USE OF HIGH RESOLUTION SAR IMAGES FOR MODELING WATERSHED RESPONSE IN SEMI-ARID REGIONS

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ABSTRACT

In this paper we propose a methodology devoted to exploit high resolution radars for monitoring water bodies in semi-arid countries. The proposed approach is based on appropriate registration, calibration and processing of SAR data, producing information ready to use by end-users. The obtained results were used to (i) estimate a relationship between surface and volume of water stored in reservoirs and (ii) validate a hydrological model that simulates the time evolution of water availability.

***Index Terms*—** Synthetic Aperture Radar, semi-arid regions, small reservoirs.

1. INTRODUCTION

Building small reservoir is a typical measure taken by farmers in semi-arid environments, in order to limit the effects of a climate characterized by a single rainy season. In Sahel, the rainy season lasts almost three months (from June to September) and small reservoirs are widely employed for facing water scarcity and climatic variability [1]. They are used for water harvesting in the rainy season and water storage in the dry season. In Burkina Faso, it is estimated that almost 1700 small reservoirs are actually used for irrigation, livestock, and many other uses.

The appropriate choice of their location of the dams, and the monitoring of their efficiency in terms of available water volumes, distribution and effects on close areas would require expensive measurement networks. In low-income contexts, the use of remote sensing tools could provide fruitful value added in applications, thanks to the available high coverage and fine resolution. Anyway, the diffusion of remote sensing techniques is limited by the cost of the data and, mainly for SAR sensors, the interpretation of the results.

In this paper we present a multidisciplinary approach devoted to define a methodology that aims at reducing the constraints posed by the above mentioned problems, also exploiting the new policies of Space Agencies that tend to provide the data at free or low-cost. The proposed approach was defined and implemented in the frame of the project “Use of high-resolution SAR data for water resource management in semi-arid regions”, developed under the aegis of the 2007 Italian Space Agency Announcement of Opportunity for the scientific use of COSMO-SkyMed data [2]–[4].

The use of Cosmo-Skymed SAR data allows outperforming the previously available methods for the monitoring of small reservoirs, mainly performed with optical data, and severely limited by the presence of cloud coverage, which is a typical condition in wet season. In particular, in this paper we present two activities: the estimation of a surface/volume relationship for small reservoirs and the development of a hydrologic model devoted to the prevision of water availability.

A case study was developed in the area of Ouahigouya, capital of the Yatenga province, in northern Burkina Faso, a region characterized by a semi-arid climate, where almost 80% of local people lives of subsistence agriculture and is dependent on the precipitations concentrated in the June-September rainy season.

The overall organization of the work is described in Figure 1, where a block diagram evidences the integration of remote sensing and hydrologic skills for reaching meaningful results.

The paper is organized as follows. Section 2 is devoted to describe the main characteristics of the SAR processing; the hydrological methods and applications are presented in Section 3. The final section is dedicated to the concluding remarks.

calibration steps. The shoreline is extracted with the

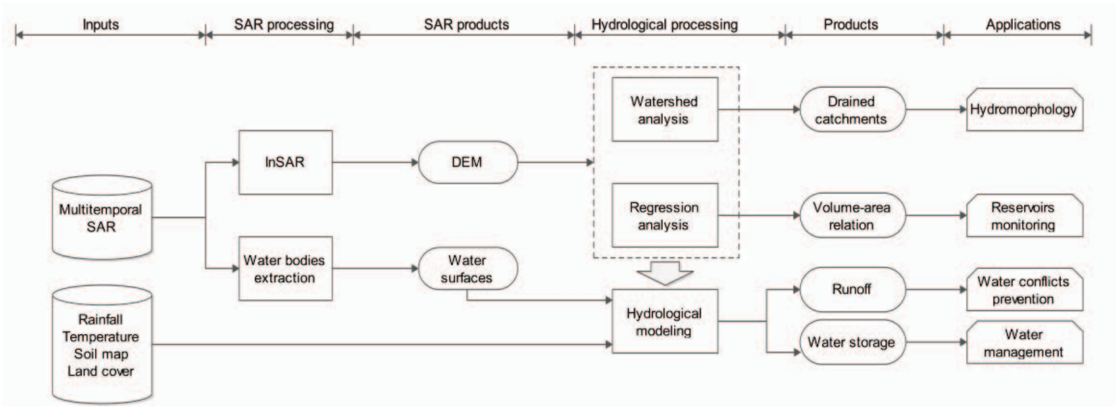


Fig. 1: Block diagram of the proposed method

2. SAR PROCESSING

In this section we present the SAR processing, with the support of the results of the case study presented in the introduction. A set of 15 stripmap (3m resolution) COSMO-SkyMed images were used for the applications presented in the following. The data cover a temporal interval of almost one year and a half, from June, 2010 to December, 2011, including two rainy seasons. All the data were acquired with medium look angle (almost 30°) and HH polarization, also for increasing the ratio between land and water reflectivities [3].

