Use of RS & GIS in Flood Forecasting and Early Warning System for Indus Basin

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***Abstract*- Inundation mapping for Indus River and its tributaries is a large as well as complex task to undertake. GIS and remote sensing technologies enable us to handle the complexity involved in the development and maintenance of such large systems. The main feature of such systems is the easy incorporation of changes to system. The influence of a revision in methodolgy at any stage of the system development lifecycle does not propagate to every other stage of the system thus allowing for incremental development. Moreover, the savings in time and project cost cannot be stressed more as use of satellite technology complements conventional engineering techniques for data gathering and lead to more information rich systems.**

I. INTRODUCTION

Development of a flood forecasting and early warning system is a colossal activity that can span over large time periods. It requires inputs from different areas viz., hydrology, remote sensing and geographical information systems etc. In case of a flood forecasting system for basins of Indus and its tributaries, there is a large mass of information associated. Handling that information by conventional engineering procedures is not practical. An approach with its basis in GIS can provide for a system that is easier to handle and maintain. GIS and remote sensing can help at almost all stages of the development life cycle of a flood forecasting and early warning system. Land cover information in the form of thematic maps with attribute data attached serves as the base for other activities. A subset of features from these thematic layers is embedded as barriers to the digital terrain model (DTM) for the flood plain. DTM generation relies on the density of elevation information for the flood plain. In this regard, remote sensing has proved successful. Remote sensing complements and utilizes conventional survey techniques for the development of information rich spatial systems. In this case, Shuttle Radar Topography Mission (SRTM – this is 90m degraded data, not 30m actual) data that gives 90m resolution elevation information has been used for DTM generation. This DTM is used later with water surface grid to derive inundation maps for the flood plains. Inundation maps are generated for different return periods. Different spatial operations allow the identification of villages, roads and cultivated land that may be endangered in different levels of flooding. Section 2 gives a brief background of Indus river system and its history of floods. The project rationale, required outcomes with the description of problems has been detailed in Section 3. Section 4 discusses in detail the approach taken for achieving the project goals. The results obtained by the execution of methodology discussed in section 4 are analyzed in section 5 and the benefits obtained by the resulting product are highlighted. Section 6 presents the conclusions that have been drawn from this study and also discusses the new knowledge that has been added to the research volume. These observations can be helpful in similar projects in future.

II. BACKGROUND

Indus River along with its tributaries, namely Chenab, Jhelum, Sutlej and Ravi, constitute one of the largest river systems in the world. It has a long history of flooding. Since 1970s, there have been six large scale floods causing immense loss to life and economy. The most recent large floods occurred in 1988 and 1992 that caused a death toll of nearly 1370 and damages estimated at $ 2.2 billion [1]. These figures reveal that damages could not be controlled even in the presence of a large battery of structural measures against flooding. Therefore, a need for non-structural measures was acknowledged and a project was conceived in 1993. The project phase that we discuss in this paper commenced in 2003.

III. PROJECT DESCRIPTION

Non-structural measures do not control flood and are basically designed to control the damage. There are two non-structural measures viz., avoidance (before flood takes place) and response (after flooding) [2]. These measures are based upon different studies that are:

- To study the mechanism of flood occurrence
- To analyze the natural and social environment in which flood occurs and develop flood risk zones
- To improve the efficiency and genuineness of flood disaster assessment

The project consists of studies related to hydrology of the Indus river system. Data for catchments and rainfall were collected. A river routing model has been developed that can predict the flood condition (discharges and stages) at known locations.

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TABLE I

DATASET FOR FLOOD PLAIN MAPPING

Layer	Geometry	Attribute
Land use	Polygon	Abandoned river bed
		Barren area
		Bund (dike)
		Cultivated area
		Canal/escape/spillway
		Dry nallah
		Drain
		Flood plain
		Grass
		Graveyard
		Hill
		Low barren area
		Mud
		Nallah (active)
		River
		Range forest
		Sand dunes
		Spur
		Village/town/settlement
		Water body
Canal	Polyline	Canal
		Feeder
		Branch
		Drain
		Distributary
		Minor
		Nallah
		Wah
		Escape
Road	Polyline	Metal
		Un-metal
		Cart track
		Railway Track

The other non-structural measures require, in the first place, digital maps of the entire Indus basin. This is where the GIS comes in to the picture. Flood plain mapping aims at producing digital maps of the flood prone areas of the Indus basin in order to show expected inundated areas for various flood scenarios. This would lead to a rationale for zoning of the flood plains and would facilitate in meeting the objectives and goals of nation-wide planning and management of floods, preparation of guidelines for flood fighting (rescue and relief). Flood plain zoning also provides a foundation for proper legislation of the use and prevention of encroachment of river adjacent areas.

