The WISDOM Project – A Water-related Information System for the Mekong Delta, Vietnam: first results of remote sensing

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Abstract

The Mekong Delta in Vietnam offers natural resources for several million inhabitants. However, a strong population increase, changing climatic conditions and regulatory measures at the upper reaches of the Mekong lead to severe changes in the Delta. Extreme flood events occur more frequently, drinking water availability is increasingly limited, soils show signs of salinization or acidification, species and complete habitats diminish.

Integrated resource management is required to face these problems. Therefore, detailed knowledge on hydrologic,-, hydraulic-, ecologic-, and sociologic factors must be available Furthermore, the cooperation of national institutes as well as national, regional and local authorities needs to be strengthened.

Aim of the WISDOM project is to design and implement an Information System for the Mekong Delta, based on a standard oriented modular software and hardware architecture comprising a data entry portal, automatic data ingestion, standardized spatial data infrastructures, a processing environment, and visualization-, query-, and analysis module. Key aspects are the derivation and integration of geodata derived as products from e.g. remotely sensed products further dealing as input to hydrologic modelling. The first demonstration unit of this Information System will be presented in detail. All results will be discussed within the context of further expected results and the user requirements of the Vietnamese partners.

This paper presents the first results of the WISDOM project from the field of remote sensing. The derivation of flood information is one crucial activity for the analysis of the Mekong habitats and livelihoods. Water masks are frequently being derived for the projects three major study areas within the Mekong Delta: Can Tho province, Tam Nong district and Tra Cu district.

Using TerraSAR-X data at 3m resolution over Cao Lanh Region in Tam Nong district from both, the rain and dry season, watermasks were derived representing the distribution of surface water. Products were derived automatically following a threshold-based image classification approach. Furthermore change detection has been performed giving quantitative information about change intensity and with that flood severity. The resulting datasets, along with digital elevation models, and hydro-meteorological data will be used as input for hydraulic model development and adjustment for flood prediction and forecast. The complete automatic process chain from TerraSAR-X product generation to hydrologic modelling and flood forecasting will be one key element of the WISDOM Information System.

Keywords: WISDOM, Vietnam, Mekong Delta, Information System, Remote Sensing, Flooding

1 Introduction

The Mekong River, with a length of more than 4800 km is one of the longest rivers in Asia. With its catchment of about 800.000 km² it is among the largest river in the world. Originating in Tibet it crosses China, Laos, Thailand, and finally splits up in Cambodia into three parts with one branch, the Tonle Sap, flowing into the Tonle Sap lake, and two branches, the Bassac and the lower Mekong flowing south into Vietnam. During the Monsoon season the river regularly overflows its banks in the lower Mekong area, usually with beneficial effects. However, extreme flood events occur more frequently causing extensive damage, on the average once every 6 to 10 years river flood levels exceed the critical beneficial level (Plate, 2007). Besides, strong population increase, pesticide use in rice farming (Huan *et al.*, 1999; Berg, 2001), changing climatic conditions and regulatory measures at the upper reaches of the Mekong lead to severe changes in the Delta. Drinking water is contaminated (Buschmann *et al.*, *In Press*), the availability of clean water is increasingly limited, soils show signs of salinization or acidification (Husson *et al.*, 2000), species and complete habitats diminish. All these problems call for an optimized, integrated resource management (Plate, 2007).

It is the goal of WISDOM (http://wisdom.caf.dlr.de) to jointly (Vietnamese and German partners) design and implement an Information System for the Mekong Delta containing information from the fields of hydrology, sociology, information technology, and earth observation. The bilateral German-Vietnamese project is tailored to facilitate a multidisciplinary approach linking both, earth sciences with social sciences and vice versa. Therefore the project is structured in goal-oriented work packages each of them executed by scientific experts at institutions from both sides, Germany and Vietnam. The scientific work packages include:

1. Knowledge Management,
2. Information System Architecture Design,
3. Water Resources, River System and Water Related Hazards,
4. Water Knowledge and Livelihoods,
5. Data Integration and Remotely Sensed Products,
6. Capacity Building.

