Chapter 4
Assessment of Climate Change-Induced Vulnerability to Floods in Hyderabad, India, Using Remote Sensing Data

Oleksandr Kit, Matthias Lüdeke, and Diana Reckien

Abstract The frequency and intensity of extreme rainfall events over Hyderabad, India, are often the cause of devastating floods in its urban and peri-urban areas. This paper introduces a quantitative approach to assessing urban vulnerability to floods in Hyderabad, identifying informal settlements via high resolution satellite photography and through the development of a flood model for urban and peri-urban areas.

Keywords Flood modelling • India • Informal settlements • Lacunarity

4.1 Introduction

Projections for future climate patterns in South Asia suggest an increase in the frequency and scale of extreme precipitation events that will amplify the risk of significant urban floods. This is especially relevant to newly industrialised countries in the region, such as India, where cities play a crucial role in socio-economic development.

Hyderabad is one of the fastest growing cities in India. It is located in the north of South India and is the capital of Andhra Pradesh state. With a population of 5.5 million people in 2001, it is the sixth largest city in India (Census of India 2001). The Municipal Corporation of Hyderabad, the city's local government body, has calculated future population scenarios for Hyderabad and estimate that the 6.5 million people that lived in the jurisdiction of the Hyderabad Urban Development Authority in 2005 will grow to 7.7 million by 2011 and 10.8 million by 2021. The urban agglomeration may therefore be considered a megacity by around 2020,

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while scenarios for the wider urban agglomeration predict that by 2015 the 10 million mark will be crossed (MCH 2005).

The frequency and intensity of extreme rainfall events over Hyderabad, coupled with inadequate infrastructure and land use planning, often cause devastating floods in the city's urban and periurban areas. Hyderabad is a typical example of an emerging megacity where flood data are often unreliable, inconsistent or simply unavailable. Furthermore, there is little formalised information on the location and extent of the most exposed and vulnerable socio-economic entities, such as the densely populated informal settlements, which are not represented in urban development plans. In the following sections we discuss the methodology and results of a flood risk assessment in the city, combined with identification of informal settlements using lacunarity analysis of remote sensing data.

4.2 Flood Risk Assessment for Hyderabad

The potential hazards resulting from the flooding of Hyderabad as an inland urban agglomeration are high inflows via surface water and extreme local rainfall events. The river Musi, which traverses the city, has a relatively small upstream basin area (its source lies only 90 km to the west of Hyderabad) and is well regulated, posing a negligible threat presently and in the future. This, however, was not the case in 1908 when an extremely destructive flood hit the city. In response, the Osman Sagar and the Himayat Sagar dams were constructed, in 1920 and 1927 respectively. These reservoirs reliably prevent the city from flooding by the Musi and are major sources of drinking water.

The city is far less adapted to extremely intensive rainfalls which occur due to the monsoon precipitation regime and are expected to occur more frequently under future climate change. On the left hand ordinate of Fig. 4.1, we show the present distribution of daily rainfall at a sample station in the Hyderabad urban agglomeration (located at Begumpet, close to the former inner city airport). On the right hand ordinate, the expected change until 2100 is depicted under the A2 global CO_2-emission scenario (Nakićenović and Swart 2000). This shows a strong increase in the frequency of intense rainfall events (Lüdeke and Budde 2009)and along with the reported severe damages by strong rain events (Reckien et al. 2009), motivates further analysis of spatial and socio-economic vulnerability towards this kind of flooding. A clear indication that slum areas are most vulnerable is the August 2000 event in which 77 slums within the city area were completely washed away (IFRC 2000).

