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Flood Risk and Impact Analysis of Varanasi City Region, India

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Abstract: **Varanasi city has spread from its original place of origin over the natural levee into the flood basin and on to the low-level floodplain. More often the city of Varanasi suffers due to storm water logging than due to flood from the Ganga river along the bank of which it is situated. Especially during 2013 and 2016 there was large scale inundation of many parts of Varanasi city both due to river flood waters as well as storm water logging. With the knowledge of field observations during these two (2013 and 2016) flood years using Survey of India topographic maps with 2m (north-western part of the city) and 5m (entire city) contour interval and with 1m DEM created using 4000 Differential Global Positioning System (DGPS) points together with several spot heights and benchmarks from Survey of India topographic maps, flood zones are digitized on very high resolution remote sensing data. Contour flooding is shown at different intervals of elevation. The flood zones and the expected contour flooding are superposed on the city map showing built up area. The extent of area, the number of houses and the number of people affected in each of the flood zones is worked out.**

Index Terms: **DEM, Flood plains, Flood zones, Storm water drainage, Urban Built-up, Urban floods.**

I. INTRODUCTION

Storm-water logging in urban places of India has become as common as floods in natural river systems due to peak rainfall events. Almost all large and medium sized cities in India are facing the problem of water logging due to even moderate rainfall of high intensities leave alone during peak rainfall events. The situation turns worse when cities along the river fronts and within the catchments of hilly torrents, receive overflowing waters above the banks of streams and rivers. With extraordinary rainfall events and with no flood prevention measures in place, floods in cities cannot be stopped. So is the case with water-logging too in the cities of India under even moderate rainfall of high intensity in a short duration because of very high runoff from urban surfaces (Swan, 2010; Ali *et al.*, 2011; Suriya and Mudgal, 2012; Zope, Eldho and Jothiprakash, 2016). Up to about 1970's heavy rainfall events used to cause water logging in low lying zones of urban areas; but post 1970's urban spread has increased at a very fast pace at the expense of water bodies, fields and other green patches outpacing storm water drainage network (Gupta, 2007). Existing storm water drainage in many of our cities, quite often, because of various reasons, is either disconnected or is poorly maintained or is not maintained at all. And, in many cities, the city sewage almost doubles as storm water drainage aggravating the problem. The cities' municipal solid waste (MSW) mainly because of polythene bags has turned a major factor choking the sewage/drains causing water logging. It is not only due to apathy of city governing bodies but also due to lack of empathy of the citizens towards their responsibilities, our cities quite often face the problem of water-logging mostly because of choking of and/or dysfunctional drains. With the expected climate change looming large over the globe, extreme rainfall events can become frequent leading to frequent floods (Guhathakurta, Sreejith and Menon, 2011; Yenneti *et al.*, 2016).In the present paper water-logging and flood are used synonymously unless specified and separated depending upon the context. The recent floods in August 2018 in Kerala, Gujarat, Rajasthan, Uttarakhand, Assam are a foreboding of what could happen due to extreme rainfall events.

Mumbai flood with 944mm of rainfall on 26th of July 2005 and Chennai flood with 490mm of rainfall on 1st December 2015, are attributed to exceptional rainfall and the failure and choking of storm water drainage and faulty sewage lines (Gupta, 2007; Rajeevan, Lokanadham, Gupta and Nikam, 2009; Menon, Levermann and Schewe, 2013; Zope, Eldho and Jothiprakash, 2016).Mumbai and Chennai are no exceptions. Almost all the cities and towns in India suffer from water-logging due to choking of drains or because of no drainage system at all. As it is, the densely populated cities and towns in the Ganga-Yamuna plains suffer due to floods/water-logging almost every year. The floods during

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August 2016due to very high and intense rainfall affected large number of cities, towns and countryside as well causing huge loss of property and lives.

The causes of floods are well known but the solutions are very difficult to implement. Though floods cannot be stopped and though fool-proof flood preventive measures cannot be put in place, one thing that can be done is management during flood to reach necessary help to the affected and to alleviate the loss and suffering. There are many aspects to flood management. One of them is demarcation of flood zones as well as the high and dry places and to generate information on the extent of area likely to be flooded, number of households and people likely to be affected in the scenario of various flood levels (Fernández and Lutz, 2010; Dewan *et al.*, 2016). Such an information will help to at least plan in advance about various steps to be taken to reduce the suffering and to deliver timely help to the affected people. This exactly is the major objective of the present study. This exercise is an attempt to: (i) map the flood and water-logging hazard zones in the city of Varanasi and its environs, (ii) to work out the number of houses and the people likely to be affected in the scenario of different levels/peaks of floods and finally (iii) to explain the various topographic reasons for flooding and water-logging in Varanasi city.

Flooding in flood plains is a natural occurrence. Floods were once considered a boon but have now turned into a bane. They have turned into a bane because the floodplains have been flooded by human habitations. It is with the knowledge of recurring flood problem humans chose to occupy the highest possible places. This has been the thumb rule in the development of human habitations within the floodplains. With explosion in population numbers, habitations have gradually crawled into flood basins and lower level flood plains. Up to about 1950s people forced into lower levels into the floodplains did not forget the thumb rule and used to construct their dwellings over 10 to 15 feet of piledup earthen elevation. But such a safety measure from flood was only within the reach of the rich and the poor remained lower down in the low-level floodplains. Gradually the thumb rule of 'higher ground' has been forgotten or is given a go-by by even the rich especially in the urban areas to reduce the construction cost. This is the paradox of the times; people occupy the low lands, water bodies and river bed sand cry foul about the flood and make hyper-critical comments against the government not coming to their rescue.

