High Resolution SAR for Monitoring of Reservoirs Sedimentation and Soil Erosion in Semi Arid Regions

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***Abstract*—High resolution SAR data can be a powerful support mainly in areas where the acquisition of in situ information is hampered by physical or economic obstacles. Purpose of this paper is to present an approach to exploit high resolution SAR data for monitoring the temporal evolution of reservoir characteristics in semi-arid regions. Classical and innovative techniques are tailored on the specific climatic conditions of these regions, characterized by the alternation of a three months wet and a nine months dry seasons. Results from a case study developed in Burkina Faso show that the combined use of amplitude and phase information allows the estimation of the eroded areas and a meaningful monitoring of the reservoirs sedimentation.**

I. Introduction

Remote sensing approaches, methods and technologies need to be customized to each specific context in order to exploit its huge potentialities. In particular, in this paper, we present a multi-disciplinar context-based approach to extract physical information from high resolution SAR images on semi-arid regions, defined as areas where the potential evapo-transpiration is higher than the precipitation [1].

The study case is located in the north of Burkina Faso, a small country in the hearth of west Africa, characterized by a variable hydrologic regime, with the alternation of intense rainy (from June to September) and long dry (From October to May) seasons. In such an extreme climate condition, the agriculture is mainly supported by the collection of water in small reservoirs during the rainy period. The stored water is then used in the dry season for agriculture, farming and human consumption. In Burkina Faso, the farmers mainly accumulate the wet season rain in small capacities and low depth reservoirs (the height of the deepest part of the water body is often lower than 5 meters). The location of the dams and the utilization of water is often left to the farmer experience and it is not planned and optimized. The exact number, location and capacity of small reservoirs is rarely recorded.

Soil erosion due to water and consequent sedimentation of reservoirs are major problems in West Africa [2]–[4]. Soil erosion determines a decline of soil productivity and therefore it is one of the causes of the low levels of crop yields of the area. The life span of reservoirs and the amount of water available for agriculture and farming are affected severely by reservoir sedimentation [5].

In this paper high resolution SAR , acquired in the frame of an AO project approved by the Italian Space Agency [6], [7] are used for the mapping of soils at risk of erosion, for the monitoring of water retention basins capacities and for the prevision of sedimentation rates, as detailed in Section 2, where an interferometric chain is presented for obtaining a digital elevation model (DEM) of the observed area. An innovative procedure, based on the combination of phase and amplitude data, for the validation of the obtained DEM is also presented.

In Section 3 we present the rationale that allowed to exploit the available high resolution SAR data and the obtained DEM for the monitoring of reservoirs sedimentation and for the identification of eroded soils.

II. SAR image processing

In this project, we used a set of 16 strip-map and 7 spotlight images with a coverage of almost one year and a half, including two rainy seasons. The high resolution SAR images were provided at no cost by the Italian Space Agency in the frame of the AO2007 call [6], [7]. The SAR images cover a rectangular area of almost 1600 km^2 of the Yatenga district in the north of Burkina Faso, with a spatial resolution of 3m.

InSAR algorithms are adopted to extract the digital elevation model (DEM) of the area of Ouahigouya. The chosen image pair was acquired at the end of the dry season (the 28th and the 29th of April), when the climate is stable and the small water reservoirs are expected to be empty. Such an extreme climatic condition allows to reduce the temporal decorrelation and to measure the capacity of the empty reservoirs. Such an approach will give the opportunity of estimating the available

