, one of the most important erosion processes. Estimations regarding the contribution of gully erosion to total soil loss vary between 10 and 90% [1, 2]. Mapping and monitoring the development of badland regions and erosion-affected areas and analyzing their relationship to other surrounding types of land-use (e.g. agricultural and urban areas) provide detailed and spatially continuous information. Nevertheless the acquisition of detailed up-to-date data from well-chosen study sites remains necessary for the investigation of process rates and dependencies under local conditions.

In this paper the concept and first results from an on-going international project on mapping, monitoring and understanding soil-erosion processes – particularly gully erosion - in the agro-industrial area around the city of Taroudannt, Souss-Massa-Drâa (Morocco) are presented. Project partners are Goethe University Frankfurt am Main, Germany (Remote Sensing & GIS Research Group, Department of Physical Geography), the University of Trier, Germany (Department of Physical Geography) and Ibn Zohr University Agadir, Morocco (Department of Geography). The project concept comprises three subject areas dealing with monitoring of gully erosion, site-specific process investigation and characterization of the gully catchment areas in a multi-scale approach. In a fourth part, the results will be combined in order to establish a conceptional model of gully-erosion risk and mitigation strategies. The aim of this paper is to present two of the core methods employed for assessing and monitoring current soil erosion processes in the study area.

2. Study Area

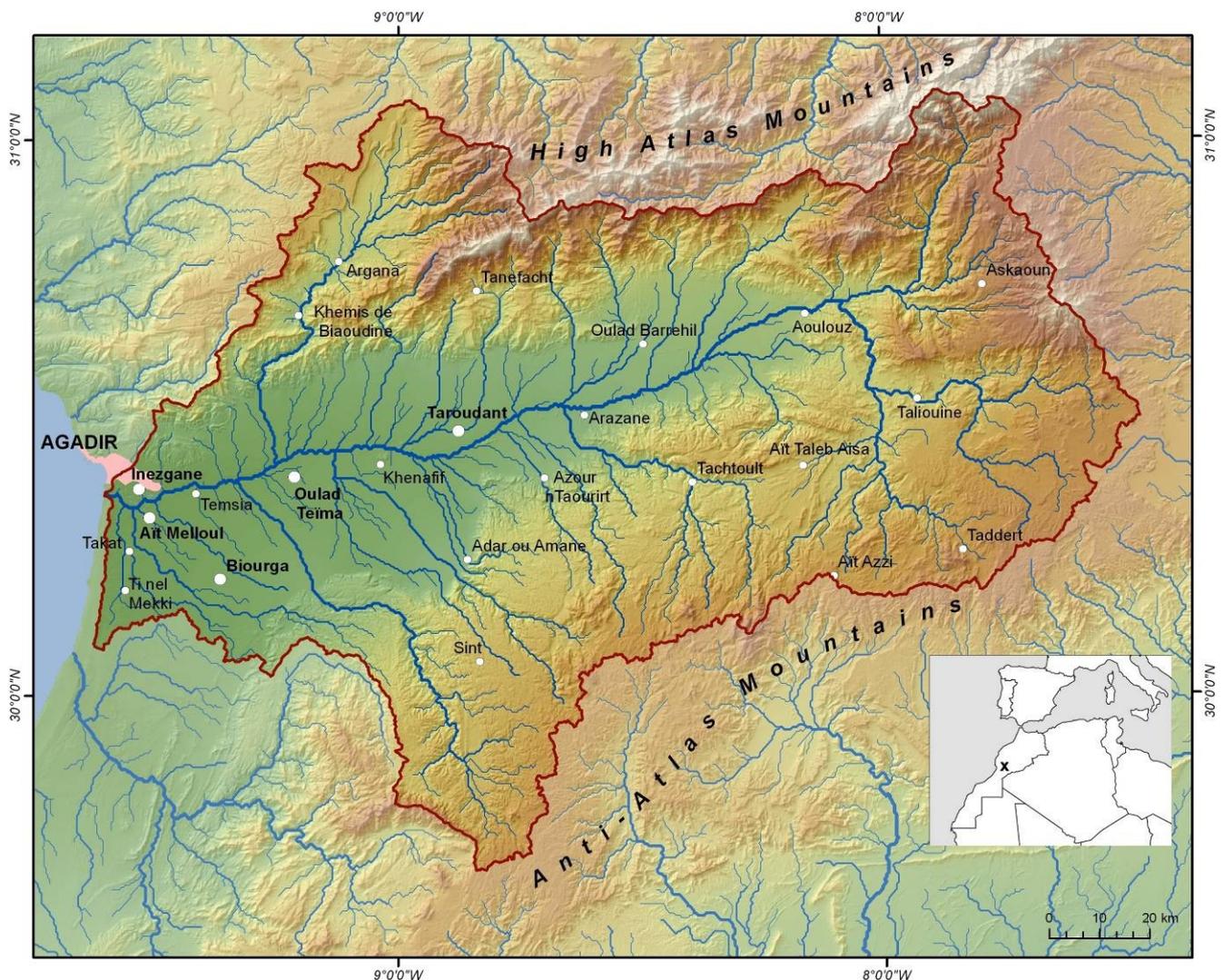
The area surrounding the city of Taroudannt, Souss-Massa-Drâa, Morocco was chosen as study area (see Fig. 1 & 3). It is located in south-west Morocco in the Souss basin between 30 and 31 degrees northern latitude and between 9 and 7 degrees western longitude [3]. The river Souss drains the whole area that is framed by the mountainous regions of the High Atlas (north) and the Anti-Atlas (south). The Souss basin is oriented East-West stretching over a length of about 150 km from its upper reaches to the coastline with an overall catchment area of 16,000 km² [3].

