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River Indus flood mapping from Chashma barrage to Sukkur through satellite images and ER Mapper

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ABSTRACT

This paper aims to integrate Satellite Remote Sensing (SRS), Geographic Information System (GIS) and Digital Image Processing (DIP) techniques for the identification of flood affected areas and flood damage assessment along the Indus River as a result of flood in the year 2005 due to abrupt snow melt in the northern areas of Pakistan. Snow melt in northern areas of Pakistan was the main cause of flooding in the year 2005, using ER Mapper Image Processing software, study of temporal changes of snow cover has also been carried out by calculating the snow cover area in the month of February for different years i.e. 2004, 2005 and 2006 using Moderate Resolution Imaging Spectro-radiometer (MODIS) onboard Aqua and TERRA satellites data. This showed that snow covered areas for the mentioned years were 56203, 67853 and 58642 sq km respectively. Calculations also reveal that the snowfall was maximum in the year 2005. Using satellite images of MODIS for May and July 2005 covering the area along the Indus from Chashma to Sukkur Barrage showed that this flood had caused huge damage in many cities of Punjab and Sindh provinces. Using images pertaining to pre and post-flooding periods, the evaluated flooded area between Chashma Barrage and Sukkur Barrage comes out to be approximately 6428 sq km (excluding the normal flow area which is 1359 sq km).

Introduction

The dangers of flood waters are associated with a number of different characteristics of the flood, like depth of water, duration, velocity, sediment load, rate of rise and frequency of occurrence (Hudson and Colditz, 2003). Pakistan is among several countries in the world that faces multiple facets of flood disaster almost every year. The region, facing floods during monsoon is often subjected to severe drought during lean season (Khan and Arsalan, 2007). Indus river basin is prone to floods, floods in these areas directly or indirectly affect the economy of the country either in the form of natural resources, lives, property or infrastructures such as houses, roads, railways, pipelines, electricity and telecom network. (Pereira, 2002). Indus River is one of the longest Rivers in the world. Pakistan extends along either side of the historic Indus River, following its course from the mountain valleys of the Himalayas down to the Arabian Sea (Majid et al., 2006).

The Indus provides the key water resources for the economy of Pakistan; However Indus River is also the region with frequent floods. In history, many extraordinary floods have ever occurred here, the huge flood damage losses not only bring about economic loss, but also greatly influence people’s mentality health in stricken areas (Saeed et al., 2006, Shahid, 2008). Therefore, evaluating system efficient estimation of flood losses is urgently required to assist flood control regulation decision, update flood post-scheme for relief and settlement, rehabilitation and make full play of structural and non-structural measures in order to avoid or reduce flood losses (Majid and Akhtar, 2007). This system will promote the healthy and stable development of economy and society of the nation (Ologunorisa and Abawua, 2005).

In light of the limited financial resources of Pakistan, the cost-benefit implications of disaster reduction alternatives must be carefully assessed. The expected damage (or risk assessment) provides one of the necessary inputs in cost-benefit analyses. Traditional methods for flood assessment are based on field surveys, hydrological and hydraulic modeling. These models are useful in depicting the spatial and temporal distribution of floods. However, few are well integrated within spatial modeling environment i.e. geographic information system (GIS). (Aguirre, 1998).

The goal of this research is to examine how efficiently satellite data could be used to measure the spatial extent of flooding along the Indus River. In this analysis remote sensing (RS), Geographic Information System (GIS) and digital image processing techniques (DIP) are used to analyze damage assessment caused by floods. RS techniques also employed for future rehabilitation and reconstruction strategies. Further, flood reduction strategies (mitigation) along the Indus River are also investigated. MODIS satellite images are used for flood monitoring/assessment along the Indus River, Pakistan.

Study Area

In history, many extraordinary floods have ever occurred here, the study area extends along the Indus River from Chashma Barrage to Sukkur Barrage (Fig.1).

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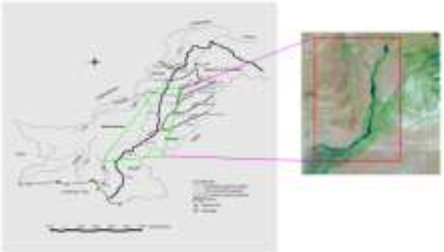


Fig.1: Location of the study area (Chashma to Sukkur Barrage) on Pakistan Map

Materials and Methods

Data Set Used

Ancillary data is useful in image interpretation and further analysis (Barraca et al 2006; Shaikh et al, 2001). Atlas of Pakistan with scale of 1:1000000, topographic maps with scale of 1:50,000 and the hydrological data for the Indus River basin were acquired from Space and Upper Atmospheric Research Commission (SUPARCO), Survey department of Pakistan and Department of Federal Flood Commission respectively.

