Flood vulnerability and slum concentration mapping in the Indian city of Kolkata: A post-Amphan analysis

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ABSTRACT
The landfall of super cyclone Amphan, which affected Southern West Bengal and Orissa in 2020 and devastated human life, exposed the failure of urban infrastructure. On May 20, 2020, the storm alone recorded a rainfall of 236 mm in 24 h in Kolkata, capital city of West Bengal, pushing the total rainfall of May to 359.1 mm while averaged value of precipitation in May (2010–2019) stands at 117.5 mm. So, it further calls for relooking at climate preparedness for the Indian cities. In 2015 also, severe floods had affected more than six million people across the country of India alone, with over 250,000 people evacuated. In this context, the urban flood risks and major contributing factors in the Indian city of Kolkata have been discussed in this paper. The recurrence of floods and the exploration of causes repeatedly point to a situation of increased precipitation due to climate change, worsened by unregulated urbanization. The vulnerability assessment and calculation of Flood Vulnerability Index (FVI) for Kolkata is also conducted. It reveals the differential degree of vulnerability of city dwellers depending on location and infrastructure. The study leads to form a data base to infer characteristics and determine priority settings for the vulnerable urban population living in slums located in poorly drained areas of the city. A basin-wise analysis in KMC area reveals major urbanization coupled with decaying drainage system in the vulnerable basins as the main reason for aggravated flooding situation.

Introduction
Hydrological (mainly floods) and meteorological (storms) disasters are the major causes for the increase in global natural disasters. Floods alone affected billions of people in the world, 95% of whom live in Asia (CRED, UNISDR, 2015). It is well recognized that climate change risks like storms and floods are concentrated in coastal cities which are already dealing with significant stressors such as rapid population growth, resource demands, environmental degradation, and poverty (IPCC, 2014). In terms of population exposed to flooding; the top five cities listed in 2005 were Kolkata (India), Mumbai (India), Dhaka (Bangladesh), Guangzhou (China) and Ho Chi Minh City (Vietnam) (Nicholls et al., 2007). Further super cyclone Amphan hitting Kolkata on 20 May 2020 exposed the weaknesses of Indian coastal cities in coping with the virulence of such high intensity storm. Parts of the city remained under water for days aggravating human misery. In this context, it becomes imperative to investigate storm preparedness of Indian cities by focusing on city specific challenges. In this paper, the city of Kolkata, the capital of West Bengal state has been selected for analysis to identify the main causes of water-logging in Kolkata and also vulnerable urban areas due to heavy storm and flooding.

Floods in West Bengal
West Bengal, a state in eastern India, is diverse and occupies a major portion of Ganga Brahmaputra Delta. Although the paper will discuss in detail the menaces of urban floods in its capital city of Kolkata, it is interesting to see how the state has a whole has been suffering from floods over a long period of time. The floods have formed a major problem bringing urban activities to a halt in monsoons and inundating croplands in rural areas leading to food insecurity and crisis in the cities as well. An analysis of area flooded in the state against years of occurrence between 1985 and 2000 is given below. As shown in Table 1, out of 68,752 sq. km of the state, more than 20,000 sq. km area got devastated in four different years and the flood of medium magnitude i.e., between 2,000 and 10,000 sq. km, occurred 10 years. Map 2 shows almost all the districts of West Bengal are flood prone.

Some of the recent floods that occurred were at Jalpaiguri, Cooch Behar and Jalpaiguri in north Bengal due to monsoonal rains in 2002, and also at Darjeeling, Jalpaiguri, Malda, and Murshidabad in 2003. Further in 2005, 3000 coastal villages were inundated, in 2006 there were floods in Birbhum, Burdwan, and Murshidabad, in 2007 floods happened due to heavy rain from tropical depression in the Bay of Bengal, and also in 2013 in Paschim & Purba
Medinipur, Howrah, Hooghly, Bardhaman and Bankura affecting 2.1 million people.

