# Monitoring soil erosion and reservoir sedimentation in semi-arid region through remote sensed SAR data: a case study in Yatenga region, Burkina Faso

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Monitoring soil erosion and consequent reservoirs sedimentation is necessary for a proper planning of water and soil conservation measures. Applicability to large scale and cheapness of the monitoring system is crucial for low income countries. The present work proposes a novel approach in which remote sensed SAR and Landsat data are used for monitoring reservoir's sedimentation and for mapping the soil erosion risk at catchment scale. Novel techniques for SAR imagery pre-processing are combined with empirical soil loss estimates. A SAR derived DEM is used to monitor the soil sedimentation rate of small reservoirs. The USLE (Universal Soil Loss Equation) method is used to draw a soil erosion risk map and to roughly estimate the total soil loss at catchment scale.

Keywords: SAR, USLE, erosion, reservoir, semi-arid regions

## 1. Introduction

The Sahel is characterized by extreme hydrologic conditions, with the alternation of intense rainy and long dry seasons. In this climatic context the role of reservoirs is crucial for the local agriculture and livestock: reservoirs capture surface runoff during the rainy season making water available in the dry season. Despite this their storage volumes and, in some cases, even their location are unknown. In the semi-arid Sahel the soils suffer from strong water and wind erosion determining land degradation and facilitating the desertification process. These phenomena have a great impact on land use and agriculture. Another important consequence of soil erosion is the sedimentation of the water reservoirs. As a result of runoff from heavy rainfall, soil particles on the surface of watersheds can be transported through the river system and are eventually deposited in reservoirs. All reservoirs are subject to some degree of sediment inflow and deposition. If the sediment inflow is large relative to the reservoir storage capacity, then the useful life of the reservoir may be very short, unless making costly sediment removal operations. Monitoring methodologies for soil erosion and consequent sedimentation of reservoirs is needed for a proper planning of water and soil conservation measures. Given the peculiar conditions of low income countries, like the studied one, the monitoring system must be employable in wide areas and not expensive. Another problem of peculiar context under study is the lack of data. The present work proposes an approach for the estimation of potential soil loss at catchment scale and for monitoring the consequent sedimentation at reservoirs. The proposed approach is enhanced by the use of remote sensed SAR and LANDSAT data. A set of 16 strip-map and 7 spotlight images with a coverage of almost one year and a half, including two rainy seasons, was considered. The high resolution SAR images were provided at no cost by the Italian Space Agency in the frame of the AO2007 call (Di Martino et al. 2012). 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. Most of the necessary data for the implementation of the method are remote sensed, therefore it can be used easily and at no expense in data scarce environment. A digital elevation model with high resolution was derived by SAR data. Based on the DEM, the soil sedimentation rate of small reservoirs has been estimated. The above mentioned estimations have been compared with the predictions of the USLE (Universal Soil Loss Equation) model (Wischmeier and Smith 1978). The application of the USLE has been performed in a spatially distributed approach, trough GIS tools.

## 2. Case Study

The case study is the catchment close to Laaba, in the north of Burkina Faso, Yatenga district (West Africa). The drained basin has an area of about 15.5 $km^2$ with a mean elevation of 380 m a.s.l. and a mean slope of about 2°. The catchment outlet is a small dam, built in 1989. The climate of the area, typical of sub-sahelian countries, is characterized by a wet season (May to October), with short intense storms, and a dry season (November to April). In the northern part of Burkina Faso, the total seasonal rainfall ranges from 100 to 650 mm. From the agricultural viewpoint, the study area presents arid soils which are in general poor. The soils suffer from water and wind erosion and degradation. The main cultivations are sorghum, millet and cotton.

## 3. Monitoring of reservoir sedimentation

A set of 8 reservoirs, including the one near Laaba, were studied (Amitrano et al. 2013). InSAR algorithms (Rosen et al. 2000) were adopted to extract the digital elevation model (DEM) of the study area. The chosen image pair was acquired at the end of the dry season when the small water reservoirs are expected to be empty and the water capacity is measurable. Such an approach allows to estimate the residual reservoir capacity in the year 2011, that resulted in 572000 $m^3$. Data on the original capacity (602000 $m^3$) and the year of construction (1989) of the reservoir were derived from a database "Base de données sur les ressources en eau" (DGH 1996) written by the Direction Générale de I'Hydraulique (DGH) of Burkina Faso. It resulted that the average annual sedimentation of the reservoir in the period was 1364 $m^3$/year. The catchment drained by the dam is entirely included in the SAR images, therefore it was possible to derive the catchment area (15.5 $km^2$) by elaborating the DEM. Assuming a sediment apparent density of 1,5 $t/m^3$ (Lamachere 2000), it resulted that the sediment trapped by the dam are 1,3 t/ha·year.

