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EVALUATION OF FLOOD AND WATERLOGGING DYNAMICS IN INDO-GANGETIC PLAIN USING GEOSPATIAL TECHNIQUE: A REVIEW

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Abstract: Waterlogging and flood therefore constitutes the main hazards in the northern Bihar plains resulting due to surplus water availability in the region. The severity of these hazards turns into a disaster due to existence of high population density with low socio-economic status. Therefore, examination of vulnerability of society to these hazards in view of changing climatic conditions need evaluation of past and present spatial occurrence of these hazards vis-a`-vis socio-economic conditions of present population existing in these regions. In order to understand the causative factor behind waterlogging and to determine geo-hydrological constraints on waterlogging it is important to examine the spatial extent of waterlogging and its seasonal variation with reference to geomorphology, subsurface lithological variation, relief, groundwater level as well as anthropogenic activity. It is imperative that recurrent floods in the region cause extensive waterlogging, therefore understanding of rainfall pattern during the southwest monsoon season in the entire catchment area of rivers draining the area can provide severity of flood induced hazards in each catchment. Relating waterlogging and flood induced hazards to socio-economic aspect can help in prioritizing the scientifically driven mitigation plans to combat ill effect of such hazards. Such studies based on Remote Sensing and Geographical Information system (GIS) can provide a better platform for developing insight into the intricate relations of various hydro-geological parameters influencing waterlogging and flood hazards in the area.

Keywords: *Flood, Waterlogging, Indo- Gangetic Plains, Remote Sensing, GIS*

I INTRODUCTION

Indian sub-continent on account of its geographical position, climate and geological setting is vulnerable to natural hazards such as cyclone, drought, floods, earthquakes, wild-fire, landslides and avalanches. India is the worst flood-affected country in the world after Bangladesh and accounts for one fifth of global death count due to floods (Agarwal and Narain, 1996). Around 40 million hectares of land in the country are flood prone and an average of 18.6 million hectares of land is affected annually. The annual average cropped area affected by floods is approximately 3.7 million hectares. Nearly 75 per cent of the total Indian rainfall is concentrated over a short monsoon season of four months (June-September) (Dhar and Nandargi, 2003). As a result the rivers witness a heavy discharge during these months, leading to widespread floods in Uttar Pradesh, Bihar, West Bengal and Assam. The Gangetic plains in the north Bihar region have recorded the highest number of floods in India in the last 30 years (Kale, 1997).

Indo-Gangetic plain (IGP) is considered as one of the largest plains in the world formed by the river systems. Indus, Ganga, Yamuna, Ghaghara, Gandak and Kosi emerging from the Himalayas and debauching the IGP are among the rivers, which carry and transport the highest sediment loads in the world (Tejwani, 1987). The alluvial plains of the IGPs are still active with general slope of the ground from west to east and elevation of about 200 m above sea level (asl) in the western parts to near sea level in the eastern parts. Average annual rainfall varies between 300 mm and 1,600 mm, roughly linearly increases eastward at the rate of 0.6 mm/km (Singh and Sontakke, 2002). The area of the IGP is nearly 13% of the total geographical area of the country and it produces about 50% of the total food grains which feed 40% of the population of the country (Srivastava *et al*., 1994).

The Indo-Gangetic Plain (IGP) is drained by some of the largest river systems in the world. These alluvial plains are also severely affected by frequently occurring disastrous floods and are presently regarded as the worst flood affected region in the world. The increase in population and industrial growth resulted in the development of more and more settlements in the flood plain area. Therefore flood hazards have become ever-increasing natural disaster resulting in the highest economic damage among all kinds of natural disasters prevalent in the area.