The integration of results from all these work packages will enable the end-user of the system to perform analyses on very specific questions; and thus will supply the end-user with a tool supporting regional planning activities.

The design of the system puts the focus on the constant integration of available and newly generated data from all different disciplines. This enables user-oriented analyses and custom designed querying to develop sustainable solutions in the field of resource management. Possible applications of the system are:

- Monitoring of floods and droughts
- Evaluation of flood and drought risk, damage potential and actual damages
- Analyses of water quality, pollution and sediment load
- The improvement of flood prediction via remotely sensed precipitation information
- Detailed adaptation of surface and sub-surface discharge models
- Information of landcover- and landuse changes
- Observation of settlement development, surface sealing and population growth

A thorough integration of natural and social sciences is of utmost importance for the development of the Water Information System, since it has to depict not only changes of the natural sciences- or bio-physical field affecting the water household, but also changes of socio-economic processes affecting the people living in the Mekong Delta.
The Information System is a software-architecture, which allows to feed in data of any kind (remote sensing data, GIS data, digital maps, in-situ data, interpolated point measurements etc,), to organize and maintain this data and – most important – to query the data in a problem-oriented way. An Information System thus consist of a data entry portal, a database in which the data is stored and organized, a visualization tool to display the data and a query mask, which allows for sophisticated analyses with respect to a certain question. One example: the database contains flood masks, which were derived from remote sensing data. Furthermore, the database contains a landcover/landuse classification of the same region. A query that could be performed now is e.g.: How much of the agriculturally used land has been flooded? Or: How many percent of the settled area were affected?
With this paper first remote sensing results within the WISDOM project are introduced.

