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Assessing the Impact Index of Urbanization Index on Urban Flood Risk

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Abstract*: The process of urbanization has changed overall Land use/Land cover patterns which are being attributed to flooding and resulting in the economic damages from flooding events. This current study aims to evaluate the implication of spatiotemporal changes of LULC Pattern on the flood risk of Surat city (Gujarat, India), Lower Tapi Basin. The Topographical maps and satellite imagery of Resources-1 of the year 1968 and the year 2006 respectively are used for analyses the urbanization index. As the flood risk is a combination of flood hazard, and vulnerability of the urbanized area, flood losses are expected to rise due to change in each of these aspects. The remote sensing and spatial analysis tools of Geographic Information System (GIS) have been used to statistically examine the flood risk index along with their different land-use scenarios. It has been observed that other than natural processes, rapid urbanization obstructions are being considered as one of the main drivers of flood risk aggravation, and if so, it has made essential for the implementation of flood management approach at the top priority for reducing the risk of flood.

Index Terms*: Flood Risk, Flood Management, Land use/Land cover, Urbanization.

I. INTRODUCTION

Floods are one of the most destructive calamities among all natural disasters it can cause severe and irreversible damage to property, loss of human life, and livestock [1]. The negative impact of flood disaster events affects both the socio-economic life of people and the country's economic development [2]. Cities, with their high population densities, multiple economic activities, and impermeable surfaces increase the impact of flooding to a large extent [3]. The world is becoming increasingly urbanized with many cities grew rapidly. An Indian urban resident is projected to rise up to 590 million by 2031 [4]. As there is a steady increase in the population, require more space to settle and more assets to organize those settlements [5]. Thus, urban infrastructures and services have been failing to keep pace with this economic growth. The urban population growth and also by the uncontrolled industrialization in flood-prone areas are the main attribute for changes in the LULC as well [6]. The changes in LULC are mainly responsible for increased urban flood risk and resulted in losses and casualties [7]. Urbanization may be as important as baseline environmental conditions in determining the flood risk [8]. Thus, risk factors have been identified and combined to understand the effect of the urban explosion in this study.

Dang et al. [9] presented an approach that, flood risk is the composition of the flood hazards and the vulnerability for each element at risk. This flood risk analysis equation is extensively used by many researchers to analyze the potential impacts of flooding. Consequently, vulnerability refers to the exposure of the urban area to flood and the economic value of assets [10]. Hazard indicator refers such as flood depth which affects the probabilities of being harmed during floods [11]. Based on the concept of risk analysis, it is, therefore, necessary to analyze the vulnerability, hazards and flood risk in urbanized areas. The subject of this study is Surat city, which is a developing coastal city of the Tapi River Delta. The city has a high-density population, most expensive properties, and higher economic activities. Because of the same the spatial pattern of LULC of the city area subjected to variation over a period of time, result in changing the flooding behavior pattern. The study area has experienced the most devastating flooding. The floods in the lower Tapi Basin are of frequent occurrence. The major flood event occurred in the years 1883, 1884, 1894, 1942, 1944, 1945, 1949, 1959, 1968, 1994, 1998, 2006 [12]. Surat has experienced damaging flood events of the year 1968 and 2006, which was the worst on record in many locations; it caused severe damage to this region [13]. Therefore, in urbanization stages, two flood events (1968 and 2006) were selected for this study. The aims of the research work are 1) to evaluate the LULC Pattern change and urbanization index for the Surat city and, 2) to quantify the implication of urban expansion on the flood risk.

II. STUDY AREA

The Tapi river begins its journey from a place called Multai (Betul district, Madhya Pradesh) having a length of 724 km, which flows through the states include Madhya Pradesh, Maharashtra, and Gujarat. Elongated shape catchment basin of 65,145 km^2 area, which has been divided into the upper, middle, and the lower Tapi basin. River Tapi flows through the Surat city and empties into the Arabian Sea, 19 km from Surat. Surat city lies at an ending tail of river Tapi with a geographical area 326.515 km^2. Surat city (Fig. 1) has a latitude of 21.0° to 21.23°N and longitude 72.38° to 74.23°E. The elevation above sea level is 13 m and has a population of over 4,467,797 [14].