II BIHAR FLOODS

The Bihar state which lies in the Gangetic basin, accounts for 16.5% of the flood-prone area and 22.1 % of the flood-affected population in India. The flood-prone area in Bihar has nearly tripled from 2.5 million hectares in 1954 to 6.8 million hectares in 1994 (Bhanumurthy*et al.,* 2010). The rivers that regularly inundate the plains are the Ganga, Kosi, Gandak and Son. The Gangetic plains of Bihar situated north of river Ganga, referred to as northern Bihar plains are drained by an extensive networks of rivers which has their upper catchment area in the Himalayas. These rivers carry high discharge and large quantities of sediments eroded from the mountainous slopes, which get deposited within the channel and adjacent gently sloping plains causing reduction in channel gradient and carrying capacity of the river. Southern Bihar plain located south of river Ganga also experiences floods due to excess discharge in the tributaries of the Ganga river like the Son, Punpun, Kiul and Harohar. Among these river only Son river cause extensive floods due to its large catchment area whereas other rivers exhibit seasonal flooding during southwest monsoon season (June-October).

Due to recurrent flooding and concomitant waterlogging vast stretches of productive agricultural lands are converted to wasteland in the North Bihar. The surface waterlogging caused due to accumulation of runoff and flood waters in depression area comprises the most dominant type of waterlogging phenomenon in the northern Bihar plains. Satellite data provides accurate assessment of surface waterlogging as well as its spatio-temporal distribution in a region. Some of the major floods in the recent past that affected the region include the floods in the year 1987, 1998, 2000, 2002, 2004, 2007 and 2008. Among these flooding events the area under flood inundation during 1987 was 47500 sq km with death of 1399 people. Due to floods in 1998, 381 people died and 25120 sq km area was inundated. During the year 2000, 336 people lost their life and 8050 sq km was inundated due to flooding. The flood in year the 2002 resulted in death of 489 people and 19690 sq km area was inundated. During the year 2004, 885 people were killed and 27000 sq km area was under flood inundation.

In the year 2007, 18833 sq km area was under flood inundation with death of 1287 people (http://disastermgmt.bih.nic.in/). It is apparent that the severity of flood hazards with reference to human casualties during flooding has increased in the recent periods in comparison to earlier years. A more recent disasterous flood in Kosiriver initiated on 18th August 2008 affected five districts in North Bihar and render 2.5 million people homeless. It also resulted in heavy loss of agricultural lands, comprising 81.45% of total flood inundation area (3089 sq km), which reflect the high vulnerability of the terrain to flood hazards (Singh *et al.,* 2011).

III WATERLOGGED DYNAMICS

In India, an estimated 2.46 million hactares of land is reported to have suffered from waterlogging (Anonymous, 1991), and the area containing salt-affected soils has been estimated to be 7.0 million hactares (Abrol and Bhumbla, 1971). Waterlogging, closely associated with salinization and/alkalinization, continues to be a threat to sustained irrigated agriculture, affecting an estimated 6 million hactares of fertile land in India (National Commission on Agriculture, 1976). About 4.5 million hectares of land have already become barren (Singh, 1992) and more lands are being encroached upon by these problems every year, depending on the climate, topographic, geohydrologic and groundwater conditions. India is estimated to have about 58.2 million hectares of wetlands (Prasad *et al.*, 2002), majority of which are distributed within the Indo-Gangetic plain. Generally regarded as ‘‘a water-surplus area’’ (Ghosh *et al.,* 2004) the entire region is characterized by palaeo levees, swamps, relict palaeo channels, meander belts, ox-bow lakes, and cut-off loops (Ahmad, 1971).

The demonstration of the potential of coarse spatial resolution LANDSAT MSS data for generating information on wastelands at 1:1 million scale with 8 categories of wastelands for entire country by National Remote Sensing Centre (erstwhile NRSA) in 1984-85 revealed that 53.30 million hactares corresponding to 16.40% of the geographical area of the country was under wasteland. A 13-fold wastelands classification system was adopted for mapping wastelands at 1:50,000 scale for entire country using satellite images from LANDSAT Thematic Mapper (TM), IRS LISS II and IRS 1C LISS III sensors. The result indicated that 63.85 million hactares of land covering 20.17% of total geographical area of the country was under wastelands (Ministry of Rural Development and NRSA, 2000). A modified classification system, with the inclusion of more classes to indicate the severity of degradation totaling 28 classes, was adopted by NRSC for deriving information on wastelands. Based on this classification an estimated 55.27 million hactares covering 17.45% of the country’s geographical area was mapped as wastelands in 2003 (Ministry of Rural Development and NRSA, 2005).