II. AREA OF STUDY

Varanasi city is locatedon the concave left bank of the river Ganga--82º93'E – 83º05'E and 25º24' N – 25º38'N (Fig.1).A large chunk of the old part of the city is located over a natural levee. Prominent natural levees along concave banks of large meandering rivers in wide floodplains offer the highest possible ground for settlements. Over the years, from over the natural levee Varanasi has spread out into the flood basin/plain and, now, including its peri-urban area measures about 145 to 150km^2. Though most of the floods in Varanasi are due to water logging because of choked, dysfunctional or no drainage/sewage system, the situation gets aggravated when actually there is flood in the river Ganga and other smaller flood plain streams draining from west to east towards the city. Basically, the surface over which the city of Varanasi is situated is a floodplain with general slope towards east and north-northeast. Though floodplains are somewhat flat but they are not altogether featureless. Prudhvi Raju and Pandey (2014) described in detail the geomorphology of Varanasi city and its environs. Varanasi is basically situated over a natural levee and when there is a prominent natural levee a prominent flood basin is a consequence. When there is a prominent flood basin receiving runoff from the hinterland (from over the natural levee and from the high level floodplain in the west) development of small to large ponds is a natural occurrence. From the river the natural levee rises up starting from around 70m up to about 80-82mamsl. It shows a prominent linear crest appearing literally as a "ridge". From the crest towards the floodplain, it slopes gently into the flood basin at around 75m altitude. After the flood basin, towards inland (away from the river), the floodplain rises up gradually to a height of about 84m amsl. In the floodplains of large rivers, many small to medium affluents to large floodplain tributaries are a common occurrence. Here, in Varanasi, a medium sized floodplain tributary of the Ganga named Varuna flows across the northern part of Varanasi city and joins the Ganga at the city's northeastern corner. Similarly, a small sized floodplain affluent called Assi passes across the southern part of the Varanasi city and joins the Ganga at the city's southeastern corner. Varanasi, the city of present study (Fig.1), witnessed second highest flood at 72.94m amsl during August 2013 after the highest recorded flood at 73.90m amsl in September 1978 (http://india-water.gov.in/ffs/hydrograph/).

III. DATA AND METHODOLOGY

The present exercise basically proceeds with direct field information gathered through field observations during 2013 and 2016 floods in Varanasi city. A digital elevation model (DEM) is created(Fig.2) using (i) about 4000 points collected with DGPS (Differential Global Positioning System) in RTK (Real Time Kinematic) mode for the southern part of Varanasi city,(ii) contours at 5m intervals, spot heights and bench marks from Survey of India's map (of 2002)of Varanasi at 1:20,000 scale and (iii) contours of 2m interval from a Survey of India map (of 1972-73) of northwestern part of Varanasi city at 1:5,000 scale. Finally, from this DEM, contours are created at 1m interval (Fig.2). And, from these contours 8 classes of relief ranges are derived--60-65m, 65-70m, 70-74m, 74-75m, 75-76m, 76-78m, 78-82 and 82-84m (Fig.3).

The first ever map of Varanasi city made by James Prinsep in 1822 (Fig.4) has also been taken as one of the bases as it clearly shows the old ponds, low agricultural (open) fields and estates and gardens along with the then city built-up area. Most of these features in due course of time have disappeared under urban cover. In an urban set up, high roads serve as dykes and may cause water-logging. But in case of Varanasi city with the exception of NH2 bypass passing through the southern limit of the city, almost all other roads are low and are not above the topographic surfaces. Of course, they were once considered as high roads at a slightly higher elevation than the adjoining built up areas and fields. Several large to medium sized ponds present in the past (Fig.4) (as per 1822 map of James Prinsep) which were filled up subsequently and got converted into built up spaces are now flood prone. So, with a combination of information from old and new maps, field observations and DGPS points, flood and water-logging hazard zones are digitized over very high resolution (1m) remote sensing data (Fig.5).

