# Early impact procedures for flood events February 2007 Mozambique flood

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## Abstract
Satellite images and GIS procedures are key elements for emergency management, especially in case of events hitting developing countries, more vulnerable to calamities and less prepared to face them. This article aims to show the procedure applied for the production of a cartography of flooded areas during the early impact phase; these activities are developed within ITHACA, centre of excellence, in charge of giving technological support to the WFP (World Food Programme), the biggest agency of the UN. The flood in Mozambique, occurred in January 2007, is illustrated as an example of events management.
**Keywords:** emergency management, Early Impact, flood, radar data, MODIS

***Procedure di Early Impact in risposta ad eventi alluvionali. Il caso dell'evento alluvionale in Mozambico 2007***

***Riassunto***
*Immagini satellitari e procedure GIS sono elementi chiave per la gestione di emergenze, in particolare nel caso di eventi che colpiscano paesi in via di sviluppo, più vulnerabili di fronte alle calamità e meno attrezzati per farvi fronte. Questo articolo intende illustrare alcune procedure per la realizzazione di cartografia delle aree colpite da eventi alluvionali, necessaria per l'intervento durante la fase di early impact (impatto precoce); tale attività è svolta all'interno di ITHACA, centro che si occupa di fornire supporto tecnologico al WFP, la maggiore agenzia delle Nazioni Unite. Vengono proposte, in particolare, le attività svolte per garantire la corretta gestione dell'emergenza che ha colpito il Mozambico nel Gennaio del 2007.*
***Parole chiave:*** *gestione delle emergenze, Early Impact, evento alluvionale, dati radar, MODIS*

## Introduzione
As widely reported by the scientific and humanitarian environment and the media, the world is facing a dramatic increase of emergencies caused by natural disasters. As a matter of fact, the number of events, affected people and causalities, not mentioning economic losses, has increased by five times in the last 30 years (see Fig. 1). The global population growth pressure forces people to live in areas historically prone to disasters, while the global warming seems to exacerbate climatic related hazards. The result is an increase of floods that strike countries

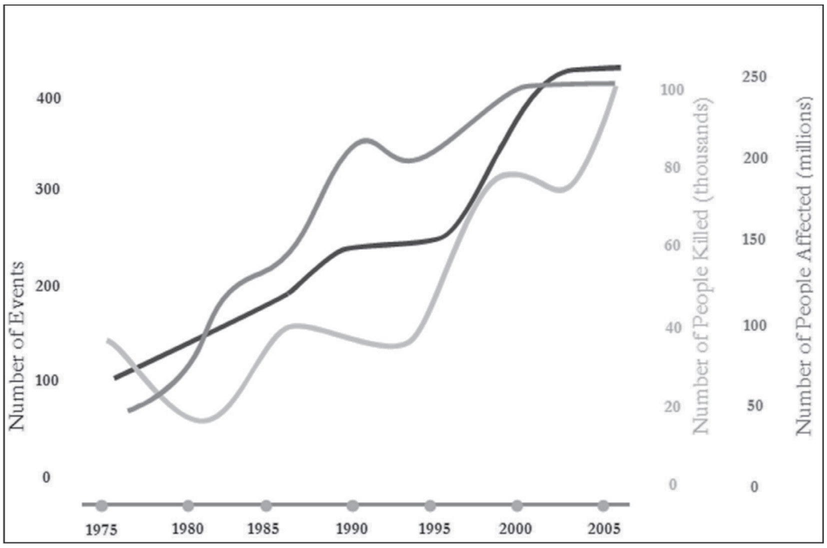


**Figure 1 - Natural Disasters reported by CRED (Center for Research on the Epidemiology of Disasters).**

with little capacity to cope with new exceptional destructive events. Flood events have a huge impact on human beings, settlements and ways of life [Henry et al., 2002]. The humanitarian and the United Nations system are therefore called to intensify their efforts to improve their capacity to provide support to the countries in need and to be better prepared to intervene. Such request came, amongst others, from the UN Secretary General in various occasions. The World Food Programme (WFP) of the United Nations is in the front line of humanitarian operations. It is the biggest UN Agency and responds to more than 120 emergencies per year worldwide [http://www.wfp.org]. According to the UN reform, WFP is also the leader of logistics for UN and international bodies during emergency response operations. WFP initiated a process to reinforce its capacity to be a leading force in the area of emergency response improving its Information Management capacity in support to emergency preparedness and response. To do so, an agreement of collaboration with the recently formed Information Technology for Humanitarian Assistance Cooperation and Action (ITHACA) Centre has been signed and a joint collaboration started in February 2007. One of the objectives of the collaboration is about the use of remote sensing in the area of Early Warning and Early Impact Analysis. WFP and ITHACA both recognize that many efforts are going on, significantly at European Union level. However, they also acknowledged that little has been tested in the field and used by the humanitarian officers to guide or support operations.

