MAPPING PAKISTAN 2010 FLOODS USING REMOTE SENSING DATA

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ABSTRACT

Natural disasters of any kind play havoc with and cause huge losses to both humans and properties. Recent flooding in Pakistan is one of the true examples of how floods of such a magnitude can put an entire country in chaos and adversely affect its economy. These floods affected all the provinces of the country badly.

Recent floods are the result of heavy and continuous spells of monsoon rains in the last week of July to the mid of August in most of the areas of the country, especially the northern areas. In most of the affected areas, an average of about 11 inches of daily rainfall was recorded for three days consecutively. These rains caused heavy flooding in the Indus, Swat and Kabul Rivers, and these remained at *very high to extremely high flood/danger* levels. As the results of these floods, over a thousand of people lost their lives, thousands of houses are damaged, a number of small villages and towns submerged, and most of the crops are destroyed. Kilometers of road segments are affected, and many bridges have been washed away. Millions of people are rendered homeless and forced to abandon their homes since the areas especially along river courses and even farther are inundated to dangerous levels. In the wake of such a wide spread disaster, remote sensing data once again proved its importance both for relief and rescue efforts. The availability of temporal remote sensing data from Landsat and ASTER has made it possible to map the flood extents, and track the movement of the flood from north to south of the country. Temporally mapped flood extent helps the authorities to monitor the progress of the floods, how and from where to access the affected urban areas to provide relief and rescue in a timely manner. It also helps in determining which of the flood protection bunds (levees) needs reinforcement, deciding where to breach to the bunds to save some of the cities, barrages and other important installations. In the future, these mapped flood extents can help the concerned authorities for damage assessment of urban areas, road infrastructure, and crops, as well as to demarcate and designate nonexistent floodplain boundaries.

KEYWORDS: Natural disasters, temporal satellite images, object-based image classification, flood mapping, damage assessment

INTRODUCTION

During the 20th century, floods were the number-one natural disaster in most of the countries of the world in terms of number of lives lost and property damage (Charles Perry, http://ks.water.usgs.gov/pubs/fact-sheets/fs.024-00.html). The damages resulting from these disasters are devastating. The July and August 2010 floods in the Khyber Pakhtunkhwa Province of Pakistan caused heavy losses to the infrastructure, urban and agricultural areas. Over a thousand people lost their lives, thousands of houses destroyed, many kilometers of road segments affected, and a number of bridges washed away. Millions of people rendered homeless and were forced to abandon their homes as mostly areas along the river courses and even further were inundated to dangerous levels. These floods were the result of weeklong heavy rainfall all over the province. The accumulated rainfall raised the water to record levels in the rivers, documented by Pakistan Meteorological Department operated gauge stations [http://www.pakmet.com.pk/]. Vast areas away from rivers were also subject to floods due to heavy surface runoff. It added more severity to the flood situation which otherwise was forecasted from the river gauge data.

Satellite remote sensing images are useful data sources to detect, determine and estimate the flood extent, damage and its impact. However, timely acquisition and availability of images is essential. Since November 2008, Landsat images have been freely available. However, satellite's revisit time limits the broad usage of these images since the flooding events can easily be missed (Hussain and Shan, 2010). RS data from optical sensors lack cloud penetration, which is another limitation in a flooding event. However, in case of clear or partial cloud cover, this may be the only data which can provide latest flood information for broad areas. Also, mapping the actual flood

extent needs to use a priori flood images collected at the same season or as close as possible to the flood period. The extent of water bodies at their normal flow can be identified by using this approach. The removal of normal water from the during-flood images gives the flood extent. This process is straightforward if optical multispectral images, such as Landsat images, are used since detecting water in those images is relatively easy. The timely provision of flood extent, its progress and impact information directly to the disaster management agencies and on the Web can support forming quick response strategies and help in the rescue and relief efforts tremendously (Shan et al., 2009).

RAINFALL AND RIVER WATER LEVELS

During the last week of July and first week of August 2010, most parts of the Khyber Pakhtunkhwa Province received approximately 200-280 millimeters heavy rainfall, especially in the surrounding of Peshawar-Charsadda, and Nowshera. It started early in the last week of July and intermittently continued until the first week of August. The highest official rainfall of 280 and 274 millimeters were recorded on July 29th at Peshawar and Risalpur respectively. The average rainfall for this month at Risalpur was 433 mm and 402 mm at Peshawar (monthly average of 46 mm), 356 mm above normal. The rainfall data for the last week of July and the first week of August (27 July- 4 August, 2010) in Table 1 shows the severity of this rainfall in Khyber Pakhtunkhwa Province.