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To controlling the repeated flood, the Ukai dam was constructed in 1972 at Ukai across the Tapi River which is situated 100 km from Surat city. Hence, it is important to control the discharge of the river at the time of the flood during the monsoon season, or during maximum inflow. LTB starts from downstream of Ukai dam and The LTB is prone to flood hazards due to its geographical location. It has been receiving excessive average yearly precipitation of about 1376 mm which repeatedly results in the excessive release of water from the Ukai dam during rainy season results in the inundation of LTB, including Surat city. The most unforgettable and severe events were the flood of 1968 and flood 2006 which has done great damage to this city.

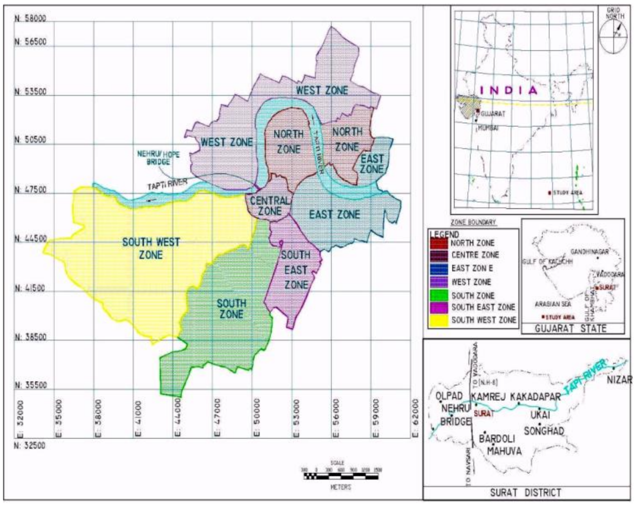

Fig. 1. Location map of Surat city

III. DATA SOURCE

1. Toposheets (46C/15 and 46C/16) at scale 1:50,000 were acquired from Survey of India have been used to evaluate the urbanization index for the year 1968.
2. For analyzing the urban expansion of the year 2006, Resourcesat-1 merged LISS-III + LISS-IV satellite image, December 2006 was procured from National Remote Sensing Centre, Hyderabad (NRSC).
3. Inundation maps of flood event 1968 and 2006 have been procured from Surat Municipal Corporation and Surat Irrigation Circle.
4. The flood depths data were collected from 2006 flood depth record, Mahanagar Palika- Vahivati Ahewal (68-69), Public Work Department report-1968, CWPRS report -2009.
5. Discharge data and flood water level data at Hop bridge have been gathered from the Central Water Commission, Surat.

A. *Flood scenario of August 1968*

The Maximum flood discharge at the Kakrapar weir was observed to be 43,891 m^3s^{-1} in the year August 1968. The floods of 1968 were unprecedented and highest ever recorded. The floods of the year 1968 which were the heaviest the living memory of the people surpass all previous records are caused vast devastation taking a heavy toll on human life and cattle. The floods of August 1968, which began on 5th August, were all the more destructive due to the following reasons:

1. The flood was with the magnitude of 43,891 m^3s^{-1} raised the gauge level 12.08 m at Hope Bridge
2. There was a simultaneous 3.65 m high tide.
3. Incessant rainfall of 17th was recorded in three days.
4. Windstorm of 80 km/hour was blowing over the city.
5. The irrigation canals passing on three sides of the city burst over its banks and spilled into the city.
6. This established strong currents and whirlpools in the city.

During these floods the river Tapi spilled its banks at various points, the main spills being on the right bank near village Mandvi, Bodhan and DhoranPardi in National Highway. No.8 upstream of the Kathor bridge on this river. The other spill was near Nana Varachha on the left bank about 6.5 km upstream of the Surat city downstream on Nana Varachha. The flood was flowing in a vast sheet of water extending on both the banks. The spill near Dhoran Pardi on the right bank out of the National highway no.8 various places breached the Hajira branch of the K.R.B.C (Kakrapar Right Bank Canal) system and spread over an extensive area. The other spill taking south-westerly course ultimately, along with the overflowing of the banks at the Utran caused breaches in the Ahmadabad-Bombay broad gauge line near Sayan, Gothan, and Surat. The spill on the left-hand side through Kakra creeks damaged the lower reaches of the Surat Branch and important part of the K.R.B.C (Kakrapar Left Bank Canal), and flowing through the railway culvert, entered the Surat City and Udhna causing heavy damage to the city of Surat and the industrial township of Udhna. Finally, the waters entered the Kharland at the north of the Mindhola River.

