Identification of Seasonally Flooded Areas in North Gujarat Using Radar Satellite Imagery: Implications for Archaeology

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**Abstract:** This research aims at exploring the potential of ENVISAT ASAR satellite data for understanding surface and near-surface water dynamics in the semi-arid archaeological landscape of North Gujarat (India). Research is done within the framework of an explorative Earth Observation project proposal from the European Space Agency (ESA E0PI) with the collaboration of the North Gujarat Archaeological Project (NoGAP) and the Active Remote Sensing Unit from the Institute of Geomatics (Barcelona, Catalonia). The amplitude component of multi-temporal ASAR C-band Single Look Complex (SLC) images from pre-monsoon, monsoon and post-monsoon seasons have been used. The mean extent of floodable areas has been estimated by comparing the mean amplitude of seasonal periods. The integration of SAR data and gearchaeological data has provided new insights to understand present-day landscape dynamics affecting archaeological preservation and visibility. Furthermore, preliminary results suggest a good correlation between Mid-Holocene settlement patterns and the distribution and extension of seasonal floodable areas, opening interesting inroads to study settlement distribution and resource availability in past socio-ecological systems.

**Keywords:** Monsoon, Hydrology, SAR, Remote Sensing, North Gujarat, Settlements, landscape Dynamics

**Introduction**
In the last 20 years, the alluvial plains of N. Gujarat have been the object of an intensive
survey program conducted by several research teams coordinated by the MS University of Baroda (see Seth et al. 2007 for the Indus Project, and Madella et al. 2010 for the North Gujarat Archaeological Project - NoGAP). These explorations revealed more than 170 archaeological sites and surface scatters belonging to, at least, three economic groups, with varying degrees of resilience and adaptability: hunter-gatherers, agro-pastoral people and Harappan urban/village groups. Many of these scatters are identified on the basis of the presence/absence of archaeological materials such as microliths, grinding stones, animal bones and pottery. The scatters are generally found on the top and/or higher slopes of fossilized sand dunes, in close relation to the seasonal rivers or monsoon-flooded depressions (Ajithprasad, 2004; Sonawane, 2004). Within the framework of the NoGAP project, satellite images have been used to expand at the regional level the field observations patterns (location of well-preserved dunes) and to direct field surveys (Balbo et al. 2013a).

Here we present an explorative remote sensing approach that uses multi temporal series of Synthetic Aperture Radar (SAR) images for detecting seasonal flooded areas (e.g. interdunes and tanks), soil moisture (e.g. paleochannels) and dry areas (e.g. villages or fossilized dunes) in the alluvial plains of N. Gujarat. This preliminary approach has two fundamental, interconnected archaeological aims focused on 1) improving our understanding of present-day landscape dynamics affecting archaeological preservation and visibility; and 2) opening new perspectives for the study of past settlement distribution and resource availability.

Regional Context

North Gujarat in north-western India is a sensitive, monsoonal-dependent, semi-arid region between the arid Thar Desert and the more humid Saurashtra (Fig. 1). Indian summer monsoon (ISM) patterns cause significant variations in seasonal precipitation at the regional and local level. Extreme climatic shifts can generate severe droughts or floods affecting resource availability. Current palaeoclimatic models suggest monsoonal stability throughout the mid-Holocene (Balbo et al. 2013b).

Fossilized sand dunes and interdunal areas, which can become seasonal lakes during the monsoon and post-monsoon season, characterize the regional geomorphology. This landscape is highly influenced by the ISM regional patterns and the tectonic implications of the Cambay palaeorift basin, as it was through the Holocene (Khadkikar et al. 1999; Chamyal et al. 2003; Jain and Tandon, 2003; Juyal et al. 2003). The West Cambay Basin Margin Fault defines a pedological and morphological change in the landscape. The fault divides an area to the SW of well-defined stabilised dunes (called dune/interdune area) from an area to the NE of less prominent, partially eroded dunes where the interdunal deposition is more active (called silt belt, see also Balbo et al. 2013a for more details) (Fig. 2-3).

Synthetic Aperture Radar: New Perspectives

Optical satellite imagery has become a mainstream tool for understanding
archaeological landscapes with increasingly improved data quality and acquisition facilities (Lasaponara and Masini, 2011). However, multispectral imagery is often of limited availability due to on-demand cover and excessive cost for high resolution data. In this monsoonal environment, optical imagery such as the common LANDSAT, ASTER or LISS III sensors cannot be used to monitoring temporal year-series of water distribution due to the high coverage of clouds in monsoonal images.

Conversely, SAR images have a significant role to play in monsoonal semi-arid archaeological landscapes due to its independence from cloud cover. In recent times, archaeologists have shown SAR manifold potential applications in semi-arid environments (Holcomb and Shingiray, 2007; Cigna et al. 2013; Lasaponara and Masini, 2013). In spite of this, radar imagery has been largely unadvertised for archaeologists working in the alluvial and fluvial plains of northwestern India. In Gujarat in particular, ENVISAT and ASAR data have been recently used for monitoring forest and soil moisture cover (Ponnurangam and Rao, 2011; Nizalapur, 2012), although little has been done to relate present-day monsoonal dynamics (which are considered to have been rather constant over the Holocene) to past settlement dynamics and resource exploitation strategies.