## 4. USLE

In the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) the average soil erosion per year (A) [t/ha/yr] is computed from the product of rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), vegetation cover (C) and support practice factor (P):

$$A = R \cdot K \cdot LS \cdot C \cdot P$$

$R$ coefficient is related to the eroding strength of the rainfall and it depends on its energy and intensity. $K$ identifies the ease of soil particle detachment and transport by rain-splash or by surface flow; it depends on soil properties and characteristics (e.g. granulometry, organic matter content, soil structure and hydraulic conductivity); it is usually calculated using the nomograph proposed by Wischmeier and Smith (1978). $LS$ considers how slope and length of the hillslope affect the sediment production; to calculate $LS$ index a GIS-based approach has been implemented (Mitasova et al. 1996). $P$ is associated with soil conservation practices related to agricultural activities. Even though soil conservation measures have been applied for decades by locals in the investigated area, their actual number and influence is considered negligible at catchment scale (Grimaldi et al. 2013), therefore P value is assumed equal to 1 ($P=1$). Factor-C represents the influence of agricultural activities and vegetation covering on erosion rates. $C$ factor maps were generated (De Jong 1994) using the maps of Normalized Difference Vegetation Index *NDVI* (Lillesand et al. 2004). These maps were derived from LANDSAT TM satellite data made available by the USGS (http://earthexplorer.usgs.gov/).

All the assessed parameters are either in spatial format and/or in numerical format. Maps and factors are integrated using USLE formula and analyzed in a GIS environment. As the aim of the proposed methodology is the monitoring of time-dependent processes, a multi-temporal USLE application has been performed; in USLE the time-dependent factors (monthly scale) are R and C.

The rainfall data from 1974 to 2013 of the Ouahigouya gauge station are used to get the R factor (Wischmeier & Smith 1978) (Fig.4.1). Table 4.1 shows type and values assumed for each parameter requested by USLE.

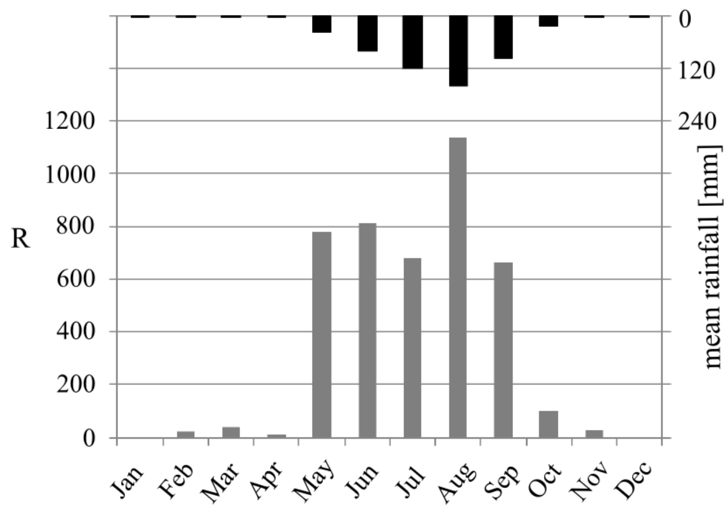


*Fig. 4.1. Mean monthly rainfall [mm] (black bars), and rainfall erosive factor (R) [Mj mm /ha/hr/yr] (grey bars).*

| | ***Units*** | ***Spatial Data Type*** | ***Timely Data Type*** | ***Value*** |
|---|---|---|---|---|
| **R** | MJ mm ha/hr/yr | uniformly distributed | monthly/ annual | 0 ~ 1140 |
| **K** | t hr /MJ mm | uniformly distributed | constant | 0.065 |
| **LS** | -- | distributed | constant | 0 ~ 63 |
| **C** | -- | Distributed | monthly | 0.431 ~ 1 |
| **P** | -- | uniformly distributed | constant | 1 |

*Tab. 4.1 Summary table of the USLE parameters used for the study case.*

The mean annual soil loss (*A*) resulted as about 118 t/ha/year. The catchment has an area of about 1550 ha; thus the mean annual soil loss for Laaba basin is estimated as1.83E+5 t/yr. The Figure 4.2 shows the differences between the results obtained in term of the monthly *A* (for three non-consecutive months) and highlights the different seasonal contributions in soil loss.