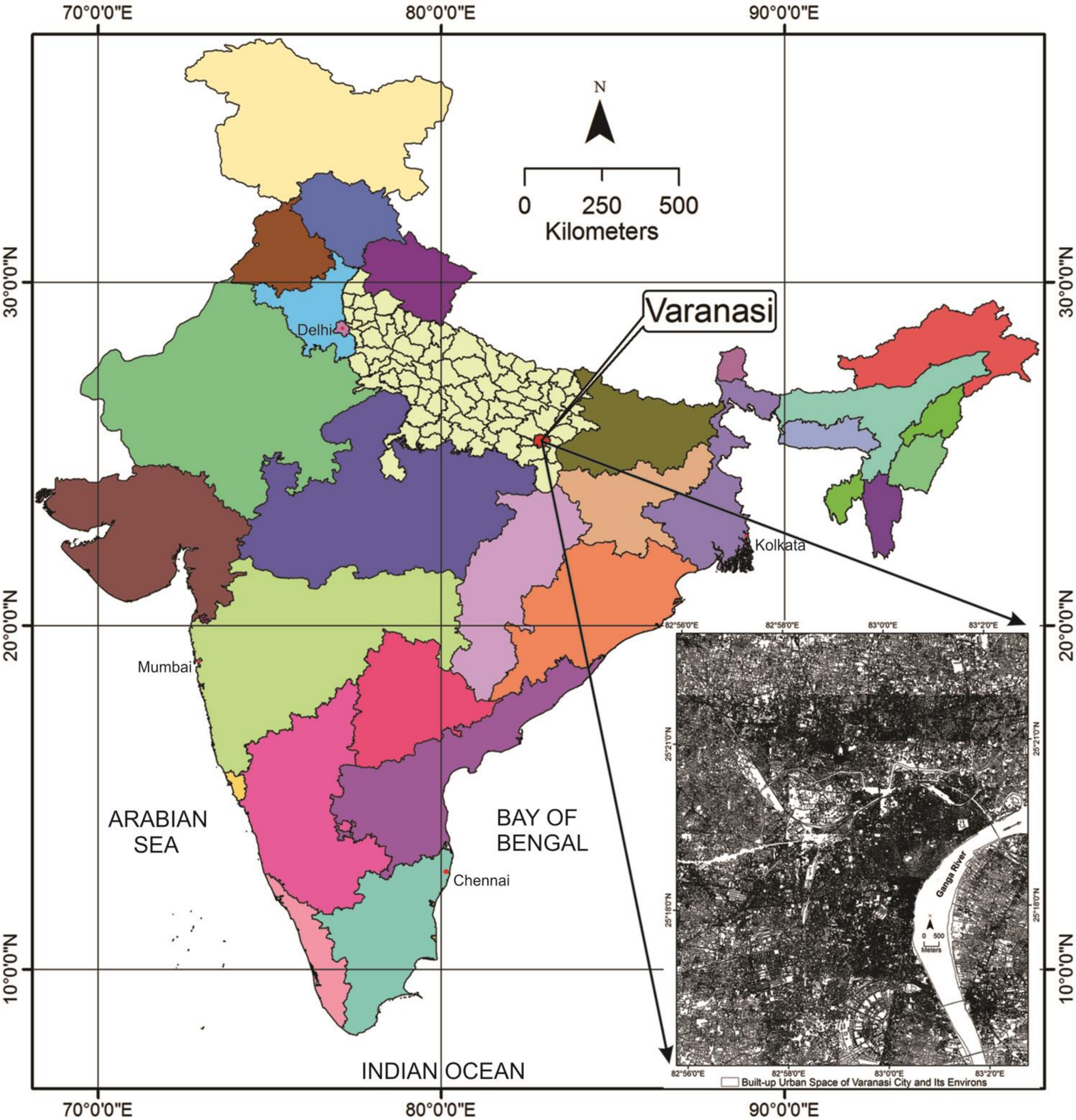

Fig.1 Location of Varanasi City Region in India

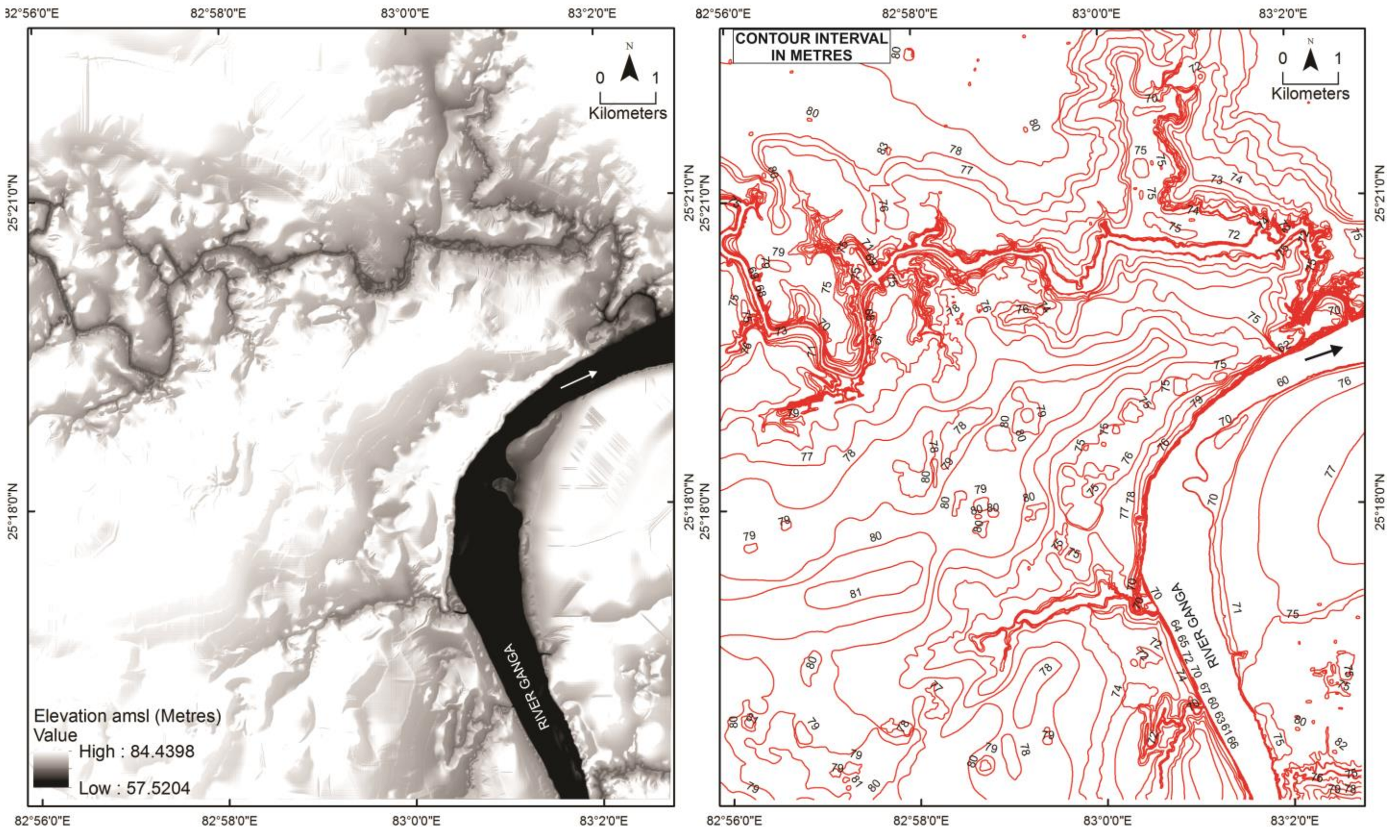

Fig.2 Digital Elevation Model (DEM) of 1m resolution and 1m contour of study area

