Physics and Chemistry of the Earth 34 (2009) 309–315

Contents lists available at ScienceDirect

Physics and Chemistry of the Earth

journal homepage: www.elsevier.com/locate/pce

Delineation of small reservoirs using radar imagery in a semi-arid environment: A case study in the upper east region of Ghana

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ARTICLE INFO

Article history:
Received 28 November 2007
Received in revised form 29 July 2008
Accepted 21 August 2008
Available online 5 September 2008

Keywords:
ENVISAT ASAR
Small reservoirs
Radar
Ghana

ABSTRACT

Small reservoirs serve many people living in semi-arid environments. Water stored in these reservoirs is used to supplement rainfed agriculture, allow for dry season irrigated agriculture and ensure the availability of water for domestic purposes. In order to manage the water effectively for competing uses, the actual storage of these reservoirs needs to be known. Recent attempts to delineate these reservoirs using remote sensing with Landsat imagery have been successful, especially in the upper east region of Ghana, West Africa.

This paper shows that radar images (ENVISAT ASAR) can be used to provide similar information all year-round. Radar images have as an important advantage that they are not impaired by cloud cover and thus can be used during the rainy season. Another advantage of radar images is that images taken during night time are usable. The paper compares satellite derived data with field measurements of 21 small reservoirs. Whereas ENVISAT images on the average tend to overestimate the surface areas of small reservoirs, in certain reservoirs these areas are systematically under-estimated due to the shallow tail-ends of reservoirs that tend to have reed vegetation. These cannot be readily distinguished from the surrounding vegetation outside the reservoirs. This paper therefore provides a proof of concept of the monitoring of small reservoir volumes by radar imagery.

1. Introduction

In periods of drought, the rural population in most semi-arid environments rely heavily on small reservoirs to sustain their livelihoods (Liebe et al., 2005; Poolman et al., 2006; Balazs, 2006; Faulkner et al., 2008). In this context, small reservoirs are defined as reservoirs with surface areas of less than 100 hectares. Water stored in these reservoirs allows for all year-round irrigated agriculture and ensures that domestic water shortages are reduced during dry periods. In order to manage the water effectively for competing uses, the actual storage of these reservoirs need to be accurately estimated. Landsat imagery has been used recently to delineate some of the reservoirs in the upper east region (UER) of Ghana, West Africa (Liebe et al., 2005), Zimbabwe (Sawunyama et al., 2005) and India (Mialhe et al., 2008). The accuracy of the lateral delineation of these reservoirs with Landsat was very good. However, Landsat images and images obtained from similar optical sensors are affected by cloud cover especially during the rainy season (Van de Giesen, 2000; Xu et al., 2004; Liebe et al., 2005).

This research focuses on how radar images from the ENVISAT advanced synthetic aperture radar (ENVISAT ASAR) can be used to provide all year-round monitoring. Radar has two important advantages relevant for this study, namely that it is independent of cloud cover (Horritt and Mason, 2001; Herold et al., 2004) and that observations can be made during night time. The goal of this research is to use radar imagery to quantify the actual volume of water stored in reservoirs, partially to overcome the fact that there is limited availability of ground data. This information may be used to enhance decision making especially for irrigation scheduling and water allocation in Ghana.

2. Description of the study area

The upper east region (UER), shown in Fig. 1, covers about 3.7% (8842 sq kms) of the landmass of Ghana. Rainfall over the past 40 years has averaged 1044 mm/a which is suitable for a single wet season crop (IFAD, 2007). Mean annual temperature of 28 °C. The mean annual rate of pan evaporation is 2540 mm/a (Gyau-Boakye and Tumbulto, 2006). The upper east region has a mean population

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doi:10.1016/j.pce.2008.08.005

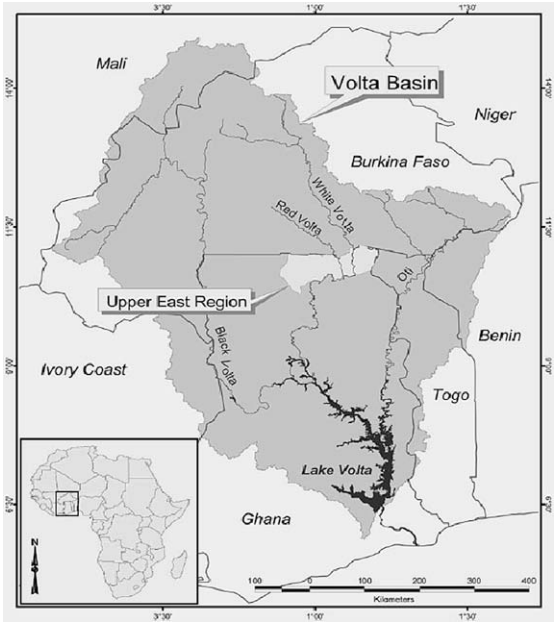

Fig. 1. The upper east region of Ghana within the Volta Basin (Adapted from Liebe et al., 2005).

density of 125 inhabitants/km^2 (IFAD, 2007). Crop and livestock farming is the main economic activity. The natural land cover is an open park savannah of grass with scattered trees. Presently, most of the UER is cultivated. Crops include rice, maize, millet, sorghum and vegetables. Access to water for livestock, fishery, irrigation and domestic uses during the dry season is a major concern for the population.