## ITHACA Early Impact activities for flood events

ITHACA support in early impact activity for flood events is conceived in provision of analytical products (maps) showing the impact of the flood on population and on infrastructures, with emphasis on road network. Furthermore, additional analysis is requested to facilitate the set up of priorities in undertaking field emergency needs assessment and finally in supporting midterm food security analysis.

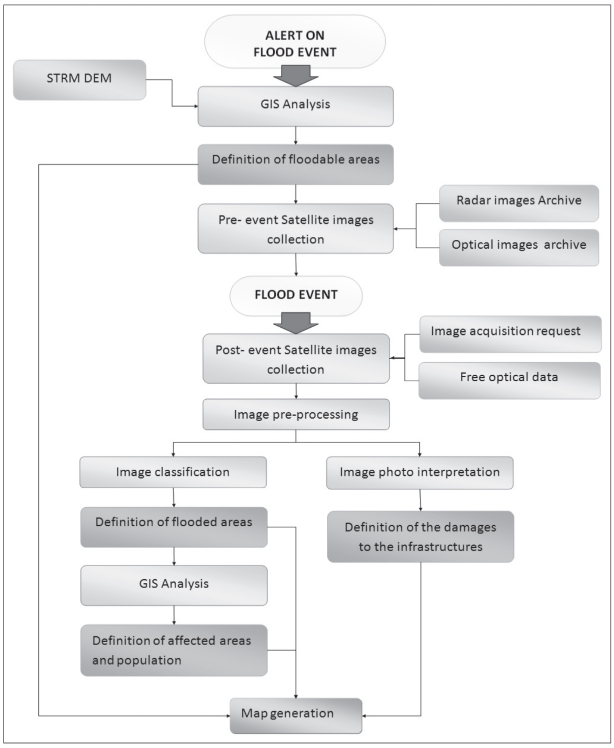


**Figure 2 - ITHACA activities: workflow during a flood emergency event.**

In operative terms, map-supporting is required at two different stages: at the first state of alert and just after the event. In both cases the response time after help-request triggering is short, lasting generally from 24 to 48 hours.
In the first state of alert, before the flood event, small scale maps indicating the areas that will be potentially interested by the floods (the so called 'floodable areas') are required: in this phase the floodable areas are defined and satellite data (Radar, MODIS, etc) about the zone of interest (before the flood) are collected.
In the second phase, after the flood hits, the following four points must be fulfilled:

1. which are the areas physically hit by the flood (the so called 'flooded areas');
2. which are the areas that could be hit directly or indirectly by the flood effect (the so called 'affected areas');
3. which are the population suffering the effects of the flood (the so called 'affected population');
4. which are the damages occurred to the infrastructures.

In order to derive those information, it is necessary to receive updated satellite data and to apply classifications, photo interpretation techniques and GIS procedures, as it is shown in the next paragraphs. After its definition, all this information need to be mapped in a suitable format, respecting the rules of clarity and easiness of distribution.
The general workflow is shown in Figure 2. The next paragraphs illustrate the mapping

procedures for the necessary information, both in a general flood emergency contest and in their application during the real case of the 2007 Mozambique flood.

***Definition of floodable areas through flood simulation***

During the early phases of humanitarian crisis management after a flooding event, it is crucial to produce a global assessment at a small scale, identifying areas and infrastructures that may have been damaged; fast production of those information will allow the organization in performing more precise and time consuming assessment (high-resolution satellite or aerial images acquisition and interpretation, land surveys, etc.) only in specific areas and after having defined priorities.

A very simple approach, using globally available geographic data and geoprocessing tools, is to use a CostDistance function over a DEM, employing the water network as a reference; the CostDistance request is basically a flooding request, but it accumulates a penalty for flooding across cells whose elevation exceeds a fixed limit. Thus, by picking the cells of zero cost, it is possible to find all cells reachable by crossing no elevations above the above mentioned limit. Iterating the procedure until a defined maximum elevation value, that must be based on available information, it is possible to simulate the evolution of a flood event. To simulate a flood more realistically, there is the possibility of adding a small positive value to the cost themes; in that case the extent of the flood is limited to n cells by selecting CostDistance values less than n times the small value.

