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# Building Resilience Fighting Back Vulnerability in the Coastal City of Khulna, Bangladesh: A Perspective of Climate-Resilient City Approach

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***Abstract –*** *Extreme weather is becoming one of the fierce symptoms of rapidly changing climate era which is causing long and short term damage at different aspects of our day-to-day life. Extreme weather events like heavy rains cause sewers to overflow and may result in urban flooding a common scenario to the cities in developing countries like Bangladesh. With a current population of 1.4 million estimated to rise to 2.9 million by 2030, Khulna is more prone to urban flooding due to lower topography and sea-level rise due to climate change. This research aims to find the different aspects of climatic vulnerability and how the city is sustaining by gaining resilience and adaptation in the hostile climatic condition due to climate change and sea level rise. Different spatial analysis viz. land use-land cover mapping, flood mapping based on Digital Elevation Model, catchment delineation, hazard and risk mapping, physical vulnerability, etc. carried out to understand the climatic hazard condition and its impacts on different aspects. It is found that 0.25m and 0.50m sea level rise (SLR) leads to inundate 5% and 9% of the city where 4% and 6% are agriculture respectively within the city. Within this range, residential uses inundate 0.50% and 1% respectively. The city has 52% open field and greeneries and 14% waterbodies which can absorb 0.50m SLR accepting 1% inundation of the residential land uses. This research would help city decision-makers to make them more familiar with the climate resilience and adaptation options in relation to the growing concern of the city and choose the right decision.*

***Keywords –*** *Climate change, flood mapping, hazards, risk, spatial analysis.*

## 1. BACKGROUND

The current population of the world is 7.7 billion and more than 50% of them live in cities and increasing with each passing year [1], [2]. According to UN projections, by 2050 more than 68% of the world's population could be concentrated in urban areas. The rate of urbanization especially in the cities of the developing countries is quite high and population in the urban areas is increasing gradually with the passage of time. The annual rate of urbanization in Bangladesh is 3.3%, significantly higher than the national population growth of 1.8% [3]. It is expected that the current urban population of about 53 million, will grow twice the size with 112 million people by 2050 [4]. The ever-growing expansion of urban cities and urban adaptation that were made have given rise to sprawling metropolises beset by a range of social and environmental problems due to the interaction between urbanization and its social and environmental impacts in respect of current and future universal challenges. Modern cities are in tremendous pressure to provide sufficient facilities to accommodate the needs of this rapidly growing trend in urban population including proper housing, sufficient scope of work and resources such as water, energy and food. Continued emission of greenhouse gases is adding extra dimension to these challenges and cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems [5]. One of the key sustainable challenges to the future of modern cities is urban resilience. Frequent and heavy rainfall, hailstorms, extreme temperatures, flooding and waterlogging, drought, cyclone and storm surges, etc. are making cities more complex urban systems and create hindrance to provide city services. Khulna, a coastal city of Bangladesh is not exceptional in this regard. Climate change and its consequences add extra dimension to this complex system [24]. Khulna City is a quintessential example in this context as it is one of the most vulnerable coastal cities in the world.

Over the past 50 years, modern cities in the different part of the world are experiencing a rapid, unplanned and uncontrolled which caused the loss of numerous permeable soils which constantly reducing the soil's ability to absorb rainwater making cities vulnerable to manage the impacts of rainstorm triggered by climate change, and consequently increasing temperature [6]. Cities in Bangladesh especially Khulna are experiencing storm water drainage problems due to a combination of proper planning, policy making, and implementation, structural and climatic factors [7]. It's likely to increase the frequency of short duration, high-intensity rainfall in the near future because of climate change [8]. Given the unplanned and inadequate condition of drainage systems in Bangladeshi cities,

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urban flooding and waterlogging are expected to intensify [9]. Urban flooding can wreak havoc in the cities and lead to significant impacts on people, the economy and on the environment. In response to the increased frequency of rainfall and the severity of flooding in cities the strategies for flood management moving away from flood proofing towards urban climate resilience. Climate resilience especially flood resilient together with technological implications have become the present aspect of critical thinking for city planners and decision-makers to manage flood risks. Flood resilience has been defined differently in various conditions and different context. Despite having different definitions, a common theme is that climate resilient cities are impacted less by extreme flood events.

For the sake of building resilient city, it is imperative to address the current gaps and challenges in the face of increasing weather extremes. So many experts focus more on the landscape and nature-based solutions in building the resilience. In this regards, these are identifying weak spots that will be affected by climate extremes, visualisation of climate information to facilitate planning processes, cooling cities by proper management of urban waterways, reducing damage caused by excess runoff water by planting trees, vaporizing water for a cooling effect, creating *wadis* (rain gardens) for water storage. Nature based solutions minimize the risk for floods, droughts and urban heat, render ecosystem services and improve the livability of cities [10]. Due to the complexity of making a city resilient, it is necessary to adopt an integrated approach along with ensuring participation at all levels to effectively transform a modern city into a resilient city. However, its way of becoming the climate resilient city should get the highest priority for Khulna City because of its importance as the political, economic, social and cultural centre of the region. So, the high vulnerability of the city to various water-related natural and man-made hazards should be minimized through a proper strategy and making it more climate resilient. This research has focused on exploring the urban flooding especially waterlogging problems triggered by climate change and sea level rise and examine the different casual factors and inter-dependencies of the different elements of the city with the given problems. In other words, how the city is behaving with the extreme climates and explore the impacts on different aspects. Opportunities especially landscape and nature-based solutions with related issues to build climate resilient city is also explored in relation to the gaps and challenges of the city.

## 2. VULNERABILITY AND CITY RESILIENCE IN CHANGING CLIMATE

Vulnerability is a concept which describes factors or constraints of an economic, social, physical or geographic nature, which reduce the ability to prepare for and cope with the impact of hazards. This research focused on the physical vulnerability which is appeared with hazards and disaster and triggered with climate change and sea level rise. The factors influencing the risk are not static and can be improved, enhancing the institutional and individual capacity to cope and act to reduce risk. It is important to mention that the organizational and community capacity in the context of response and recovery from disasters has paramount importance and can be linked to the concept of disaster and development including the concepts of resiliency, policy creation, and governance [26]. Climate change brings many challenges for the cities though they are fighting with numerous problems at present. In other words, climate change is making cities more vulnerable and will exacerbate the situation in the future. Frequent flooding and prolonged inundation cause damage to properties and affect livelihood, and the impacts are multiplied for densely populated areas [24]. Climate variability has contributed to the unpredictability of precipitation in many parts of the world and also to the frequent urban flooding. Climate change induced corollary effects impact every aspects of the cities especially the urban infrastructure, livelihood of the residents, natural and man-made environment [31][30].