The Ghana poverty reduction strategy paper (GPRSP, 2005) identifies northern Ghana as the number one poverty endemic area in Ghana. In 1986, it was estimated that 67% of small holders (those farming less than 1.6 ha and in the UER 2.4 ha) in Ghana were living in poverty (IFAD, 2007). This was a major justification for the government in 1998 to launch a land conservation and smallholder rehabilitation project (LACOSREP) that would provide farm families with adequate supplies of irrigation water. The rehabilitation of existing small dams or reservoirs and the formation and strengthening of water users associations are key activities of this programme.

In the UER the wet period is relatively short and is further marked by variations in arrival time, duration and intensity of rainfall. This creates inter-year variations in agricultural production potential (IFAD, 2007). In turn, this explains the reliance of smallholder farmers on small reservoirs which often is the only source of water available for dry-season crops.

Accurate estimation of the actual volume of water stored in reservoirs at regular time intervals (e.g. monthly) is important for effective planning and management. Knowledge of the storage volume would enable the relevant agencies, including the irrigation development authority (IDA) and the ministry of food and agriculture (MOFA), to advise farmers on the type of crops to grow. Most of the reservoirs in the UER were built by different agencies and are mainly managed by MOFA, IDA and the district assemblies. These institutions find it difficult to continuously monitor the status of these small reservoirs due to lack of resources and inadequate human capacity. Their reliance on ground surveys to estimate actual storage volumes turns out to be time-consuming and prohibitively expensive and hence the institutions are unable to monitor the storage in the reservoirs themselves. This research demonstrates the possibility of monitoring water storage in small reservoirs all year round by remote sensing using satellite imagery from ENVISAT ASAR.

3. Materials and methods

3.1. Delineation of reservoirs by remote sensing using passive and active sensors

The infrared, visible red and near-infrared bands found in Landsat/TM and similar satellite imagery is used to distinguish between land and water and map the extent of open water surface (Toyra et al., 2002; Liebe et al., 2005). In Landsat ETM+, bands 4–7 (infrared) are used to distinguish between water and vegetation. Water, when not turbulent, absorbs energy in the near-infrared and infrared wavelengths hence appear darker in the imagery whereas land and vegetation are seen as bright spots. The techniques used for the delineation of open water range from visual interpretation by density slicing and band–ratio-approaches such as the normalised difference water index (NDWI) to different methods of supervised and unsupervised classification (Liebe, 2002).

As mentioned earlier on, cloud cover and the presence of reeds and other suspended organic and inorganic materials on the surface of reservoirs makes it difficult to distinguish between land and water using Landsat. This suggests the use of ENVISAT ASAR imagery, which is weather independent, as a possible alternative for, or complement to, Landsat imagery.

ENVISAT ASAR is a follow up of ERS-1 and ERS-2 satellites. It is on board the ENVISAT satellite which is operated by the European Space Agency (ESA) and was launched from Kourou in French Guiana on 1st March, 2002. The ENVISAT ASAR uses the C-band (5.331 GHz). Outgoing and incoming signals can be like-polarized; both horizontal (HH) or both vertical (VV). Alternatively, outgoing and incoming signals can be cross-polarized (VH or HV). ENVISAT can be programmed to acquire images in dual-polarization mode. In that case, scenes can be imaged simultaneously with two of the possible polarization combinations. For this study, we used dual polarization mode as this mode was anticipated to have advantages over single polarized images. ENVISAT ASAR has a temporal resolution of 35 days and a spatial resolution of 30 m.

3.2. Lateral delineation of reservoirs

For this research, six ENVISAT SLC alternating polarization mode data were acquired in the framework of ESA's Tiger program. The description of the data is given in Table 1. In this study, the magnitude of the polarization channels (C-HH and C-HV) was used for the classification of land and water. The channels were also combined to study their ability to enhance the land/water contrast in the images.

The single look complex (SLC) images were imported into ERDAS Imagine software. Radar images often have lots of speckles or noise; this was reduced with the gamma-map filter (Fig. 2). Many filters like Lee, Lee-Sigma and Frost assume that the noise is Gaussian distributed. Studies conducted recently especially on natural vegetated areas have proven that a gamma distribution is

Table 1
Description of Envisat ASAR data used to develop the model

No	Product	Swath	Date	Resolution (m)
1	ASA_APH	I1	6/1/07	12
2	ASA_APH	I4	9/1/07	10
3	ASA_APH	I1	22/1/07	12
4	ASA_APH	I2	25/1/07	11
5	ASA_APH	I4	28/1/07	10
6	ASA_APH	I7	31/1/07	7.5