A potential problem with this approach is that no flood maintains a constant elevation: it too, it flows and its elevation descends as the river descends; for that reason the development of water flow models must be considered as an option to significally increment the reliability of those estimates.

Figure 3 is a representation of the results of that approach realized in the early stages of the flood event that hit northern part of Madagascar in February/March 2007.

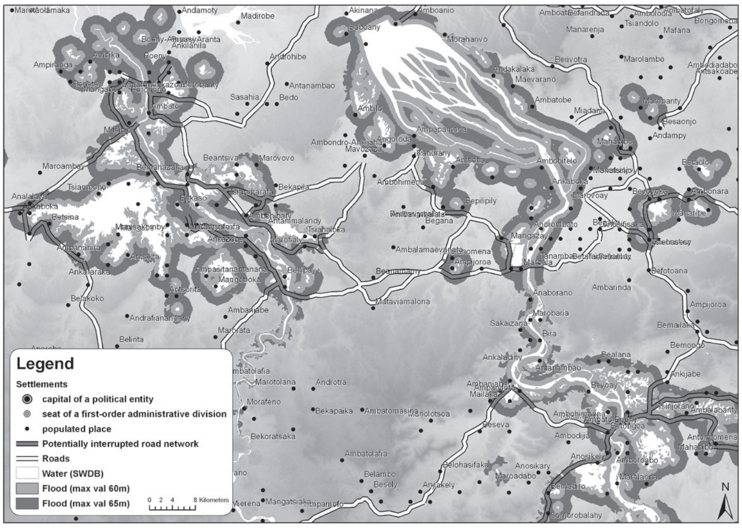


**Figure 3 - Example of mapping of floodable areas by GIS applications.**

***Definition of flooded areas***

According to what afore said, the results of the floodable areas analysis phase can be useful to identify areas and infrastructures that may have been damaged, allowing to set a priority list of the specific areas that should require a more precise assessment. The same areas should be the target for rush satellite imagery acquisition requests, generally performed by the International Charter "Space and Major Disaster". The International Charter is a unified system of space data acquisition and delivery to those populations affected by natural or man-made disasters through authorized users.

If the Charter is triggered, normally, in a few days, different kinds of satellite images are available, such as radar images and high resolution ones, suitable for the definition of the flooded areas.

## Definition of flooded areas through radar images

Radar images (geometric resolution varying from about1m to 150m) enable to easily identify water bodies on the scene, therefore they are the main input data for flood analyses [Aduah et al., 2007; Henry et al., 2003]. On the other side, they are affected by geometric distortions (layover, foreshortening and radar shadows) hard to be modelled, especially in mountain regions. In detail, the radar images acquired by satellite platforms (Envisat, Ers,…) before and after the event are used for the definition of flooded area: the request for an archive radar image can be skipped if reliable and updated water bodies data are available [Wang et al., 2002]. Both images have to be georeferenced through attitude and position information (generally supplied as metadata) exploiting the sensor depending procedure provided by commercial softwares. In order to improve the mapping accuracy, it is possible to perform a further image-to-image georeferencing, through a simple polynomial transformation, of the radar image preceding the flood with respect to the following one.

From a radiometric point of view it is generally advisable to preliminary apply a despeckle filter on the images, to reduce the noise that affect radar images. Then, the areas presenting water can be spotted on both images, exploiting their reflexive behaviour towards the electromagnetic radiation emitted by the radar sensor, assimilable, roughly, to that of a specular surface. It turned out that water can be easily identified (Fig. 4), being characterized by low radiometric values (Fig. 4 left).

By using change detection techniques it is therefore possible to isolate only the flooded areas, distinguishing them from water bodies, as shown in Figure 4 right. Classified images often suffer from a lack of spatial coherency (speckle or holes in classified areas). In order to improve the topology of the classified flooded areas, it is possible to further process the results applying filtering algorithms aimed to remove isolated water pixels by using blob grouping and to clump adjacent similar water areas together through the use of morphological operators. It is then advisable to mask the final result using the floodable areas layers that will allow to remove classification errors mainly due to radar shadows and speckle noise.