In urban areas where ground surface is paved with asphalt and concrete, rainwater mostly remains on the surface, which is subsequently drained by networks of drainage system. However, floodwater from persistent heavy rainfall sometimes exceeds the capacity of the drainage system in many urban areas [24]. Flood risk management in urban areas relies on structural concrete infrastructure for flood prevention and management. Nevertheless, evidence shows that resilience and flood adaptive capacity of urban residents (i.e., non-structural strategy) are key to effective flood reduction and management in cities and urban areas. Effective urban flood prevention requires holistic urban infrastructure planning which takes into account technological capabilities, land use, floodwater drainage, and flood prevention strategies [25], [27]. Risk assessment is an initial step to determine the risk by analysing hazards and evaluating vulnerability conditions and exposure of the property, services, livelihoods, and the environment [29]. Building resilience of the city will be the main focus of the city decision makers to fight back the vulnerability through innovative climate-proofing solutions. A resilient city is characterized by its ability to withstand or absorb the impact of a hazard through resistance or adaptation, which enable it to maintain certain basic functions and structures during a crisis, and bounce back or recover from an event [11]. To achieve sustainable development of the city, integrated DRR and resilience must be part of urban design and strategies through multi-stakeholder alliances and broad participation [26].

In a word, a resilient city is continued to sustain enduring the extreme climates keeping functioning of the physical and socio-economic infrastructure. It means it has ability to tolerate the impacts on the city system.

When the future hazard strikes, the city will minimize the impacts on the society, economy and environment. All the component of the complex system of the city viz. technological, natural and social acts together to hinder the unexpected events. [12]. Along with the complex risk governance system, the effective early warning system required well-developed governance and institutional arrangements to support the successful development and sustainability to encourage local decision making [28]. Carefully designed sociotechnical systems and incorporating a process of continuing organizational, inter-organizational, and interjurisdictional learning may manage the risk more efficiently and effectively [32].

## 3. STUDY AREA

Khulna is a linear shaped city. Its shape and growth are conditioned by geo-environmental controls such as physiography, natural and man-made drainage pattern, geological structure, soil condition, fluvial factors and climatic condition along with most of economic and socio-political factors [13]. Khulna is the third-largest city of Bangladesh with an area of 46 sq.km located in southwestern Bangladesh (Fig. **1**), on the banks of the Rupsha and Bhairab River to the east. In the west of the city, Mayur River is situated. The city consists of 31 wards (Fig. **2**) starting numbering from the north and ending to the south.

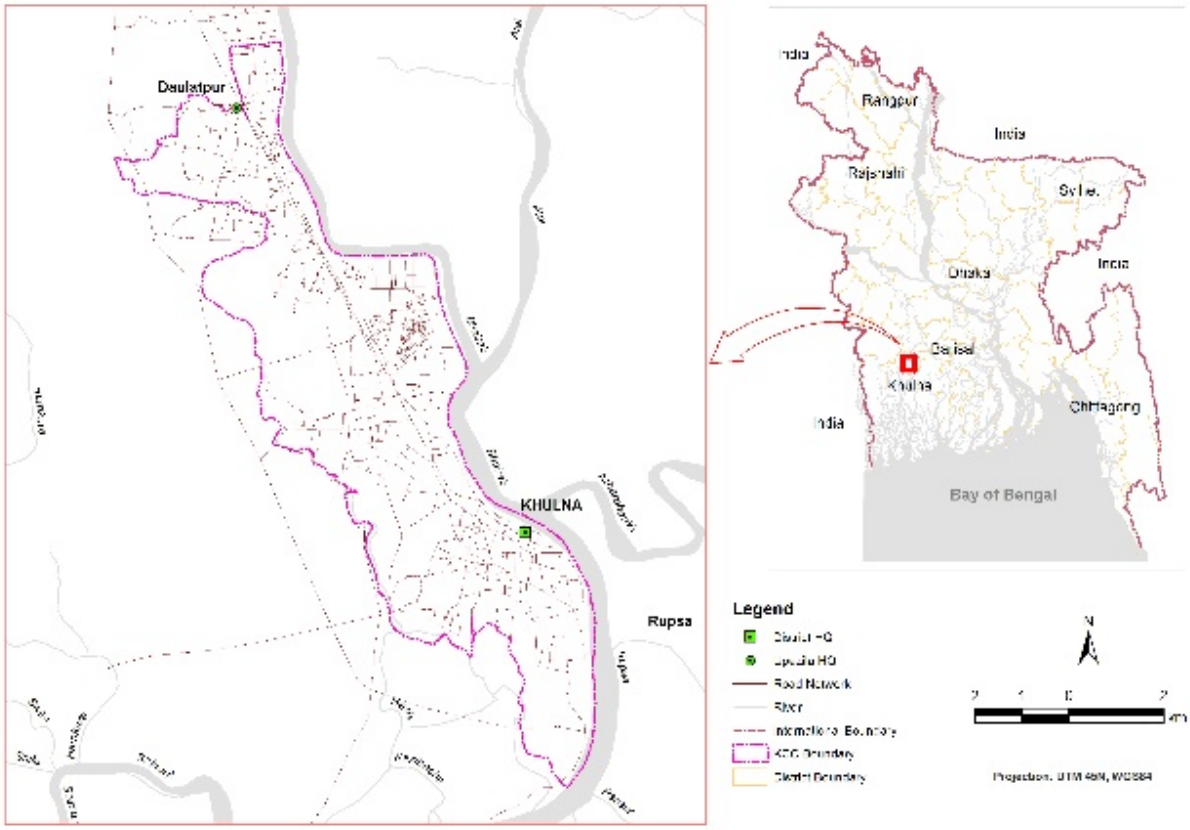



**Fig. 1. Location of Khulna City.**
Source: Authors, 2020

Khulna is humid during summer and pleasant in winter. The annual average rainfall of Khulna is 1,809.4 millimetres and average highest and lowest temperature is 40.5ºC and 7.0 ºC for Khulna, have been found in June and January respectively in 2013 [14]. It is also found from the Fig. **3** that monthly average of the maximum temperature for 17 years from 2000 to 2017 found highest in April and May. It is evident from the Fig. **4** that there are variations in yearly average temperature over 17 years but at present it is moving upwards. Approximately 87% of the annual average rainfall occurs between May and October [15]. Fig. **5** shows that almost in every decade, there was a major fluctuation in the occurrence of rainfall and highest amount of annual rainfall found in 1974. It is also noticed from the same figure that after 2014, rainfall showed uprising trend, and it is 2337mm in 2017.