In India, an estimated 6 million hactares land is subject to waterlogging of which, 3.4 million hactares are waterlogged due to surface flooding and the rest of the area i.e 2.6 million hactares due to rise of ground water table (National Commission on Agriculture, 1976). Land degradation mapping carried out for the entire country on 1: 500,000 scale using multi-temporal ResourcesatAWiFS data revealed that 32.07% of the total geographic area of the country is subjected to land degradation (Ajai*et al.*, 2009). Statewise distribution of land degradation indicate that Bihar state comprise 414, 983 hactares area under land degradation, of which waterlogging constitute 188,070 hactares (45.31%). Waterlogging exhibit seasonal variation due to changes in the groundwater levels as well drying up of surface waterlogging area due to high rate of evaporation during the pre-monsoon season.This seasonal variation can be mapped using temporal satellite data in order to develop effective mitigation measure to restore the productivity of soil.

The largely monotonous looking terrain of the Indo-Gangetic Plain (IGP) is divisible from north to south into a number of geomorphic surfaces of regional extent (Ghosh and Singh, 1988; Prakash *et al.,* 2000; Shukla and Bora, 2003; Sinha *et al.,* 2002). The IGP shows a series of terraces, bars and meandering scars resulting in microhigh and microlow area on the apparently smooth topography (Pal *et al.*, 2003). Many studies (Gupta and Subramaniam, 1994; Singh and Ghosh, 1994; Singh, 1996) provide insight in the geomorphology, sedimentology and geochemistry of Ganga Plain, and also emphasize the need to study the nature of anthropogenic impact on Ganga Plain in conjunction with the geomorphology.

IV FLOOD DYNAMICS

A number of rivers like Ganga, Kosiriver, Gandak river and many others draining the Gangetic plains show spatio-temporal shifting of their channels. A very high avulsion rate of Kosiriver is apparent due to its westward migration by 110 km in the last 200 years (Agarwal and Bhoj, 1992; Gole and Chitale, 1966) in comparison to the Gandak river which has recorded a lateral eastward migration of about 80 km in the last 5000 years (Mohindra*et al.*, 1992). Kale (2002) remarked that there is also significant spatial variation in the magnitude, frequency and power of floods, on account of regional variations in monsoon rainfall, basin characteristics and channel geometry. Kale (2003) suggested that the flood induced changes are conspicuous in parts of Indo-Gangetic plain and they result in the variation of the channel dimension, position and pattern of major rivers. Sinha and Friend (1994) identified the different classes of river systems in the Gangetic plains of North Bihar based on their source area and distinctive morphological, hydrological, and sediment transport characteristics. The rivers draining the Gangetic plains exhibit remarkable geomorphic diversity in terms of differences in stream power and sediment supply from the catchment area.

The rivers draining the eastern Gangetic plains viz., Kosi, Gandak, BurhiGandak, Kamla-Balan etc. are characterized by lower stream power and higher sediment yield that results in aggradation. The variation of stream power is attributed to differences in rainfall and rate of uplift in the hinterland (Sinha *et al.*, 2005). The normal annual rainfall in the Gangetic Plains varies from 60 cm to more than 160 cm over the foothills and northern parts of plains (Singh, 1994). Therefore these rivers pose three major fluvial hazards: rapid lateral migration, frequent flooding and extensive bank erosion. Overbank flooding is a perennial problem, with most of the rivers of the north Bihar plains causing enormous damage to life and property (Sinha, 1998a). Zade*et al*. (2005) made an attempt to quantify and analyse intra and inter-basin runoff potential for all basins of India using multi-date remote sensing data, curve number approach and normal rainfall data of 376 stations. Hydrological characteristics, sedimentological readjustments and neotectonic tilting are the important factors triggering avulsions and thereby influencing the development of anabranching (Jain and Sinha, 2003a). The Plain rivers in the Ganga catchment appear to be aggrading, thereby exacerbating the annual overbank flood in the plain (Wasson, 2003).