## Definition of flooded areas through MODIS data classification

A different approach for the definition of flooded areas is based on multispectral data processing. For several reasons, the MODIS sensor is generally used for large-scale flood monitoring [Brakenridge et Anderson, 2003; Aduah, 2007]. The MODIS (Moderate Resolution Imaging Spectroradiometer) mission grants a worldwide coverage providing daily images and derived

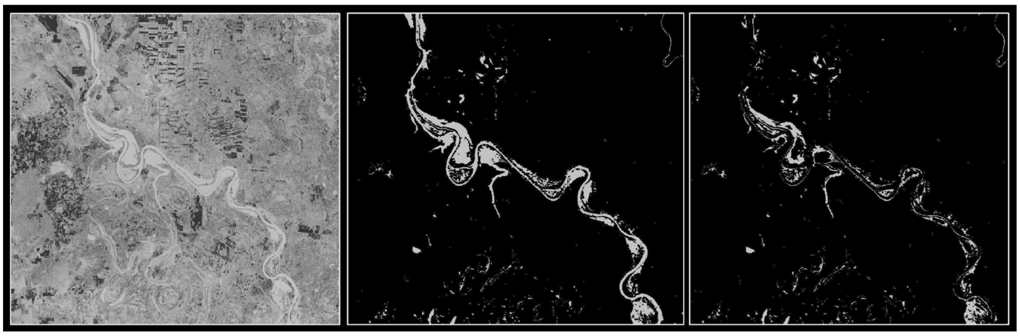

**Figure 4 - Left: post-event SAR image. Centre: extraction or water bodies. Right: identification of flood-affected areas.**

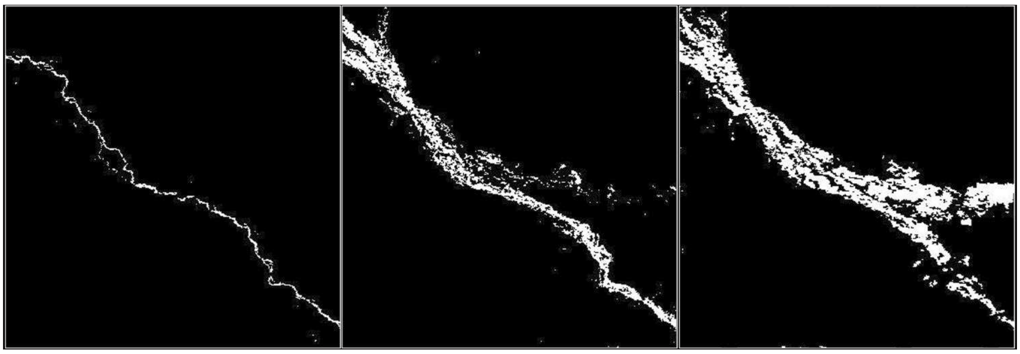

**Figure 5 - Flood event evolution. Water bodies and flooded areas extracted from MODIS data. Left: January. Centre: early February. Right: late February.**

products that are completely free of charge. Furthermore, low geometric re solution (250-500-1000 m) of MODIS data allows a regional view of the observed pheno-mena. Therefore, the use of MODIS data permits to carry out multi temporal small scale analysis of the flood event evolution in the areas of interest.

The detection of water bodies and flooded areas is the result of a classifying procedure of MODIS primary reflectance data (MOD02 - MODIS Level 1B Calibrated, *Geolocated Radiances*).

The MOD02 product is distributed by NASA to users with a low processing level (*Swath* format), which performs only a first geometric correction step and which contains some residual geometric distortions due to the system's peculiar scanning geometry [Nishihama et al., 1997]. Therefore, a geometric data correction step is accomplished using a specific software tool, the MRTSwath tool. In order to correctly compare multi temporal MODIS data, the images are also preventively radiometrically pre-processed and co-registered. The atmospheric correction of the reflectance data is performed through the simplified Dark Subtraction approach.

Unlike radar data, the usability of passive optical remote sensing data is restricted by cloud cover. Since considered MODIS data for the areas of interest are available daily, temporal composite techniques are used in order to reduce cloud cover presence.