The flood plain mapping of Indus involves preparation of digital GIS maps for rivers Indus, Jhelum, Chenab, Ravi and Sutlej at a scale of 1:50,000. The whole basin is covered by a total of 186 such sheets (approx. 140,000km^2). The purpose of preparing digital GIS maps is to instantaneously show the outputs from flood routing models in the form of inundated areas so that early warning can be issued to threatened villages / towns / settlements in addition to carrying out flood damage assessment. The use of these digital maps will be discussed in detail in a later section. The following section takes us through the different stages in the development of flood risk maps.

IV. METHODOLOGY

The development of flood risk maps requires thorough preparations with respect to data availability. An immense digitization activity was launched that resulted in a large dataset comprising of different layers. The methodology followed is illustrated in Fig 1.

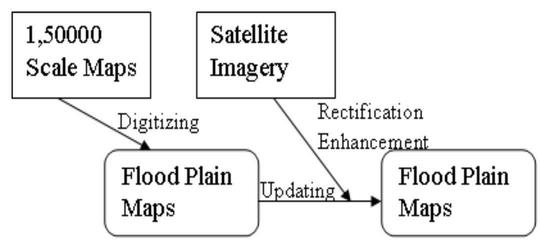

Fig. 1 Workflow for development of flood plain maps and digital elevation model

The initial maps were prepared using scanned sheets and later on updating using satellite imagery. Fig. 2 shows a snapshot of the landuse and infrastructure map. It is not possible to show the names of villages at this level of detail.

A. Dataset

As can be seen in Fig. 1, initial digitization was carried out using Survey of Pakistan (SoP) sheets. The dataset consists of layers as listed in Table 1. A published map contains many 'themes' of information in a single layer. After the segregation of thematic data, a rich dataset was created. Since the topographic map sheets acquired from SoP mostly date back to 1970s and 1980s, it had been foreseen at the start of project that 20m resolution, 4 band satellite images will be used for updating the dataset. The updating process improved the landuse maps in the case of settlement boundaries and new roads. More significant improvements were observed in the case of new dikes along the river, river training works and new course of the river.

B. DTM generation

The development of a digital terrain model (DTM) for a flood plain is a non-trivial task. But when one talks about Indus basin, it becomes more complicated by the mere area to be included. In such large flood plains, it is neither practical, nor possible to carry out a detailed survey. An approach was established to use Shuttle Radar Topography Mission (SRTM) data for the generation of a DTM.

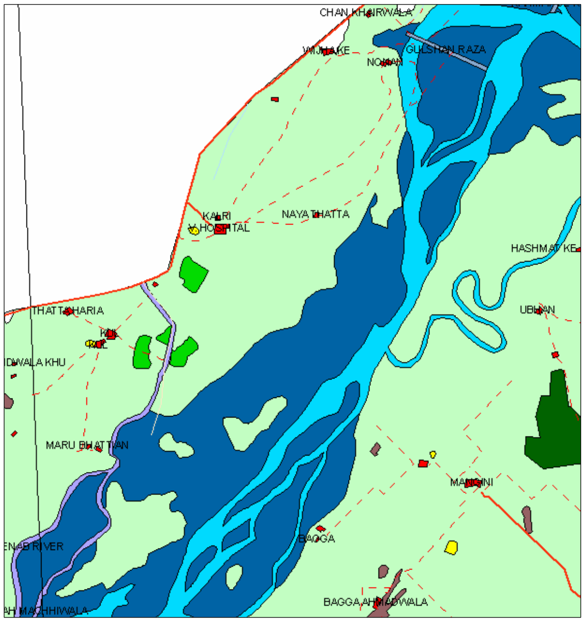

Fig. 2 Landuse and infrastructure mapping

C. Rationale for Using SRTM

As mentioned earlier, Indus flood plain area is not easy to cover by conventional survey techniques. An alternate way to generate the DTM would have been to acquire stereo pairs of satellite imagery.