This city is attractive to people, majority of them came from the neighboring districts due to employment opportunities. In addition, people from the coastal risk prone areas migrate to this city after disasters. The major concerns for Khulna City are frequent and increased level of floods, storm surges, the intensity of cyclones; water logging, saline intrusion, and sedimentation and river erosion, which are expected to be particularly severe due to the consequences of climate change. On the other hand, Khulna has a lot of opportunities to fight back the risk and vulnerabilities arising from the

hazards. The city is surrounded by rivers and crisscrossed by a number of canals. Though the main city area is dense, another part of the city still has a vast amount of land to be developed. It is observed that city land areas that are less used for urban purposes covers a significant number of waterbodies.

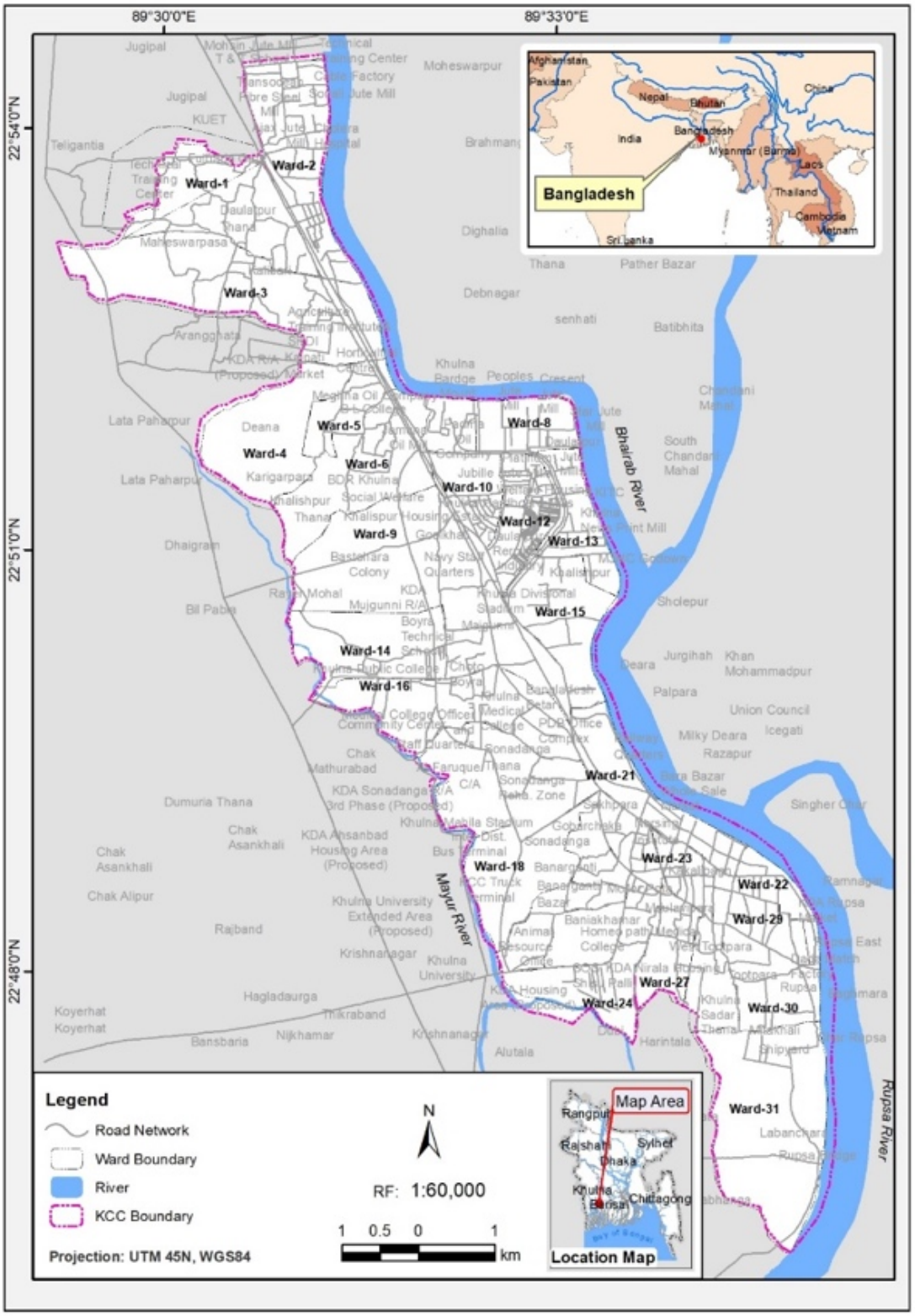



**Fig. 2. Study area with respect to Bangladesh and South-East Asia.**
Source: Authors, 2020

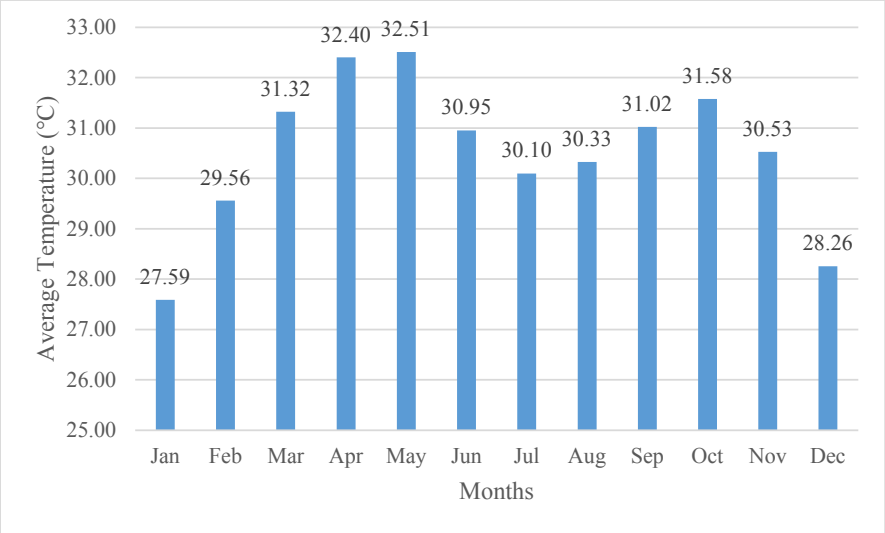



**Fig. 3. Monthly average temperature distribution for 2000 to 2017.**
Source: Bangladesh Meteorological Department (BMD), 2020