In the floods of 2017, an estimated total loss of Rs. 553 crore (USD 86.6 USD million) was reported in the state (The Asian Age, 2017). In July and August 2017, the Indian state of West Bengal was affected by severe flooding following heavy rain - the city of Kolkata alone received 621.5 mm rainfall in July. About 50 people died and approximately 2 million were displaced in more than 160 villages, which remained inundated for days. 2,301 people were evacuated from their houses. Around 7,868 houses were entirely destroyed while 44,361 were partially damaged in West Bengal (The Hindu, 2017). More than 70 wards in Kolkata were inundated. In Kolkata and its neighboring areas, daily commuters had a harrowing time due to waterlogged streets at Ultadanga, Central Avenue, Shyambazar, Garia, Esplanade, Barasat, Lake Town, and Behala (News18 Com, 2017). About 11,974 hectares of paddy fields, 23,096 hectares of land under vegetable cultivation and about 1,79,321 hectares of paddy seed beds were damaged (Firstpost, 2017). With flood waters inundating farmlands and disrupting supply chains between urban and rural areas for 3 days in a row, the crisis was felt in urban areas as well, where the food prices of vegetables soared. Tomatoes, which were selling for Rs. 45 per kg in Kolkata markets earlier that month, sky rocketed to Rs. 100, an unthinkable amount for the urban poor. Prices of vegetables such as striped gourd, ridge gourd, green chilies, and okra escalated at different markets as well (Hindustan Times, 2017). This triggered severe panic and food insecurity, especially, in the poor urban communities.

Under the influence of the most recent severe storm event of super-cyclone Amphan; Gangetic West Bengal again witnessed havoc loss of human lives, livestock and property as well as disruption of basic services bringing urban life to a halt. The severe cyclonic storm made landfall at the coastal area of West Bengal with winds of 155 km/h (100 mph) (CNN, 2020). In the city of Kolkata the cyclone continued with wind speed of 112 km/h (70 mph) and gusts of 190 km/h (120 mph) damaging homes and uprooting trees and electric poles (TimesNowNews. com, 2020). The storm along with a recorded rainfall of 236 mm in Kolkata resulted in widespread flooding. Seventy two people were reported to have been killed in West Bengal while millions had been displaced (Figure 1).

**Flood vulnerability of Kolkata**

The capital city of Kolkata located on the River Hooghly, as shown in the location Map 1, is the third most populous urban agglomerate in India and is ranked in the top 20 most populous cities in the
Table 1. An analysis of area flooded against years of occurrence (Source: http://wbmd.gov.in/pages/flood2.aspx).

| Flood affected area (in sq. km) | Years during which the flood occurred | Total No. of years |
|---------------------------------|--------------------------------------|--------------------|
| Below 500                       | 1985, 89, 92, 94 & 97                | 5                  |
| 500–2000                        | 1962, 63, 64, 65, 66, 72, 75 & 96    | 8                  |
| 2000–5000                       | 1960, 61, 67, 69, 70, 74, 76, 80, 81 & 82 | 10                 |
| 5000–10,000                     | 1973, 77, 93, 95 & 98                | 5                  |
| 10,000–15,000                   | 1968, 79, 83, 90 & 99                | 5                  |
| 15,000–20,000                   | 1971, 86, 87 & 88                    | 4                  |
| Above 20,000                    | 1978, 84, 91 & 2000                  | 4                  |

Map 2. Map of West Bengal showing districts or parts of districts affected by flood. (Source: http://wbmd.gov.in/pages/flood2.aspx).

Figure 1. Satellite image showing Amphan approaching East India on 19 May 2020 (Source – https://www.nv.nasa.gov/view/globaldata.html#TRUE).

Heavy rainfall, overtopping of the River Hooghly due to water rise in the monsoons as well as increased inflow from the catchment and storm effects are the major contributors to urban flooding in Kolkata (The World Bank, 2010). A study conducted by Kolkata Municipal corporation and British Deputy High Commission in 2015 presented the flood maps which shows extent of flooding under various extreme situations like 300 mm rainfall and 400 mm rainfall in 24 h and 3 m and 5 m storm surge during high tide. Under 300 mm and 400 mm rainfall in 24 h condition almost the entire city is likely to get flooded while under 3 m and 5 m storm surge (abnormal rise of water generated by a storm, over and above the predicted astronomical tide) condition all the areas along the river is under serious threat, as shown in Figure 2.