![Figure 1](image-url)  
Figure 1: Location map of the study area within N. Gujarat. Map shows: (i) climatic zones and regional isohyets, (ii) maximum fossil extent of Thar Desert, (iii) flood prone areas (grey shading along river basin areas).
Figure 2 a: LANDSAT TM5 (23 Jan 2000) false colour composite (4-3-2) showing NoGAP research area. 2 b) regional slope gradient (SRTM v2)

Figure 3: ASTER (02 Oct 2004) false colour composite (3N-2-1) showing the dune/interdune area with the Khari River and the archaeological scatters of Loteshwar and VaharvoTmbo.
Methods

Radar backscattering offers the best performance for detecting water bodies and soil moisture. Here we use a direct backscatter threshold extraction for a set of six ENVISAT ASAR images (ascending mode) acquired between 13 October 2004 and 16 December 2009 (Fig. 4). Images were co-registered to a selected master scene (the six images were put on the same geometry). The amplitude component of the radar backscattering was obtained from each scene. A multilook 5x1 factor in slant range coordinates was applied using ENVI 4.5 software to reduce radar speckle. Single scenes were used to extract the mean amplitudes (MA) for monsoonal (M) and post-monsoonal (PM) seasons. A single ascending scene represents the amplitude for the dry (D) season (Fig. 5).

For each period, three significant subsets (Fig. 6) of the dune/interdune (DI), the Khari River (Kr) and the dune/silt belt (DS) areas have been tested.

MA images and single scenes were equalized by dividing MA values by the mean value of a supervised MA flooded area (water content) to increase the differences between flooded and dry areas. MA images were filtered using a Frost 3x1 Filter to reduce speckle (Wang et al. 2012) (Fig. 7).

A threshold supervised classification was used in each single and MA images to classify the amplitude component into three land cover types (1=water; 2=soil moisture; 3=dry soil) (Fig. 8-9) to simplify post-classification statistics.
Figure 5: Multilook equalized scenes and MA seasonal images (Nc: Narmada canal)

Figure 6: ASTER (02 Oct 2004) false colour composite (3N-2-1) showing subset areas (DI: dune/interdune; KR: Khari River; DS: dune/silt belt)
First Results
For the first time in NW India, ENVISAT ASAR images provide a complete sequence showing differential seasonal water retention in soil and water bodies of a monsoonal semi-arid area. This draws attention to the on the ground effects of the high precipitation variance that is recorded in the region during the year (dry versus wet season). Fig. 4 shows that the selected images represent normal monsoonal events, which are representative for addressing long-term observations.

In the monsoonal period flooded interdunal fields (lower lands) and riverbeds appear as water bodies, and tanks and lakes have their maximum extension (see Fig. 8). Other cultivated fields show abundant soil moisture but not water logging. Dunes and present-day villages appear as dry areas, because of their elevation. In the post-monsoonal period, the water from in cultivated interdunal fields becomes extremely reduced. During the dry season, water bodies are reduced to the village water tanks and perennial lakes. Interestingly, the water that was retained in the soils of the silt belt during the monsoon starts to migrate towards the river network and it becomes evident in the water table of the fields within the ephemeral river basin areas. This change is also seen using a colour range image (Figure 9), which shows soil moisture retention in the areas located above the 40m asl, while the dune-interdune areas (located below this line) show loss of water due to evaporation and mechanical water extraction.

Discussion
ASAR analysis confirms that in North Gujarat (a monsoonal and tectonic dominated environment(Balbo et al. 2013a) there are active morphogenetic process affecting pedological conditions and water distribution (Fig. 8-9).
The separation between the area of dune-interdune and the silt belt fields is marked by a conspicuous difference in sediment characteristics along the 40m asl contour line, which follows the West Cambay tectonic fault.

Figure 8: Khari River subset area. Application of supervised threshold classification in amplitude single scenes from monsoon (13 Sep 2006), post-monsoon (13 Oct 2004) and dry season (04 Feb 2009).
Rift and underwater reservoirs in the silt-belt are richer possibly due to subsiding tectonics and soils’ characteristics (silt-sized sediments). The silt-belt sustains more intensive agriculture and consequently higher erosional processes that affect the archaeological preservation of Holocene sites. Areas SW of the fault line are characterized by well-preserved sand dunes that remain dry throughout the year, together with the seasonally flooded fields representing the interdunal areas. The main watercourses of the study area (West Banas, Saraswati, Rupen and Khari) discharge...
their water into the Little Rann. These rivers have frequent avulsions flooding the well-defined palaeochannels. Although the main discharge of these rivers happens during the monsoon, amplitude response in post-monsoon suggests abundant water retention/acquisition in the water table (rise). This dynamic (seasonal and sedimentological) of the water discharge and retention is probably one of the variables behind the historical patterns of landscape exploitation by hunter-gatherers and farmers. Indeed, the archaeological evidence shows an occupation of the drier areas (dune’s top, e.g. Loteshwar or Vaharvo Timbo) nearby areas with higher water retention (e.g. interdunes, lakes, riverbeds) potentially representing resources-rich spots.

**Future Perspectives**

Our results represent an initial step for furthering the archaeological use of ASAR data. Next developments will integrate more ENVISAT ASAR images to provide more robust Mean Amplitude (MA) statistics. Images are going to be geocoded to allow in-depth analysis of monsoonal dynamics for our study area. Future works will also explore the impact of groundwater irrigation (wells) and canal irrigation (e.g. Narmada canal) in the observed land-cover patterns of seasonally available surface water.

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**References**