Table 1. Rainfall data from July 28 to August 4 (Courtesy: Flood Forecasting Division)

Location	JULY 2010 Rainfall (mm)				Monthly Total (mm)	Monthly Normal (mm)	August Rainfall (mm)				Total Till 4th Aug	Monthly Normal (mm)
	28	29	30	31			1	2	3	4		
Cherat	33	*257*	81	0	*388*	93.4	0	0	1	48	49	96.46
Peshawar A/P	-	*274*	59	0	*402*	46.1	0	0	0	29	29	72.6
Peshawar City	0	*204*	22	0	*294*	-	0	0	0	0	-	-
Risalpur	5	*280*	121	-	*433*	-	0	0	-	27	27	125.9

These high rainfalls resulted in severe flooding in the rivers flowing through Central and Eastern Khyber Pakhtunkhwa Province and caused heavy destruction to both urban areas and agricultural land. River water levels even crossed the danger level and reached the "Very High Flood" stage as recorded by the Flood Forecasting Division operated gauging stations [http://www.pakmet.com.pk/FFD/cp/floodpage0.asp]. These water levels were much higher than previous many years. These data helped Flood Forecasting Division to predict floods downstream this area. The major rivers flowing through these areas are Kabul, Swat and Kalpani and numbers of nullahs (a term used for medium to large streams). The heavy flooding situation in these water channels remained for about a week. Kabul River remained in the high to very high flood stage (221,000 Cusecs) till August 8, 2010. Water recorded at Nowshera for Kabul River show the severity of this heavy flooding, as given in Table 2 below.

Table2. Kabul River Water flow data (Courtesy: Flood Forecasting Division)

| Kabul River	Site	Flood/Danger Level				
	Nowshera	Low	Medium	High	Very High	Extremely High
Water Flow (Cusecs)		45,000	47,000	100,000	200,000	400,000
Recorded on July 28		60,000	-	130,000	-	-
Recorded on July 29		130,000	-	-	240,000	-
Recorded on August 8		120,000	-	-	221,000	-

# REMOTE SENSING DATA AND FLOOD MAPPING

Landsat Data

Using satellite remote sensing data is a cost effective and accurate method of mapping natural hazards such as floods spread over broad areas. Remote sensing data are appropriate for such events due to their large area coverage, timely availability and temporal frequency. They help the authorities in their rescue and relief efforts, damage assessment and future planning to plan remedial measures and actions to tackle such events effectively. A range of satellite data sources are suitable for varying degrees of damage assessment, including Landsat, SPOT, IKONOS, QuickBird and OrbView. Selection of a particular data source depends mainly upon the timely coverage, its availability, spatial, spectral and temporal resolution and finally the cost. The International Charter – Space and Disasters is one of the primary sources that promote cooperation among its member space agencies and industries in the use of disaster related satellite data (Stryker and Jones, 2009). It facilitates the provision of relevant data to the affected countries or regions to enable them to effectively manage the rescue, relief and rehabilitation efforts during and after disasters (Shan et al., 2010).

August 04, 2010 was a clear sky day in the central Khyber Pakhtunkhwa, thus resulted with a better record of the flood situation by Landsat-7 satellite imagery. This Landsat image was made available on August 5, 2010, courtesy of Hazards Data Distribution System (HDDS), United States Geological Survey (USGS) [http://hdds.usgs.gov/hdds/]. This image covered the severely flooded areas of Charsadda and Nowshera, and helped to visualize the extent of the flood all along the river courses. Another pre flood event Landsat image acquired on July 11, 2010 over the same area shows the slightly above normal water situation in the rivers and other nullahs in this area because of the normal monsoon rainfalls. The water in these rivers at other times of the year generally remains very low. This image was obtained from USGS, Earth Resources Observation and Science Center (EROS) [http://glovis.usgs.gov/]. The availability of temporal dataset helped greatly to analyze the changes occurred due to the flooding.