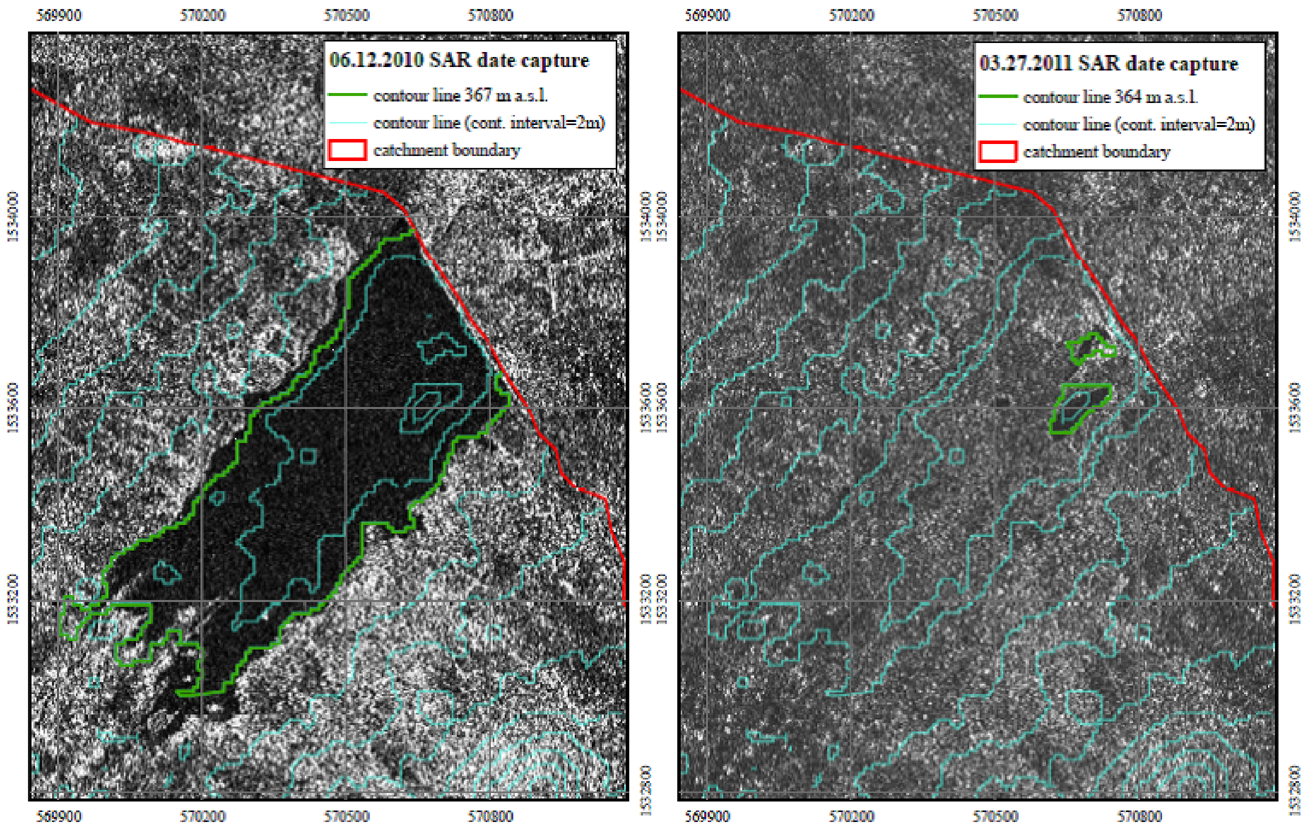

Fig. 1: Comparison between DEM derived contour lines and reservoirs border lines at Laaba.

water volume decreasing in time due to the deposition of water transported sediments.

An original technique has been used to test the DEM accuracy. The border line of the water retention basins, present in the study area, can be observed in the SAR images for any water retention basin at different time steps both in wet and dry seasons. The reservoirs borders constitute a topographic contour lines. Therefore, the DEM accuracy can be estimated through the comparison of water borders and contour lines computed on the basis of the DEM. In Fig. 1, we show how we used the amplitude image for verifying the presence of a small hole identified by the DEM inspection in the Laaba dam.

III. Monitoring of reservoirs sedimentation and soil erosion

A. *Monitoring of reservoirs sedimentation*

A set of 8 reservoirs has been identified in the study area. The two biggest reservoirs cannot be monitored with the developed technique because they maintain a big amount of water also in the dry season. As it is not possible to derive the DEM in the area covered by water, we cannot estimate the reservoir capacity for these basins.

Data on the original capacity of the reservoirs and the year of construction were derived from the Inventaire des Barrages au Burkina Faso. The loss in reservoirs capacity due to sedimentation of solid material transported by the tributary river has been then estimated. Because of the high rate of soil erosion in the area [4] in about 25 years most of the reservoirs lost from 50 to 100% of their original capacity.

When the catchments drained by the dams are entirely included in the SAR images, it is possible to extract the catchments area by elaborating the DEM. Neglecting the sediment volume that may overflow the dam, and the possible loss of sediment due to reservoir dredging, it is possible to provide a rough estimation of the average soil erosion. The values reported in TABLE I are obtained assuming a sediment apparent density of 1.5 T/m^3 [8]. The obtained values are in the range of the values estimated for the area [4], [8]. The catchment drained by the Saya dam shows an average soil loss, that is one order of magnitude greater than the others. This peculiarity of the Saya basin determined a change of use and actually the reservoir is no more used for collecting water but it is exploited for the extraction of silt to be employed in the production of bricks.