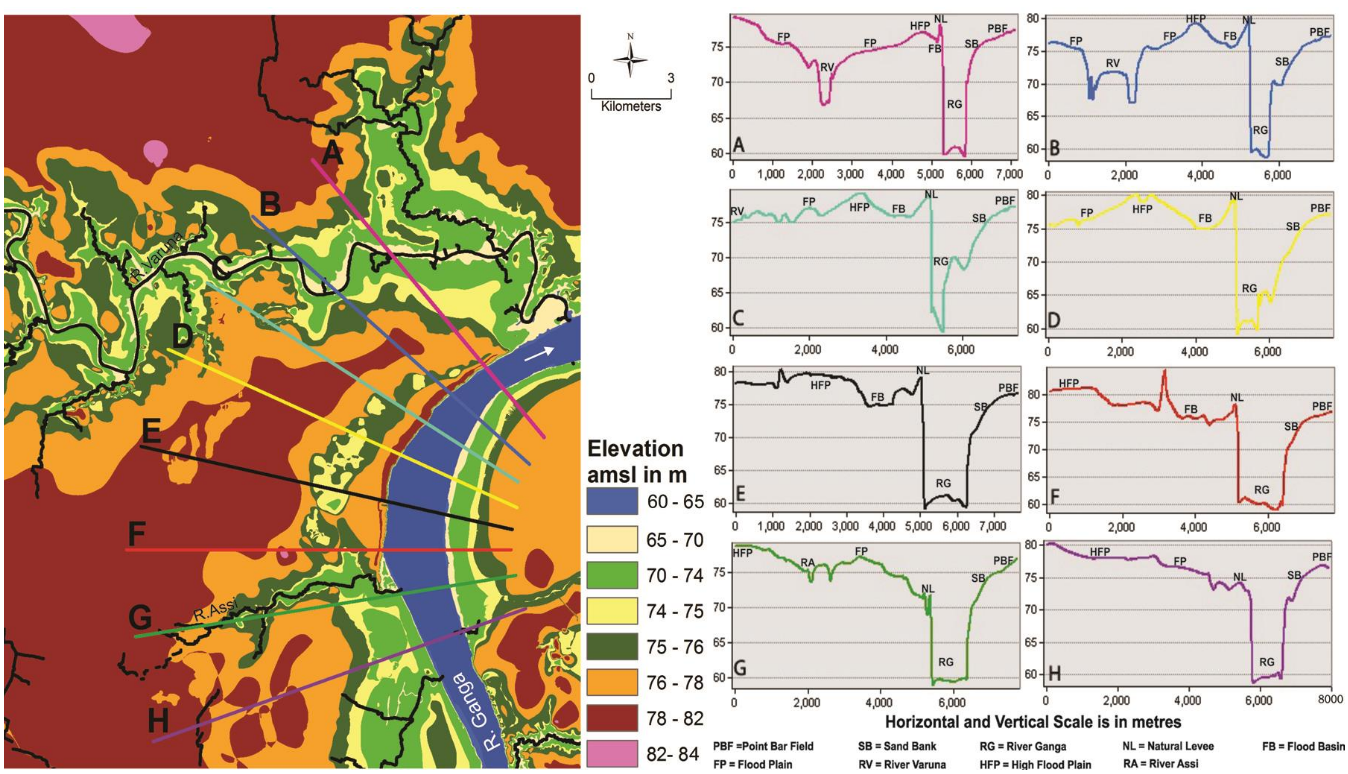

Fig.3 Contour flood zones and topographic profiles

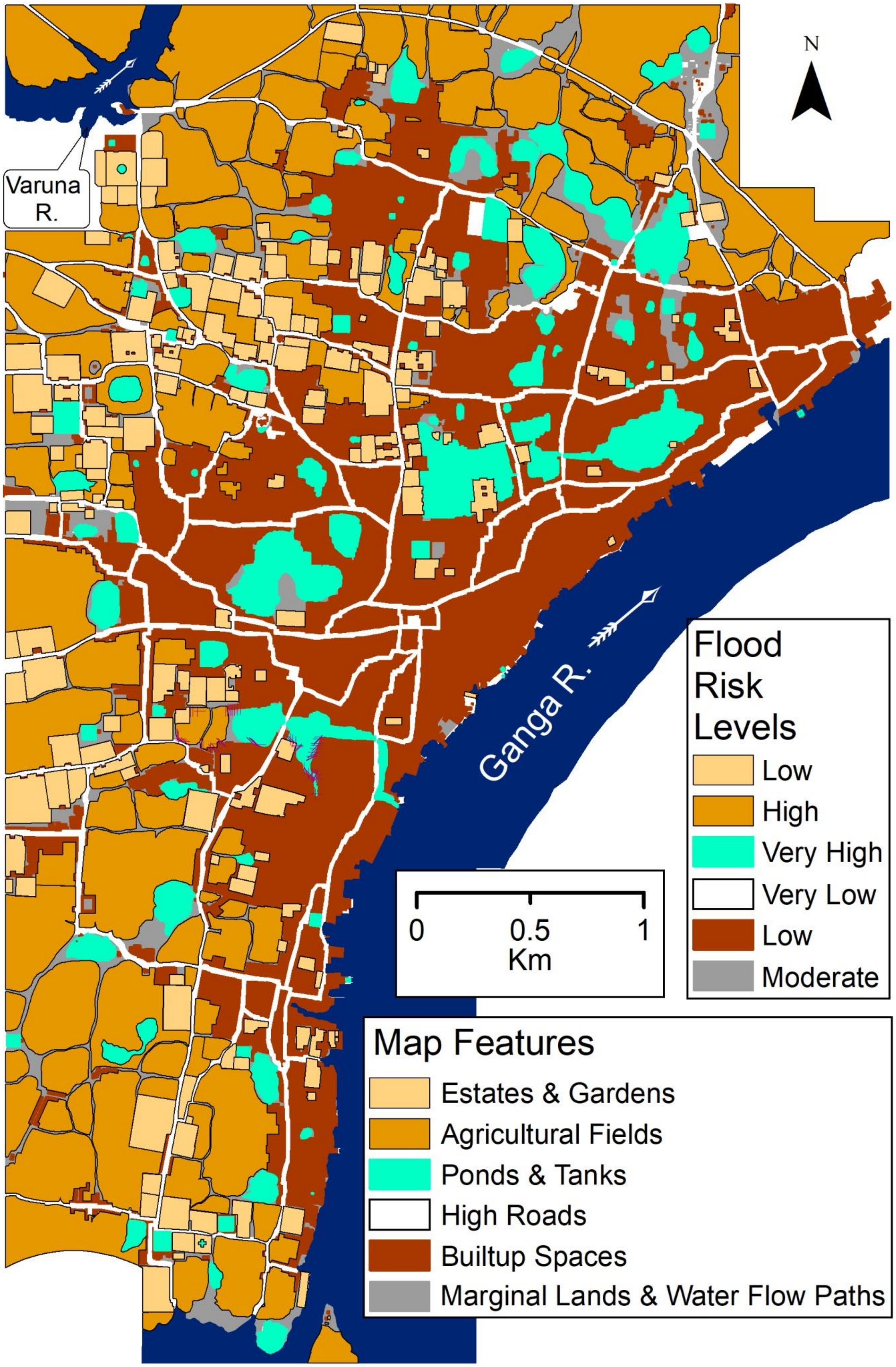

Fig.4 Digitized map of James Prinsep of 1822 showing flood risk levels of different map features