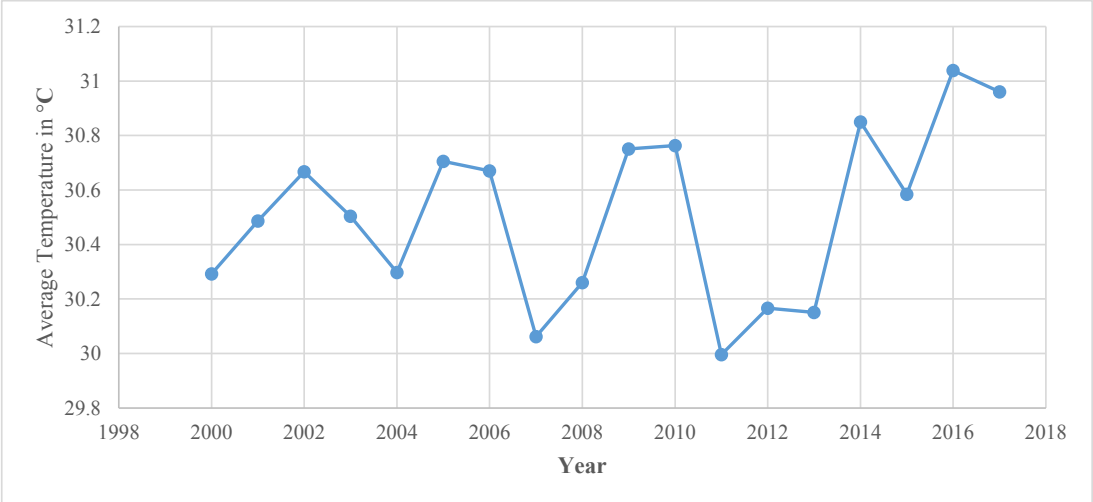



**Fig. 4. Yearly average temperature distribution for 2000 to 2017.**
Source: Bangladesh Meteorological Department (BMD), 2020

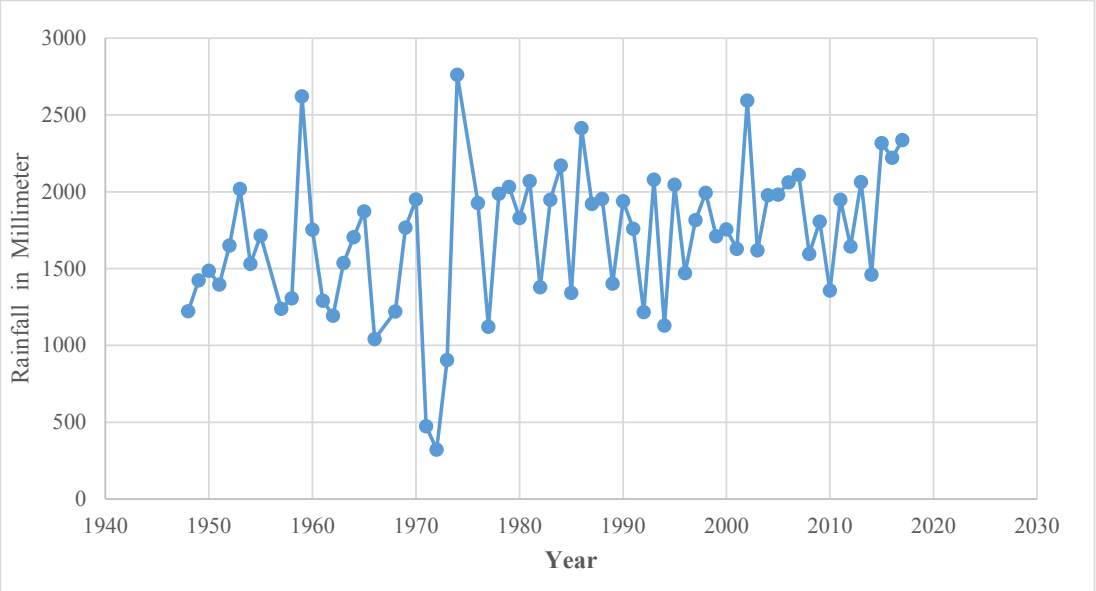



**Fig. 5. Yearly rainfall distribution for 1948 to 2017.**
Source: Bangladesh Meteorological Department (BMD), 2020

Population growth rate for Khulna City is comparatively slower than other major cities in Bangladesh. In 1991, population growth rate was 1.51 and it was reduced to 1.35 in 2001. During this 10-year, population increased by 16.15% whereas from 2001 to 2010 population increased by only 10.59% (948,814) [33], [34], [35]. According to population projection under KDA Detailed Area Plan (2001 - 2020), population for 2020 will reach out to1190000 where KCC will experience 25.42% population increase.

Household survey (2012) under Detailed Area Plan preparation by KDA shows that about 44% population migrated in the city from other places. Another study named Household Survey (1998) under Khulna Master Plan preparation by KDA shows that around 50% population migrated to this city. It is evident that after a major catastrophic event like cyclone and storm surge, people mostly from the hazard risk prone areas migrated to this city. Firewood is still the most dominating fuel in the KCC area where about 76% of the households use firewood as their main fuel. Among them, around 60% use firewood which indicates that majority people cannot afford LPG gas [17].

## 4. MATERIALS AND METHODS

This study is based on mainly secondary data sources, which were collected from sources such as government institutions, research centres and experts, development authorities, etc. More specifically KDA for planning data, Bangladesh Bureau of Statistics (BBS) for socioeconomic data, Google Earth for satellite images, Bangladesh Meteorological Department (BMD) for climatic data and other organizations. Beyond these, it required some primary data such as waterlogging observations during the raining in different parts of the city, field observations, which were collected through field survey, and interpersonal communications with the city officials of Khulna Development Authority, Khulna WASA and Khulna City Corporation. Data collected both from primary and secondary sources were checked, processed and prepared for carrying out different types of spatial analysis with MS Excel, GIS and Remote Sensing platform.

Based on topographic survey data carried out under Detailed Area Plan (DAP) in 2012 by Khulna Development Authority, high resolution (1m) DEM produced through Triangulated Irregular Network (TIN) and Natural Neighbor Interpolation technique and extracted for the Khulna City Corporation Area in ArcGIS Platform. This DEM is the major source of risk assessment and mapping due to flooding, sea level rise, and climate change, and watershed analysis. More than 200 catchments were generated using ArcGIS hydrology tools based on the generated DEM, which simplified into 60 catchments based on flow accumulation and flow direction for making the analysis process easier as catchments represents unit of analysis like drainage density, area, etc. Land use data came from the KDA Detailed Area Plan report. Land use and land cover maps generated from satellite images for 2005, 2010, 2015 and 2018. Satellite image for 2005 came from quickbird satellite. On the other hand, Google Earth images for 2010, 2015 and 2019 downloaded and further processed for maintaining accuracy. Image are classified using supervised classification method for land use and land cover mapping. Authors produced on an average of 500 training samples for each classification for ensuring better results. Overall accuracy for image classification was between 70% and 80% whereas Kappa coefficient was between 0.70 and 0.75 for all image classification of different years.