Spaceborne multispectral data, by virtue of providing synoptic views of fairly large area at regular intervals, have been found to be very effective in providing the necessary information on salt-affected soils and waterlogged area in a timely and cost-effective manner (Dwivedi, 1997). Visual interpretation of the IRS data was used to delineate salt affected and waterlogged soils (Sharma and Bhargava, 1988; Sharma *et al.*, 2000; Sujatha *et al.*, 2000). Permanently and seasonally waterlogged area was successfully mapped with remote sensing data (Mandal and Sharma, 2001).

V SALINITY AND WATERLOGGING

On a global scale, irrigation induced salinity and waterlogging severely affects about 30 million ha (El-Ashry and Duda, 1999). Waterlogging, closely associated with salinization and/alkalinization, continues to be a threat to sustained irrigated agriculture, affecting an estimated 6 million ha of fertile land in India (National Commission on Agriculture, 1976). Waterlogging and salinity are the potentially serious problems for the agricultural industry and can reduce the potential yield by as much as 30-80% for many crops (McFarlane and Williamson, 2002). In India, the total area suffering from waterlogging is estimated to be about 33000 sq km (Bhattacharya, 1992), in which the state of Bihar constitutes an area of nearly 9000 sq km. LANDSAT and IRS satellite images have been successfully used for the assessment of waterlogging in different irrigated command area in India (Bouwer *et al.,* 1990; Choubey, 1997;Lohani*et al.,* 1999; Sidhu *et al.,* 1991).

Waterlogging in low lying area is created by seepage of water from irrigated uplands and from canal systems. Continued irrigation with excess water induces rising of the groundwater table (Bouwer *et al.,* 1990). Drainage congestion causing surface waterlogging and flooding in area suitable for Kharif crops (monsoon season) and Rabi crops (winter season) are a common problem during monsoon season in most of the downstream stretches of river basins in India (Ganga Flood Control Commission, 1986; Bhattacharya, 1992). Examination of the historical pattern of land cover/use change in an area provides the necessary context for framing modern ecological studies and designing conservation efforts (Boyle *et al.,* 1997).

The salinity problem in irrigated agriculture is frequently associated with groundwater table within one to two meters below the ground surface (Stuyt*et al*., 2000). Area with saline soils associated with a high water table conditions promote unfavourable growth conditions for green vegetation (Murty and Srivastava, 1990). Hachicha*et al.* (2000) assessed the impact of irrigation on changes of the groundwater level and soil salinity in Northern Tunisia and evaluated the future salinization risk.

Irrigation development brings about large scale changes in the local geohydrological regime which often result in mobilization of salts stored in the underlying substrata (Smedema and Shiati, 2002). Pearce and Warford (1994) stated that irrigation-induced salinity was reckoned as a pervasive threat to agricultural production and to the environment due to its adverse effects on the sustainable use of land and water resources. Srivastava *et al.* (1997) established remote sensing and GIS techniques for regional investigations of groundwater zones in Indo-Gangetic plains and stated that high salinity correspond to depressions in the bedrock. High relief, steep slopes and high drainage density impart higher runoff causing less infiltration, while low relief, gentle slope and low drainage density result in low runoff and comparatively high infiltration (Saraf and Choudhury, 1998).

VI FLOOD AND WATERLOGGING MODELING

Satellite images are increasingly used in ground water exploration because of their utility in identifying various ground features, which may serve as either direct or indirect indicators of presence of groundwater (Bahuguna*et al.,* 2003; Das *et al.,* 1997). Hydrogeomorphological mapping is very helpful in delineation of groundwater prospect and deficit zones (Carver, 1991; Goyal *et al.,* 1999). Remote sensing and GIS applications have been used in delineation of groundwater potential zones (Ghose, 1993; Khan and Moharana, 2002; Krishnamurthy *et al.,* 1996; Pradeep, 1998; Sankar, 2002; Saraf and Choudhary, 1998).