The storm Amphan was one such extreme phenomenon which combined both the conditions of extreme rainfall and high storm surge in Bay of Bengal. It proved the predictions to be true by drowning the city under flood and uncertainty for days and even weeks in some parts of the city. It triggered widespread water-logging around the city due to extremely heavy rainfall - about 236 mm in 24 h. This was combined with an estimated storm surge of 5 m (16 ft). The areas like College Street, Behala, New Alipore and Sukia Street were submerged with very high depth of water. The satellite Imagery shows almost the entire city partially waterlogged due to such incessant rain fall along with substantial parts of Maheshtala Municipality in the south-west part of the KMC area.

world. Hence with flooding as a recurrent problem, the city needs immediate exploration in terms of urban flood management and planning.

Population and economy in Kolkata have grown parallel along with its environmental degradation and increase in climate vulnerability. Combining these have made the city more susceptible to disasters mainly floods, which occur every year in many parts of the city during the monsoon as the city receives increased amount of rainfall. Flooding not only brings about large scale human suffering but results in huge economic losses. Certain parts remain water logged for over three days. Over the years, not only has there been an increase in the depth and duration of water logging in these areas, there has also been a significant rise in the extent of area flooded.
The objective of this paper is to analyze flood vulnerability of Kolkata and draw relationship with slum population to plan for storm preparedness. A borough wise (borough is an administrative unit in Kolkata Municipal Corporation) analysis has been done in a quantitative form by calculation of Flood Vulnerability Index (FVI). The study attempts to form a database to identify characteristics or relationships of vulnerable population living in slums and poorly drained areas of the city (Figure 3).

**Methodology for vulnerability analysis of Kolkata**

The framework consisted of analysis of two sets of factors contributing to floods in the city – global and city specific, which is mostly literature study based. The data collection from various sources then leads to the Vulnerability analysis in a quantitative method which involved calculation of FVI based on two factors (depth of water logging and duration of water logging in various parts of the city during floods) (as shown in Figure 4). The mapping of Kolkata based on different values of FVI was then overlaid with map showing occurrence of slums to infer the characteristics of population affected.

**Global factors**

**Concerns of coastal cities**

Low-lying coastal areas constitute only 2 percent of land area in the world, but contain 13% of the urban

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**Figure 2.** Flood maps of KMC showing projected extent of flooding under various extreme situations like 300 mm rainfall and 400 mm rainfall in 24 h and 3 m and 5 m storm surge during high tide (source: KMC, 2017).
Some of the probable risks are accelerated sea-level rise, increase in sea temperatures, rise of cyclones, extreme waves and storm surges, high levels of precipitation and runoff causing urban floods and ocean acidification (Nicholls et al., 2007). Further, a recent study of the port cities revealed that increase in exposure of population and assets to flooding is expected in cities of developing countries mainly, especially in East and South Asia (World Bank, ADB, and JICA, 2010).

**Climate change factors**

Globally, changes in temperature and rainfall patterns are being observed due to global warming. Figure 5 shows the observed temperature change across the world with location of Kolkata marked. Kolkata, the capital city of West Bengal is no exception to this global trend with a significant rise of about 1°C over the period. It has a warm-humid climate and there have been noticeable climate variations, changes in rainfall, air temperature and extreme events like cyclones in Kolkata. A major reason for this is the increase in the surface air temperature (KMC, British Deputy High Commission, 2017). Further, the recent temperature graph of Kolkata (2010–2020) shown in Figure 6 shows the maximum temperature remains almost same but the lowest point of minimum temperature keeps rising over the past years. Increase in temperature also increases the potential for heavy rain falls (Royal Meteorological Society). Moreover, tropical cyclones act like huge engines that use warm moist air as fuel like Amphan was intensified by warm surface temperatures (Maity, Bandyopadhyay, 2020).

The monsoons are prolonged generally starting from mid June and extending till September. Rains are brought by the Bay of Bengal branch of South-West monsoon and supply the city with most of its annual rainfall which is about 194 cm (2017).
The annual rainfall data show an upward direction of the linear trend line as shown in Figure 7, indicating an increase in annual precipitation over the years in Kolkata.