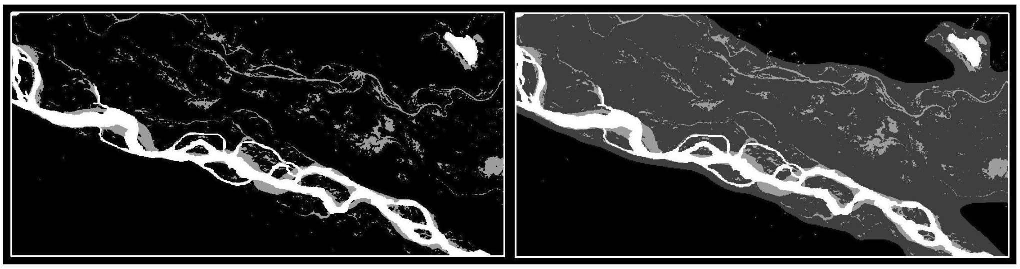

**Figure 6 - Reference water and flooded areas on the left image. Affected areas (grey polygon) on the right.**

For the classification purposes (Fig. 5), specific radiometric indexes, useful for water bodies and flooded areas detection and for cloud effects reduction, are defined by using Red (620-670 nm) and Near-Infrared (841-876 nm) MODIS bands (which are the only bands with spatial resolution of 250 m). These indexes are mostly based on particular band ratios. Common indexes, as the NDVI (Normalized Difference Vegetation Index) and other ones defined by authors according to the specific areas of interest, are considered. Using reliable water bodies data, it is then possible to isolate only flooded areas.
Moreover, it is possible to create synthetic products showing temporal evolution of flood event and the different flooded area distribution (Fig. 10).

***Definition of affected areas***
In order to define the population affected by the event it is necessary to define the overall area that can be indirectly affected by the flood, the so called "affected areas". It is therefore necessary to process the flooded areas in order to extract the required affected areas. The goal is to have homogeneous large polygons that frame all the flood polygons, taking into consideration only the floodable areas, as illustrated in Figure 6.
The methodology defined to perform this task is based on mathematical morphology filtering. First of all, it is performed a dilation of the rasterized flood polygons followed by subsequent erosion using the same structural element ("closing" filtering). This procedure allows to smooth the contours, fuse narrow breaks and long thin gulfs, eliminate small holes, and fill gaps in the contours of an image. After that, it is possible to accomplish a majority analysis of the classified image in order to assign spurious pixels to a large single class where they are spatially located. Since high details are not required to define affected areas, better results are obtained applying the described methodology to the flood polygon image resampled at a lower resolution. Finally a masking is performed to remove any pixel that cannot be flooded, according to the already performed GIS flood simulation.

***Definition of affected population***
The number and distribution of potentially affected populations is another major information requested by managers of humanitarian helps distribution. A rapid estimate of this parameter can be obtained crossing potentially flooded and effectively flood affected areas with population distribution data; one globally consistent source of that kind of data is the LandScan Global Population dataset dataset [Dobson et al., 2000].
Using GIS Zonal Statistics function is a way to calculate statistics on values of a raster (as

Landscan data is) within the zones of another dataset: the affected areas in that case. That procedure allows an estimate of people living in potentially or currently flooded areas, or in areas isolated by floods. On-field assessment, even on statistic samples, should permit to correct the estimates.

***Definition of the damages to the infrastructures***

The use of high spatial resolution satellite data (geometric resolution varying from 0.6 m to 2.5 m) permits to create specific products showing the flood impact on the infrastructures, with particular emphasis on road network. This phase aims to provide information on accessibility, in the context of the emergency response operations undertaken by WFP. As a matter of facts, in the food supplying process after a flood event, WFP often has to face troubles related to transportation and food aid distribution; it is therefore necessary to quickly know the condition of roads, tracks and trails where food trucks should run through.
In order to perform an assessment of damages caused by flood events, common photointerpretation and change detection techniques are used. Moreover, the use of image fusion procedures, as the pan-sharpening techniques, can improve the object identification activities. In this phase, colour photographs, provided by WFP Local Offices, can also support the satellite image interpretation.
Figure 7 shows examples of particular extraction obtained using photointerpretation coupled with pan-sharpening techniques (HSV transform). Three low-resolution bands (Near-Infrared, Red and Green, 8 m) are used as main inputs in the process to produce a high-resolution (2 m) colour image (Fig. 7). This false colour combination was selected because artificial particulars are easily perceived and discriminated from natural objects.