Landsat image of August 04, 2010 was probably the first available post-event imagery and proved to be the best data for mapping the extent of this flood with an acquisition date very close to the peak flooding in these areas. By this time, the water from the northern parts and the adjoining areas hardly receded in the rivers and nullahs. The real time rainfall data reported by Meteorological Department and the readings from established gauge stations show that the Kabul River has seen heavy surges, along with the other small rivers and nullahs. Visual observation of the imagery revealed that the areas from North West of Charsadda to the East of Nowshera were the most affected, and thus selected as the study area. The pre- and post- flood event Landsat image data are shown below in Figure 1 and 2.
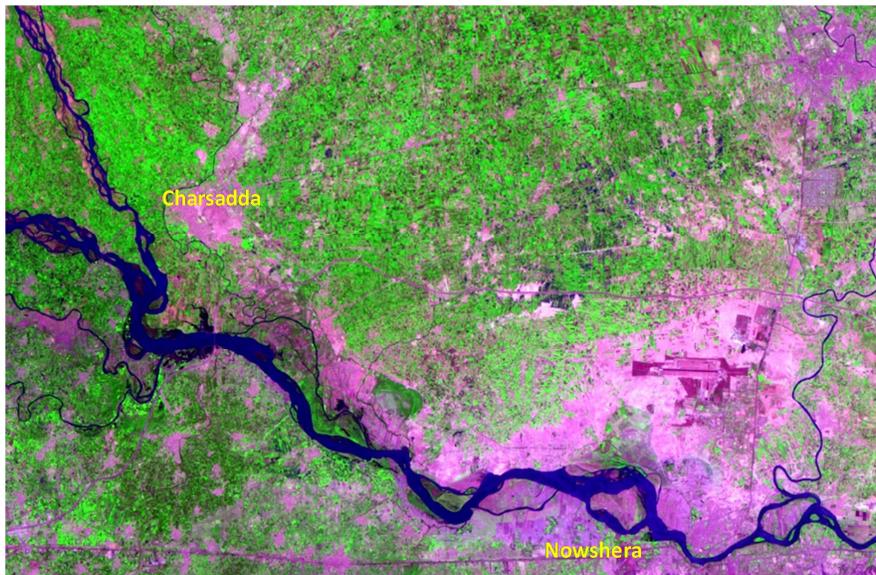

Figure1. Pre-flood event Landsat Image July 11, 2010.
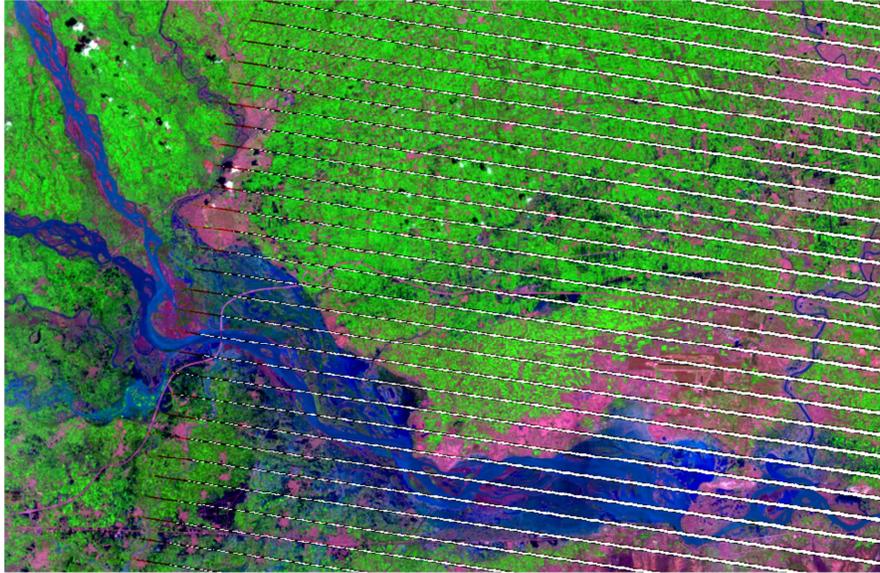
Figure 2. Post -flood event Landsat Image of August 04, 2010.