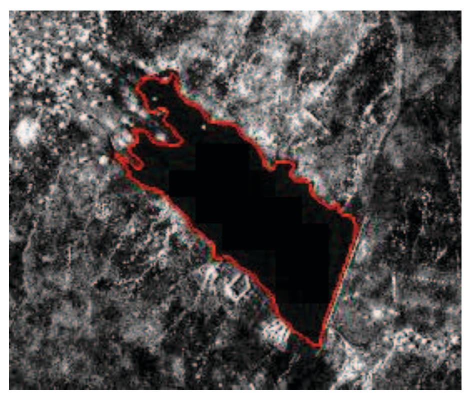
Both phase and amplitude data were elaborated. In particular, we developed an interferometric chain devoted to obtain a 9 meter resolution DEM from a couple of Cosmo SkyMed images, appropriately acquired at the peak of the 2011 dry season. This choice allowed to exploit the fact that after nine months of dryness, the smallest reservoirs are empty and the obtained DEM can be used also for bathymetric analysis.

As for the amplitude images, calibration, registration and despeckling procedures are proposed for exploiting the temporal diversity of the SAR images. We applied metadata-based calibration to the intensity map in order to obtain COSMO-SkyMed SLC balanced products with absolute radiometric calibration accuracy smaller than 1 dB. Then, we adopted the optimal weighting multitemporal De Grandi despeckling filter [5], in order to amplify the water-land contrast and to produce more accurate water surface information. This allows the enhancement of the land-water ratio and, as a consequence, an effective extraction of the shorelines by applying an intensity threshold. The selection of the threshold value is guided by the evaluation of the histogram of a subset around the basins under analysis.

The threshold-guided segmentation allows a quick preliminary estimate of the water surface, as shown in the example depicted in Fig. 2, where we present the SAR image of the Laaba basin after the despeckling and application of a mode filter, the use of morphological operators, and the Roberts' operator. The estimated shoreline is superimposed in red on the SAR filtered image in Fig. 2.

The above presented technique allowed to extract the shorelines for all the available basins in a 40 x 40 km^2 area. The knowledge of the basin contour and of the bathymetry estimated from the DEM leads to compute the water volume V contained into the basin considering each pixel of the water mask as a water column, whose height h_i is calculated from the DEM and whose area S_i is equal to the pixel extension:

$$V = \sum_{i=1}^{N} S_i \cdot h_i \cdot \tag{1}$$



(b)

Fig. 2: Shoreline extraction: superposition of the obtained contour line on the intensity De Grandi-filtered map.

3. HYDROLOGICAL MODELING

In this section we present two methods devoted to produce value added information for the hydrological analysis of the area under observation from the SAR products presented above.

3.1. Estimation of reservoir storage volumes as a function of their surface areas

The estimation of the reservoirs intakes in a large area with rare or no measurement gauges is a challenging task. Many remote sensing sensors can easily (and cheaply) detect the surface covered by water, but a measurement of volume requires more expensive bathymetric surveys. Therefore, in this section we show how the information retrieved by SAR and presented in Section 2 can be used to estimate a relation between surface and volume of a water in a small reservoir, providing a useful technique to estimate the available water in a given area. In the area under observation, a unique area-volume relation may be extrapolated thanks to the homogeneous morphology of the region.

Area–volume relationships are available in literature from both theoretical and empirical methods. Basing on an extensive bathymetrical survey in the Upper East Region of Ghana, in [6] an empirical relationship was obtained.

In our work, we used the DEM extracted from SAR images in order to perform a regression analysis on 5 reservoirs (Laaba, Ouahigouya 1 and 2, Aoérama and Derhogo). Therefore, we achieved the derivation of a new surface-area relationship, which is compared in Fig. 3, with that obtained in [6]. Note that, thanks to the morphologically and morphometrically regularity of the region, area based volume estimation is possible with good approximation,.

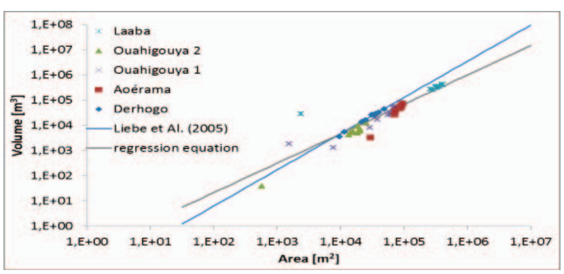


Fig. 3: Reservoir storage volumes as a function of their surface areas

3.2. Rainfall-runoff model

The development of hydrological models is crucial in order to improve the management of the water resources, mainly in contexts where *in situ* measurements are limited. The peculiar context of the semiarid regions of West Africa is characterized by scarcity of environmental data and particularly of hydrological data.