## 5. RESULTS AND DISCUSSION

### *5.1 Water System and Physiography*

The physiography of Khulna is broadly characterized by tidal flood plains having lower relief and crisscrossed by innumerable river channels. Khulna City is on the natural levee of the *Rupsha-Bhairab River* (Fig. **2**) and its elevation sharply falls down to the east and gradually decreases to the west directions. Settlements along with other developments starts from the bank of the rivers. In the north south direction, the city finds its way to expand naturally on moderately elevated lands. But the western parts of the city are gradually expanding which has lower topography. The western part is enclosed by Mayur River, which is one of the major drainage channels through which a large volume of water, both, from the city and adjacent *Beel Pabla* and *Beel Dakatia* area is discharged into the river Rupsha [16]. This river is playing an important role to drain out excess water from the urban area as well as from the vulnerable *Beel Dakatia. Moyur River* fell into the *Passur River* at *Alutala* 10 vent sluice-gate. There are 22 existing canals besides the rivers with a number of small to large waterbodies which consists of an area of 2.5 sq.km (5.5 percent of the city area) shown in Figure 7 (a). There are more than 1000 ponds accounted for 43% waterbody and are playing a major role in managing the climate especially micro-climate and controlling the temperature and contain a huge amount of water during rain. Canals cover 10% waterbody and collects water from different watersheds and carry water to the rivers. Around 50% waterbody termed as ditches which are the retention areas for containing the rainwater. Figure 7 (b) shows the drainage networks which are man-made under covered, earthen and concrete categories. Among them, there are around 3600 concrete drains, 250 earthen drains and 278 covered drains which covers around 700km altogether. It is worth to mention that there is no underground drainage system in the city. About 68% households do not have any drainage facilities [17].

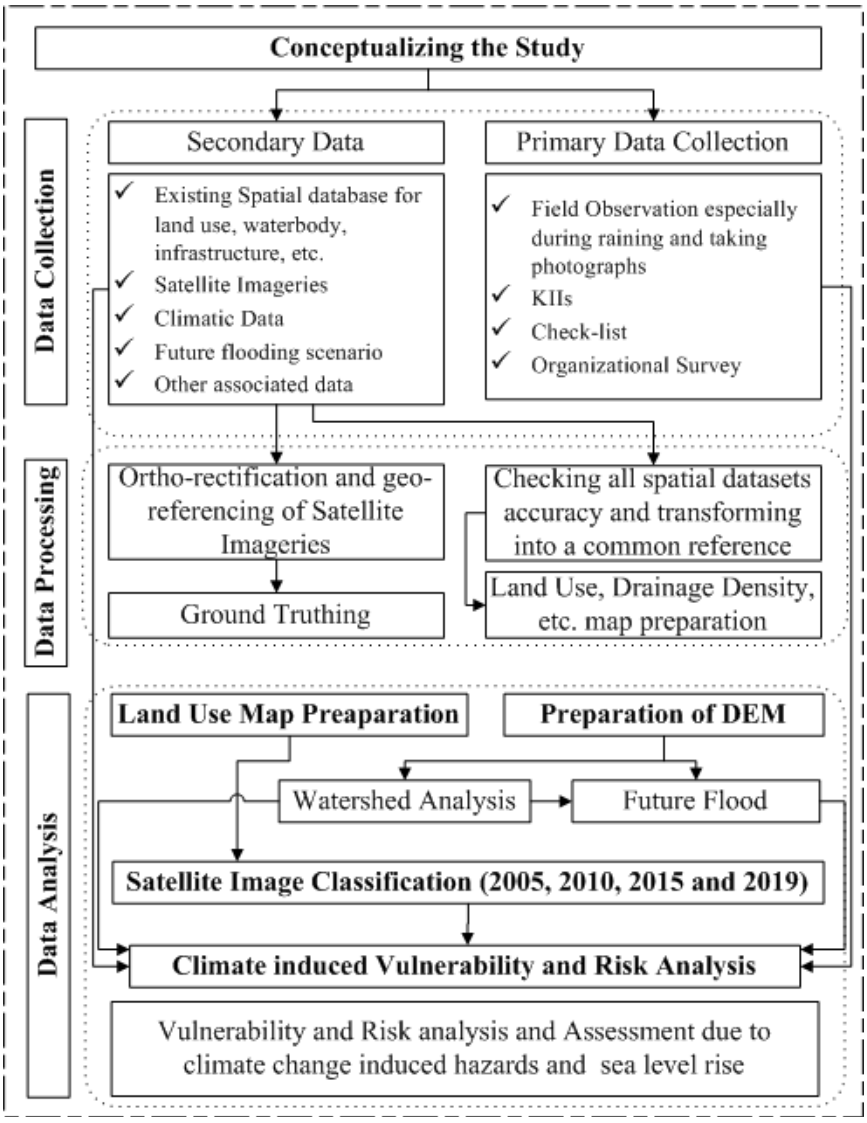



**Fig. 6. Methodological flowchart.**

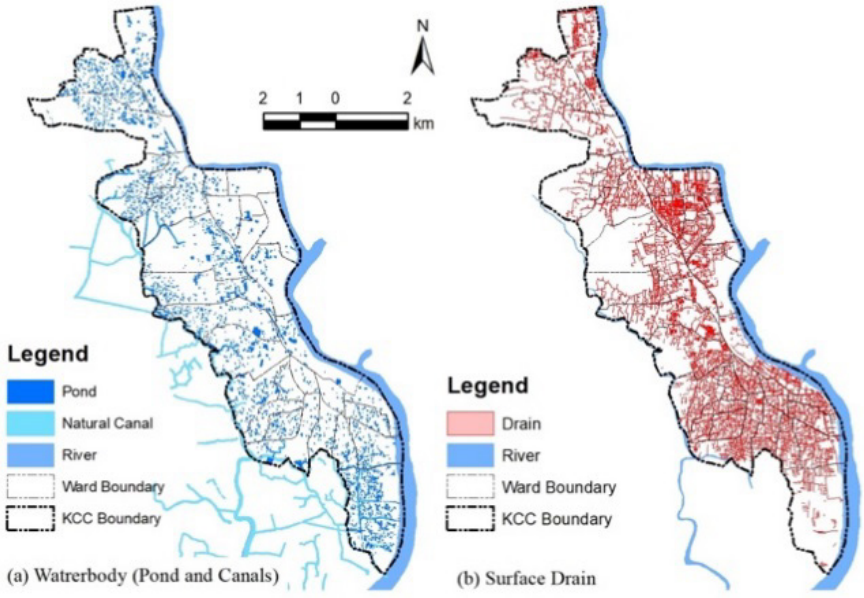



**Fig. 7. (a) Waterbodies within the city (b) Drainage networks (both concrete and earthen).**
Source: Authors, 2020 based on [17]

Watershed analysis in Fig. **8** shows the drainage density in 60 catchments over the city area. Through watershed analysis, 60 catchments resulted based on high resolution Digital Elevation Model. Highest amount of drainage density (31 – 40 km/ sq.km) is observed in 9 and 18 catchments at *Khalishpur* area where catchment 56 has no drains. But majority drainage networks are concentrated in the core part of the city. On the other hand, highest number of waterbodies in terms of area is found in catchment 4 and 31 where catchment 22 has no waterbodies. It is surprisingly observed that in the main part of the city, there is less number of waterbodies.