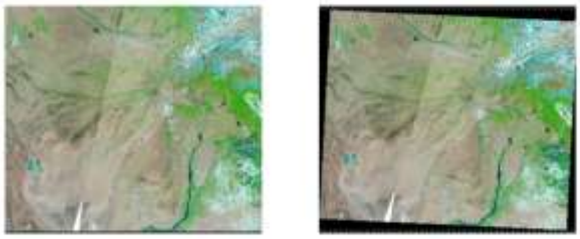
Several images from moderate imaging resolution spectroradiometer (MODIS) of 250 m resolution are used in this analysis. The ability to detect flood depends on the date of Image acquision and the weather / atmospheric condition, therefore cloud free images of flooding season are selected. As time series images are required for the study of the temporal dynamic of flood, all the available cloud free images are used together along Mapper 7.1 and ENVI 4.2.

Image Processing

Geometric Corrections

As regards method, geometric correction of the MODIS RAW images was carried out using ERMapper. First of all a single MODIS RAW image was geometrically corrected using rectification technique, for which whole Atlas of Pakistan of the scale 1:1000000 was scanned, and then it was rectified using ER Mapper through the latitude and longitude values on it. Registration of the Satellite image to the 1:1000, 000 scale topographic maps was done by selecting 25 Ground Control Points (GCPs). The Root Mean Square (RMS) error accepted was less than 1 pixel (250 m) at the first order and the nearest neighborhood transformation. Once a single image is rectified, the remaining images were rectified using image-to-image rectification technique. Average RMS error of less than 0.5 was achieved for all the images. The total number of points and their corresponding RMS errors are shown in the Table 1. Also the location of Ground Control Points (GCPs) on the RAW image is shown in the Fig.2, and similarly the SPOT RAW images were geometrically corrected, but for this registration of the image to the 1:50,000 scale topographic maps were done by selecting 25 Ground control Points (GCPs).

As the area of study is from Chashma Barrage to Sukkur Barrage along the Indus River, and a single satellite image could not cover this area, therefore two MODIS imagers were covering area of study used, one from Chashma to Guddu Barrage having datum Indian 75, and map projection LM1PAK1, and the other one from Guddu to Sukkur Barrage having datum Indian 75, and map projection LM1PAK2. All scenes were geometrically corrected to a map projection LM1PAK1 and geodetic datum INDIAN 75. The other Images covering study area from Guddu to Sukkur Barrage was also rectified in the same way keeping datum Indian 75,and map projection LM1PAK2 which were t hen mosaiced for further analysis. Some enhancement techniques were also applied to all of the scenes to enhance its information. Geometrically corrected and RAW MODIS scenes are shown in Fig.2. The corrected Image covers area of study from Chashma to Guddu Barrage.



RAW Imagery **Rectified Imagery Registered to LM1PAK1, INDIAN75**

Fig.2: Rectification of MODIS Imagery

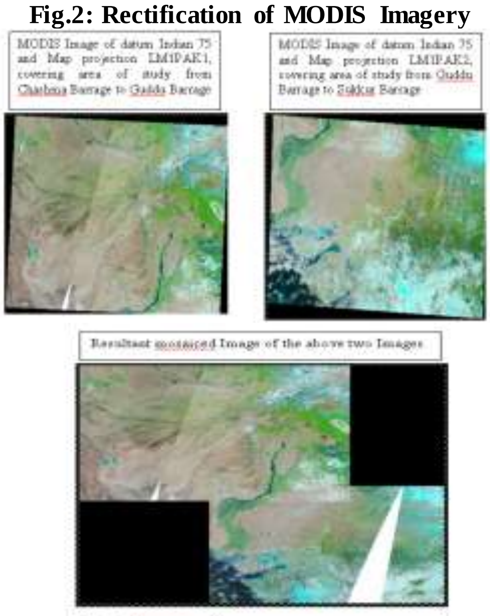


Fig 3: Mosaicing of Images

Mosaicing of multiple Images

Stitching or combining multiple adjacent images together into one large image is called Mosaicing. For flood mapping and flood classification along Indus River, images are stitched to achieve the most possible accurate results using ER Mapper. The out put mosaiced image is shown in Fig.3.