The whole area is precisely characterized geomorphologically by Aït Hssaine & Bridgland [4]. A detailed description on the geomorphological evolution of the Piedmont in the Taroudannt region was also given by Aït Hssaine [5].

The plain of the Souss basin represents one of the most intensive agricultural regions of Morocco with a strong focus on fruit-tree plantations and irrigated greenhouses. It is characterized by high

population and land-use dynamics. Thus, the already fragile and vulnerable natural environment is subject to numerous threats to environmental, social and economic sustainability, particularly with respect to water scarcity, the impacts of climate change and globalization processes. The project presented here focuses on the cultivated areas, which are being threatened by gully erosion and rapid badland development. The spatial association of high-tech irrigation areas for fruit orchards and greenhouse horticulture – often created by land-leveling measures – with geomorphologically highly dynamic gullies presents an increasing risk to both the agro-industrial land use and the population settlements in badland vicinity.

Figure 1. The Souss catchment in South Morocco (Basemap: USGS HydroSHEDS)



3. Monitoring gully development using UAV and satellite data

Monitoring of gully erosion in the study area is done using a multi-scale object-based remote sensing approach that investigates the development of individual gullies as well as the wider-area distribution of gully sites in the study area: Very detailed analysis of gully development (growth/shrinking by land-leveling and infilling) is carried out on the site-scale level using small format aerial photography (SFAP) derived from an unmanned aerial vehicle (UAV). In a more

complex remote sensing approach, a combination of different data on several scale levels is used for the detection of gully distribution based on satellite imagery on the region-scale level. On this region-scale level the current and developing gully distribution may be analyzed. This work is carried out in an ongoing PhD thesis by the Frankfurt project member Sebastian d'Oleire-Oltmanns.

3.1. UAV data for site-scale analysis

For detailed information on the development of gullies at individual sites, a very high spatial resolution is necessary representing a very large map-scale level. The change in gully growth taking place within several years may vary from some centimeters to several meters [2, 6, 7]. In the study area the gully sites are often neighboring agricultural or residential areas. Therefore a precise analysis is necessary to identify gully growth in time for conserving existing settlement and farming areas.

The possibilities concerning the acquisition of very high resolution (VHR) data using UAVs have been rapidly growing for the last few years [8]. The potential for site-specific small-area investigations is enormous since all different types of sensors may be carried on such UAVs. In the current project, a fixed-wing aircraft type *Sirius I* (MAVinci, Germany) is employed (see Fig. 2). As optical onboard sensor a digital interchangeable lens system camera is installed (Panasonic Lumix GF1 with 20 mm Pancake lens).