Also, recent reports show June rainfall has increased sharply from 223.5 mm in 2014 to 419.4 mm in 2018, which is about 87.6% over a span of 5 years, resulting in a very sharp rise of the trendline as shown in Figure 8.

Analysis of rainfall records show increase in total annual rainfall as well as monthly rainfall in monsoon months like June making the conditions worse over the time with drainage capacity failing to cope with increased storm water runoff over a given time.
The India Meteorological Department’s weather monitoring station at Alipure in Kolkata has recorded exceptionally high rainfall of 236 mm in 24 h during the storm Amphan in 2020 (INDIA NEWS, 2020). But the pumping system can cater maximum 150 mm per day or 6 mm per hour (Chatterjee, 2020). These startling facts show how such a calamity was in waiting given the constant and abrupt rise of precipitation due to climate variations.

**Specific urban factors**

**Geographic factors**

Low-lying coastal areas are particularly at risk of devastation due to climate change. The Fourth Assessment Report (IPCC, 2007) identifies a number of hotspots, including heavily urbanized areas in the low-lying deltas, as extremely vulnerable to climate-related impacts as shown in map below.

Kolkata, the city in focus in this paper, is located on the extremely vulnerable Ganga-Brahmaputra coastal delta region shown in the map above and has an elevation of 1.5–9 m above sea level (5–30 ft) (NASA, 1999). Amphan, one of the strongest tropical cyclone to strike the Ganga Delta and the first super cyclonic storm to have formed in the Bay of Bengal, hit Kolkata on 20 May 2020. Causing over US$13 billion of damage, Amphan is also the costliest coastal cyclone ever recorded in the North Indian Ocean (Sud et al., 2020).

**Demographic factors**

The total population of the Kolkata metropolitan area (KMA) was 14 million (2011 census) while that in KMC was 4.4 million. But not all are
equally vulnerable. As per The United Nations Population Fund (2007), the impacts of climate hazards affect the people more "who live in slum and squatter settlements on steep hillsides, in poorly drained areas, or in low-lying coastal zones." The urban poor often live in unsafe urban environments, work in the informal economy, and have fewer assets. Hence, they are most at risk from exposure to hazards (Satterthwaite, 2007).

More than one third of the total population of KMA lives in slum. These slums not only lack basic infrastructure and services, but are also the hub of many informal manufacturing activities. This mixed residential and commercial/industrial land use in slums makes these areas highly vulnerable to extreme weather-related events, especially flooding.

Amphan hitting the city with a top speed of 112 kmph left thousands of people homeless while others suffered from lack of basic services like water and electricity. Hundreds of people living in slums were shifted to local clubs, ward offices and even subways (The Times of India, 2020). It is thus important to identify such areas prone to flooding with levels of inundation and vulnerable population for creating adequate safety measures.

**Topographic factors**

The overall slope in KMC is from west to east (as shown in Map 4) – from the Hooghly River in the west to the wetlands in the east. Therefore, Kolkata is located on a land that slopes away from the river Hooghly, which could have acted as the main drainage channel, making natural overflow into the river impossible. The topography shows east Kolkata marsh land as the natural catchment of storm water.
Urbanization factor

"Urban sprawl" is an occurrence of random growth of built-up areas in and around an urban unit over a period of time (Vision 2025, KMDA). The city of Kolkata has been growing in an unregulated and haphazard manner since World War II and Partition of Bengal and continued throughout the whole of the second half of 20th century. The rise of built up area from 61.8% to 87.7% in KMC from 1911 to 2001 (as shown in Table 2) is alarming and adds to the impervious ground cover of the city. The fast growing demand for services has long exceeded the capacity of drainage and sewerage infrastructure.