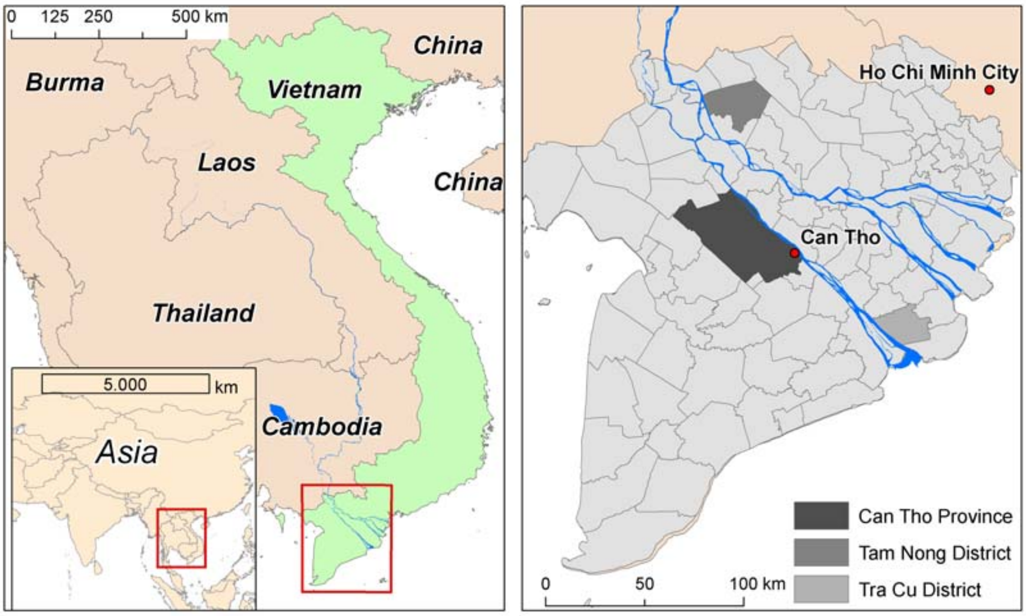

Figure 1: Working areas of the WISDOM project in the Mekong Delta, Vietnam

2 Study areas

From upstream to downstream of Mekong River within Mekong Delta, three case study sites have been chosen representing for the main characteristics of Mekong Delta (Figure 1). The areas are: the Can Tho province, the Tam Nong district, and the Tra Cu district. Can Tho city, regarded as "Western capital", with an estimated population of 1.121.000 as of 2004, is the biggest city in the Mekong Delta. The city is located on the south bank of Hau River, the bigger branch of the Mekong River. It is 169 km from Hồ Chí Minh City, Vietnam’s largest city. The cities and its vicinities characteristics relevant for the WISDOM research topics are increasing urbanisation, immigration, presence of Khmer ethnics, average innundated area, rice production, aquaculture, pig, and poultry production, and pesticide usage for rice production. The Tam Nong district in the Dong Thap province is situated in the north-western part of the Mekong Delta also referred to as "Plain of Reeds". It is characterized by regularly deep inundated areas in the rainy season, major rice production, presence of social minorities and poverty, plans for immigration settlements. Tra Cu district in the Tra Vinh province is situated in the eastern part of the Mekong Delta and is heavily influenced by the effects of rainy and dry season.

3 Materials and methods

3.1 Satellite data

Radar remote sensing data are well suited to tropical wetland ecosystems monitoring, because of the all-weather capability of Synthetic Aperture Radar (SAR) systems, and because SAR data are sensitive to biomass and the structure of flooded vegetation (Martinez and Le Toan, 2007). SAR remote sensing records reflections or backscatter from Earth in the microwave part of the spectrum. The return signal sensed by the satellite is controlled by several factors: depression angle (or orientation) of the sensor to the surface, composition of the materials being sensed, surface roughness and topography, and the frequency and polarization of the microwave signal (Townsend and Walsh, 1998). In general, radar backscatter returns are lower over inundated canopy free areas.

The Terra SAR-X satellite was launched on June 15th, 2007, from Baikonur, Ukraine with a Dnjepr-1 launcher in a 514 km dawn–dusk orbit. The 1023 kg satellite delivers X-Band SAR data in various modes. The Spot-Light mode will yield the finest resolution data with about 1m pixel size for a 10 km × 10 km image. The Strip-Map mode enables images at 3m resolution at 30 km swath. The ScanSAR mode delivers 16m resolution at 100 km swath. All imaging modes offer a full polarization capability (Schreier *et al.*, *In Press*). Two Strip-Map images over Cao Lanh Region in Tam Nong district were acquired for October 20th in 2007 and January 05th in 2008 with the first image in the rainy season and the latter in the dry season (Figure 2).