B. *Flood scenario of August 2006*

The devastating flood occurred in the year 2006 was the magnitude of 25,768 m^3s^{-1} and level at Hop Bridge was 12.09 m. During 04th to 10th August 2006, there was sustained precipitation in the upstream catchment of the Tapi in the state of Madhya Pradesh and Maharashtra. The total 400 mm rainfall occurred within two days of intense rainfall period at some of gauging stations. On account of this sustained rainfall in the upstream catchment of Tapi in Madhya Pradesh and Maharashtra, inflows to Ukai dam started rising from about 2831 m^3s^{-1} at 00 hours of 06th August to about 14158 m^3s^{-1} at 24:00 hours. On 07th August the peak inflow reached 33980 m^3s^{-1} at 15:00 hours. The inflow remained sustained between 33980 m^3s^{-1} to 22653 m^3s^{-1} from 07th to 09th August. Daily records of Ukai reservoir level, inflows, and outflows during 01st to 15th August 2006 are shown in Table 1.

Table 1. Detail of inflows, outflows and water level of flood 2006

Date	Level at Ukai (m.)	Inflow at Ukai (Cusec.)	Inflow at Ukai (m^3/s)	Outflow from Ukai (Cusec)	Outflow from Ukai (m^3/s)	Water Level at Hop-pul l (m)
01/08/0	101.0	62903	1781	1200	33.98	2.30
02/08/0	101.5	75263	2131	1200	33.98	2.36
03/08/0	101.9	73715	2087	23784	673	1.90
04/08/0	102.1	73413	2078	23680	670	2.20
05/08/0	102.2	150047	4248	125464	3552	0.90
06/08/0	102.7	503027	14244	352056	9969	6.90
07/08/0	104.5	116639	33028	829829	23498	11.90
08/08/0	105.3	922629	26125	908994	25,768	12.09
09/08/0	105.4	719575	20376	650417	18417	12.07
10/08/0	105.2	363632	10296	544795	15426	11.25
11/08/0	104.9	234355	6636	299785	8488	8.90

12/08/0	105.0	209250	5925	300775	8516	6.50
13/08/0	104.2	141817	4015	297203	8415	7.90
14/08/0	103.1	134318	3803	312168	8839	8.00
15/08/0	102.4	122704	3474	147916	4188	6.92

(Source: Surat Municipal Corporation)

The Surat city was subjected to sustained flood for 4 days between 7th to 10th August 2006. This flooding was due to the entry of flood water through a portion of incomplete flood embankment walls as well as breaches in flood embankments on both the banks on upstream and downstream of Singanpur weir at about 50 locations. Almost 90% of Surat city and surrounding towns/villages were inundated/flooded [15].

IV. METHODOLOGY

The spatial-temporal analysis of two scenarios (the flood event 1968 and 2006) was conducted to evaluate the implication of urban expansion on the flood risk for the Surat city. The approach to evaluating the effect of LULC change on flood risk involved the following steps shown in Fig. 2.

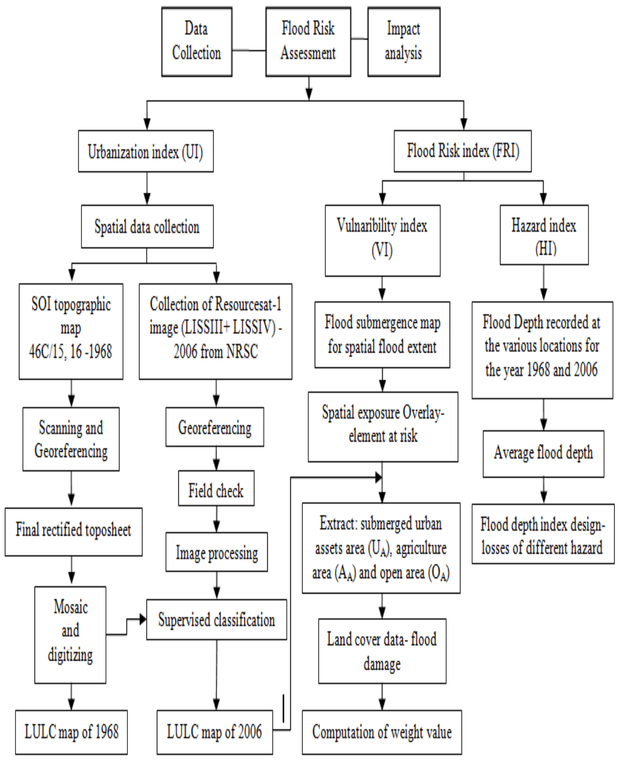

Fig. 2. Methodology for impact assessment of urbanization on Flood Risk.