DATA PROCESSING

Flood water extent has been mapped through the object based image classification technique (Benz et al., 2004). This technique divides an image into contiguous and homogeneous objects in the first step and then these objects are classified using their spectral, contextual and textural properties. This process was used for both the during-flood images and the pre-flood images. Later on, a multi-temporal post-classification approach was applied in order to assess the pre- and post- flood changes between the two images and to produce change maps. For this purpose, the water extent from Landsat image of July 11, 2010 was considered as the base of pre-flood normal water. By comparing this water extent with the one extracted from August 04, 2010, the actual flood extent has been extracted. The change map shows before and after floods in the extent of water bodies and helps to locate the most flood prone areas. The visual analysis of the flood image revealed the most serious flooding along the river courses as compared to other land areas. The same observation was verified by the change map. This change map helped to quantify the areas subject to the flood. These classification results were then converted to shape files for further analysis and assessment through GIS. The analysis of water classes for both the pre- (5482 hectares) and post- flood events and related statistical results show an increase of about 13438 hectares of area subject to flood waters. The worst hit and most affected urban areas includes Rajar, Charsadda, Nawan Kili, Kheshgi Payan, Mohib Banda, Nowshera kalan and Cantonment and Pir Sabaq mainly from the overflowing river waters. Areas from Charsadda to Nowshera Cantonment were mostly affected by Kabul and Swat Rivers. Kalpani River downwards from Risalpur to Kabul River badly hit Risalpur and Pir Sabaq areas. The change detection to assess flooding in urban areas was however limited by the low spatial resolution (30 m) of the images and detail damage assessment was not possible. However, the flood extent provides synoptic view of the areas with flood waters. It likely mapped some of the very high moisture areas as waters, where the waters physically may have receded leaving the soil still wet. It is likely that water extent at places may reflect both under and overestimations. Figure 3 below shows the classification results for water only for both pre and post flood imagery and the change map of flood water. The red color in the change map indicates the excess water to that of pre flood image.
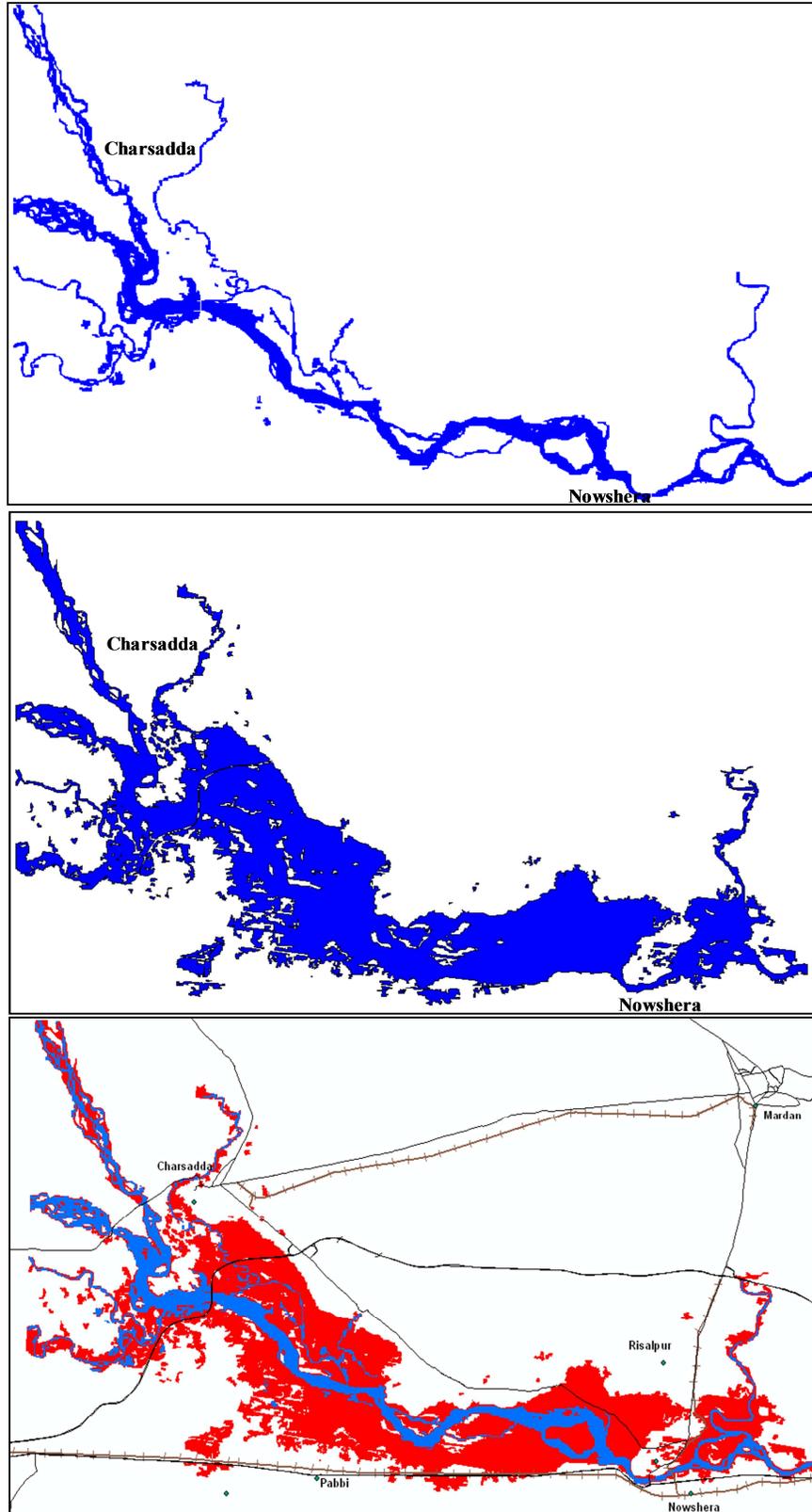
Figure 3. Pre-event flood water of July 11, 2010 (top), post- event flood of Aug 04, 2010 (middle), both extracted from Landsat images, and actual flood water (red); removing water of July 11, 2010 from Aug 04, 2010 (bottom).