Remote sensing data from airborne (aircraft) and space borne (spacecraft/satellite) platforms, can provide essential information for a variety of flood impact mitigation strategies including improved prediction of extreme events (Engman, 1998). Such data can be gathered using a variety of remote sensing systems and formats including multispectral satellite imagery (Ali *et al.,* 1989; Okamoto *et al.,* 1998; Rango and Salomonson, 1974; Yamagata and Akiyama, 1988) and active microwave satellite (Adam *et al.,* 1998; Imhoff*et al*., 1987; Ormsby et *al*., 1985).

Microwave remote sensing satellite systems such as RADARSAT provide the most effective tools currently available for flood mapping and monitoring applications world-wide due to their ability to provide synoptic coverage on a global scale under all weather and lighting conditions at comparatively fine temporal and spatial resolution (Fung *et al.,* 1998). Satellite-based remote sensing images have been used to map the extent of flood inundation since the early 1970s (Deutsch *et al.,* 1973). During the last two decades, satellite-borne Synthetic Aperture Radar (SAR) with its cloud-penetrating capability has been used with considerable success for mapping the areal extent of flooding in some of the major floodplains and river basins of the world (Wilson and Rashid, 2005). Increasingly available and a virtually uninterrupted supply of satellite-estimated rainfall data is gradually becoming a cost-effective source of input for flood prediction (Harris *et al.,* 2007). Asante *et al.* (2007) described the application of remotely sensed precipitation to the monitoring of floods in the Limpopo basin, South Africa to monitor extreme flood events and provide at-risk communities with early warning information.

Sinha *et al.* (2008) performed a GIS based flood risk analysis in the Kosi river basin, North Bihar using multi-parametric approach of Analytical Hierarchy Process (AHP) and integrated geomorphological, land cover, topographic and social (population density) parameters to propose a Flood Risk Index (FRI). Shahid and Behrawan (2008) used GIS to analyse rainfall variability and emphasized the combined role of hazard and vulnerability in defining risk for spatial assessment of drought risk in Bangladesh. Dewan *et al.* (2006) utilized multi-date RADARSAT Synthetic Aperture Radar (SAR) data and Geographical Information System (GIS) to delineate flood hazard area for the major flood of 1998 in Greater Dhaka. Dapeng*et al.* (2008) used waterlogging affected frequency map and landuse map to assess waterlogging risk in Lixiahe region of Jiangsu province based on AVHRR and MODIS satellite images.

VII CONCLUSIONS

In the present research work we identified the temporal pattern of floods and waterlogging in the Northern Bihar plains and evaluated the effect of various terrain, hydrological and anthropogenic factors on waterlogging. We also examined the risk of flood and waterlogging hazards to society based on the hazard proneness and social vulnerability. The climate change would have profound effect in the northern Bihar plains as the region has a dominantly agrarian economy and the positive changes in the rainfall pattern would result in excess waterlogging in the region. The changing climatic conditions with more intense rainfall predicated for this region in future may trigger more sediment flux in the upper catchments making the river channels shallow and prone to flooding.

The watershed area of all the major river draining the area extent up to the Higher Himalayas and Tibetan plateau region. The snow and glacier covered regions in the upper parts of the catchment would shrink with the perceived increased temperature conditions. Under these conditions there would be an increase in the cases of glacier lakes outburst floods (GLOF) which may leads to flash floods in the lower catchment area and plain regions. Therefore future work will be directed towards use of satellite data in evaluating landuse-landcover changes, river hydrodynamics and morpho-tectonics and their relationship with the flood events and concurrent waterlogging. The variability in climatic conditions through spatial and statistical computation of rainfall, temperature, river discharge, sediment flux etc. would be evaluated. The flood risk analysis using high resolution satellite data at village level would be attempted to provide technology driven solutions to administrator dealing with flood management in the region.

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