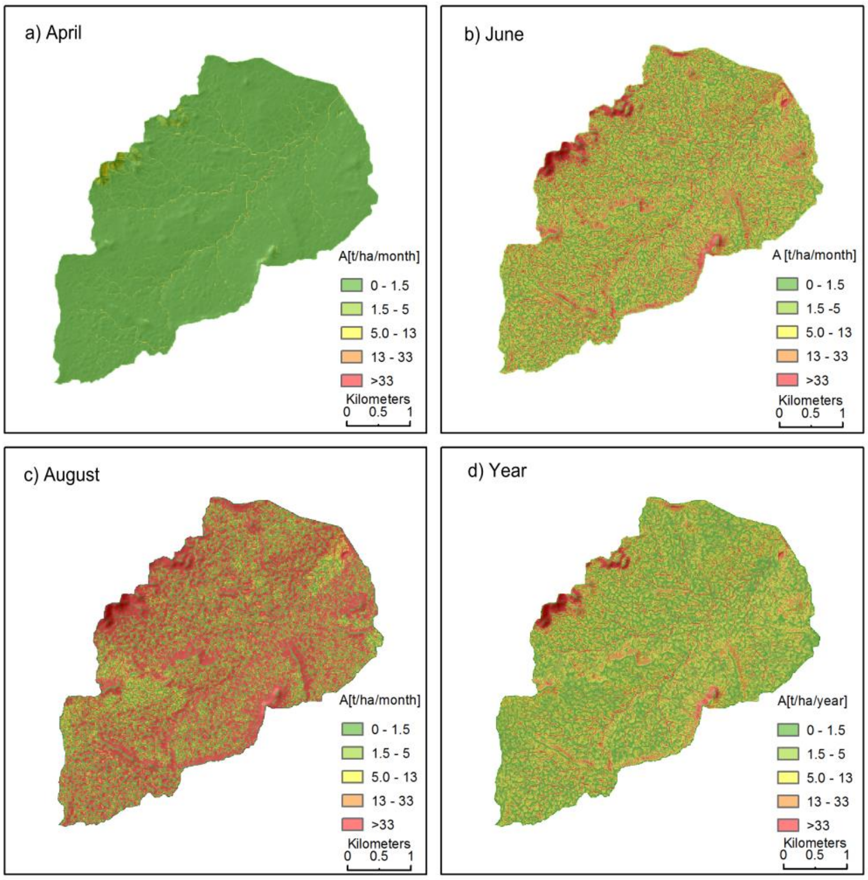


*Fig. 4.2. a),b) and c): mean A rate maps respectively per April, June and August d) mean monthly soil loss rate per year.*

The results reflect the monthly *R* trends and doesn't show considerable effects of the vegetation; this is probably due to the poor-performance of the NDVI for arid region vegetation (Baugh and Groeneveld 2006).

Inconsistencies between the estimates of soil erosion at catchment scale (1.83E+5 t/yr) and the sedimentation rates of the reservoir (2.05E+3 t/yr) (Amitrano et al. 2013) have been observed. This can be explained given that the Laaba reservoir fills up completely after the first rains. For the major part of the rainy season the water discharge overflows the dam. The water volume retained at the

Laaba reservoirs and its time evolution has been monitored with SAR data by Amitrano et Al. (2013).

## 5. Conclusions

The use of remote sensed data allowed for an estimation of the reservoir sedimentation and of the soil erosion susceptibility in a data scarce environment without expensive field campaign. The methods can be simply applied to wide areas.

The monitoring of reservoir sedimentation at regional scale may provide an important input for the water resources management.

Given the simplicity of the modeling approach and the uncertainties linked to the estimation of some of the governing factors, the estimation of soil erosion due to water may be affected by considerable error. Therefore, the method is not suitable for a precise estimation of the total annual soil loss but it can be effectively used to map different grade of susceptibility in wide areas and to prioritize the mitigation measures.

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