Moreover the growth has been unbalanced. Over the past two decades, the central city’s growth has not been much, adding 87,000 people from 1991 to 2011, while the suburbs added more than 3 million population, pushing the urban boundary further away (Wendell, 2012). As a result the fringe agricultural land got converted into settlement areas for human habitation and engulfed into the urban fabric. This also resulted in the shrinkage of the wetlands along the eastern fringe which is an important cause of urban floods in the city. The peripheral boroughs VII, XII, XI, and XIV lost most part of its blues and greens as shown in Map 5. As already mentioned, the general slope of the land in Kolkata is from west to east. Previously wetlands along this eastern edge had the capacity to hold the rain water runoff from the city proper (Mukherjee, Bardhan, 2018).

Failure of urban drainage system

Numerous natural and man-made channels make up the drainage system for Kolkata. It consists of the River Hooghly, the Circular Canal, the Bagjola, Kestopur, the DWF and SWF channel, the Tolly’s Nullah and the Boat Canal network as shown in Maps 6 and 7. The other main channels like Monikhal Canal in the south-west and Churial Canal in the south of KMC area also drain a large part of runoff to river Hooghly.

Out of these, the Hooghly River directly flows into the Bay of Bengal. The Tolly’s Nullah and Boat Canal are now tidal creeks of the Hooghly River. The Circular Canal mainly contributes drainage to the Hooghly River and the remaining part of its drainage goes to the Kestopur Canal. The Bagjola and Kestopur Canals run eastward almost parallel to each other and meet the Kulti River. The DWF and SWF channels also flow in a similar way and discharge into the Kulti at Ghushigata about 2 km south of the meeting point of Bagjola and Kestopur Canals. The tidal nature of the

![Map 4. Land elevation map of Kolkata and its environs (source- retrieved from https://en-gb.topographic-map.com/maps/lpjs/Kolkata/).](image)

Table 2. Pattern of land cover in KMC from 1911–2001. (Source- KMDA, 2001).

| Year | Total Area (sq km) | Built-up Area (sq km) | Nonbuilt-up Area (sq km) | Built-up (%) | Non built-up (%) |
|------|-------------------|-----------------------|--------------------------|--------------|-----------------|
| 1911 | 53.0              | 32.75                 | 20.25                    | 61.8%        | 38.2%           |
| 1963 | 104.0             | 77.85                 | 26.14                    | 74.86%       | 25.14%          |
| 1980 | 104.0             | 83.20                 | 20.80                    | 80.0%        | 20.00%          |
| 1990 | 187.33            | 159.04                | 28.29                    | 84.9%        | 15.10%          |
| 2001 | 187.33            | 164.29                | 23.04                    | 87.7%        | 12.30%          |
stream makes it essential to have the discharges into them directly controlled by sluices.

The combined flow produced by Maniktala, Town & Topsia canal systems is finally pumped by the terminal lifting pumping stations and discharged finally into the Storm Water Flow (SWF) channel and Dry Weather Flow (DWF) channel for ultimate discharge into the Kulti River at Ghushigata, 36 km away.

Monikhali canal system with several tributaries drains vast area of Maheshtala Municipality and

Map 5. Land utilization changes in and around Kolkata city (1985, 2005) (Source- developed by author based on map from NATMO).
adjoining Behala & Garden Reach area of KMC (as shown in Map 6). Churial canal also drains a large area of Behala, Thakurpukur area of KMC (as shown in Map 6) and huge expanse of surrounding village areas during rainy season.

The Kolkata Municipal Corporation (KMC) area, on the basis of the outfall canal it drains into, can be divided into ten catchment/drainage basins - Bagiola Basin, Town System, Suburban System, Maniktala Basin, Tangra Topsia Basin, Tollygunge Panchannagram Basin (T.P. Basin), Tolly’s Nallah Basin, Churial Basin, Monikhali Basin and Hoogly Basin as shown in Map 7 (KEIP, 2007).

Failure of Kolkata’s old canal system, which acted as an efficient drainage system for about three centuries, occurred due to the following reasons-

- The northern part of the network which started functioning during 1876 has been designed with a rainfall of **150 mm per day with 100% run off** and the southern part (Suburban System) established in 1890 or so has been designed with **100 mm per day**. (Chatterjee, 2020). Thus, it is evident that when rainfall in a day in Kolkata exceeds **200 mm during storms like Amphan urban flooding is inevitable**.
- Hydraulic capacity of the existing city drainage system and the outfall canal system has been reduced due to siltation and haphazard dumping of solid wastes. Lack of periodic maintenance of existing drainage system, solid waste management, public awareness on disposal of solid waste into
drainage system and others are the major concerns. Deposition of silt in the canal bed during tide lockage period is another challenge.