Figure 2. Fixed-wing aircraft Sirius I by MAVinci (Photo: C. Giudici 2010).



In order to allow georeferencing and metric analysis of the UAV images, a sound survey design is required for purposeful data acquisition [8]. First the chosen study site has to be prepared with ground control points (GCPs) which are subsequently measured to high precision with a total station. A self-

defined local coordinate system is used since official survey points are not available and GPS measuring is not precise enough.

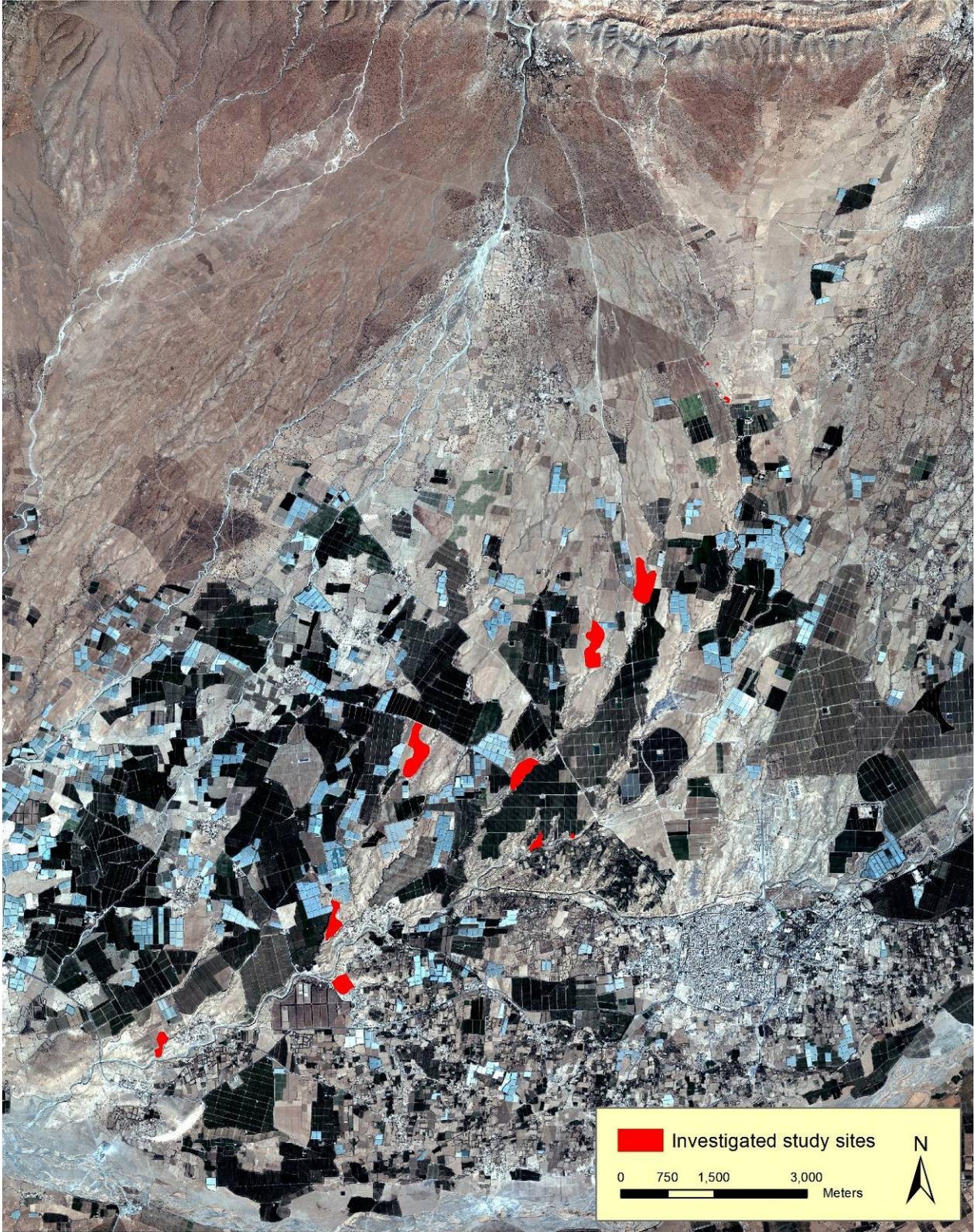
Systematical aerial survey of chosen sites follow a flight plan designed within the controlling software on the laptop. One important requirement for further processing is an in-track overlap of at least 60% of one aerial photograph to the next. Therefore the designed flight plan has to cover an area larger than the overall extent of the selected study site assuring sufficient coverage of aerial photographs. Furthermore the time-range where best possible weather conditions exist has to be met. In the context of gully monitoring shadowing has to be avoided which makes a zenith position of the sun preferable. Even more preferable are weather conditions with indirect lighting situation since then contrast properties are distributed best [9].