Image Classification

The pre flood image of may 2005 and flood Image of July 2005 was superimposed, and was then classified through ER Mapper into four classes. These are open water, flood extent from Chashma to Sukkur Barrage, Reservoir, and Vegetation. The image classification methods included the statistical method of maximum likelihood enhanced.

The objective of image classification is therefore to categorize each image pixel according to the classes they represent on the ground. The spectral pattern within the remotely sensed image is the basis for the categorization. The principle involved is that different features manifest spectral reflectance and remittance properties. In order to detect the floodwater in the study area, the pre and post flood superimposed image was classified into four classes. Different color have been assigned to these different classes/regions for analysis and defined in legend.

The final classified image (Fig.4) and the desired calculated statistics (Table 2) are shown below.

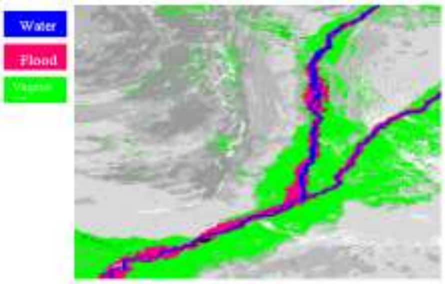


Fig 4: The classified MODIS Image of July 09 along the Indus River

Fig 4: The classified MODIS Image of July 09 along the Indus River

MODIS Flood Maps along the Indus River from Chashma to Sukkur Barrage

Flood monitoring from Satellite data provides the opportunity to quickly and precisely overview flooded area. The Indus flood in summer 2005 is mapped using a set of satellite images for the evaluation of flooded areas between Chashma and Sukkur Barrage, satellite data of MODIS sensor was used to derive the flood extent (Figs.5-9). For different sections Satellite data of multiple dates are used to perform the best fit to the flood peak along the river and it is found that the lower areas of Punjab i.e. Layyah, Bhakkar, Darya Khan, Muzaffargarh, Dera Ghazi Khan, Rahimyar Khan, Jampur, Rajanpur and Rojhan were highly affected cities, while in the Sindh Province the affected cities were Ghotki, Kashmore, Sukkur, Shikarpur, Kandkot and Pano Akil.

Calculations show that the flooded area is about 6428 km^2 where as the length of the mapped river section is approximately 1960 km. The spatial resolution of the data set used (MODIS) is 250m.

(a) Pre Flood Image May 2005

(b) During Flood Image July 2005

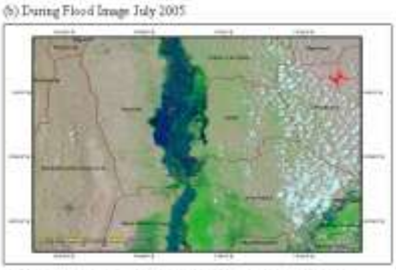


Fig 5: The above figure shows the Cities affected, Karor, Taunsa, Leiah, and D G Khan

(a) Pre Flood Image May 2005

(b) During Flood Image July 2005

Fig 6: This figure shows the cities affected, Muzaffargarh, Jampur, Rajanpur, and Alipur

(a) Pre Flood Image May 2005

(a) During Flood Image July 2005

Fig 7: shows the cities affected, Rojhan, Rahimyar Khan, and Khanpur and Rahim Yar Khan

(a) Pre Flood Image May 2005

(b) During Flood Image July 2005

Fig 8: shows the cities affected, Sadiq abad, kashmore and Ghotki

(a) Pre Flood Image May 2005

(b) During Flood Image July 2005

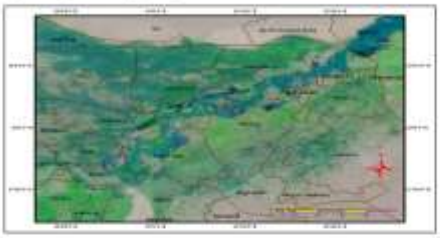


Fig 9: shows the cities affected, kandhkot, Khanpur, Panoaqil, Lakhi, Sukkur, and Garhi Yasin

Temporal Flood extent comparison of Rajanpur, Dera Ghazi Khan and Muzaffargarh districts through MODIS Images