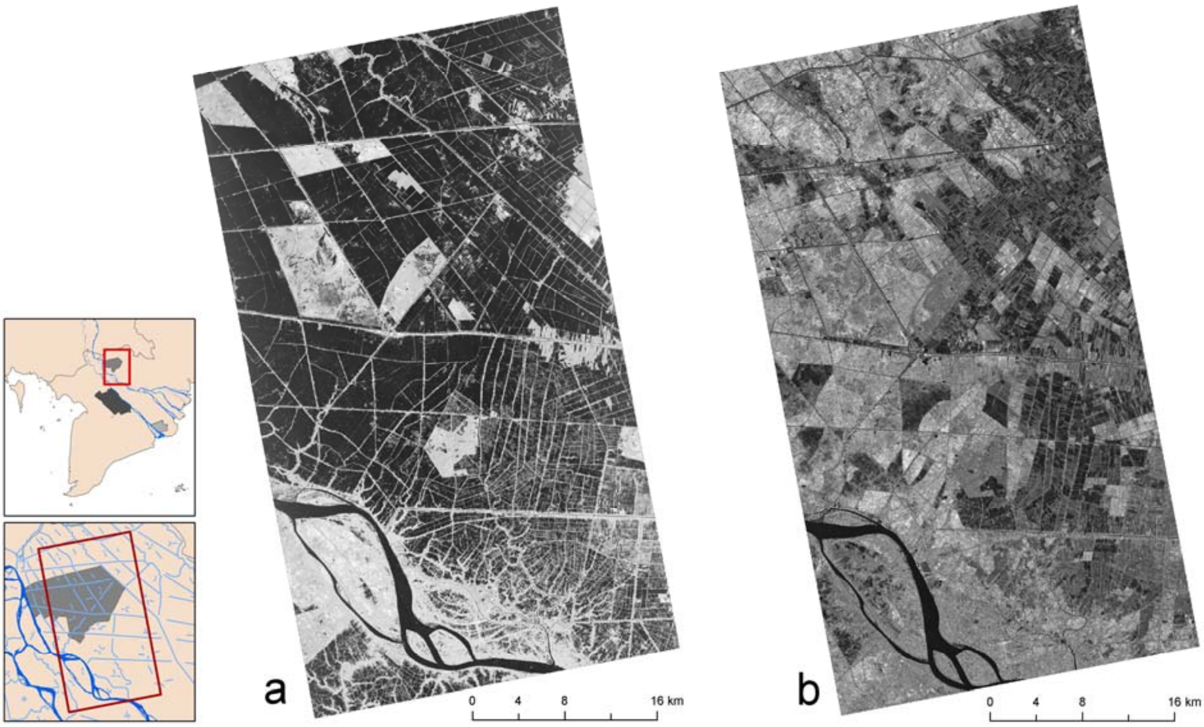

Figure 2: Terra SAR-X images from October 20th in 2007 (a) in the rainy season and January 5th in 2008 (b), dry season

3.2 Derivation of watermasks

Figure 2 demonstrates the outstanding differences in inundation of the presented are between the rainy season (a) and the dry season (b). Dark regions in the October image mainly represent flooded rice paddies, while light areas represent areas, which are not inundated such as elevated river banks, dams, roads, and fields at higher elevation. In figure 2b darker areas represent relatively wet areas, however only few limited areas are still flooded, probably flooded paddies due to rice cropping management system. A common approach for deriving so called water-masks from SAR images is a threshold based image classifier. The methodology used in the presented analysis is following such an approach, developed by the radar group of the German Remote Sensing Data Center of the German Aerospace Center. A main problem for SAR image interpretation and classification is the Speckle effect, due to the coherent interference of waves reflected from many elementary scatterers, yielding in a noisy salt and pepper effect in the SAR images. Various techniques to filter speckle noise have been developed, e.g. the Frost- or the Lee filter, however, another simple approach is using standard convolution filtering (e.g. median filter). With the used algorithm median filtering is performed on the input image in a first processing step. Based on the filtered image thresholding is applied to separate water- from the non-water pixels in the image resulting in a binary. The respective backscatter threshold was derived empirically. Afterwards morphological image closing is performed on the resulting binary image which is an image dilation followed by an erosion. Additionally the minimum size for islands and lakes is defined and according to these two values islands and lakes are removed. The result is then stored to raster file.

3.3 Change detection

A normalized change index *(NCI)* was calculated as

$$NCI = \frac{BS_2 - BS_1}{BS_2 + BS_1},$$

where BS_1 and BS_2 are the backscatter signals (pixel values) in the SAR images from October 2007 and January 2008, respectively. NCI ranges from -1 to 1 with zero values showing no change. Values towards to 1 depict increasing backscatter signals from October to January and hence indicate flooded pixels in the October image. The higher the index value the stronger the change (flood). Using the calculated *NCI* image a false colour composite was generated.

3.4 Land cover classification

To classify a satellite data set, so-called “training areas,” which represent a certain land cover class, need to be provided to the classification algorithm. Areas of a specific land cover class were mapped so as to be highly representative for a spectral class, to be representative for the variance within an object class, to contain an appropriate number of pixels, and finally not to contain pixels of other adjacent classes. The principle was adopted that the minimum number of pixels in a training area should exceed 10 *n*, where *n* is the number of bands of the satellite image (Richards, 1986; Congalton, 1991). A Landsat scene of the Mekong area was classified into 10 major classes as presented in Figure 6 (here only 6 are visible). All available bands were used as input channels. The maximum likelihood algorithm applied belongs to the class of parametric classifiers, assuming that the data are distributed according to a previously defined probability model whose parameters are derived automatically through the statistics of the input training data. The final images were majority filtered with a 3 x 3 matrix to exclude single scattered misclassified pixels and to smooth the overall appearance of the classification results.