MAPPING AFFECTED ROADS AND RAIL LINES

   Roads and streets data layer produced by GEOFABRIK has been used for mapping flood affected roads and streets. This layer does not include detailed road and street data, but was the one with slightly more roads as compared to other publicly available road data layers. These roads were compared and checked with the flood water classification layer. Some of the roads observed under the flood waters may not be accurate, as the width of some roads may not commensurate with the image pixel size. Even when the road is higher than the adjacent land, it is considered within the flood category since its width is too small and its adjacent land area is under flood. The analysis of these results revealed that mostly the local roads connecting small villages and towns passing through the floodplains are affected. Charsadda-Nowshera road is one of the badly affected roads. Also, a few segments of Motorway and GT roads are affected by flood waters. A small segment of Mardan-Nowshera railway line between Risalpur and Nowshera Kalan is also affected. Figure 4 below show the flood affected roads.
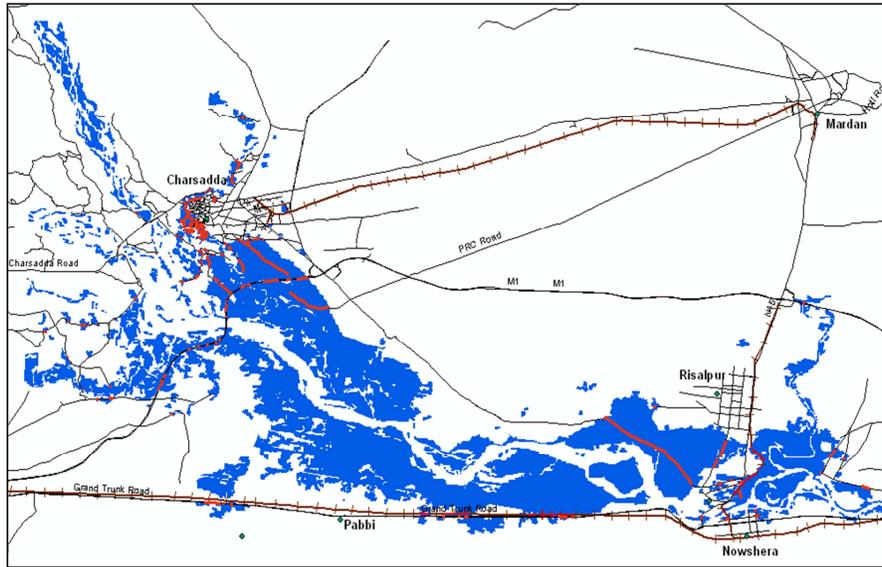
Figure 4. Flood affected roads and railway lines within the study (red).