The resulting aerial photographs are then analyzed using digital photogrammetry and geographical information systems for the creation of digital surface models (DSMs). These DSMs are then used for further 3D analysis, quantifying gully volume and growth (see chapter 5.1).

3.2. Satellite data for region- scale analysis

Since the detailed-scale investigation of single gully sites is not sufficient for understanding the whole context of this type of soil erosion in the study area, the transfer onto another scale level is necessary [10]. Quickbird satellite data (Quickbird2; 2009/10/26; 0.6 x 0.6 m resolution) was chosen for regional-scale analysis. On the level of satellite data the investigation focus is put not longer on single gully sites but rather on their distribution in the whole study area (see Fig. 3). This allows at the same time to analyze the high dynamics of land-use and land-cover change (LULCC) within this region. Moreover it provides a good way of mapping and monitoring the development of gully erosion threatening buildings, agro-industrial economies and all other existing users of the resource soil in the Souss basin. Technically the Quickbird data is analyzed using eCognition Developer© software incorporating all necessary properties (i.e. pixel values, size, area, context and more) for an object-based image analysis (OBIA).

Figure 3. Overview about the distribution of investigated gully sites in autumn 2010
(Quickbird2; 2009/10/26)



4. Understanding erosive processes using rainfall simulation analysis

Rainfall events are the main drivers for the loss of soil by water erosion, and the investigation of their impact on different soil surfaces in the gully catchments is at the core of one of the project's subject areas. However, measuring of natural erosion events is highly time-consuming and difficult, because of their complexity and high spatial and temporal variability. Therefore using artificial rainfall simulations is a quick and reproducible way to quantify site-specific runoff and erosion processes on different soil surface types and thus to characterize gully catchments. It is further possible to investigate the role of different soil surface properties such as slope, soil moisture, and crust or vegetation cover [11]. Cerdà [12] gives an overview of existing applications of artificial rainfall simulations.

The nozzle rainfall simulator used here is based on the one designed by [13, 14]. The test plot (circular, diameter 60 cm, area 0.28 m²) is delimited by a steel ring with an outlet. The water flow is regulated by a flow meter and the fall height of the raindrops is 2 m (see Fig. 4). The rainfall intensity is around 40 mm h⁻¹, which is considered to be mean thunderstorm rainfall intensity with a return period of 3-5 years [15, 16]. Within the presented project, this work is carried out in an ongoing PhD thesis by the Trier project member Klaus Daniel Peter. More details on the experimental setup and data evaluation possibilities are given in [1].

Figure 4. Rainfall simulator setup (Test site TAL, Souss, 2010/11/18; Photo: K. D. Peter 2010)