But the project cost did not permit such an acquisition. SRTM data with a density of 90m grid spot elevations provides a near to reality topographic picture of the flood plains. To make our system more reliable from engineering viewpoint, SRTM data has been analyzed and found to have two types of noise in spot elevations by two different sources viz., atmosphere and sensor. Therefore, SRTM data has been processed using two denoising procedures described below. Fig. 3 shows a comparison of cross-section from survey to the one extracted from SRTM.

D. Correction for Bias

Bias is additive noise which can originate from different sources, one of which is the sensor. The SRTM data for each reach of a river is calibrated with respect to the bathymetric surveys conducted across the river plain at varying intervals of 1km to 5km. The SRTM data is first used to create a Triangulated Irregular Network (TIN) to get a surface for reading elevations at any location. Then, corresponding elevations from SRTM TIN and from bathymetric surveys are regressed [3]. For each reach, a correction, positive or negative is applied to the SRTM spot elevations.

E. Removal of speckle noise

Simultaneous visual inspection of survey cross-sections and sections extracted from SRTM TIN reveal that there exists speckle type noise in spot elevations. The correction for bias led to de-trending of data and affected only the general trend of data, globally and did not affect the individual spot levels. Speckle is usually high frequency noise that can originate from sensor or atmosphere and affects individual readings as can be observed in Fig. 3. High frequency noise can be easily removed by simple low pass filtering. The SRTM data was low pass filtered to remove high frequency noise components thus providing smooth cross-sections. The smoothened SRTM TIN is appropriate for inundation mapping as sudden changes in elevation and slope have been removed.

F. Flood barriers

The features acting as barriers to water have been shown highlighted in Table I. Elevations for these barriers have been established by different sources. Elevation data have been gathered from irrigation authorities, past consultant reports or visits to the site for which data is not available. But this process of data gathering can be adopted for a small subset of features that are significant in flood control such as dikes (bunds). There are other features like roads, canal embankments and railway tracks for which data is not available and is neither practical nor possible to collect by site visits or to offices of authorities. In case of such barriers, elevations have been based upon the neighbouring SRTM spot levels. A constant factor is added to the neighbouring spot elevations in majority and the new value is assigned to the feature as elevation. The features are embedded into the DTM formed by SRTM spot elevations. SRTM points are removed from locations where barriers have to be embedded. As can be seen in Fig. 4, each feature is embedded as a hard line feature

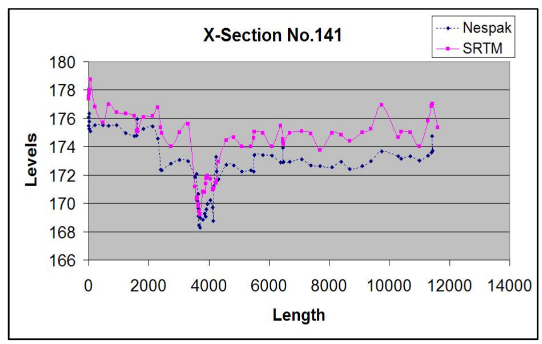

Fig. 3 Comparison of cross-sections obtained by survey and SRTM

so that slopes are discontinued across a feature. This is in compliance with reality.

G. Inundation Maps

Generation of flood maps requires another input. Inundation results from the subtraction of natural surface level from water level at a given point. In this case, water levels were provided by river flow modeling. These water levels established by river flow models are used to generate a water level surface by linear interpolation. Water levels at different locations along the river path are represented by lines having a water level attribute. A TIN is generated using these lines and linear interpolation. The resulting surface has water level for each location. Such water level surfaces are generated for different return period flood water levels.

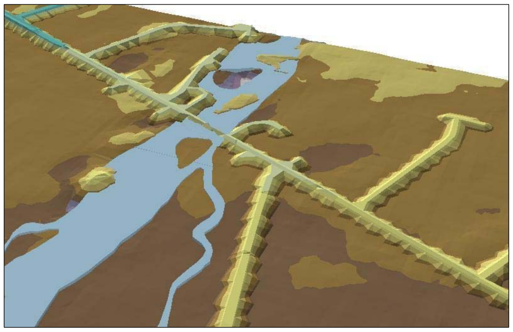

Fig. 4. 3D- view from upper Indus showing barriers

The water surface is then converted into a 80m cell size grid. A similar grid is generated from the TIN for flood plain DTM. The subtraction of the two grids results in an inundation grid. The zero elevation contour extracted from this inundation grid marks the extent of flood inundation for a given return period. Fig. 5 shows the inundation map for 50 yrs return period for the same area as shown in Fig. 2. The blue colour shows highly inundated areas while the red colour marks the area with least depth of inundation.