4.3 Identification of Flood Prone Areas

Low lying areas are frequently used as a first approximation for flood prone areas, e.g., in the context of sea level rise (Nicholls and Tol 2006). But this simple approach is inappropriate for assessing the impact of intensive rainfall events since

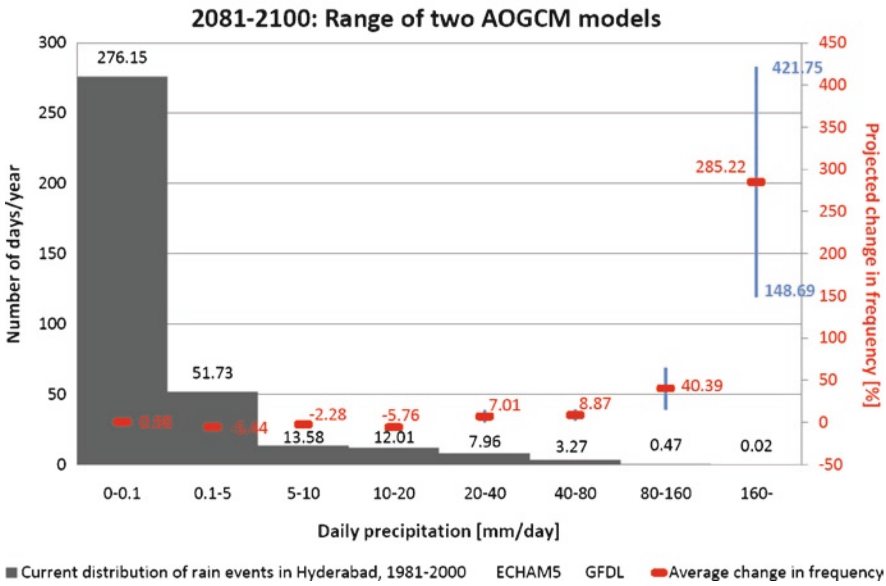

Fig. 4.1 Current distribution of daily rainfall (*left hand ordinate*) and expected change (*right hand ordinate*) for Hyderabad, India

rapid water flows generated at the surface can cause major damages, making a static analysis insufficient. On the other hand, a full hydrodynamic model that represents water flows and their momentum is very demanding with respect to the details of the orography and the spatial and temporal pattern of the rainfall events. As an intermediate step, then, we used a so-called flow accumulation map (Flacc, see e.g., Jenson and Domingue 1988) which describes the water flow at a particular location ('pixel') to be expected during a spatially homogenous strong rainfall event. This is calculated via the determination of the area of the upstream basin of the considered pixel; i.e., all locations are identified from where water flows to the considered pixel. From this it becomes clear that Flacc is a relative measure – the absolute amount of the flows depend on the rainfall intensity, but for any rain event, double Flacc means double water flow through the pixel.

As input data we used a digital elevation model derived from the latest available version of the Shuttle Radar Topographic Mission dataset (Jarvis et al. 2008) and dealt with noise and errors in the data in the order of 2 m by ignoring small orographic sinks that interrupt water flows artificially. After applying the respective algorithm to the digital elevation model for the Hyderabad agglomeration area we obtained a map that reproduced the natural surface waters (reservoirs and rivers) perfectly and, additionally, showed the net of water flows occurring under strong rain events (see Fig. 4.2). Comparison against the artificial sewerage and storm water channels network showed that some of the calculated flow paths are regulated while others are not. The flow accumulation map also identifies vulnerable areas along the clogged or encroached channels.