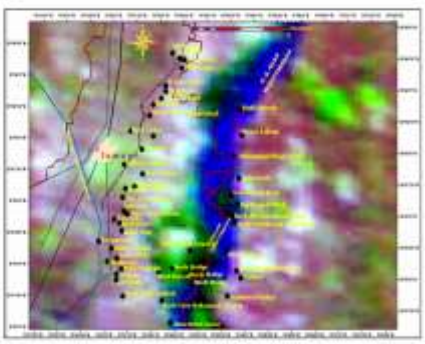
For detail analysis of damages assessment, for some of the flood-affected cities, satellite images of Rajanpur, Dera Ghazi Khan and Muzaffargarh districts are processed. The temporal changes in the extent of flood have been determined (Figs.10(a-b)-10(c-d),11). This map illustrates Satellite detected floodwater Changes over the affected districts of Rajanpur, DeraGhazi Khan and Muzzafaragarh during thirty-five days period (June 04 to July 09 2005). Flood estimates represent approximate measurements of the flood extent. It is seen that as the extent of flood increases gradually (Fig.12, Table 3) number of villages affected by flood also increases (Table 3). This analysis is made using MODIS terra imagery recorded during this period.

Results and Discussion

The Remote Sensing and GIS techniques can be used to monitor flood in all regions of Pakistan including Indus River. It can effectively support disaster mitigation. Flood assessment along Indus River describes the damage done in the prceeding paragraph. The high snowfall, was followed by a prolonged spell of high temperature (Barredo et al, 2005) shown in Fig.13, results in increase potential of high volume of runoff and subsequent flooding in the tributaries of Indus river and then in Indus

The floodwater in July 2005 covered 7787 sq km of the study area. During normal conditions, water was occupying around 1359 sq km. This means that roughly five times the amount of water is visible in the study area in July than in May 2005; we have obtained (Fig.5a,b) by processing the satellite images using ER Mapper for the flood damage assessment of the year, 2005. Fig.5(a) shows the pre flood image of May, 2005, while Fig.5(b) shows the post flood image of July, 2005, in which the cities of Taunsa, Karor, Leiah and Dera Ghazi Khan were affected, the difference of water extent is clear in Fig.5(a) and 5(b). Similarly, Figs.6-9 show that the affected cities were Muzaffargarh, Jampur, Rahimyar Khan, Khanpur, Rojhan, RahimYar Khan, Khanpur, Sadiqabad, Kashmore, Ghotki, Kandhkot, Panoaqil, Lakhi, Sukkur, and Garhi Yasin.

(a) Flood extent on 04 June 2005



(b) Flood extent on 25 June 2005

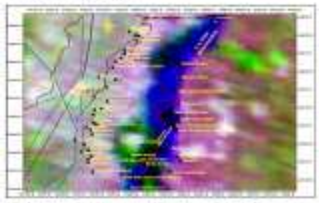
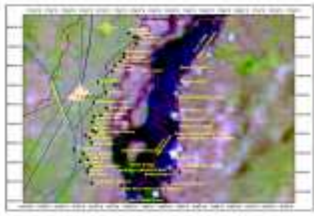


Fig 10 (a-b): Temporal comparison of flood extent at Rajanpur, Dera Ghazi Khan and Muzaffargarh city

(c) Flood extent at 30 June 2005



(d) Flood extent at 09 July 2005

Fig 10 (c-d): Temporal comparison of flood extent at the Rajanpur, Dera Ghazi Khan and Muzaffargarh city

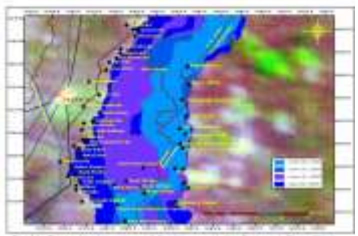


Fig 11: Temporal comparison of flood extent at the Rajanpur, Dera Ghazi Khan and Muzaffargarh city

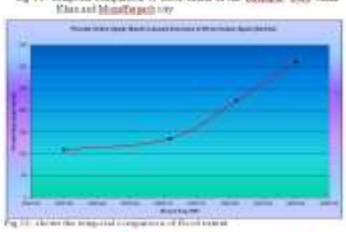


Fig 12: shows the temporal comparison of flood extent

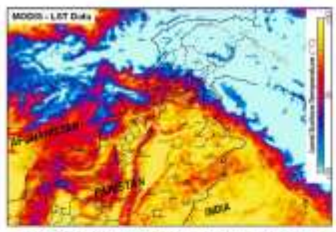


Fig 13: (June 2005 LST Data): As it is clear from the legend on the right side of the image, the yellow color is representing the Land Surface Temperature (LST) in the range 48-58 °C

The temporal comparison of flood extent at the Rajanpur, Dera Ghazi Khan and Muzaffargarh cities is shown in Fig.10-11, it is clear from the figure that flood covering area increases gradually which is affecting more villages day by day and it is also concluded that flood is prolonged for more than one month as it started from June 4, 2005 and lasted till July 9, 2005. The number of villages affected at different dates during flood 2005 in Table 3, and the flood covering area at different dates is shown in Table 3, as the flood affected villages are shown in a gap of around 10 days, it means that if it these techniques are applied at the time of flooding, it could be very fruitful in warning to vacate homes which could save their lives and property as well.