The spatial growth of Khulna City based on the topography and situated on the natural levee on either side of the *Bhairab-Rupsha* River which varies from (2.13 m to 4.27 m) above MSL and the levee extends about ½ km. to 4 km inside from the river on both sides [17]. Average topography of the city is 1.95m and only the flood plains is between 1.22 m to 1.52 m and beyond the flood plains, there exist ditches of lower topography which, is unsuitable for development. Fig. **9** shows that how the area varies with the change of elevation. Around 20% area is under 1m and 50% area falls within 2m elevation. Any rise in the sea level will affect these areas directly. It is mentioned here that rivers around the city are subject to tide. The low tide water level has been found (-) 0.92m at *Rupsha*. The high tide water level has been found (+) 3.75 m for the same area. About 25% of KCC area may have continuous gravity drainage [38]. During the high tide, river's water swells up and ingress in canals and drains through inlets and cannot escape during the low tide. As a result, the situation leads to cause temporary waterlogging in the local areas. During the monsoon, the situation become worst.

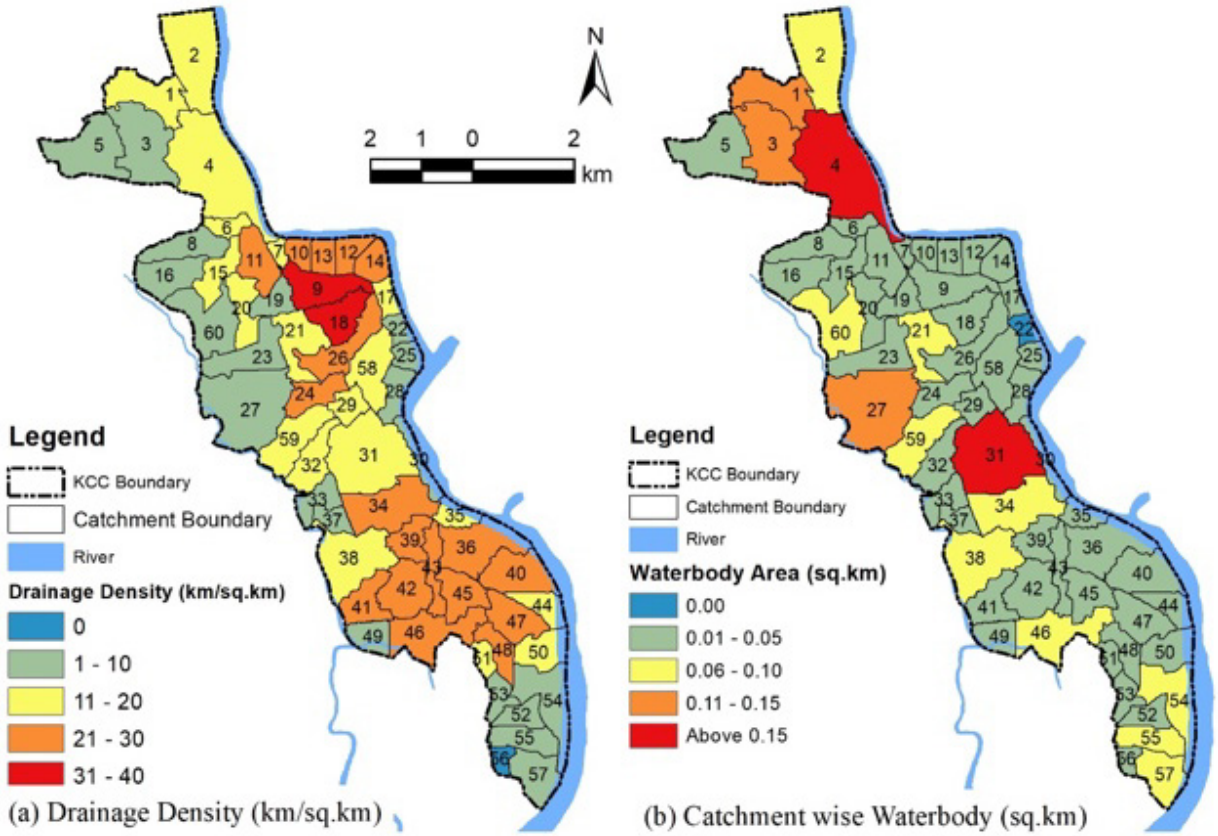



**Fig. 8. (a) Catchment wise drainage density (km/sq.km); (b) Catchment wise among of waterbodies (sq.km).**
Data Source: Authors, 2020

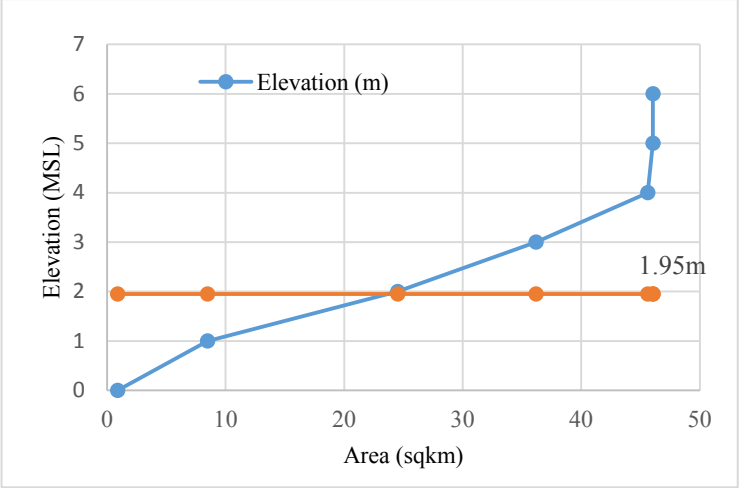



**Fig. 9. Area elevation curve for Khulna City.**
Data Source: Authors, 2020

Encroachments in the form of building structures in the hinterland (floodplains), connecting roads across the canals, etc. hinders the hydrological process. As a result, surface runoff finds nowhere to go and stuck in the surround areas and caused flooding. Cluster and larger developments that are poorly planned, designed without consideration of natural process or public safety, or located in areas with no real planning can have cumulative and ongoing impacts to floodplains, wetlands and the functions they provide. [18]. Lack of planning considerations and in some cases, absence of planning while establishing infrastructure in the floodplains and wetlands especially the hinterlands aggravate the flooding scenario during rainy seasons and cause permanent inundation in some areas.