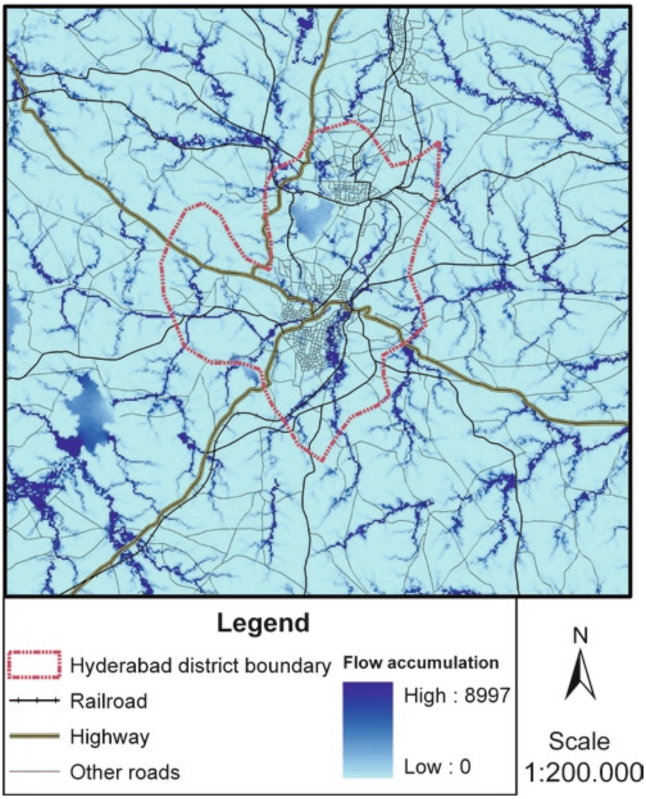

Fig. 4.2 Flow accumulation map for Hyderabad

4.4 Identification of Informal Settlements

Approximately 38% of Hyderabad's population is estimated to be living in informal settlements (MCH 2005), most being situated in rapidly growing outer municipalities. Confronted with high growth rates, urban planners and administrators in Hyderabad require up-to-date information on city-wide land use patterns. The informal and often temporary character of slums means that they are often difficult to track using ordinary methods. Remote sensing is a swift and unbiased technique of land use data acquisition, while the methodology proposed in this paper describes a promising data analysis technique capable of making qualified, spatially enabled statements on the location of informal settlements.

An informal settlement in India is often characterized as a 'compact area of poorly built congested tenements in an unhygienic environment usually with inadequate infrastructure and lacking proper sanitary and drinking water facilities' (Census of

India 2001). Such areas are frequently characterised by small dwelling units, narrow intrasettlement roads and high housing density – features that clearly distinguish them from other residential neighbourhoods and make remote sensing an appropriate data acquisition method for slum recognition.

There have been several attempts to perform informal settlement identification in India, and particularly in Hyderabad using spectral radiance values. Taubenböck et al. (2007) performed a land cover change study in Hyderabad using supervised classification techniques. While this approach was approximately 78% accurate in its recognition of built-up areas versus other land uses, the methodology was not capable of reliably distinguishing formal and informal settlements. Another study (Jain 2007) successfully used tonal variation in high spatial resolution data to identify rooftops within an isolated settlement. This approach, however, suffers from spectral noise and does not take into account morphological features of informal settlements.

The variability of materials used for roof construction in informal settlements and the extensive use of roofs for cloth drying or water storage equipment make identification of individual houses – a prerequisite of settlement density calculation in the Indian urban context – nearly impossible. A successful slum identification methodology must therefore take into account other surface properties, such as morphology and internal structure.

Cities can be viewed as complex systems composed of non-linear and multiple scale iterations of spatial and physical heterogeneous components (Amorim et al. 2009) and can thus be analysed by means of fractal mathematics. According to Gefen et al. (1983), lacunarity is a measure of the deviation of a geometric object, such as a fractal, from translational invariance, and as such is a suitable indicator to measure spatial heterogeneity. Since lacunarity values represent the distribution of gaps within an image at various scales, it is considered to be a promising tool for assessing urban structure and isolating distinctive morphological features.