- Siltation in the canals over many years and poor maintenance has allowed deposition of silt in canal beds and the raising of canal bed level. The capacity of existing canals has therefore been reduced. The estimated reduction of carrying capacity of the various canals is in the range of 15% to 50% (City Sanitation Plan, KMC, 2011) (Table 3).
- Sluice gate and outlet structure maintenance have also been neglected. Both Hooghly River and Kulti River, the ultimate recipients of the surface runoff generated from the city has got strong tidal influence. To prevent tidal water ingress into the canals, control structures have been installed at canal outfall locations. Due to scarcity of fund and inadequate manpower, outfall structures are

| Name of the Canal | Average Depth of Siltation |
|-------------------|---------------------------|
| Bagjola           | 1.2 m                     |
| Town Head Cut & Suburban Cut | 1.0 m |
| DWF Channel      | 0.5 m                     |
| SWF Channel      | 0.3 m                     |
| T P Canal        | 1.5 m                     |
| New Cut – Krishnapur – Bhangar Kata Khal, Circular | 0.4 m |
| -Beliaghata Canal & Eastern Drainage Channel | |
| Churial          | 1.5 m                     |
| Tolly’s Nullah   | 0.5 m                     |
| Chetla Boat      | 1.6 m                     |
| Keorspukur       | 1.6 m                     |

*Map 7. Drainage basins in and around KMC area (Source- Author, developed from maps of KMC, KMDA and KEIP).*
not maintained and operated properly resulting in their dire condition and need for repair. Outlet structures constructed long back have aged with time and strengthening works are long pending.

**Flood vulnerability analysis**

A vulnerability analysis is done to establish the factors contributing to flooding and its severity in different parts of the city. In this study, although the analysis is particularly focused on the KMC area, reference to the post-Amphan flood situation of Maheshtala municipality (an immediate neighbor of KMC to the southwest) is also made as and when relevant.

**Flood Vulnerability Index (FVI) calculation**

The main objective to determine vulnerability is to inform decision-makers or specific stakeholders about the need and options for adapting to the impact of floods (Douben, 2006). FVI is a powerful tool for policy and decision-makers to prioritize investments, identifying areas with high flood vulnerability and thereby making process toward a better way of dealing with floods by societies (UNESCO-IHE).

**Flood Vulnerability Index (FVI)** is based on two variables - the depth and duration of flooding. Higher the values of these variables, higher are the vulnerability. The vulnerability index for each variable \( (V_N) \) is defined as the ratio of the value of that variable in each borough \( (V_n) \) to the maximum value \( (V_{max}) \) for the variable in the city (Wu, S. Y., Yarnal, B., & Fisher, A., 2002),

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FVI_N = \frac{V_N}{V_{max}}
\]

**Flood Vulnerability Index depending on water depth** during water logging period \( (FVI_D) \) is calculated based on KMC borough wise data (Sourced from KMC report, 2013) where the maximum depth \( (D_{max}) \) recorded is 42 cm.

**Flood Vulnerability Index depending on water logging period** (in hours) \( (FVI_T) \) is calculated based on KMC ward wise data (sourced from Environment Cell, KMDA, 2010) where the maximum and minimum periods of water logging due to a heavy rainfall in KMC wards, are 101 h and 0 h, respectively. A borough comprises of many smaller administrative units called wards, so for each borough the minimum time among the ward-wise data has been considered as Water Logging period \( (T) \) for calculation. The maximum duration \( (T_{max}) \) was found to be as severe as 101 h, i.e., more than four days (Table 4).

The composite FVI for each borough is calculated by adding respective \( FVI_D \) and \( FVI_T \).