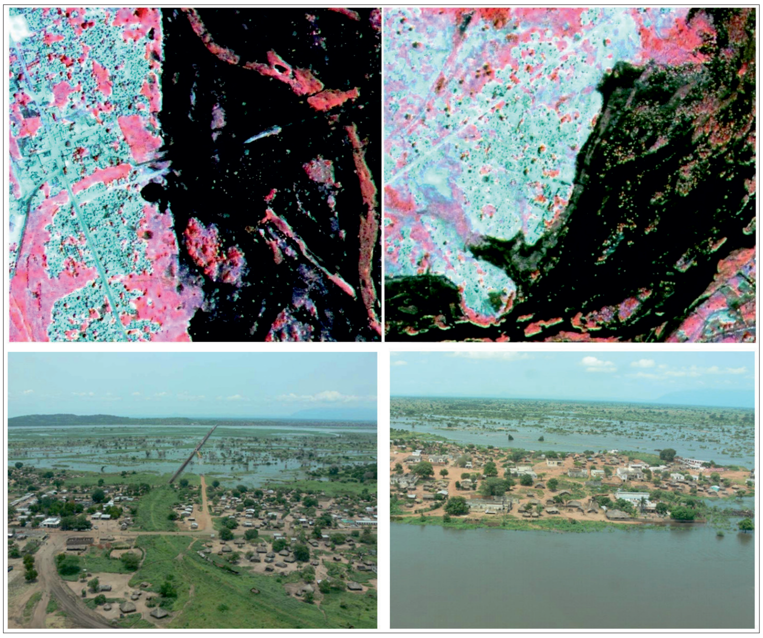

**Figure 7 - Formosat false colour (pan-sharpened) images (2m) of Muturara area (Mozambique). Flood impact on the infrastructures: road interruption (upper left) and water erosion in urban areas (upper right). On the bottom, photographs from Maputo WFP office.**

## Case study: 2007 Mozambique flood

The following case-study refers to the early impact stage of a flood event that hit Mozambique in February 2007. More specifically, the floods started when unusual early and heavy rains pounded southern Africa in January and February 2007. The National Institute for Disaster Management (INGC) declared a red alert on February the 4th for the Zambezi River basin, due to the fact that other rivers in Northern Mozambique were expected to flood. The roads to Mutarara were cut off. The rains triggered floods that affected nearly 170,000 people in Angola, Madagascar, Malawi, Mozambique, Zambia, and Zimbabwe (source: *United Nations Office for the Coordination of Humanitarian Affairs – OCHA*).
WFP local offices asked for assistance to the branch in Rome, which demanded UNOSAT to help in triggering the International Charter "Space and Major Disasters" through the UN Office for Outer Space Affairs. The procedure of priority acquisition of optic and radar data and the research of suitable imagery in the archives started on February the 9th. On February the 12th the first images were captured, and made available by the agency UNOSAT the following day.
The data available for the Mozambique flood are listed and described in Table 1.
ITHACA was asked to produce a small scale map indicating the flooded areas and the affected areas. The themes object of the required maps was generated by processing radar supplied data as described in details in the previous paragraph. The theme generated, the pre-event and post-event optical images and the worldwide cartographic database were integrated into a GIS environment in order to produce or update flood monitoring maps (an example is reported in Fig. 8).
In order to perform an assessment of damages caused by flood event, high resolution optical imagery acquired by Formosat sensor was used, allowing the production of medium/large map scale products (Fig. 9).
Moreover, the availability of multi temporal data allowed to create synthetic value added products showing the temporal evolution of the flood, through the comparison of optical images (Fig. 10, right insets) and the overlapping of vector polygons representing the areas covered by water at different dates (Fig. 10, bottom left inset).

## Outcomes

Several investigations carried out by the Ithaca association in the field of emergency management proved that the use of remote sensing and GIS technologies, combined with up-to-date, reliable and easily accessible reference base geographic datasets, constitute a key factor for the success of emergency response activities. Such approach supports fast and accurate planning and management of rescue operations as well.
The experience gained cooperating with WFP during several natural disaster, allows to state that, in order to supply more and more effective products, it is mandatory to assure a close collaboration with all the entities engaged in aid operations (located both in headquarters and in local offices). In such a way it will be possible to take advantage of the accurate definition of the initial needs and the continuous feedback coming from the field.
The research group's activities are currently focused on the improvement of the described methodologies, with two main goals:

- to make the procedures devoted to extraction of the information related to the disaster as automatic as possible, minimizing the supervision of the operator;
- to increase the dissemination of the valued added products, creating web application customized according to the user needs.

**Table 1 - Data available for the flood of February 2007 in Mozambique.**

| **Post-event data** | | |
|---|---|---|
| *Platform* | *Date (D.M.Y)* | *Geometric resolution (m)* |
| Radarsat S4 | 12.02.2007 | 12.5 |
| Radarsat | 26.02.2007 | 25.0 |
| Formosat | 11.02.2006 | 2.0 (pan) – 8.0 (xs) |
| Formosat | 15.02.2006 | 2.0 (pan) – 8.0 (xs) |
| **Pre-event data** | | |
| *Platform* | *Date (D.M.Y)* | *Geometric resolution (m)* |
| Radarsat S7 | 26.03.2006 | 12.5 |
| Landsat 7 ETM+ | 30.12.2000 | 30.0 – orthoprojection |
| Spot-5 XS | 22.10.2006 | 20.0 |
| **GeoDataBase** | | |
| *Description* | *Format* | *Source* |
| Map layers Level 0 | Vector | US Imagery and Mapping Ag. |
| Toponymy | ASCII | Geographic Names Database |
| Waterbodies | Vector | SWBD water |
| Global Population | Raster | LandScan 2005 |