Figure 4.3 schematically represents the algorithm used for identification of informal settlements in Hyderabad. Two sets of cloudless QuickBird high resolution remote sensing imagery (acquired in March 2008) were used in this study: image 1 which covers the 7.29 km^2 to the west of Hussain Sagar reservoir and contains Sanjeeviah Nagar slum has been used for algorithm calibration, while the equally large image 2 which covers the area to the east of Hussain Sagar is used for algorithm application and testing. First, principal component analysis was performed on the imagery, producing high contrast matrices, M_1 and $M_{2,}$ holding individual values stretching from 0 to 255 and clearly distinguishing between built areas and other land use types. Those matrices were then converted into binary datasets, $B_{48}{}^1$, $B_{50}{}^1$ and $B_{52}{}^1$, using 48%, 50% and 52% thresholds respectively. Each matrix has been further split into 100 × 100 pixel blocks (approximately 60 × 60 m^2 as per QuickBird resolution of 0.61 m). For each block the lacunarity value has been computed. We consider this box size to be an appropriate scale for identification of morphology of informal settlements as it accommodates fine scale intrasettlement structure, while leaving out large features that are more characteristic of industrial and formal residential areas.

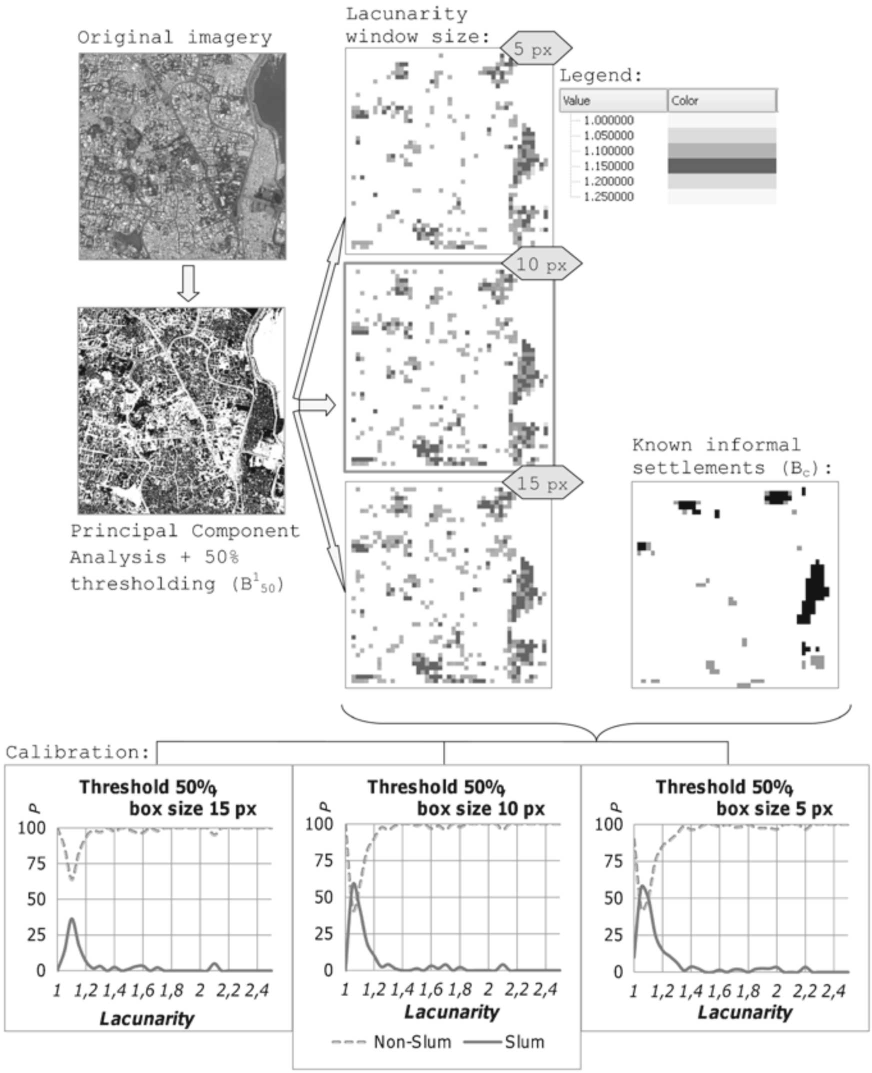

Fig. 4.3 Informal settlements detection algorithm and its calibration (for details see text)