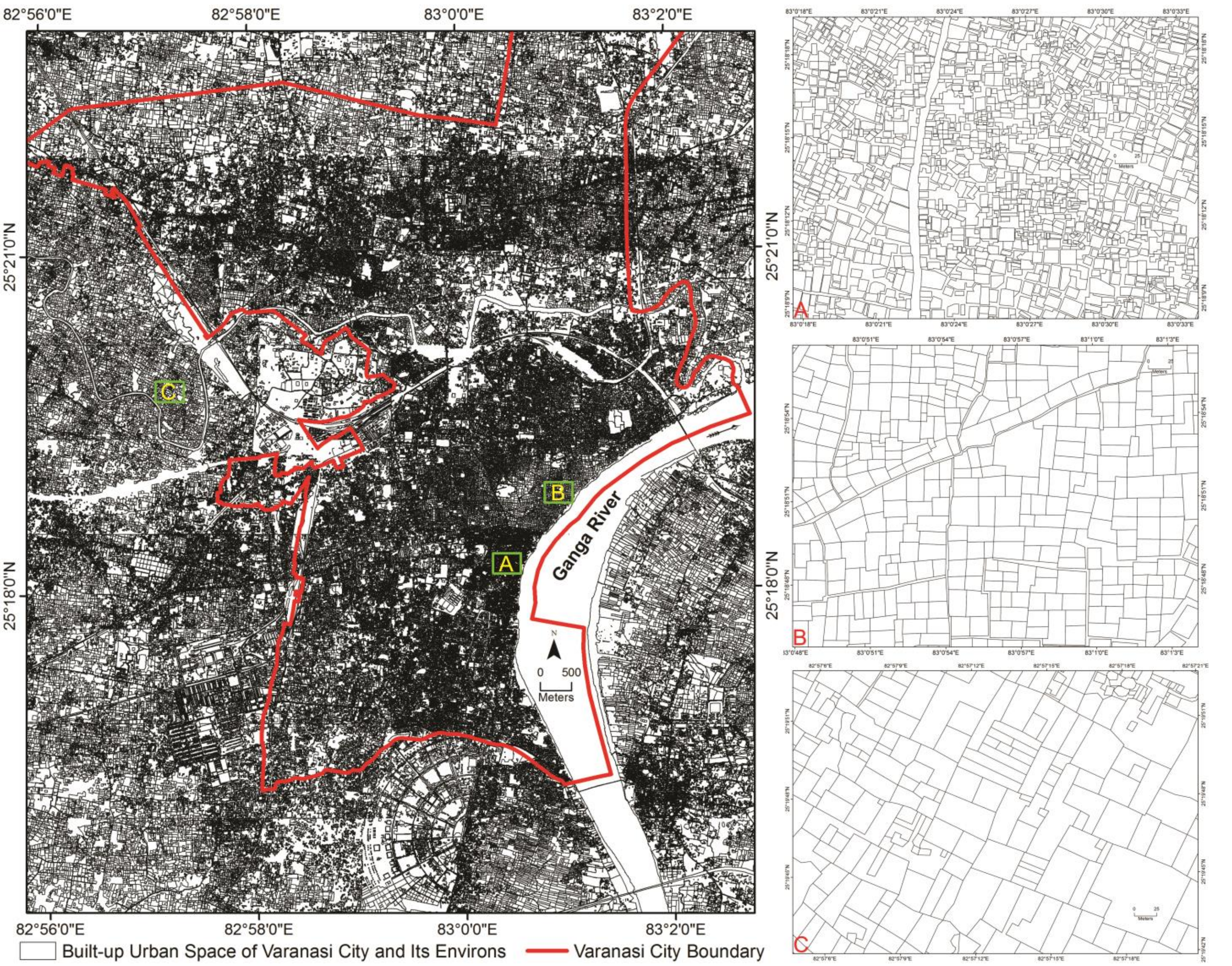

Fig.5 Map of Varanasi city and environs showing urban built-up space with three samples showing (A) highly dense; (B) moderately dense; and (C) sparsely dense urban features.