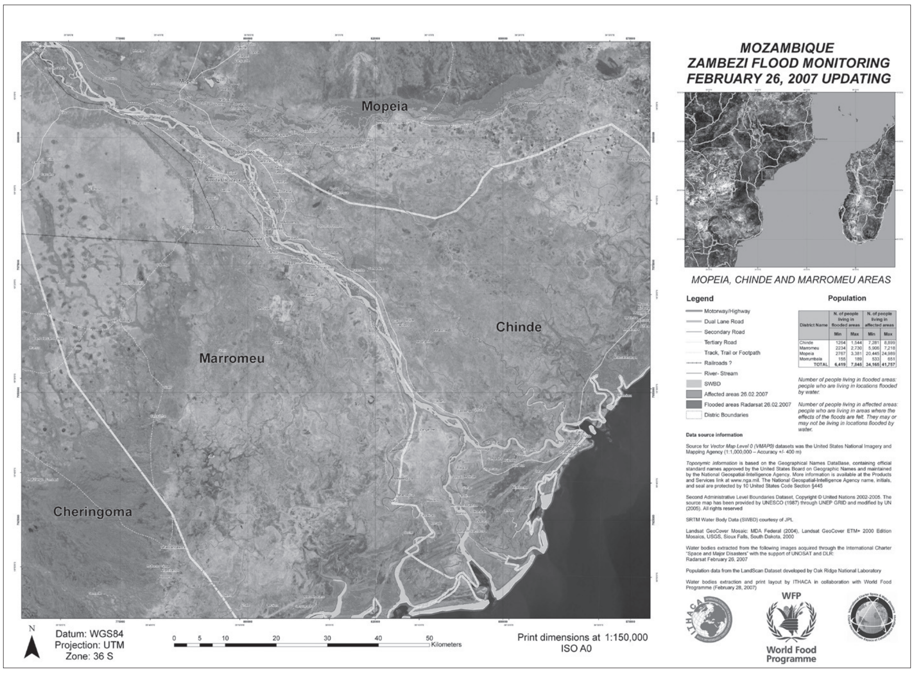


**Figure 8 - Mapping of flooded and affected areas in Mozambique (Marromeu and Chinde areas). Produced by Ithaca in collaboration with WFP in 24 hours.**

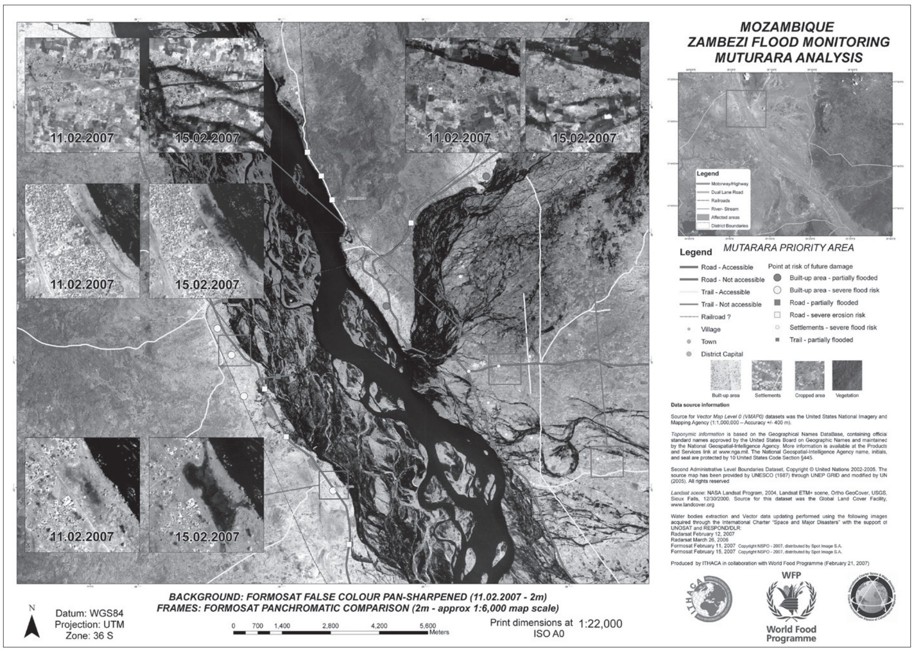


**Figure 9 – Multi temporal analysis showing the flood impact on the infrastructures based on Formosat imagery (Muturara area). Produced by Ithaca in collaboration with WFP.**