5. First results

5.1. UAV data

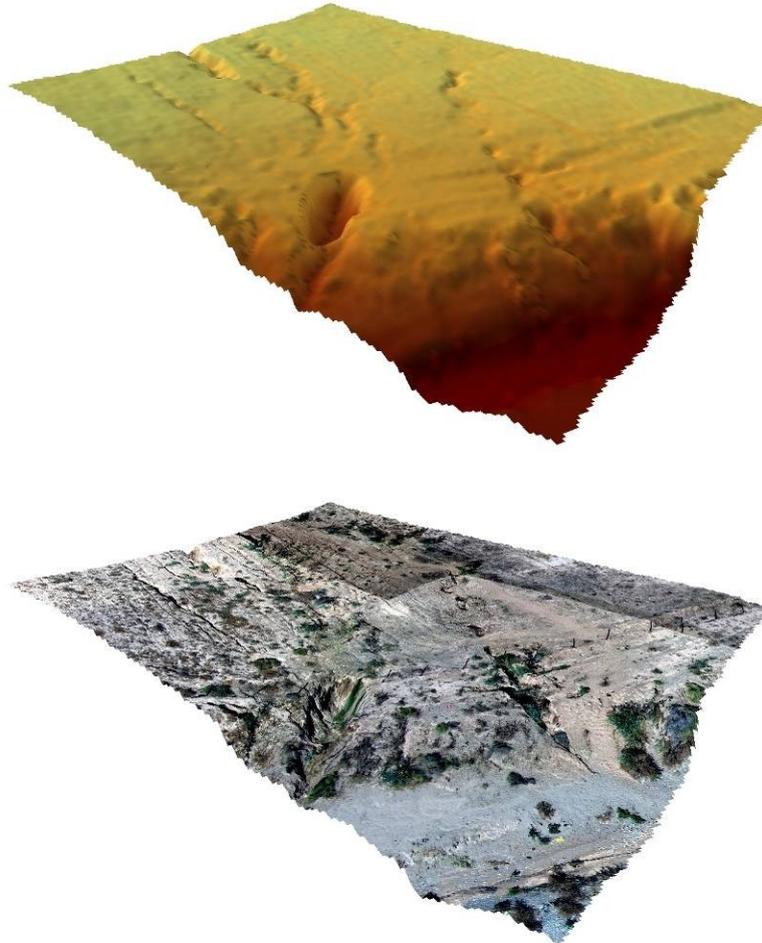
During the first major field campaign in autumn 2010, approx. 12,500 aerial photographs were acquired over 11 test sites in the study area. The flight heights were varied from 50 to 600 meter above ground. The processing of the UAV data delivers very detailed results regarding the analysis of single gully sites. Figure 5 shows an example of a mosaic of selected ortho-corrected images covering one of the gully sites. Due to VHR such image maps allow very detailed planimetric quantification of the gully area as well as mapping of local conditions such as vegetation cover, ploughing or planification patterns, rill erosion processes etc.

Figure 5. Mosaic of aerial images (Test site GLA, Souss, 2010/09/29)



Stereo-photogrammetric analysis of the aerial images allows the creation of a DSM as a basis for 3D analysis (in progress). The combined visualization of the orthophoto mosaics and DSM data is also well suited for visual interpretation of the gully-erosion process in its local context (see Fig. 6).

Figure 6. 3D view of DSM derived from UAV data and below a combination of image and DSM data (Test site GLA, subset).