### *5.2 Land Use Characteristics and Land Use-Land Cover Change*

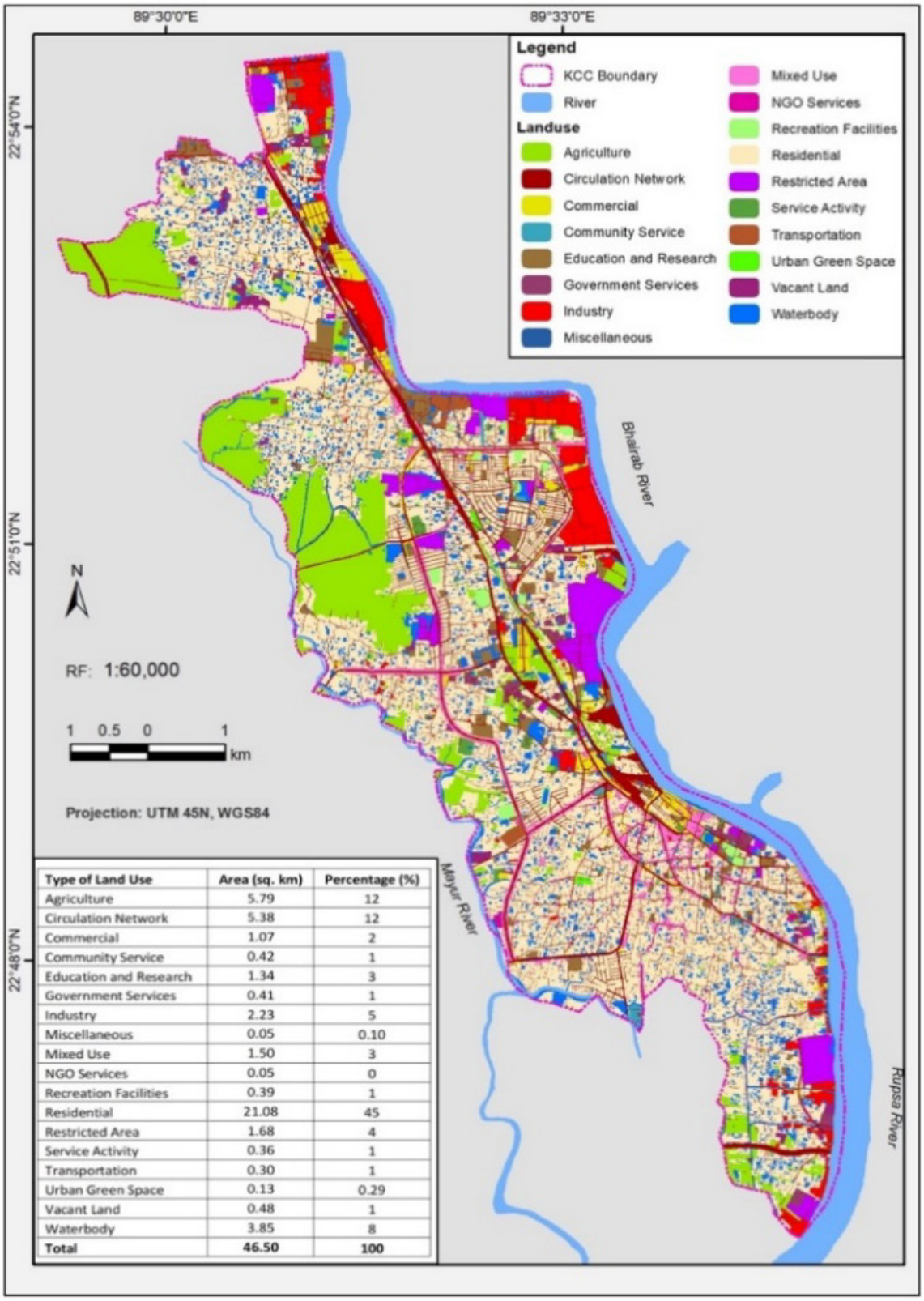
Land use is the major determinants of functions for any city. In broader sense, pattern and distribution of land uses over city has a profound impact on the city's functioning. Fig. **10** shows the existing major land uses for the KCC where 45% area is allocated for residential purpose. But in the master plan component [13], the highest amount of land (48.45%) have been allocated for residential use which usually forms the principal part of the urban built up area. Agricultural land accounts for 12% and it is decreasing with times. 5% Waterbodies without rivers is playing major role in determining the climatic condition of the city. Agricultural land uses bear great importance as it includes majority portion as shrimp cultivation. Field observation and land use – land cover analysis shows that most agricultural land retains water all through the year. So, these areas act as retention pond during the monsoon. Khulna is an industry-based city, which encompasses 5% area. Recreational facilities and urban green spaces cover only 1.5% area which is really a major concern for the city planners thinking of the open space availability standard for ensuring the healthy and sound environment.

History of Development plan for Khulna city dates back in 1960s. But due to land use declaration criteria, pattern of survey and survey techniques, difficulties of comparing land uses of different time horizons for change detection is quite difficult. Furthermore, it is proven that land use change in the past especially before 1990s was slower than the present. For 14 years, from 1998 to 2012, 41% agricultural and 36% industrial and manufacturing land were reduced and transformed into other uses. On the other hand, there was an increase of 56% commercial and 25 residential land in the same period of time [17], [36].

It is evident that once the city was functioning based on industrial and manicuring activity and now it is decreasing. This indicates that the city is facing de-industrialization. Commercial activities are increasing, which indicates positive economic growth in the city and surroundings during the period under consideration. Detection of Land use and land cover changes calls for the need of assessing the environmental condition especially micro climatic at local levels, climate change for keeping the sustainability of the biodiversity at greater sense. As there is no survey data after 2012, land use-land cover changes resulted based on satellite images for 2005, 2010, 2015, 2019.