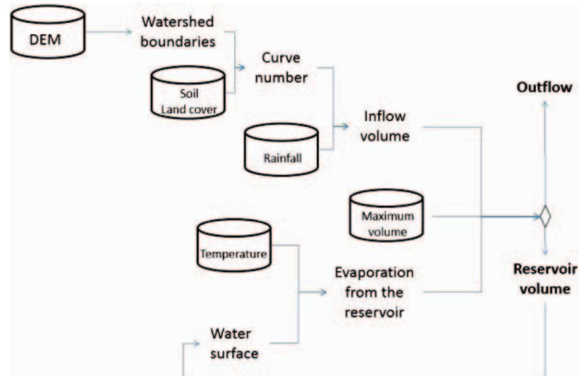


Fig. 4:Block diagram of the hydrologic model

Therefore, it is necessary to improve data availability through the development of cost effective monitoring technics and to adapt hydrological models to the limited available data.

This approach was followed in Ghana in [6], where remote sensing data were used for estimating reservoir sizes over time in order to test a runoff model and characterize runoff processes. Reservoir surface areas were extracted from twelve Envisat advanced synthetic aperture radar (ASAR) images at a spatial resolution of 30 m and reservoir's retention volumes were derived through an empirical relationship.

In this study the reservoir's retention volumes were derived with significantly higher resolution through the methodology described in Section 3, thanks to the availability of Cosmo-Skymed data. We used the Soil Conservation Service Method (SCS), a simple, widely used and calibrated model able to simulate runoff in small ungauged watersheds. The model simulate the depth of runoff as a function of precipitation, potential maximum retention and initial abstraction. The water volumes retained in the reservoirs were modeled, on a daily basis, as a balance between runoff, evapotranspiration and previously stored volumes, until the maximum retention volume of the reservoir is reached. The overall rationale of the approach is described by the block diagram presented in Fig. 4

In Fig. 5 we show a comparison of the reservoirs' retention volumes estimated and those evaluated from SAR for two reservoirs located close to the city of Ouahigouya. The results show a good agreement between the simulated and actual data. A similar agreement was experienced for almost all the studied catchments. The main limits were encountered in big catchments and in presence of multiple water retention basins which reciprocally influence the discharge regime at the outlet.

4. CONCLUSIONS

Coverage, resolution, and revisit time of available SAR systems allow a detailed, continuous and wide observation of the land that deserves to be exploited in regions where *in situ* measurements are impervious and expensive. Despite these potentialities, the diffuse use of SAR data in applicative scenarios is still limited by the lack of image interpretation tools that could help non expert users to exploit the instrument.

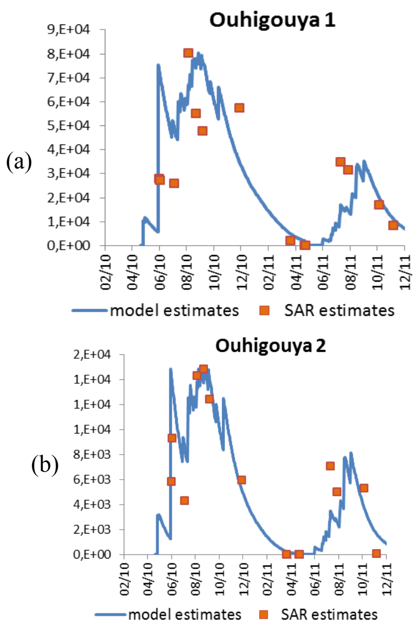


Fig. 5: Comparison between simulated and observed reservoir retention volumes for two basins close to Ouahigouya

In this paper we presented a new multidisciplinary methodology devoted to extract meaningful physical information from SAR data. The obtained information is used to feed appropriate hydrological models applied to the monitoring of small reservoirs in semi-arid regions.

The proposed approach is based on the appropriate processing of a set of Cosmo-Skymed stripmap images, devoted to retrieve the presence, extension and volume of small reservoirs in Burkina Faso.

An interferometric chain allowed to retrieve an estimation of topography and bathymetry of the smallest reservoirs. In addition, a multitemporal despeckling approach supported the extraction of shorelines of the basins of the observed areas.

From the obtained information, two applications were presented concerning the estimation of a relationship between area and volume of water in small reservoirs and the development of a hydrological model for estimating the available water during the year.

The area-volume relationship provides a meaningful information in all applications were only measurements of the water surface are available, which is the case in most of the applicative scenarios concerning remote sensing applications.

The derived model can be used for the optimization of the reservoirs management in order to maximize the benefits in terms of crop production. Another possible application of the model is the estimation of the impact of existing or planned reservoirs on the downstream flow. This information is crucial in case of conflicts between different users of the resource.

6. ACKNOWLEDGMENTS

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