Depending on the values of FVI, three categories have been derived by dividing the observed total range into three equal classes and the boroughs were given relative ranks/degree of vulnerability. The categories are presented in Table 5 and spatially indicated in Map 7 as follows:

**Flood vulnerability mapping**

Therefore, the most flood vulnerable boroughs occupy major portions of Monikhalı Basin, Hooghly Basin, Churial Basin and Topsia-Tangra Basin. Adjacent to Boroughs XIV and XV lies Maheshtala Municipality draining partly into Hooghly, Monikhalı and Churial basins (as shown in Map 6 and 7). It is to be noted that post-Amphan this area remained waterlogged for about 264 h. National Disaster Response Force (NDRF) had to drain out the water from localities of Maheshtala using portable pumps after 11 days (Sengupta, 2020). This shows the severity of problem in these basins.

A basin wise analysis in KMC reveals major urbanization coupled with decaying drainage system in these basins.

**Tangra-Topsia Basin**, comprising major portion of Borough VII, is a low lying area and a part of this area is below the full supply level of the SWF Channel, which flows through this basin. As a result, considerable areas are prone to water logging which lasts for a long time. Moreover, part of wetlands in this area have been reclaimed for urban settlement (as shown in Map 5), which resulted in loss of detention storages, which absorbed the excess rain water during times of

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### Table 4. Borough wise calculation of Flood Vulnerability Index (FVI) in KMC area.

| Borough | Water depth during water logging period (in cm) \( (D) \) | Water Logging period (in hours) \( (T) \) | \( FVI_D \) \( \frac{D}{D_{max}} \) | \( FVI_T \) \( \frac{T}{T_{max}} \) | \( FVI \) \( \frac{FVI_D + FVI_T}{2} \) |
|---------|-------------------------------------------------|-----------------|----------------------------|----------------------|------------------|
| I       | 36                                              | 0.86            | 8                          | 0.08                 | 0.9              |
| II      | 8                                               | 0.19            | 14                         | 0.14                 | 0.3              |
| III     | 8                                               | 0.19            | 12                         | 0.12                 | 0.3              |
| IV      | 8                                               | 0.19            | 30                         | 0.30                 | 0.5              |
| V       | 42                                              | 1.00            | 26                         | 0.26                 | 1.3              |
| VI      | 42                                              | 1.00            | 4                          | 0.04                 | 1.0              |
| VII     | 42                                              | 1.00            | 72                         | 0.72                 | 1.7              |
| VIII    | 36                                              | 0.86            | 8                          | 0.08                 | 0.9              |
| IX      | 36                                              | 0.86            | 8                          | 0.08                 | 0.9              |
| X       | 42                                              | 1.00            | 0                          | 0.00                 | 1.0              |
| XI      | 36                                              | 0.86            | 8                          | 0.08                 | 0.9              |
| XII     | 42                                              | 1.00            | 2                          | 0.02                 | 1.0              |
| XIII    | 42                                              | 1.00            | 2                          | 0.02                 | 1.0              |
| XIV     | 36                                              | 0.86            | 101                        | 1.00                 | 1.9              |
| XV      | 36                                              | 0.86            | 72                         | 0.72                 | 1.6              |

### Table 5. Categories of flood vulnerability based on calculation of FVI (Source – Author).

| FVI   | Borough nos. | Relative Ranks/ Degree Of Flood Vulnerability |
|-------|--------------|---------------------------------------------|
| 3–8   | III, II, IV  | Low                                         |
| 8–1.4 | I, V, VI, VIII, IX, X, XI, XII, XIII | Medium                                      |
| 1.4–  | XV, VII, XIV | High                                        |
| 1.9   |               |                                             |

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heavy storm. This basin, thus, shows an increase in the water logged area and the average duration of water logging is more than a day here.

**Hooghly basin** (comprising major portion of Borough XV) borders Hooghly river. The industrial and commercial establishments have mushroomed along the bank of the river eating up its open spaces (as shown in changes in land utilization of KMC area in Map 5). The existing drainage pattern of Hooghly basin is predominantly through open surface drains, with Dhankheti canal and Khaldhari canal as the two major drainage outlets. There are also numerous surface drains which discharge the combined flow directly to the river (Mukherjee, et al. 2018). Condition of these drainage canals and major surface drains is very poor due to siltation and dumping of solid waste into these channels.