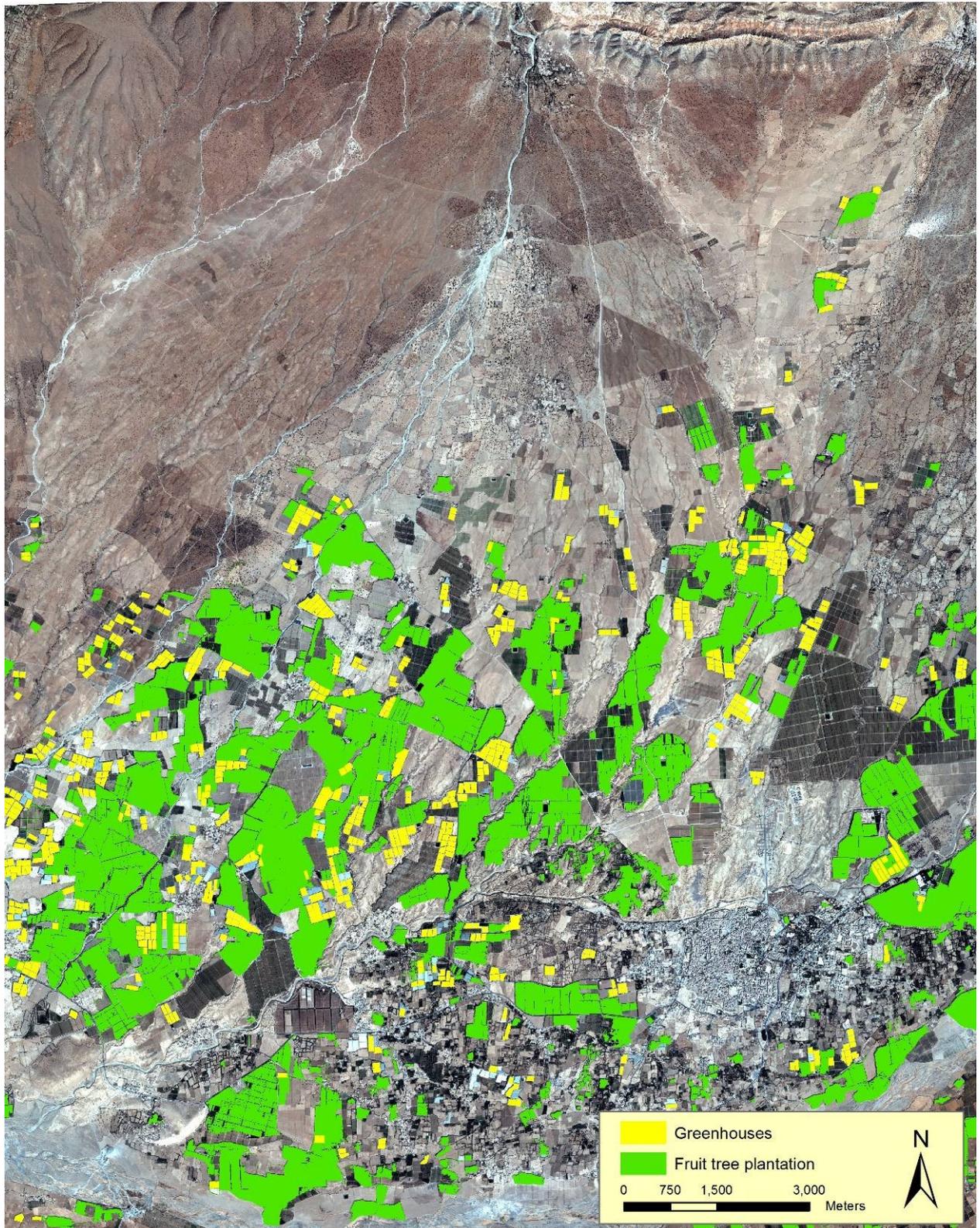
5.2. Satellite data

Using object-based image analysis (OBIA) for classification of the available Quickbird satellite data supports understanding of the importance of gully erosion in the agro-industrial area of the Souss basin. Current data represent the distribution of greenhouses and fruit tree plantation (see Fig. 7).

For this classification approach on the one hand spectral information were used. On the other hand features such as area, geometric properties and relationships within selected objects to be classified significantly improved the accuracy and therefore quality of classification results.

Future analysis will aim to differentiate further land-cover classes such as settlements, dry-farming areas and pasture land and will particularly endeavor to extract and classify the badland areas and linear incisions of gully erosion. A profound accuracy assessment for this stage of classification was not yet necessary but will surely be processed for the overall accuracy of the developed classification rule-set.