A. *LULC map for study area*

A precise assessment of spatial trends is essential to understand the implication of urban expansion on the flood risk. The variation in the Urbanization Index between the years 1968 and 2006 was studied in this study. Different spatio-temporal Land use changes are classified as water bodies, vegetation area, an urban area, as well as open area. A supervised classification method was used for classified the LULC map for various temporal periods, that is the year 1968 and 2006. The aforementioned method bases itself on training samples. Furthermore, this LULC was extracted on the basis of digitizing the toposheet of the year 1968 in ArcGIS 10.5 software. A maximum likelihood method is one of the supervised classification techniques was employed to classify pixels or areas in the georeferenced Resources-1 (2006) satellite image. Land use/land cover maps (1968 and 2006) for the Surat city are shown in Fig. 3. The urban area from the year 1968 to 2006 increased by 44.12 km^2 to 75.32 km^2 respectively. Here, 310.04 km^2 area is being taken for comparison of Urbanization Index. The Urbanization Index (UI) for the year 1968 and 2006 are 14.23% and 24.29% respectively. Table 2 shows the area statistics of land use/land cover changes.

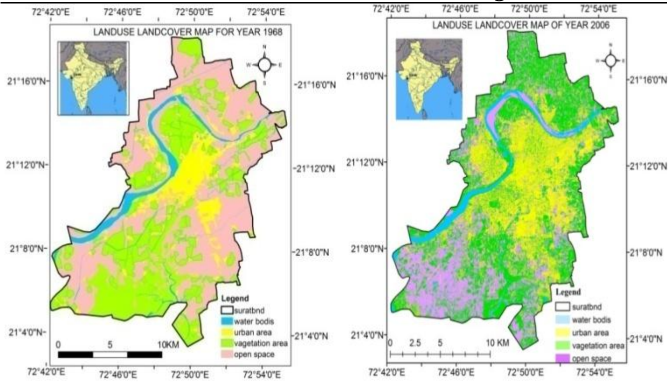

Fig. 3 (a). LULC map for the year 1968 **(b). LULC map for the year 1968**

Table 2. Land use- Land covers statistics of the study area

No.	Category	Year 1968 Area km^2	Year 1968 % To Total Area	Year 2006 Area km^2	Year 2006 % To Total
1	Urban area	49.49	15.96	75.32	24.29
2	Water bodies	15.82	5.10	13.72	4.44
3	Vegetation area	100.28	32.35	120.52	38.87
4	Open space	144.45	46.59	100.48	32.40

B. *Flood risk analysis*

It also examines vulnerability and hazard indicators, which are the main drivers of trends for analyzing the impacts of urbanization on flood risk. Few studies have shown that urban development increases the flood risk in cities [16, 17]. The historical risk assessment method was applied to the study area. Historical flood event data were used to calculate the Flood Risk Index (FRI) for urbanization stages (1968, 2006). For assessing the flood risk, risk analysis is conducted by the product of vulnerability and flood hazard of each element at risk [18]. Flood Risk can be written as Risk = Vulnerability x Hazard [19]. Depth of inundation is the main determining parameter in defining the flood hazard [20] and its vulnerability; assets in areas at risk were considered as well [21]. Accordingly, two kinds of indices were conducted under the assessment of Flood Risk Index: Hazard Index (HI) and Vulnerability Index (VI). Equation 1 is used to calculate the Flood Risk Index (FRI) for the region.

$$FRI = HI \times VI \quad (1)$$

1) Vulnerability Index (VI)

The vulnerability assessment was made with regard to the exposed land use patterns in the flooded areas. Urban expansion and economic growth increase vulnerability with more urban area exposed to flood and the amount of damage caused by a particular hazard [10]. Urban assets and agriculture activity were considered as a stock and main income in the study area. Vulnerability Index (VI) was found as an area covered with urban assets and the agriculture area was exposed during the flood events. Following steps are used to prepare the Vulnerability Index (VI):

1) Inundation area $A_{inundation}$ for flood event 1968 and 2006.