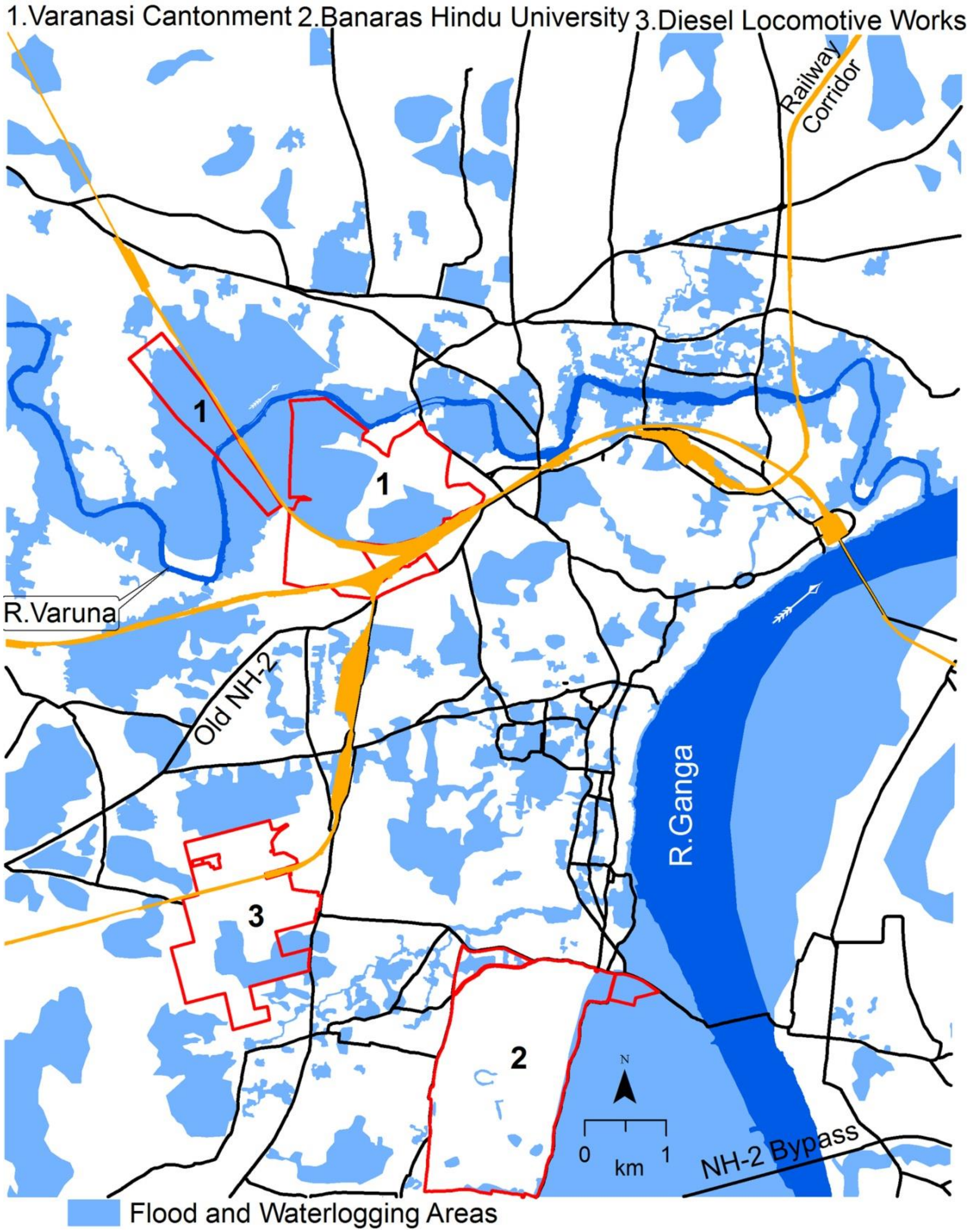

Fig.6 Map showing water-logging and flooded areas in Varanasi city during 2013 and 2016.

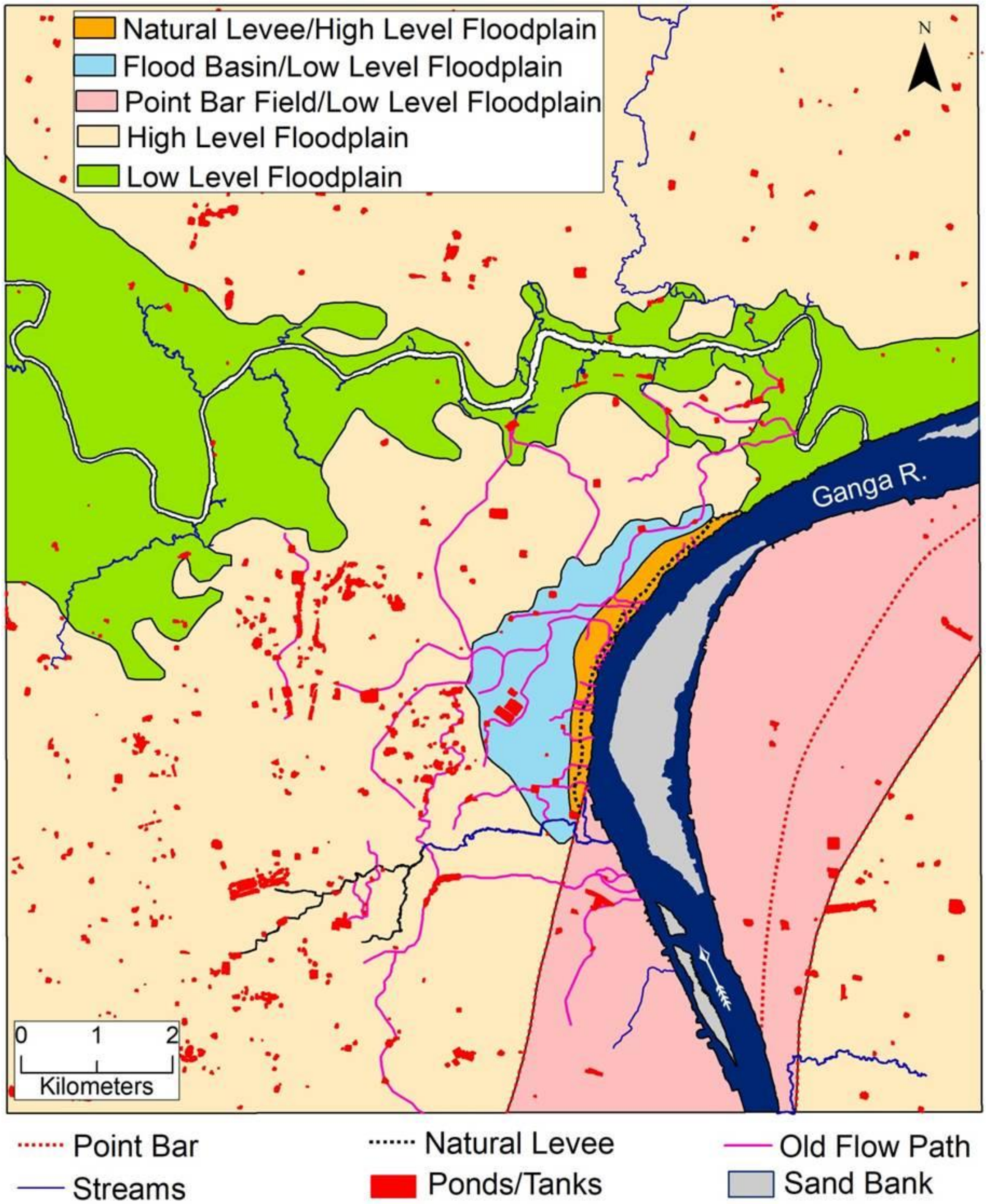

Fig.7 General Geomorphic Map of Varanasi City Region

The extent of area, the number of houses and people affected at various levels of contour flooding are worked out from a detailed map of Varanasi urban space in each of the flood zones. Taking an average of 6.2 (city Census 2011) persons per household, total number of people expected to be affected in each of the flood zones has been worked out. The number of houses per square kilometer is worked by averaging three sample areas (highly dense, moderately dense and sparsely dense) of Varanasi urban space (Fig.6). The number of houses per sq. km. is 4,201. At this density of houses and with 6.2 persons per one house, the number of affected people is worked out (Table I). A study on these lines for Varanasi city had not been attempted so far and none has so far prepared flood and water logging hazard map for the present study area.