4 Results

The derived watermasks from both Terra SAR-X images are shown in Figure 3 a and b. The images depict the strong changes, which occur in the Mekong Delta between the rainy season and the dry season. During the rainy season nearly the complete agricultural are is inundated with water. Only higher elevated fields as well as the dams and most roads alongside the river and major canals are still dry. During the dry season one of the nine main arms of the Mekong as well as large and small canals were extracted as water. The same applies for some inundated fields, which are irrigated rice paddies. The next step planned for remote sensing analyses is now the evaluation of a Terra SAR-X time series with bi-monthly images over a complete year. Water masks derived at such frequent intervals will allow for a very detailed visulization of the development of the flooded area and subsequent drying.

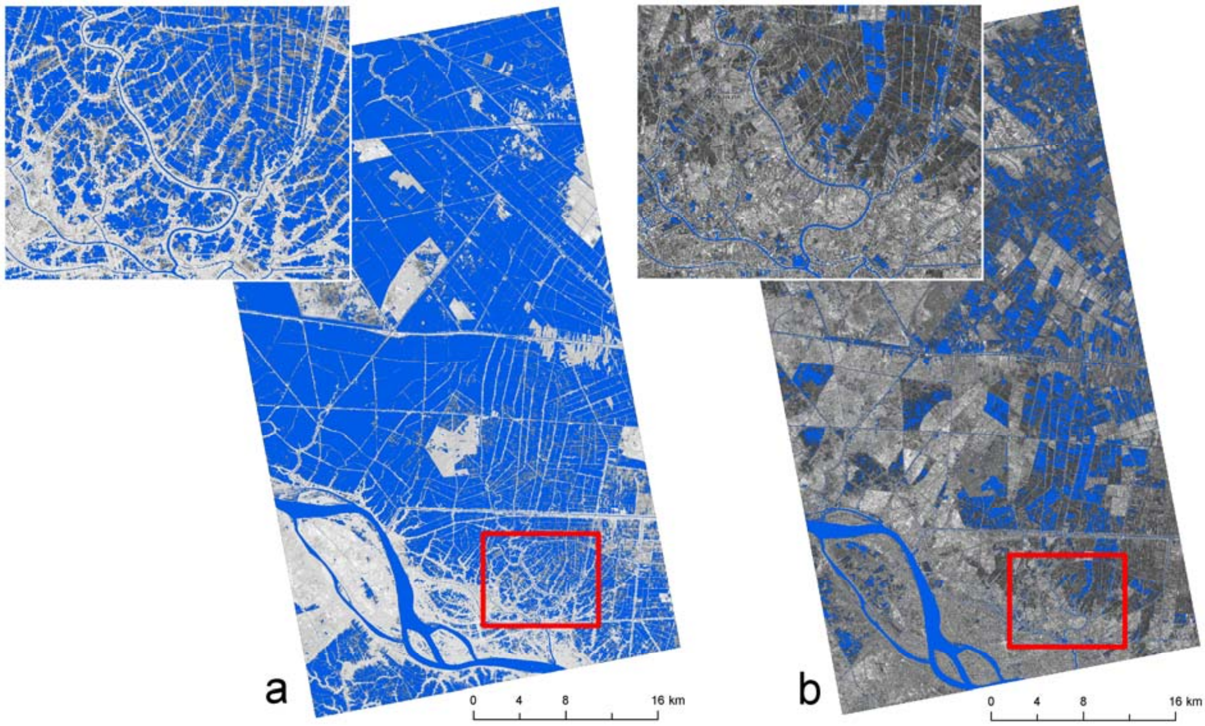

Figure 3: The SAR images from October 20th 2007 (a) and January 5th 2008 (b) superimposed with the derived watermasks. The zoomed images show the high detail of the sensor and the derived results and the rate of change in both images.

Based on equation one, Figure 5 presents the results of the normalized change index image (TSX October 2007 - TSX January 2008) as a false colour image. The figure presents a three channel image, where the red green and blue bands are occupied following: Red: Index Band (-1 to 1), Blue: October image, Green: January image. In this visualization scheme blue areas are regions, which are always covered with water (the river and fields which are flooded in the rainy as well as in the dry season. Reddish tones indicate areas with strong change between the rainy and the dry season – the more intense and pure the reddish colour the stronger the change. Violet colours (mix between red and blue) are parcels with less dominant change (so fields which are a little wetter but not inundated in the dry season. White areas (even mix of all three colours) are regions, which are always dry (no change, but dry) – such as canal embankments, roads, higher elevated fields etc.