Optimal moving window size has been empirically determined by calculating three lacunarity matrices for each binary matrix with moving window sizes 5, 10 and 15 pixels respectively (methodology adopted from Amazon forest classification by Malhi and Román-Cuesta 2008). Since the area covered by M_1 was relatively well-studied during fieldwork in Hyderabad in November 2009 and March 2010, it was possible to construct a binary calibration dataset, $B_{c,}^{1}$ which describes the location of informal settlements and all other areas. Using the B_c^1 dataset as a mask, it became possible to calculate probabilities of each lacunarity in matrices B_{48}^{1}–B_{52}^{1} to belong to slum or non-slum class (Fig. 4.3, bottom charts) and to conclude that the combination of 50% binarisation threshold and 10 pixel moving window sizes are optimal parameters for plausible identification of informal settlements in Hyderabad. This result is consistent with a previous study in this field (Barros Filho and Sobreira 2008), which showed that high spatial resolution satellite images from urban areas with better habitability have higher lacunarity values than those with worse conditions.

The empirically calibrated lacunarity calculation parameters were then applied to B_{50}^{2} matrix, which was the 'unknown territory' for the algorithm. As illustrated by Figs. 4.4 and 4.5, the algorithm has identified a large area of low lacunarity values in the upper left corner of the area of interest. Closer examination of the high resolution satellite imagery and analysis of ground truth data (Fig. 4.4) have revealed that the identified area does indeed belong to a high-density settlement known locally as Bholakpur slum.

Since the suggested methodology requires intensive computing power, the calculated spatial distribution of informal settlements in Hyderabad has not yet been applied to the city's whole urban area. Once this is carried out, the results should help refine spatially undetermined official figures and greatly assist the planning and management processes in the city.

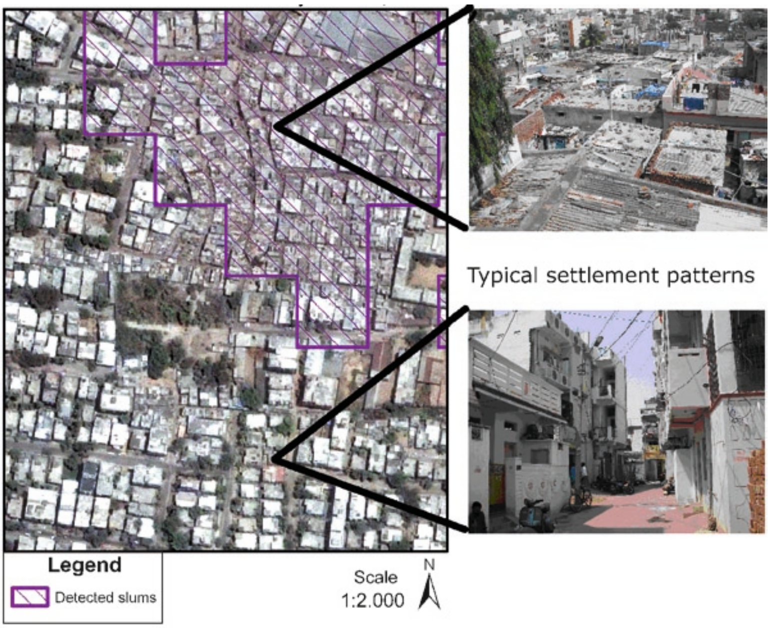

Fig. 4.4 Validation of slum detection algorithm for Hyderabad (Photograph by Martin Budde/PIK)