The drainage system within **Churial Basin** (comprising of the southern part of Borough XV) is grossly inadequate and mostly through open drainage network. The southern portion of this basin is predominantly rural in nature, low-lying and lacking an organized drainage system. There has been a major increase in built-up area at the cost of agricultural lands around these areas (as shown in Map 5). Moreover, unlined condition of the many existing drains adds to the problem. Further, the outlet system from the STP is not fully developed and due to lack of an adequate disposal arrangement of the storm water flow, the flooding in this area has aggravated. Flooding in these areas persists for months.

Condition of the canals in **Monikhali basin** is very poor therefore they spill very often during monsoon period. Treated effluent from Garden Reach Sewage
Treatment Plant is also discharged to Monikhali canal near Santoshpur railway station. Excess water from Garden Reach Water Treatment Plant is also conveyed to and discharged in the Monikhali canal. After the addition of these areas to the core city of Kolkata in the year 1984, the built-up area has tremendously increased here, yet there is no proper drainage outfall arrangement from the municipal area as well as in KMC area to this canal system. Increase in the imperious area has resulted in an increase of runoff which accounts for higher level of water logging in these basins.

These findings highlight loss of water bodies, open spaces and vegetation in the Boroughs XV, VII and XIV (as shown in changes in land utilization of KMC area in Map 5) and associated shortfall of infrastructure as one of the main man-made causes of flooding, apart from increased precipitation due to climate change.

Overlaying with occurrence of slum population

Overlaying flood vulnerability with occurrence of slum population is important. The objective is to infer the characteristics of resource poor urban population getting disproportionately affected by cyclones and resulting flooding and hence needing priority. The urban poor are more vulnerable to flooding because of their practical inaccessibility to areas that are fit for safe and healthy habitation and limited access to livelihood opportunities and basic amenities.

Given below is the percentage of slum population in each Borough. The available borough-wise slum population data (Slum Department, Kolkata Municipal Corporation, 2009) and nearest population data of Census 2011 are used for calculation of percentage of slum population (Table 6).

It is interesting to note that the two slum populated boroughs (slum population more than 50%) are also the most flood vulnerable boroughs (as shown in Map 8). Invariably, with degraded infrastructure and low inhabitability, these areas have high concentration of slums. Therefore, these boroughs with high water logging depth and time as well as higher concentration of slums have maximum exposure to risk from floods like damage or loss of habitat, outbreak of water borne diseases and other climate-related hazards making them high on vulnerability and low on coping capacity.

Thus, Borough VII and XV are most vulnerable and needs priority settings in terms of flood management initiatives and habitat up-gradation.

Conclusion

The recurrence of floods and the investigation of causes in the cities of India point to a situation of increased precipitation worsened by unregulated urbanization and failing drainage system. The calculation of FVI, mapping and its overlay with the concentration of slum population further identified the most vulnerable population living in the poorly drained parts of the city. The study highlights the danger of letting the development grow at the cost of natural resources mainly wetlands and vegetation that act as urban sponge in these areas that are already low-lying. In fact, an innovative way of flood mitigation is construction of “Urban storm water wetlands” which is an affordable solution of capturing and purifying storm water while giving recreational benefits (Friar, 2018).

A comprehensive city drainage plan to cope with the ongoing pace of urbanization and increasing events of heavy rainfall and tropical cyclones like Amphan is necessary. A city drainage plan needs to be prepared as a flexible, responsive, and live document that is open to implementation as per changing climate, socio-economic factors and degrading infrastructure. Rehabilitation of existing drainage systems must be taken up in parts of the city where the sewerage system exists but has become nonfunctional. Along with desilting of canals to increase their carrying capacity, dependable pumping stations should be built capable of handling increased volumes of storm water. Regulations and amendments in building bylaws are equally essential to limit occurrence of similar vulnerable pockets in the new urban extensions.

Finally, inclusive participatory planning is important for a comprehensive solution as urban poor needs special attention. The planning process has to be a consultative one with stakeholders of varied groups for formulation of development objectives, identification of priorities and disaster risk management measures.
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Map 9. Borough-wise flood vulnerability map of KMC and overlay with concentration of slum population (Source – Author).
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