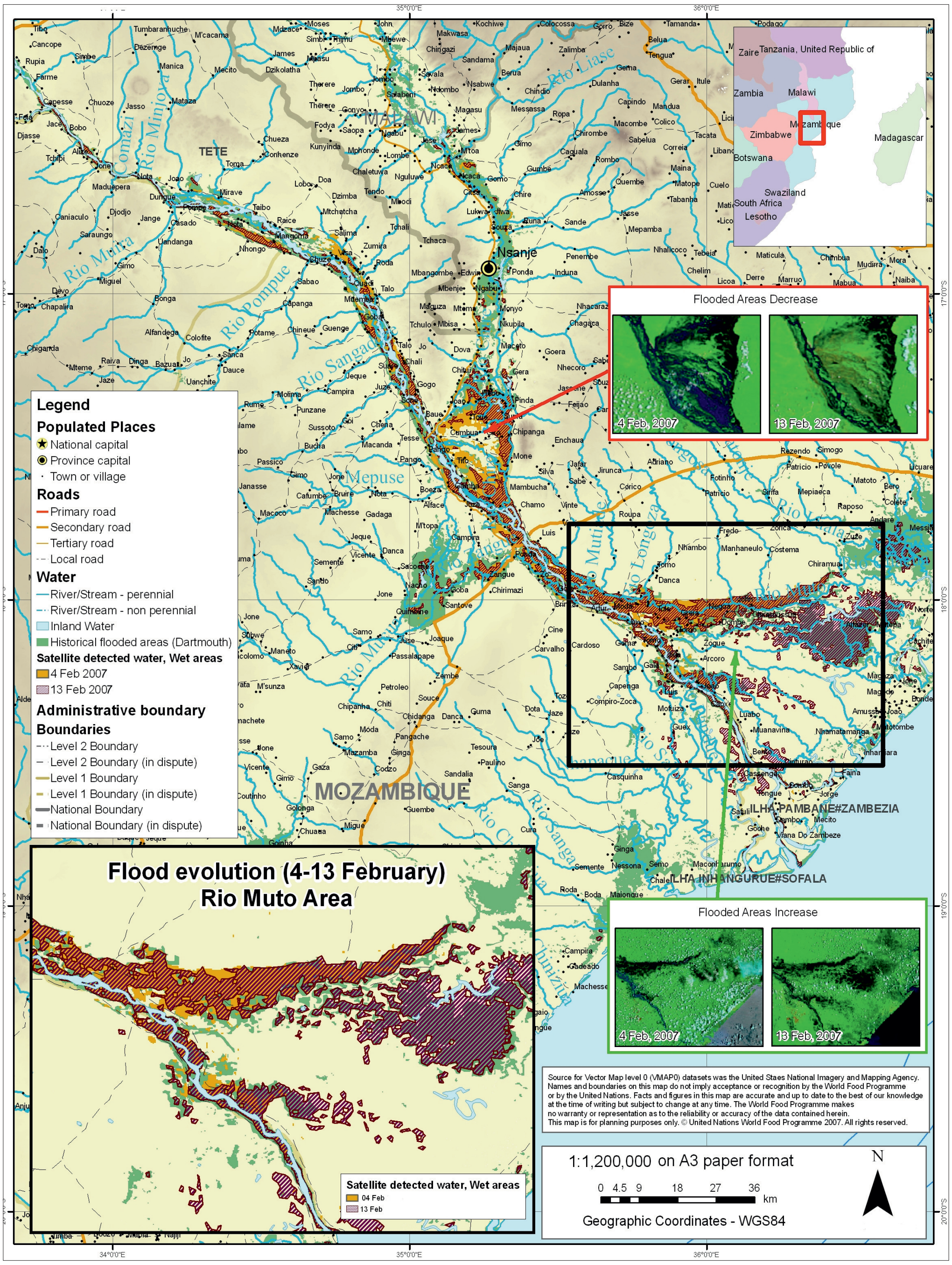


**Figure 10 - Mozambique, February 2007: temporal evolution of the flood event. Flooded areas distribution obtained by MODIS data analysis.**

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