GOOGLE EARTH VIRTUAL GLOBE

   Publishing the flood mapping results on the Web through Google Earth for a better visualization with the high spatial resolution imagery helps the authorities and the general public to visualize the geospatial distribution and extent of floods in a timely way and take any necessary remedial actions (Shan et al, 2009). The extracted results such as the pre-flood, post-flood and flood water extent, and the flood affected roads and railway lines data have been converted to Esri™ shapefile format as well as KML format [http://www.opengeospatial.org/standards/kml/]. KML is an XML grammar for encoding and transporting geographic data for earth browsers like Google Earth™. These kml files can be loaded on to the Google Earth™ virtual globe for visualization using its high resolution base imagery. Figure 5 below show August 4 water extent (blue), affected roads (yellow) and rail lines (red) in Google Earth™ virtual globe.
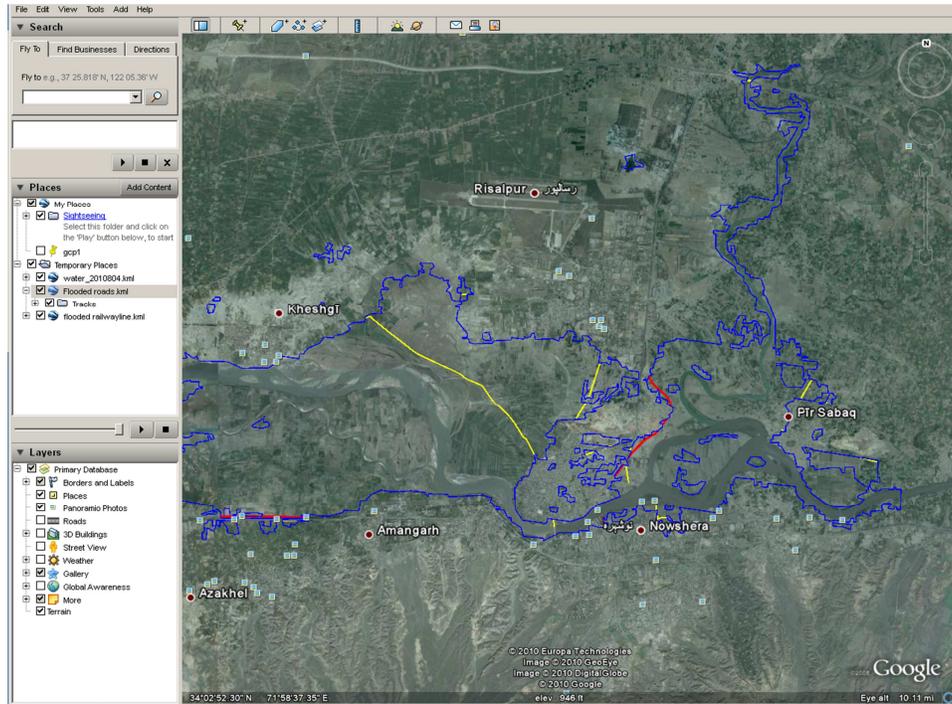
Figure 5. A subset of water extent derived from August 4, 2010 Landsat imagery, displayed on Google Earth™.
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DISCUSSION

The spatial distributions of estimated damages show a high concentration of losses to agricultural lands (crops) along the rivers and nullahs. This area, being part of the highly fertile lands, produces a variety of summer crops, and fruits. However, due to non availability of detailed crops data, no further analysis can be performed for the estimation of damage to crops. A large number of road segments are affected by flood water, including Motorway, GT roads, and many other small roads. In this study only the flood extent has been mapped. However, if detailed GIS data (property, streets, crops etc.) is integrated, detailed damage estimation can be enhanced to a very fine level of details depending on the accuracy of the GIS data.

No floodplain data for the study area are available nor do they exist. Therefore, these mapped flood extent of one of the historic floods can be very effectively used to create general floodplain boundaries which are often produced based on certain flood modeling. These designated floodplains can help restrict future urbanization within their limits to avoid and minimize loss to human and properties.

CONCLUSIONS

The primary objective of the use of remote sensing data for the mapping of widespread natural disasters and publishing the results on the Web is to provide the planners and disaster management institutions a quick view of the ground conditions and disaster impact. This information can also help them make a quick response plan and move swiftly to take appropriate remedial measures. It can help the residents in the flood affected areas to visualize and assess the amount of flooding and losses to their property. The effectiveness of the remote sensing imagery for flood mapping has been amply demonstrated for many recent flood events.

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