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Evaluating influence of active tectonics on spatial distribution pattern of floods along eastern Tamil Nadu, India

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ABSTRACT

Flooding is a naturally recurrent phenomenon that causes severe damage to lives and property. Predictions on flood-prone zones are made based on intensity–duration of rainfall, carrying capacity of drainage, and natural or man-made obstructions. Particularly, the lower part of the drainage system and its adjacent geomorphic landforms like floodplains and deltaic plains are considered for analysis, but stagnation in parts of basins that are far away from major riverine systems is less unveiled. Similarly, uncharacteristic flooding in the upper and middle parts of drainage, especially in zones of an anomalous drainage pattern, is also least understood. Even though topographic differences are attributed for such anomalous spatial occurrence of floods, its genetic cause has to be identified for effective management practice. Added to structural and lithological variations, tectonic movements too impart micro-scale terrain undulations. Because active tectonic movements are slow-occurring, long-term geological processes, its resultant topographical variations and drainage anomalies are least correlated with floods. The recent floods of Tamil Nadu also exhibit a unique distribution pattern emphasizing the role of tectonics over it. Hence a detailed geoinformatics-based analysis was carried out to envisage the relationship between spatial distribution of flood and active tectonic elements such as regional arches and deeps, block faults, and graben and drainage anomalies such as deflected drainage, compressed meander, and eyed drainages. The analysis reveals that micro-scale topographic highs and lows imparted by active tectonic movements and its further induced drainage anomalies have substantially controlled the distribution pattern of flood.

1. Introduction

Rainfall is the primary cause of flooding, while its spatial distribution is caused by many factors. To ascertain the causative factor, quantitative models are developed on short-term processes like intensity and duration of rainfall, terrain topography, basin geometry, and carrying capacity of river. Models emphasize more on landforms adjacent to fluvial systems (Horton, 1932; Patton, 1988; Kale, 2003; Mohapatra and Singh, 2003). However, stagnation in the interior parts of the basin is less revealed. Though long-term tectonic processes may not have a direct relevance, its resultant spatial heterogeneity in the basin cannot be neglected (Khalequzzaman, 1994). Active fault movements impose gradient change, facilitating stagnation even at places far from major drainages (Timar and Racz, 2002).

Similarly, overbank flooding is a characteristic of lower sectors of a drainage system. However inundations are also common in upper and middle sectors, in general, attributed to structural aberrations and lithological variations along their river course, which inflict anomalous flow patterns, obstruct free flow, and thus facilitate inundation. However, owing to the high erosive potential of the drainages, particularly in their upper and middle sections, the structural and lithological barriers will be superposed by them in the course of time while active tectonic movements will sustain the anomalies even against erosion. Amongst anomalies like meandering, deflection in their course, increased flow length, and eyed drainage are common. During the time of excess flow, the anomalies impede free movement of water, enabling inundation over the adjacent environs (Jain and Sinha, 2005). Thus, tectonically induced topographic and fluviogeomorphic anomalies can also be plausible factors in controlling the spatial distribution pattern of flood.

Tamil Nadu — as being vested with a number of major river systems such as Palar, Ponnaiyar, Cauvery, Vaigai, and Tamiraparani — often faces major flooding. In the recent past, the region was confronted with disastrous floods during the years 1976, 1985, 1996, and 1998. In 2005, the northeast monsoon hailed in three phases with 100-mm excess rainfall against the normally occurring value. The first phase on October 27 swamped many areas in the northern part of Tamil Nadu, while the second phase on November 25 submerged the delta districts in the central and southern regions and the third phase on December 4 again flooded Chennai and its environ of the northern part (Annual Report

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on Natural Calamities, 2005–2006). Conspicuously, the 2005 floods of Tamil Nadu exhibit a unique distribution pattern indicating the influence of tectonics. In general, comprehensive studies on the plausible role of tectonics in governing the spatial distribution pattern are few. Hence we presume to enumerate the influence of active tectonics and the resultant fluvial and topographical anomalies on spatial distribution pattern.

2. Regional setting

The study area is bounded by the north latitudes 8°04′ and 13°40′ and the east longitudes 77°42′ and 80°21′ comprising the eastern part of Tamil Nadu from Pulicat Lake in the north to Cape Comorin in the south and a maximum breadth of 60 km in the east–west direction. It is characterized by a gentle easterly gradient and is vested by Bay of Bengal bounded rivers, namely Palar, Ponnaiyar, Cauvery, Vellar, Manimuthar, Vaigai, and Tamiraparani. These rivers have formed a well-defined deltaic configuration all along the coast, and in fact the apex of the deltas forms the western boundary of the present study area. Geologically it is comprised of complex igneous and metamorphic rocks of the Archeozoic–Proterozoic era in its major parts and of Mesozoic, Tertiary, and Quaternary sediments along the eastern coastal fringes. In general south India, particularly Tamil Nadu, is comprised of Precambrian basement; hence the geoscientists considered it as inactive to younger earth movements, while the frequent seismicity of moderate magnitude affirms that the area is tectonically active (Chandra, 1977; Rastogi, 1992; Ramasamy, 2006; Menon et al., 2010).