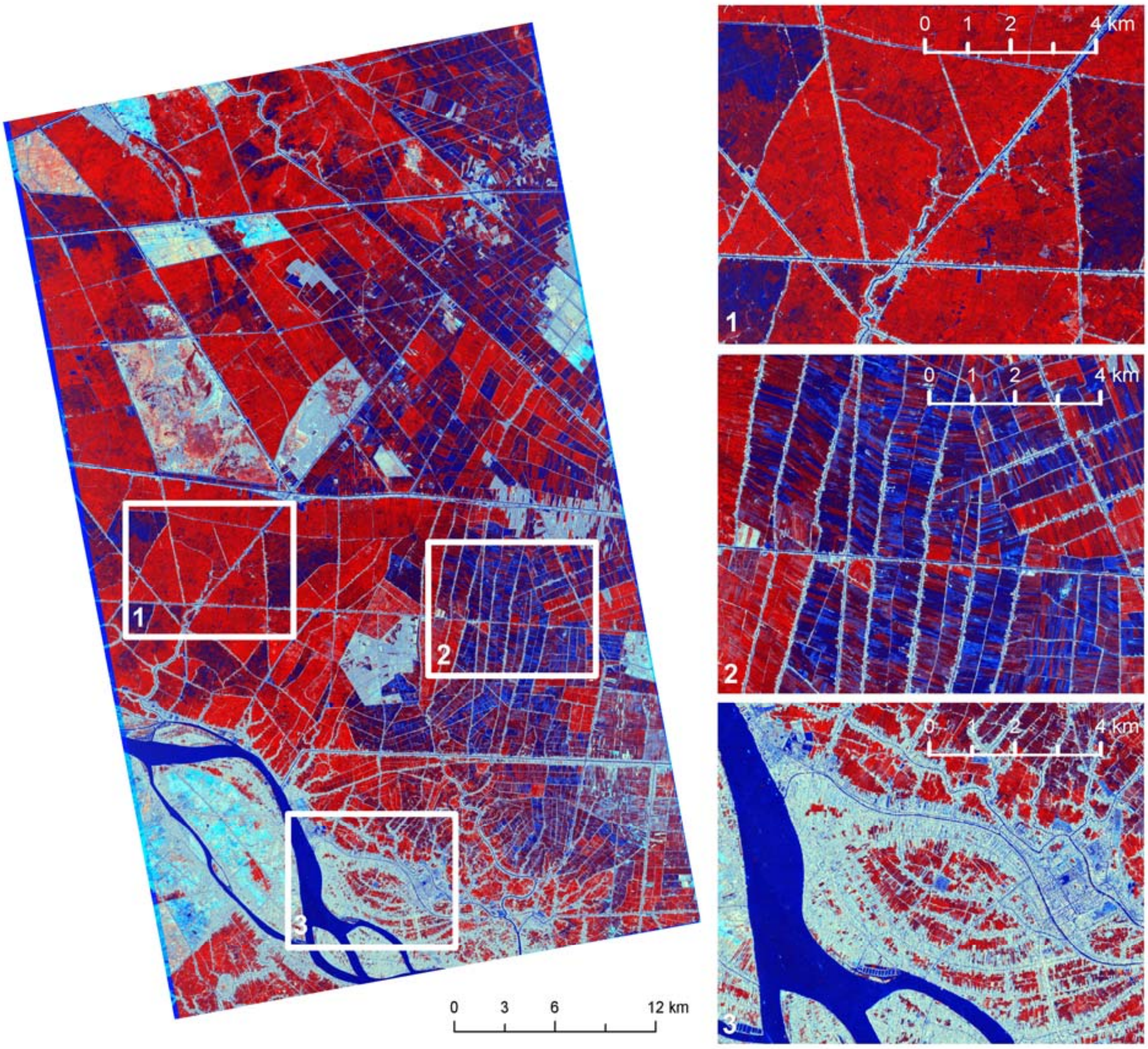

Figure 4: False colour composite (red-green-blue: normalized change index image-TSX October 2007-TSX January 2008)