The technique here presented may be employed for monitoring the reservoir sedimentation, and consequently the soil erosion at catchment scale, on an annual basis if a couple of interferometric SAR images are regularly acquired each year at the end of the dry season, i.e. at the end of April, in order to obtain the required DEM.

TABLE I:
Reservoir database

Reservoir	Year of construction	Original capacity (10^3 m^3)	Capacity in 2011 (10^3 m^3)	Sedimentation (m^3/year)	Drained catchment (km^2)	Average catchment erosion (10^3 kg/ (ha×year))
Pogoro	1987	330	0	13750	55.9	3.7
Saya	1981	20	0.02	666	0.3	31.6
Gouinre	1967	-	-	-	141.5	-
Gourga	1988	24	0.06	1041	43	0.4
Ouahigouya	1977	2700	-	-	-	-
Dinguela	1985	22	5.9	732	5.5	2
Derhogo	1987	14	3.8	425	4.2	1.5
Laaba	1989	602	572	1364	15.5	1.3

B. Eroded soil identification

Eroded soils are portions of land that lost their nutritional properties and their crop production potential. They are no more able to absorb and drain water, so that their humidity and, as a consequence, their dielectric constant and conductivity are almost independent by the precipitation. By comparing SAR images acquired during the rainy and the dry seasons (see Fig. 2), the eroded soils do not change their reflectivity and they can be identified by change detection techniques. In this work we employ innovative change detection techniques which exploits the temporal evolution of the terrain reflectivity measured during the year and the appropriate combination of amplitude and coherence images maps [7].
Bayesian techniques are employed in order to extract land cover maps and evidence the presence of terrains that lost their productivity.

IV. Conclusions

An improved water resource management at regional scale requires updated information about the capacity of the retention basins of the entire region. In low-income countries, the building of new reservoirs is performed without a preliminary study on the sedimentation rate and the consequent life span of the facility. A low cost system for the monitoring of water retention basins capacity for an entire region is here presented. An investigation of the soil erosion and consequent reservoir sedimentation processes is here described with the aim of providing simple tools for the best location and design of new water collection infrastructures. One of the results of this study is the implementation of a low cost technique for the realization of wide scale maps of soils at risk of erosion for planning appropriate soil erosion countermeasures and the verifying their effectiveness.

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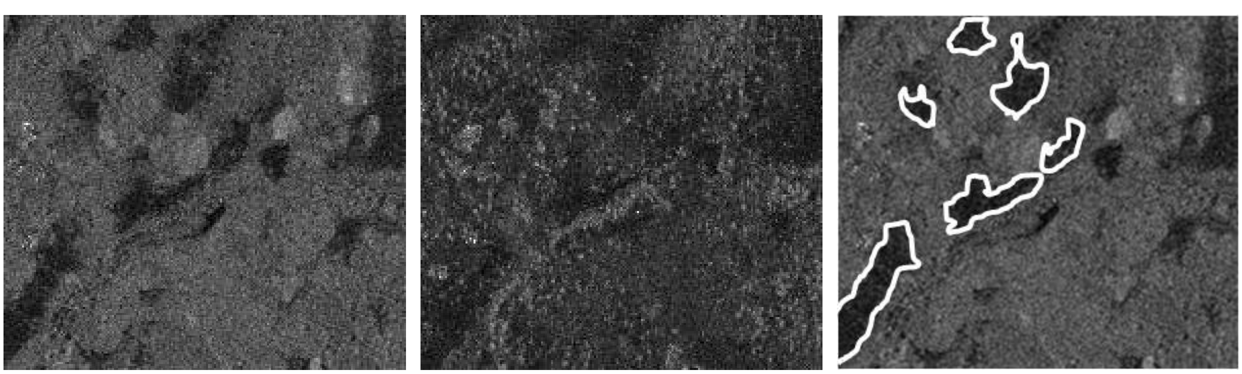

(a) (b) (c)

Fig. 2: SAR images of the Bidi dam during the rainy (a) and dry (b) seasons. White frames (c) identify eroded soils.

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