Flood inundation maps (1968, 2006) were constructed from the flood submergence map 1968 collected from the Surat irrigation circle and flood submergence - 2006 a map in the form of AutoCAD file prepared by SMC, utilized for finding out the inundation area. Flood inundation areas are 170.05 km^2 and 110.00 km^2 for flood event 1968 and 2006 respectively, out of the 310.04 km^2 (total study area). Fig.4 shows the submergence maps of the study area for the flood event 1968 and 2006.

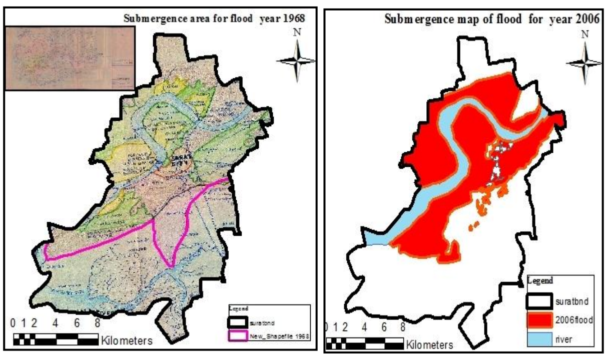

Fig. 4 (a). Flood submergence map for year 1968 **(b). Flood submergence map for year 2006**

2) Exposed urban built-up area U_A, agriculture area A_A, and open space area O_A to flood event.

A total urban area exposed during the flood event is considered as an exposed urban assets area (U_A). Urban exposed area (U_A), agriculture area (A_A) and open area (O_A) exposed during the flood event 1968 are 35.45 km^2, 48.00 km^2, and 86.55 km^2 respectively. Urban exposed area (U_A), agriculture area (A_A) and open space area (O_A) exposed in flood event 2006 are 45.00 km^2, 42.00 km^2, and 23.00 km^2 respectively. Urban area and Agriculture area submergence map for the flood event 1968 and 2006 are shown in Fig. 5.

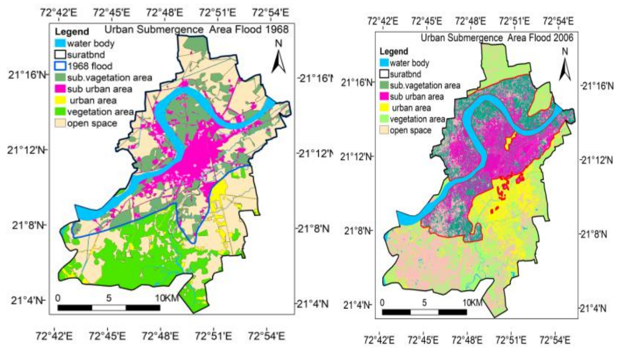

Fig. 5(a). Urban submergence map for year 1968 **(b). Urban submergence map for year 2006**

3) Weight the vulnerability factor for the different submerged land use categories

Actual damage corresponding to the damage that really occurred in the past is considered as the monetary worth of the various land use classes vulnerable to flood. Table 3 shows the intensity of damage impacted by flood varies among the different LULC classes. In this study, the vulnerability factor of 0.50 is given agriculture area with greater tolerance to flooding and less economical damage values exhibited compares to an urban class. The economic damage values of the urban class are 20 times that of agriculture land as an urban class with high urban assets. Therefore, for evaluation, vulnerability factor 10 and 0.5 were assigned to represent the inundation area of urban assets and agriculture area respectively. Flooding occurs in an uninhabited area in the open space area, and then there is no risk [22] as vulnerability factor 0 was assigned to represent the open area class. Vulnerability Index (VI) was calculated by Equation 2.

$$VI = (10\,U_A + 0.5\,A_A + 0\,O_A) / A_{inunnndation} \quad (2)$$

U_A = Urban submerged area, A_A = Agriculture submerged area, and A_0 = Open submerged area, $A_{inundation}$ = total inundation area during a flood event, $A_{inundation}$= 170.05 km^2 (1968), $A_{inundation}$ = 110.00 km^2 (2006), from equation 2; VI = 2.23 and VI = 4.28 for year 1968 and 2006 respectively.