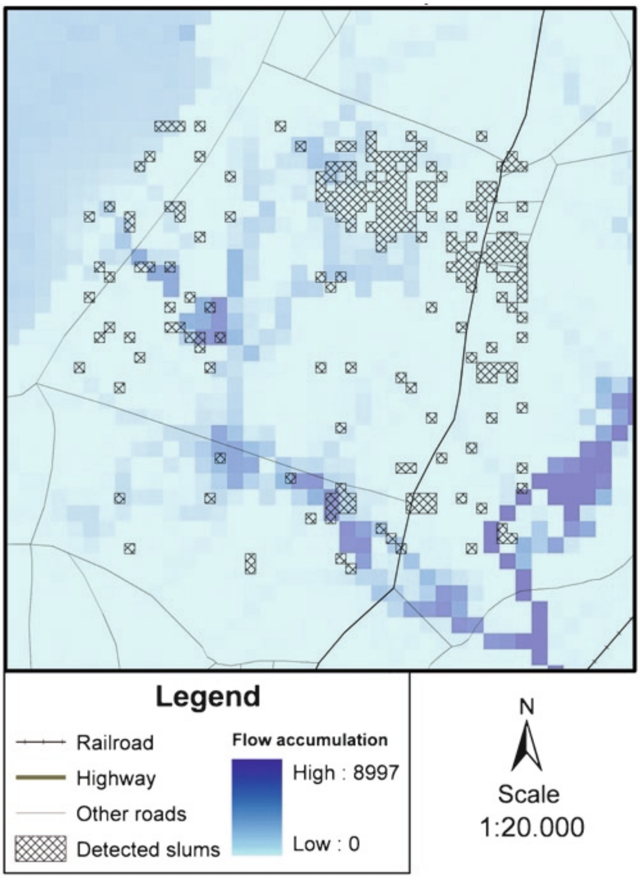

Fig. 4.5 Vulnerability of informal settlements to floods in Hyderabad

4.5 Conclusions

The comparison of flow accumulation maps with slum locations indicate high vulnerability to floods where informal settlements overlap with flow concentration areas. The Bholakpur slum's proneness to flooding, as detected on the informal settlements map in Fig. 4.5 (large red area in the upper part of the map), can be assessed as relatively low and can certainly be further reduced by appropriate urban planning and engineering measures. However, risk of flooding (hence vulnerability) is significantly higher in the informal settlements along the Hussain Sagar surplus drainage channel and Ashok Nagar Road in the Chikkadpally neighbourhood (approximately 0.02 km^2 area in the lower central part of the Fig. 4.5). This claim has been verified by visual examination of the satellite photography that revealed distinctive high density settlements on the banks of the drainage channel. As the frequency of extreme precipitation events in Hyderabad increases, so does the risk of increased water flow through the Hussain Sagar surplus drainage channel, which endangers the long term survival of weak informal structures on its banks if no flood defence infrastructure is in place.

This result illustrates how the methodology developed in this paper can successfully identify hotspots of climate change vulnerability on the basis of satellite based, globally available data sets. The calibration of the slum area identification algorithm requires additional knowledge of a small subarea of the urban agglomeration that includes known slum- and non-slum areas (B_c^1 in Fig. 4.3). It is quite possible that the calibration for Hyderabad also works for other Indian (or even developing world) urban agglomerations, but this will become clear during further applications. In our opinion, an important property of the suggested approach is its immediate transferability to other large urban agglomerations of the developing world that lack reliable large scale ground data.

Our first results corroborate the general claim that slums are often located in rainwater accumulation areas and frequently lack appropriate flood defence and rainwater drainage infrastructure. More importantly, it is possible to detect which slum areas will be most endangered by climate change and which will require the most attention with respect to adaptation measures. Along the basic dimensions of adaptation to climate change, 'accommodate – protect – retreat – avoid', the avoidance of new informal settlements in endangered areas is one of the most important options as slum areas rapidly grow. This demands a better understanding of where and why new slums occur. Applying the presented slum area identification algorithm to past time slices of satellite imagery will constitute a time series of the spatial slum distribution and allow for the development and testing of causal hypothesis of slum formation. This empirically tested understanding could be used to prevent the establishment of informal settlements in unfit locations while revealing superior settlement alternatives.

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