Table I The area of extent, houses and people expected to be affected in various flood zones

Flood zone elevation (amsl)	Area (Km^2)	Household affected	Population affected
60-65 m	0.35	1459	9046
65-70 m	1.124	4738	29380
70-74 m	16.99	71384	442582
74-75 m	08.92	37496	232475
75-76 m	21.27	89381	554167
76-78 m	31.50	132323	820400
78-82m	58.71	246633	1529123
82-84m	0.0048	20	125
Total	138.87	583435	361729

IV. GEOMORPHOLOGY OF VARANASI: A FACTOR IN FLOODS

The floodplains of large rivers like the plains of the Indus, the Ganga, the Brahmaputra etc., are normally prone to floods especially during rainy season in India. The floods could be due to breaching of river banks and/or due to overflow of water above the banks. Large rivers normally have meandering courses in the flood plains and where there are prominent meanders, natural levees are built up along the concave banks and point bars on the convex bank side of the meander loops. When there is a prominent natural levee, a flood basin on the leeward side of the levee (away from the river towards the flood plain) is a natural occurrence (Fig.7). This elongated depression running almost parallel to the main axis of the river is prone to flooding and also to water logging. Prudhvi Raju and Pandey (op cit) have given an elaborate description of geomorphology of Varanasi city.

It is a lower level flood plain towards the south and southeast of Varanasi city which gets flooded by the flood waters of the river Ganga (Fig.7). From here water used to flow freely northwards towards the downstream reaches towards the confluence of Varuna river.With a segment of National Highway (NH2) bypass passing through the south acting as a flood dyke, the flow of water from the south towards north into the flood basin is now reduced; but, still through many under-passes water flows slowly during high flood events. The railway corridor and old NH2 serve as flood dykes on the west of the city which reduce free flow of water into the flood basin from the high level flood plain from west. The east-west road running from Lanka towards DLW serves as another flood dyke which prevents the free flow of water towards north into and through flood basin. In years 2013 and 2016, the flood waters flowed through many underpasses from under NH2 bypass adding to the waters of the Assi and the Varuna rivers. Coupled with the storm water coming from the west into the flood basin, most of the parts of the flood basin get submerged under flood water. A vast built-up tract of Varanasi city falls within this flood basin. There used to be many large ponds within the flood basin (Fig.3). Most of these ponds have disappeared and occupied by urban built-up space and water accumulates into all these occupied spaces during rainy season. There used to be around 94 ponds/kunds in 1822 (Prudhvi Raju and Bhatt Diva, 2016) and at present only 22 out of these 94 are left within the area corresponding to the city area in Prinsep's map. And most of these old water bodies left (and are present now) are kunds connected with temples. As the general slope is towards the north (from south), there is maximum concentration of water towards northern parts of the city coinciding with the flood basin.

The natural levee gently slopes west towards the flood basin (Fig.3). So, the storm water gradually floods the city parts first in the flood basin and with increase in storm water, flood would gradually submerge the crest of the levee too. Fortunately, the Ganga water never spilled over the natural levee in the recent times whose crestline stands at a general elevation of 84masl at some places. There were about six medium to small streams (now just turned into flow paths)flowing across the city and cutting through the natural levee and flowing into the river Ganga. Storm/flood water still flows through these paths and concentrates downstream resulting in flooding of vast tracts of urban space. Where these streams joined the Ganga there used to be prominent mouths with moderate slope into the Ganga; and waters of the Ganga enter into these 'once mouths' of these streams. The houses and many religious places that have occupied such low-lying parts at the mouths of these streams get flooded.

V. FLOOD HAZARD MAPS

Two types of flood hazard maps are prepared in the present study. With the understanding of flooded and waterlogged areas during 2013 and 2016 floods, a flood hazard map is prepared through on-screen digitization over very high resolution data (1m Google Earth Image) (Fig.6) Figure 3is a map prepared based on contour flooding. Most of the area of Varanasi city post 19th century has developed around the many ponds of Varanasi and within the flood basin. The old city of Varanasi situated over the natural levee is normally not a flood prone area. There is no record of river spilling its waters above this natural levee during the20thcentury. Areas higher than 75mamsl remained high and dry in the flood of 1916 and the subsequent floods of 1978, 2013 and 2016.From James Prinsep's map (Fig.4) flood risk levels are inferred based on map features and flood risk level of each map feature is indicated in the legend. For example, the built-up spaces and estates and gardens are taken as low flood risk zones as they occupied the highest possible places and ponds (most of them filled up and covered by urban landscape), tanks and marginal lands and water flow paths are taken as very high-risk zones. Open fields (as given in the legend in Prinsep's map) which are actually agricultural fields are taken as high-risk levels.In general, all the open fields, all the marginal lands and most of the ponds are covered by urban space and are liable for flood.

DISCUSSION AND CONCLUSION

Most of theflood basin area like many other low-lying areas within the city gets inundated during rainy season due to water-logging and not always because of flood waters of the river entering it. Flood in the city is caused mainly by the concentration water from the river Ganga (water coming from south and flowing towards north) and of other streams flowing from west in to the flood basin. During heavy rains, there is backflow of sewage and subsequent water-logging because of addition of storm water collection and concentration in low lying areas especially the flood basin zone.

With the flood of 1978 standing at 73.90m there was not much of a loss, and not as many houses as the number submerged in 2013 flood, were submerged. The reason is, many areas submerged under flood of 1978 were then empty spaces or very sparsely built up. But, the same empty and sparsely built-up areas were gradually occupied by dense urban space by 2013. This is the reason, though the flood of 2013 stood at 72.94m, it resulted in much loss and suffering. The recent flood of August 2016 stood at 72.56m. Depending on the situation and location, the individual buildings at certain places (south east of Varanasi and along the rivers Varuna and Assi) in 70-74m zone were submerged up to about 2-3m above their plinth level (Plate I). In the same zone (70-74m), the houses along the natural levee towards the Ganga river, the waters touched the plinth of buildings. There was widespread water-logging in the interior of the city because of the backflow and blocking of sewage. As it is, the storm water drainage in the city is very poor and is not properly interconnected. Most of the Indian cities and towns do not have separate storm-water drainage system and Varanasi city is no exception. The old sewage doubles for storm water discharge also.