Table 3. Damages of Tapi flood in August 1968 and August 2006

No	Details	Year 1968	Year 2006
1	Number of Population affected	5,51,800	1,90,000
2	Number of Cattle and other animal lost	5673	4,474
3	Number of Human lives lost	114	155
4	Houses/huts damage	Rs. 2,71,19,000	Rs. 2500 crore
5	Damage to agriculture land	Rs.3,34,00,000	Rs. 2000 crore
6	Damage to other engineering structure	Rs.3,94,30,545	Rs.17000 crore
	Total damages	Rs.10,10,22,445	Rs.21500 crore

(Source: P.W.D. Govt. of Gujarat, 1971 and People's committee on Gujarat Floods 2006: A Report: Thakar, 2007 [23].

2) Hazard Index (HI)

The flood water level is considered as the most important criteria for flood damages estimation [24]. Hazard index was constructed using the inundation status of 50 points in the specific location of the study area during the flood event. The comparisons of flood level at a peak period of the flood event 1968 and the flood event 2006 are shown in Table 4. The average inundation depths are 1.49 m and 2.07 m for the year 1968 and the year 2006 respectively. The impact of flooding can be classified according to the water level in the urban area as, low, medium and high hazard [21]. The hazard index value ranging from 1 to 3 was assigned corresponded to low, medium and high hazards based on the concept of difficulties experienced by people in their daily routine and damaged to property (Table 5). The Hazard Index (HI) is 2.00 assigned for the year 1968 and 3.00 and assigned for the year 2006.

Table 4. Floodwater levels at the various points in the city.

Sr No.	Place Name	Flood Levels (m) Year 1968	Flood Levels (m) Year 2006
1	Varachha water works compound	0.9	1.27
2	Lal darwaja (Moti seri)	0.6	0.9
3	Zapa bazaar (Masjid)	1.8	2.15
4	Tower	0.6	0.83
5	Mali faliu (Maskati)	0.6	0.91
6	Bhagal char rasta	0.45	0.83
7	Chowk Bazar (Museum)	2.4	3.45
8	Gujarat Mitra (Old Civil Chawk)	2.7	3.27
9	Makkai pool (Swimming pool)	0.45	0.77
10	Kadarshad ni nad (Sigma school)	3.3	4.28
11	Duch Road Opp. GIDC Office	0.9	1.31
12	Dutch garden post office	0.6	0.83
13	Mahila bank (Balaji road)	0	0.15
14	Chuata bazaar char rasta	1.2	1.78
15	Ambaji road	0.6	1.13
16	Chuata bazar	2.1	2.89
17	Dhastipura (Masjid)	3	4.09
18	Sahpore	0.45	0.76
19	Saiyad Pura (Main road)	2.1	2.59
20	Sayedpura pumping, Near Police Chawki	3.5	4.63
21	Variyavi bazaar (Madariwad)	3.2	4.65
22	Haripura (Garden mill)	0.9	1.43
23	Badekha Chakla	1.8	2.59
24	Pani ni bhit char rasta	1.2	2.28
25	Subhash chowk	0	0.69
26	Gopipura (Hanuman mandir)	1.8	2.24

27	Navsari bazaar (Thakor farsan)	3	3.69
28	Sagram pura (Zanda sheri)	1.2	1.5
29	Sagrampura main road	1.5	1.73
30	Khapatiya Chakla	1.05	1.21
31	Gopipura main road	0.9	1.21
32	Mahidhar pura (Ramji mandir)	0.75	1.29
33	Nanavat (Government reshning)	0.3	1.06
34	Athwa gate char rasta (Yatimkhana)	1.5	1.78
35	Gandhi engineering college	0.6	0.97
36	Adarsh society	1.2	1.37
37	Pal Rander	3	3.35
38	Sugam society (Adajan)	2.7	3.65
39	Lalgate	0.9	1.5
40	Surat Electricity company	0.3	0.6
41	Lal darwaja unapani road	0.45	0.7
42	Rander (Tarvadi gorath)	2.7	4.57
43	Falsavadi (Niranjan mill)	2.1	3
44	Mota Varachha gam	2.4	3.3
45	Hodi bungalow	1.2	1.6
46	Kadampalli	1.2	1.52
47	Adajan depo	2.7	3.15
48	Bhavanivad (Haripura)	0.9	1.5
49	Bhagatalav	2.4	3.45
50	Adajan Patiya	2.5	3.3
	Total flood depth	74.6	103.7
	Average flood depth	1.492	2.074

Source: Surat Mahanagarpalika Vahivati Ahewal 68 to 69, Gujarat Mitra Newspaper, Book: Tapi's RudhraSvarup, Public interview, SMC- 2006 flood depth data.