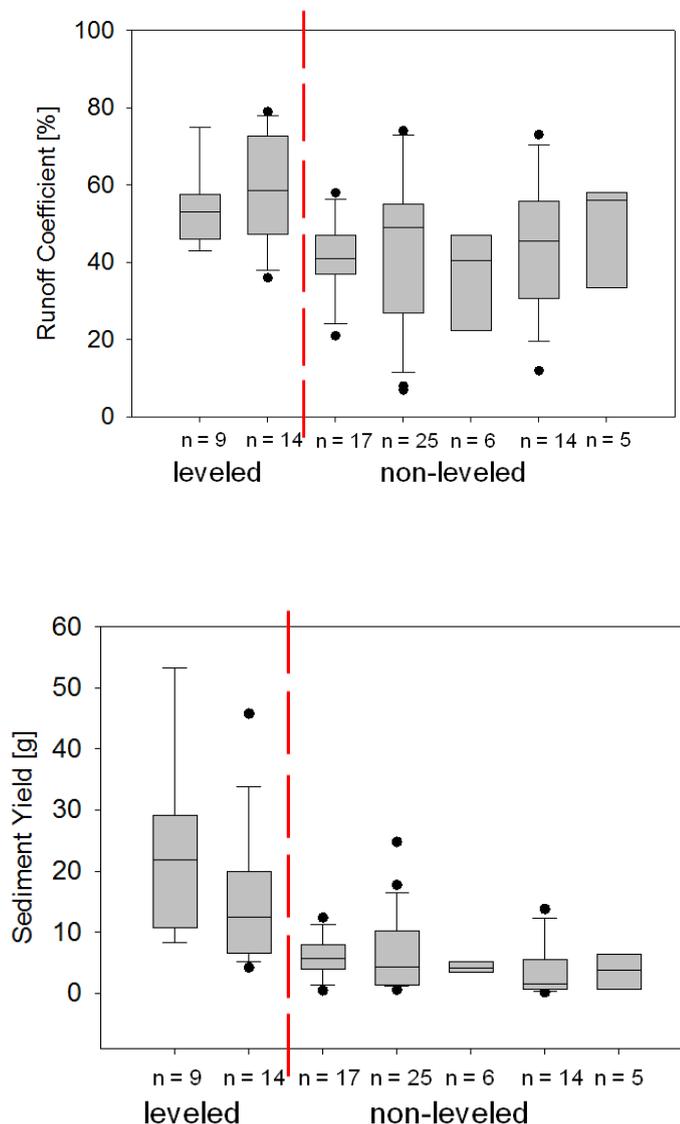
Figure 7. Map of plantation and arable land distribution in 2009/10/26.



5.3. Rainfall simulation

Up to now, 90 rainfall simulations have been carried out on 7 selected test sites in the study area. First results of the rainfall simulations show an increase in runoff and erosion on leveled test sites (Fig. 8). These sites had previously been affected by rill or gully erosion and were leveled with heavy machinery – sometimes infilling gullies as deep as 7 m – in order to create agricultural land for irrigation farming or greenhouse construction. Here the mean runoff coefficients are between 54 and 59 % compared to 36 to 48 % on non-leveled test sites. The mean sediment yields reach 52.1 to 81.8 g m⁻² on leveled test sites. On non-leveled test sites the results show only 13.2 to 23.2 g m⁻² of sediment. Accordingly, the correspondent mean sediment concentrations show high values from 4.18 to 7.86 g l⁻¹ on the leveled test sites and low values from 1.24 to 2.63 g l⁻¹ on the other test sites.

Figure 8. Runoff coefficients and sediment yields on the seven test sites (autumn 2010: 49 experiments, spring 2011: 41 experiments)



To analyze the influence of plot characteristics on runoff generation and sediment production a Spearman-Rho correlation is used. It shows a slight but significant (at the 0.01 level) negative correlation between vegetation cover and sediment production of $p = 0.5$. Furthermore there is a clearer correlation between crust cover and runoff generation or sediment production of $p = 0.65$ or $p = 0.79$ respectively. Because on leveled test sites the lowest rates of vegetation cover but the highest rates of crust cover are reached, these resulting factors can be seen to take partly account for the high runoff generation and sediment erosion.

6. Conclusions

The chosen approach for the delineation of gullies as complex landforms presents good results. The classification approach is designed top-down. The overall study area (i.e. the whole extent of the Quickbird satellite scene) will be classified on a coarse level identifying main LC classes such as vegetation and water. This leads to a reduction of the remaining study area – which is other LC and LU classes besides those being already classified on the coarse level – requiring analysis steps on more detailed levels. In this article successful working steps are illustrated showing the delineation of *greenhouses* and *fruit tree plantation* as two land-use classes (see Figure 6). The final goal remains the identification of gullies on a regional scale level in order to understand their impact on the study area. This aim contains the field of landform classification which then requires more than information derived only from optical data. Therefore the presented classification approach has to be broadened by incorporating additional spatial data (digital elevation data). Further improvement and analysis of the chosen approach is necessary.

Regarding the results of the rainfall simulation the possible factors leading to these results are the strong compaction and the increased crusting of the soil. Further investigation of the complex correlations is ongoing.