Figure 6 shows the result of a supervised landcover classification derived from a Landsat-7 ETM+ data set. Within the subset the classes deep water, shallow water, wet bare soil, a mix of water and vegetation, pure vegetation and clouds were differentiated. Landcover classifications can be derived from multiple sources of remote sensing data at different scale – e.g. here from Landsat at a pixel resolution of 30m, but within the project also object oriented landcover and landuse products derived from high resolution data such as Quickbird or Ikonos (60cm to 1m) are envisaged. The intersection of watermasks (during flood season) and landcover allows to visualise which crop types were affected by flooding.

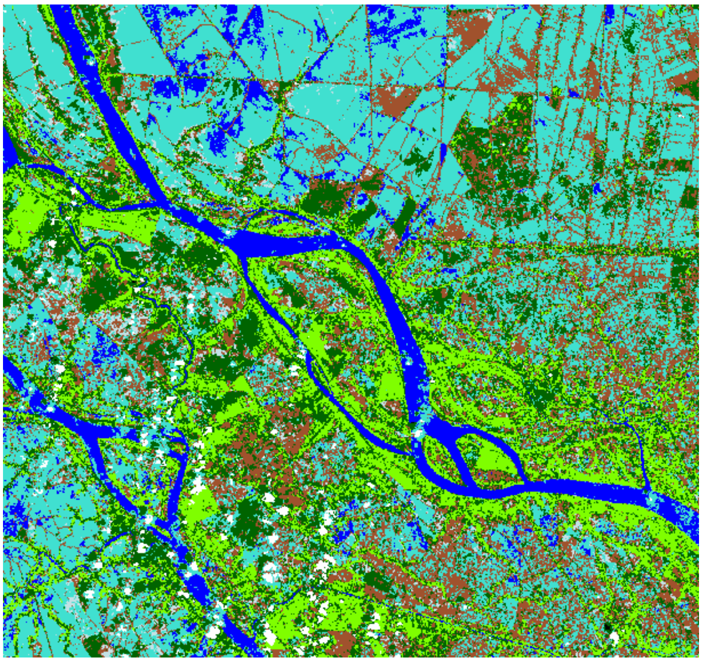

Figure 6: Supervised landcover classification derived from a Landsat 7 ETM+ Landsat scene from December 2001 (no timely overlap with the radar data).

5 Discussion and outlook

With the available Terra SAR-X images in the present study only limited information about the flood situation and severity can be extracted, because the time period between both images is very long. For better information retrieval more dense datasets at smaller time interval are required. With the Terra SAR-X satellite a repetition rate of 11 days is available. Thus, each region can theoretically be scanned at least 2 times per month, and watermasks can be derived at bi-weekly basis.The same applies for the change detection approach. A dense timely data coverage required, a monitoring system could be established utilized for either disaster- or water resource management. However, with these results the potential to support either disaster management or resource planning could be shown. The very high spatial resolved image data allow for very detailed extraction of inundated areas and severity, even allowing for the identification of individual buildings surrounded by water.

The derived watermasks will be ingested to the WISDOM Information System in an automatic manner and will also be available to subsequent processors, e.g. flood modelling. They can directly be used for further geostatistical analysis, e.g. by intersection with landuse- or population datasets to quantitatively derive information on how many people or which crops are affected by the flood. However, water or landcover products are only one source of remotely derived information in the WISDOM Information System. Remote sensing based change detection products, fire detection, precipitation estimation and water quality products will all be incorporated to jointly analyse a larger set of data. For such an analysis it is crucial that a datastack of all these different data sets is available from the same period of time and the same spatial area. The combination of all this information plus many other sources of information delivered by non-remote-sensing partners in the WISDOM project (modelling outputs, vulnerability analyses GIS datasets, reports, queries from field surveys, etc.) allow for multiple analyses supporting multiple planning processes at administrative level.

6 Acknowledgements

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