Table 5. Categorization of flood hazard severity.

Flood depth	Description	Hazard index
$D < 0.6$ m	The number of causalities due to flood, in terms of death or injuries and damage to property, is expected to be very low	1
0.6 m $\leq D < 1.5$ m	Causalities, in terms of depth and injuries, are considerable.	2
1.5 m $\leq D$	Damage to property is extensive and the probability of having dead and injured people is high.	3

V. RESULT

The city of Surat and its economy have been hit by a number of floods over the past. Rapid urbanization and industrial development created erratic growth and severe encroachment on the Tapi river floodplains. The process of urbanization has changed the natural landscape and increased flooding problems in the city of Surat, Gujarat, India. Nearly the same amount of the flood level of 12.09 m had reached at Nehru Bridge in flood event 1968 and 2006. Yet the 2006 flood event was more devastating for the study area as compared to the 1968 flood event. Industrial growth, as well as the commercial considerable extent that has led to the migration of people at the surrounding of the study area and this increase, is added to the present population. This unexpected increase in population growth leads to more extreme changes in LULC. In this research, approaches have been used to analyzing the effect of temporal and spatial expansion of the urban class on flood risk.

Table 6. Flood exposure of year 1968 and year 2006.

Flood year	Urban area	Flooded area Sq.km.	Submerge Urban area Sq.km.	Avg. flood depth m	Flood damage RS.
Aug. 06,1968	15.96%	170.05	35.45	1.60	10,10,22,445
Aug.08,2006	24.29%	110.00	45.00	2.09	21000 crore

A statistical Table 6 shows that the LULC class of the built area had occupied about 49.49 km^2 (1968) and had increased to 75.32 km^2 (2006) out of the total study area. The urban class has increased to 25.83 km^2 and nearly 25.70% of low lying open lands have been converted to urban class from the years 1968 to 2006. The flood inundation maps show that 55% of the study area was submerged in 1968, while in 2006 the percentage of the submergence area was 35%. This data was incorporated with Land use land cover map of respective flood events. The study revealed that the flood water spreading area decreased but due to the urban obstruction, their effect can show on the depth of flood water. A subsequently increase in the average flood depth by 38 %. Flood losses have also increased from Rs. 10,00,000 (1968) to Rs. 21000 crore (2006), which clearly indicates that flood

losses have increased due to urban expansion. The flood water depth increases and so that significant increased flood damage condition in the Surat city. Consequently, flood risk has also increased from 4.46 and 12.84 can be attributed to the corresponding urban land-use change for the year 1968 and 2006 respectively.

VI. CONCLUSION

During the flooding, urban obstructions do not allow further spreading of floodwaters over a floodplain. With the Accelerated urbanization has resulted in an impervious obstruction in which the spreading of the flood could spread had shrunk. The area where the flood water could spread had decreased and caused the flood water level to rise. By analyzing the statistical data, it reveals that as the Urbanization Index (UI) increase from 14.23% to 24.29% for the year 1968 and 2006 respectively. Flood inundation area $A_{inundation}$ decreased from 170.05 km2 (1968)) to 110.00 km2 (2006), and the average flood depth has increased from 2 to 3, with the decreasing submerged area in the region. The result shows that, if Vulnerability Index (VI) for exposed urban areas and hazard index (HI) has increased with an acceleration of urbanization, then the Flood Risk Index (FRI) has also increased from 4.46 to 12.84 in the study area, which consequently showed that the causalities too increased from the year 1968 to the year 2006. As a result, flood vulnerability of the exposed urban area had increased with the hazard depth and hence valuable assets are now exposed to risks. Thus, this has shown the severity of flood risk in the study area. Reviewing the fact that, we have all contributes to increasing the impact of the flooding and flood risk in the region. During the urbanization process, the drainage and the floodwater storage capacity had been reduced as many streams had disappeared. Negative impacts of human activities can often cause limited natural retention and the multiplication of economic damage in the basin. As a result of this process, the natural drainage got covered and the ground levels got raised in the Surat. Thereby, the damage has also been increased due to the obstructions of the waterways or absence and inadequacy of natural drains incorporated into development patterns. In fact, due to the urbanization process of recent years and the consequent sealing of flood water, has become more difficult to manage floods, Moreover, in the context of urban growth, it is almost a necessity to develop integrated flood management measurements.

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