Plate I Flood levels in Varanasi—Bhagawanpur in August 2016 (A), near Assi in August 2013 (B), near NH2 bypass in August 2013 (C) and near Mangalagouri temple in August 2013 (D)

The flood effect in terms of water entering the houses basically depends on the plinth elevation of houses. It is advisable to have at least 4-5m of plinth elevation from the local ground level in floodplain areas. Unfortunately, this general unwritten rule is more flouted than followed! Water-logging because of sewage backflow and storm water concentration during flood times cannot be controlled but blockage of drains can be prevented. Hydrograph for Varanasi for year 2016(CWC's station code for Varanasi--006-MGD3VNS) available at http://india-water.gov.in/ffs/hydrograph/shows three levels of flood-warning level at 70.25m in yellow, danger level at 71.25m in golden and at 74 m and above high flood level in red (Fig.8). Between warning level to high flood level (70m-74), the extent of city urban area is about 17 sq. km. and the number of houses is 71384 and number of people expected to be affected is about 4,42,582. The total area covered under the flood zones (Fig.6) is about 32 sq. km. and the people affected stands at 8,36,137. On the other side of the Ganga (east of its right bank), the area being rural the flood zones are excluded from the calculations of flood affected area, houses and people.

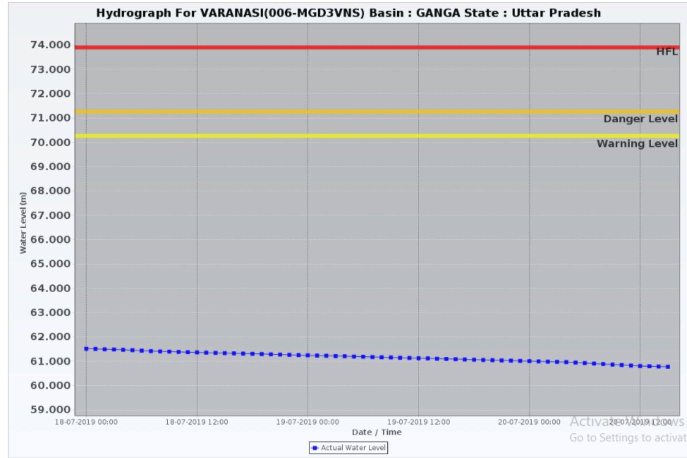

Fig.8 Hydrograph for Varanasi station showing different flood levels during 4-7 September 2017

Going by contour flooding, a look into Table I shows that flood standing at 74m would affect about 17 sq. km. of area and about 4.42 lakhs of people. With the expected climate change and a scenario of extreme rainfall events becoming more frequent, a flood level between 74-75m is a possible occurrence and this just one-meter increase of flood would alone envelope 2.32 lakhs of people in about 9 sq. km. of area. In the worst scenario of flood going above 76m and above would submerge almost three-fourths of the city. The type of flood zone maps prepared for Varanasi city in this study will be of help in rescue and relief operations and to have an estimate of people and properties affected.

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REFERENCES

Ali, M. *et al.*(2011). Simulation of the impacts of land-use change on surface runoff of Lai Nullah Basin in Islamabad, Pakistan, *Landscape and Urban Planning*. Elsevier B.V., 102(4),271–279. doi: 10.1016/j.landurbplan.2011.05.006.

Dewan, A. M. *et al.*(2016). Flood Hazard Delineation in Greater Dhaka , Bangladesh Using an Integrated GIS and Remote Sensing Approach Flood Hazard Delineation in Greater Dhaka ,Bangladesh Using an Integrated GIS and Remote Sensing Approach, 6049doi: 10.1080/10106040608542381.

Fernández, D. S. and Lutz, M. A.(2010). Urban flood hazard zoning in Tucumán Province , Argentina , using GIS and multicriteria decision analysis, *Engineering Geology*. Elsevier B.V., 111(1–4), 90–98. doi: 10.1016/j.enggeo.2009.12.006.

Guhathakurta, P., Sreejith, O. P. and Menon, P. A. (2011). Impact of climate change on extreme rainfall events and flood risk in India, 3, 359–373.

Gupta, K. (2007). Urban flood resilience planning and management and lessons for the future: a case study of Mumbai, India, *Urban Water Journal*, 4(3),183–194. doi: 10.1080/15730620701464141.

Lokanadham, B., Gupta, K. and Nikam, V. (2009). Characterization of Spatial and Temporal Distribution of Monsoon Rainfall Over

Mumbai, *ISH Journal of Hydraulic Engineering*, 15(2), 69–80. doi: 10.1080/09715010.2009.10514941.

Menon, A., Levermann, A. and Schewe, J.(2013). Enhanced future variability during India's rainy season, *Geophysical Research Letters*, 40(12),3242–3247. doi: 10.1002/grl.50583.

Prudhvi Raju, K.N. and Pandey, M.K.,(2013).Varanasi: Origin and Growth from a Geomorphic Perspective. In: Jayaswal, V. (ed.), Varanasi: Myths and Scientific Studies. Aryan Books International, New Delhi, 134-150.DOI: 10.13140/RG.2.1.4649.3281

Prudhvi Raju, K.N. and Bhatt, D.(2014). Water in Ancient Indian Perspective and Ponds of Varanasi as Water Harvesting Structures. In: Raju, N. J., Gossel,W.,Ramanathan A. L. and Sudhakar, M. (ed.), Management of Water energy and Bio-resources in the Era of Climate Change: Emerging Issues and Challenges,63-72.DOI:10.1007/978-3-319-05969-3_6

Rajeevan, M., Bhate, J. and Jaswal, A. K.(2008). Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data, *Geophysical Research Letters*, 35(18), 1–6. doi: 10.1029/2008GL035143.

Suriya, S. and Mudgal, B. V.,(2012). Impact of urbanization on flooding : The Thirusoolam sub watershed – A case study,, *Journal of Hydrology*. Elsevier B.V., 412–413, 210–219. doi: 10.1016/j.jhydrol.2011.05.008.

Swan, A.(2010). 'How increased urbanisation has induced flooding problems in the UK : A lesson for African cities ?', *Physics and Chemistry of the Earth*. Elsevier Ltd, 35(13–14), 643–647. doi: 10.1016/j.pce.2010.07.007.

Yenneti, K. *et al.*(2016). 'The truly disadvantaged ? Assessing social vulnerability to climate change in urban India', *Habitat International*. Elsevier Ltd, 56124–135. doi: 10.1016/j.habitatint.2016.05.001.

Zope, P. E., Eldho, T. I. and Jothiprakash, V. (2016). Impacts of land use – land cover change and urbanization on flooding : A case study of Oshiwara River Basin in Mumbai , India, *Catena*. Elsevier B.V., 145,142–154. doi: 10.1016/j.catena.2016.06.009.

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