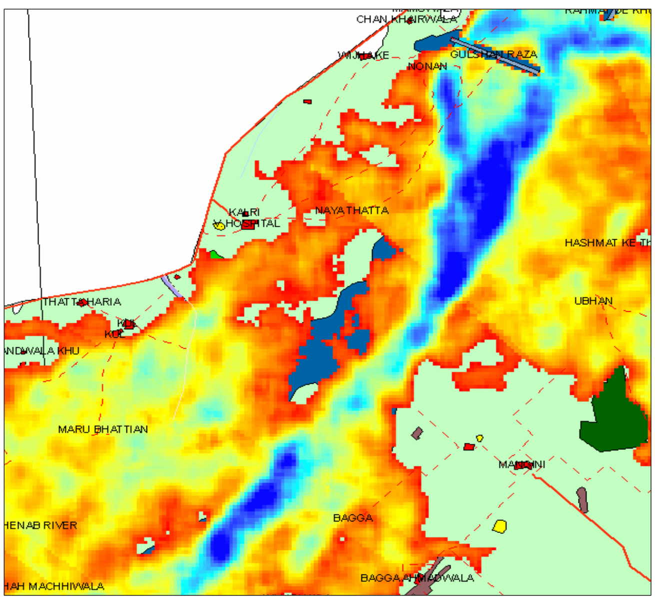

Fig. 5 Inundation map with high depth of inundation in blue and least depth of inundation in red

But this automated procedure does not suffice to get the true inundation extents for some areas. These problematic areas are generated where barriers are discontinued and water can go around these barriers and travel against slope till it exhausts its head or hits another defense line. Manual intervention is thus required for such locations to correct the flood inundation extents.

V. Results and Discussion

The main result from the application of above mentioned methodology is the inundation map. Inundation maps have been generated for different return periods. The extents of the inundation maps allow us to identify settlements that are affected by floods. Settlements can now be categorized on the basis of flood threat level. Secondly, assessments of agricultural damages done by floods can be calculated by simple on-screen operations. Similar information can be extracted for roads and categorization can be done to identify road segments in maximally flooded zones. Lengths for these roads in inundation or prone to flooding can be calculated easily.

This system shall also serve as the basis and rationale for the development of flood zones and processes for flood damage assessments.

Since the flood inundation maps, landuse maps and DTMs are in electronic form, it is very easy to incorporate a change in the system that may be forced by the entry of a new dike or road in the flood plain.

VI. Conclusions

Geographical information systems lessen the complexity of handling data for large flood plains. Remote sensing can cut down project cost and time by complementing conventional survey techniques. A very important conclusion drawn from this project is that systems have to be flexible so that changes to the methodology can be incorporated easily at any stage of project. And that change should have a controlled influence on past stages of the system development life cycle. Incremental development of systems cannot be stressed more as large systems are developed over large time periods during which physical and technological changes can induce changes in methodology. Such factors demand the use of computer based GIS for water engineering projects.

References

[1] Country Profile for Natural Disasters – Pakistan, http://www.em-dat.net/disasters/Visualisation/profiles/natural-table-emdat.php?country=Pakistan&Submit=Display+Country+Profile

[2] Z. Yuan-chang, “Development of Flood Risk Study and Its Perspectives in China”, in the *proceedings of the Conference on Information Technologies for Flood Management*, Beijing, P.R. China, September 17th, 2001

[3] E. W. Ronald, H. M. Raymond, L. M. Sharon and K. Ye, *Probability & Statistics for Engineers & Scientists,* Sixth Edition, Prentice Hall, February 1998

[4] S. L. Cutter, “GI Science, Disasters, and Emergency Management”, *Transactions in GIS*, 2003, 7(4):439-445

[5] D. Lumbroso, “Guidance on Flood Risk Assessments”, HR Wallingford Report No. EX5096

[6] X. Yang and B. Rystedt, “Predicting Flood Inundation and Risk Using GIS and Hydrodynamic Model: A Case Study at Eskilstuna, Sweden”, *Indian Cartographer*, 2002, MFDM-04

[7] F.Naz and M. Shafique, “Data integration for Flood risk analysis by using GIS/RS as tools”, Map Asia 2000