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References and Notes

1. Seeger, M. Uncertainty of factors determining runoff and erosion processes as quantified by rainfall simulations. *Catena* **2007**, 71, 56–67.
2. Poesen, J.; Nachtergaele, J.; Verstraeten, G.; Valentin, C.; Gully erosion and environmental change: importance and research needs. *Catena* **2003**, 50, 91–133.

3. Elmouden, A.; Bouchaou, L.; Snoussi, M. Constraints on alluvial clay mineral assemblages in semiarid regions. The Souss Wadi Basin (Morocco, Northwestern Africa). *Geologica Acta* **2005**, *3*, 3–13.
4. Aït Hssaine, A.; Bridgland, D. Pliocene–Quaternary fluvial and aeolian records in the Souss Basin, southwest Morocco: A geomorphological model. *Global and Planetary Change* **2009**, *68*(4), 288–296.
5. Aït Hssaine, A. Evolution géomorphologique du piémont sud-atlasique dans la région de Taroudant (SW-Maroc) au cours du Tertiaire et du Pléistocène inférieur. *Bulletin de l'Institut Scientifique* **2000**, *22*, 17–28.
6. Marzloff, I.; Ries, J. B. & Poesen, J. Short-term vs. medium-term monitoring for detecting gully-erosion variability in a Mediterranean environment. *Earth Surface Processes and Landforms* **2011**, *36*, 1604–1623. DOI: 10.1002/esp.2172.
7. Marzloff, I.; Ries, J. B. Gully monitoring in semi-arid landscapes. *Zeitschrift für Geomorphologie* **2007**, *51*, 405–425. DOI: 10.1127/0372-8854/2007/0051-0405
8. Aber, J.; Marzloff, I.; Ries, J. B. *Small Format Aerial Photography: Principles, techniques and geoscience applications*. Elsevier et al.: Amsterdam, 2010; pp. 256.
9. Giménez, R.; Marzloff, I.; Campo, M.A.; Seeger, M.; Ries, J. B.; Casali, J.; Álvarez-Mozos, J. High-resolution photogrammetric and field measurements of gullies with contrasting morphology. *Earth Surface Processes and Landforms* **2009**, *34*, 1915–1926. DOI: 10.1002/esp.1868.
10. Vrieling, A.; de Jong, S.; Sterk, G.; Rodrigues, S. Timing of erosion and satellite data: A multi-resolution approach to soil erosion risk mapping. *International Journal of Applied Earth Observation and Geoinformation* **2008**, *10*, 267–281.
11. Fister, W.; Iserloh, T.; Ries, J. B.; Schmidt, R. Comparison of rainfall characteristics of a small portable rainfall simulator and a combined portable wind and rainfall simulator. *Zeitschrift für Geomorphologie* **2011**, *55*(3), 109–126.
12. Cerdà A. Simuladores de lluvia y su aplicación a la Geomorfología. Estado de la cuestión. *Cuadernos de Investigación Geográfica* **1999**, *25*, 45–84.
13. Calvo Cases, A.; Gisbert, J.; Palau, E.; Romero, M. Un simulador de lluvia portátil de fácil construcción. In *Métodos y técnicas para la medición en el campo de procesos geomorfológicos*, Sala, M., Gallart, F., Eds.; 1988, pp. 6–15.
14. Lasanta, T.; Pérez Rontomé, M.; García Ruiz, J. Efectos hidromorfológicos de diferentes alternativas de retirada de tierras en ambientes semiáridos de la depresión del Ebro. In: *Efectos geomorfológicos del abandono de tierras*, García Ruiz, J., Lasanta, T., Eds.; 1994, pp. 69–82.
15. Ries, J. B.; Langer, M.; Rehberg, Ch. Experimental investigations on water and wind erosion on abandoned fields and arable land in the Central Ebro Basin, Aragón/Spain. *Z. Geomorph. N.F.* **2000**, Suppl.-Bd. 121: 91–108.
16. Ries, J. B.; Langer, M. Runoff generation of abandoned fields in the central Ebro Basin. Results from rainfall simulation experiments. In: *Environmental change and Water Sustainability*, García-Ruiz, J., Jones, J., Arnáez, J., Eds.; 2002, pp. 65–82.