3. Materials and methods

Remote sensing has proved to be an effective tool in mapping the geological processes and flood inundated zones. Using MODIS (Moderate Resolution Imaging Spectroradiometer) satellite data, the spatial distribution pattern of the 2005 floods was mapped. Subsequently from IRS P6 satellite data, faults of varying azimuths were interpreted, and by corroborating with published data sets, vertical and lateral movements (specifically along the N–S, NE–SW, NW–SE, and E–W oriented faults) were inferred. By amalgamating interpreted (Selvakumar, 2008) and inferred data (Grady, 1971; Ramasamy and Balaji, 1995; Ramasamy, 2006), the morphotectonic framework of the study area was fabricated. Similarly, as drainage anomalies also promote inundation, anomalous drainage patterns such as deflected drainages, eyed drainages, and compressed meanders were interpreted by means of satellite imagery. A GIS (Geographic Information System) database was generated on flood, active tectonics, and drainage anomalies. Aided by the spatial analysis tool in ArcGIS software, the interface dynamics between flood and active tectonics — as well as flood and drainage anomalies — were envisaged.

3.1. Inundation mapping

The data on inundated areas during November–December 2005 were collected from websites, newspaper reports, and government bulletins and were demarcated geographically. Remote sensing technology has been demonstrated as an excellent tool in precisely mapping spatial distribution of disasters (Hansen et al., 2000). The MODIS satellite data from the post-flood event (dated 18, 20, 26, 28, and 29 of October 2005 and 15, 25, 29, and 30 of November 2005) were collected and by using digital enhancement techniques, inundated areas were interpreted and mapped (Fig. 1). The flood zones deduced from the MODIS satellite were corroborated with the collateral data, and further through rigorous field checks, were validated. Consequently, a flood map (2005) was prepared and converted into a GIS database using ArcGIS software (Fig. 2). Inundation in 153 locations (flood polygons) of varying aerial extent was witnessed. Further perusal of data clearly shows that most of the inundated zones seem to occur far away from major river systems, indicating that the stagnation is caused by topographic lows. Because the study area is devoid of general causes of land subsidence such as aquifer-system compaction, underground mining, or sinkholes (Galloway et al., 2000), the role of active tectonics can be presumed. The rainfall data from 11 rain gauge stations for the months of November and December during the year 2005 indicate that the flooding is of in situ nature (IMD, 2006).

3.2. Active tectonics and floods

The southern part of the Indian Peninsula, including the state of Tamil Nadu, has all along been thought as inert to younger earth movements. Recent recurring moderate seismicities signify ongoing neotectonism and reactivation of faults (Ramasamy et al., 2009; Murthy et al., 2010). Active fault movements and induced morphological variations will substantially cause flooding (Marple and Talwani, 2000). Hence faults were interpreted using IRS P6 satellite images and through geomorphic anomalies and corroborated with published information, vertical and lateral movements along them were deciphered (Subramanian and Muraleedharan, 1985; Ramasamy and Balaji, 1995). The fabricated morphotectonic framework (Fig. 3A) shows that the study area is characterized by two E–W trending regional cymatogenic arches, one in the north along Chennai and the other in the south along Rameswaram, intervened by a regional topographic deep along Manamelkudi (Ramasamy et al., 2011). The area further comprised active faults with well-defined morphologies such as block faulting along N–S faults, sinistral and dextral couple movements along NE–SW and NW–SE faults, respectively, and release failures with grabening at places in E–W oriented faults (Grady, 1971; Agarwal and Mitra, 1991; Ramasamy, 2006).

In order to decipher the interface dynamics, spatial analysis was carried out by integrating the GIS layers on flood (Fig. 2) and active tectonics (Fig. 3A). The same shows that along the E–W oriented regional Chennai emerging sector (1, Fig. 3B) and N–S block faulting in Pattukkottai–Vedaranniyam Mio-Pliocene sandstone area (2), occurrence of floods is much less. While in complimentary regional tectonic subsiding zones, especially in the south of the Manamelkudi and Thanjavur deltaic regions, occurrence of flood polygons is relatively more (3, Fig. 3B). Furthermore, the detailed analysis between the flood polygons and the faults of various azimuths has indicated that out of 153 flood polygons, 22 coincide with NW–SE faults, 12 fall along NE–SW faults, 11 along the N–S faults, and 4 with the E–W fault bounded region (Fig. 3C). Thus rough parallelism and confinement exhibited by 49 flood polygons along these fault bounded regions emphasize their influence.

3.3. Drainage anomalies and floods

The ongoing tectonics significantly controls the drainage pattern (Chen and Stanley, 1995; Matmon et al., 1999). Specifically at the juncture of active faults, rivers and drainages exhibit an anomalous pattern in their course (Ouchi, 1985; Valdiya and Rajagopalan, 2000). As these drainage anomalies obviously check the free flow, they act as one of the contributing factors of floods (Mitra et al., 2005). By analyzing the IRS P6 satellite images, taking into account the morphotectonic framework, the drainage anomalies were interpreted. Mostly the drainage anomalies inferred in the area were deflected drainages, compressed meanders, and eyed drainages; subsequently, GIS layers were prepared on the drainage anomalies (Fig. 4A). To elucidate the relationship, the GIS layer having drainage anomalies was superposed over the flood layer (Fig. 2B), and the same shows that amongst the 153 flood polygons, the spatial coincidence of 48 polygons with drainage anomalies indicates their influence.

Compressed meanders are drainages that are otherwise flowing rectilinearly, which take anomalous compression or meandering, especially when they either intersect with the lineament/fault or confine