Recommendations and Future Directions

Mapping and monitoring of floods should be a regular activity. There is the need to collect field data especially during flood season each year. This would provide enough field data for accuracy assessments making future mapping and monitoring more accurate. This hopefully would lead to the creation of a database of time-series geo-referenced flood information useful for management.

In terms of cost effectiveness, MODIS images are recommended for flood monitoring, mapping and assessment, as MODIS data have high temporal resolution of one day. They are free and readily available on the Internet. However, if high resolution flood maps are required then the choice should be the real-time cloud free LANDSAT ETM+, SPOT, IKONOS etc. in the situation where clouds prevent use of optical images, L or P-band radar images are ideal choice.

GIS and RS techniques can effectively be used to monitor flood in all regions of Pakistan including Indus River. It can effectively support disaster mitigation. These techniques are more economical and efficient than conventional means of flood damage assessment.

Many problems or difficulties still exist. The cover range of image is wide enough to satisfy the request to monitor flood at the river scale, but problem about image is that the spatial resolution is course (250 meters) which is incapable to monitor some local but pivotal damages such as to railway, dikes, roads, buildings and infrastructure. Prevailing clouds during floods may cause problems in getting clod free MODIS images.

Keeping in view the frequent floods in the catchments and their related losses, it has been proposed that the construction of Munda Dam, Kalam Dam, Skardu Dam and Basha Dam will mitigate the flood risk caused by abrupt melting of temporary snow and seasonal torrential rains in the upper areas of the country. Besides producing hydroelectric power these Dams will control the decrease of reservoir's capacity in the lower areas, caused by sedimentation transported from upper areas.

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Table 1: The GCPs and the RMS values

#	Cell X	Cell Y	Easting	Northing	RMS
1	65.24	728.65	1435852.79E	2189378.85N	0.07
2	104.97	162.87	1454499.22E	2331114.96N	0.20
3	384.56	540.51	1523519.37E	2233336.41N	0.09
4	66.72	1227.51	1429102.04E	2064115.88N	0.16
5	135.18	1771.55	1439447.81E	1926664.99N	0.34
6	146.04	2623.23	1430169.46E	1712688.28N	0.13
7	100.57	3013.35	1412433.87E	1615142.49N	0.33
8	88.40	3754.65	1398639.51E	1429165.03N	0.08
9	70.07	4485.28	1383202.97E	1245897.18N	0.29
10	95.83	4544.99	1389279.06E	1230624.86N	0.17
11	729.64	4456.72	1559245.21E	1246143.51N	0.09
12	1695.03	4514.05	1815426.08E	1221674.95N	0.23
13	2971.25	4396.93	2156836.35E	1237932.58N	0.23
14	4869.01	4121.37	2665995.82E	1287362.35N	0.20
15	5415.35	4051.69	2812314.51E	1299186.09N	0.23
16	5459.34	3646.43	2829885.89E	1400508.90N	0.05
17	5458.14	2983.43	2839164.24E	1567026.47N	0.31
18	5435.53	2128.13	2845322.43E	1782070.60N	0.02
19	5466.89	1484.08	2862893.81E	1943497.39N	0.06
20	4919.98	560.55	2730533.70E	2181121.57N	0.12
21	4718.70	150.08	2682828.22E	2286303.52N	0.17
22	872.71	530.59	1653670.85E	2230797.67N	0.30
23	642.42	446.95	1593566.88E	2254116.69N	0.20
24	626.79	1325.77	1576816.59E	2033571.24N	0.23
25	1790.17	2124.74	1874955.28E	1820826.17N	0.14

Table 2: Flooded areas derived from maximum likelihood classification

Date	Sensor	Flooded area (Km^2)	Water level at Chashma Barrage (In feets)
June -4-2005	MODIS	3200	640
June-20- 2005	MODIS	3900	645
June -30-2005	MODIS	4700	645
July-9- 2005	MODIS	6428	646

Table 3: Flood extent and villages affected at different dates

Day	River Span (Sq km)	No. of villages Affected
June 04, 2005	108.529531	11
June 20, 2005	134.090708	12
June 30, 2005	221.024095	16
July 09, 2005	309.814832	30