It is evident from Figure 11 that a substantial amount of vegetation together with open agricultural field is dominant in four different time horizons though it is decreased from 69% in 2005 to 52% in 2019. Furthermore, it is also observed that amount of water body is increased from 7% to 14% within the 14 years. In 2010, waterbody increased to 12% and 14% in 2015 and remained the same till 2019. Transformation of agricultural land into waterbodies for shrimp culture, retention of water during the rainy seasons, inundation during the tides, etc. are the major reasons for increasing the waterbodies. Built-up areas cover 24% of the city in 2005 and increased to 32% in 2010 and remained the same till 2015. In 2019, 34% built-up area is detected and a total of 10% expansion of built-up area was found where the yearly rate of conversion is less than 1%. In a

nutshell, an increase of waterbody, and a slower rate of increase of built-up areas indicates the positive aspects for ensuring the overall environmental condition.




| Type of Land Use | Area (sq. km) | Percentage (%) |
|---|---|---|
| Agriculture | 5.79 | 12 |
| Circulation Network | 5.38 | 12 |
| Commercial | 1.07 | 2 |
| Community Service | 0.42 | 1 |
| Education and Research | 1.34 | 3 |
| Government Services | 0.41 | 1 |
| Industry | 2.23 | 5 |
| Miscellaneous | 0.05 | 0.10 |
| Mixed Use | 1.50 | 3 |
| NGO Services | 0.05 | 0 |
| Recreation Facilities | 0.39 | 1 |
| Residential | 21.08 | 45 |
| Restricted Area | 1.68 | 4 |
| Service Activity | 0.36 | 1 |
| Transportation | 0.30 | 1 |
| Urban Green Space | 0.13 | 0.29 |
| Vacant Land | 0.48 | 1 |
| Waterbody | 3.85 | 8 |
| **Total** | **46.50** | **100** |

**Fig. 10. Land use for KCC area.**
Data Source: Authors, 2020 based on [17]

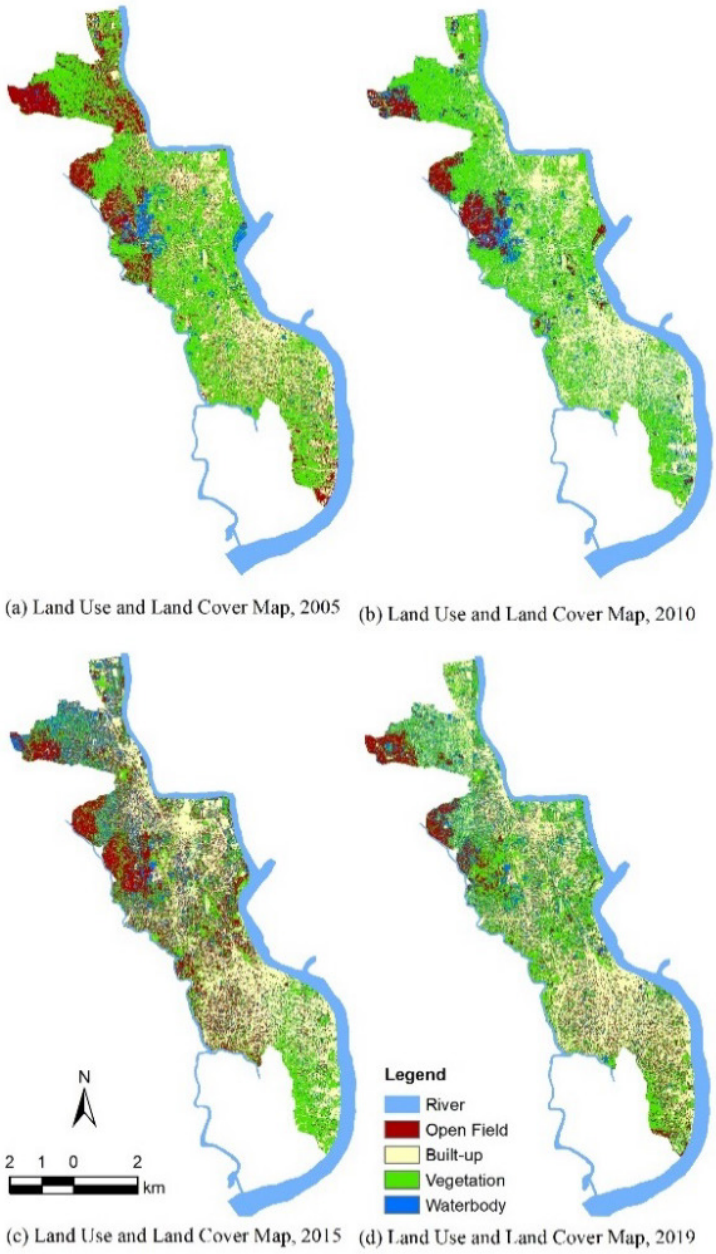



**Fig. 11. Land use – Land cover changes for 2005, 2010, 2015, and 2019.**
Source: Quickbird Satellite Image (2005), Google Earth Image (2010, 2015 and 2019)

### *5.3 Risk and Vulnerability under Climatic Change and Sea Level Rise*

Bangladesh with a vast dynamic coastal zone is under the threat of sea level rise due to climate change. Climate change impact is not faraway now in Bangladesh and rather it has the far-reaching impacts on various aspects. Frequency and severity of natural hazards like flood, cyclones, storm surges, landslides, etc. are increasing with times. A recent evidence showed that a third of the flood-prone country is underwater after heaviest rains in a decade and at least 1.5 million people were affected, with village homes and roads flooded [19]. Due to her inherent nature especially vast low-lying areas, situated in the mouth of the funnel like Bay of Bengal, Bangladesh is regarded as one of the most climate vulnerable countries in the world. The coastal zone of Bangladesh is perceived as the zone of multiple disasters covering 19 districts (32% of the country) out of 64 representing around 30% of the population [20]. The coastal zone of Bangladesh has the highest concentration of natural hazards in the world which are cyclone and storm surge, land erosion, flood, drainage congestion, salinity intrusion, draught, earthquake, shortage of drinking water and arsenic contamination, ecosystem degradation, pollution and climate change [21]. Among them, drainage congestion, urban flooding, climate change, salinity intrusion is very common at the coastal cities.

Khulna City has been identified as one of the 15 most vulnerable cities under climate change impact and

it has been considered as one of the most vulnerable coastal cities [22]. The city has a great tidal influence from the Bay of Bengal and has the increasing trend of salinity intrusion into the city waters. Water supply in the city is seriously hampered by excessive presence of salinity in the groundwater (GW) as well as surface water (SW) sources. Frequency of climate change induced hazards like cyclone, storm surges and their severity are increasing and adversely affects the salinity intrusion. A 10% intensification of the current 1-in-100-year storm surge combined with a 1m Sea Level Rise (SLR) could affect around 23% of Bangladesh's total coastal land area. Increases in salinity intrusion as a result of SLR pose a serious issue for Bangladesh [37]. Asean Developmetn Bank (2010) study report anticipated sea level rise for the city which has a major impact on the blue, green and grey features along with the drainage infrastructure. The different parts of the city face frequent waterlogging during the rainy season. The report also shows that the possible increase in precipitation due to climate change coupled with sea level rise will make the situation even worse. In that study, Khulna Urban Drainage (KUD) model was developed for the first time for Khulna City considering A2 regional growth scenario with 10 years return period to show the waterlogging condition. A2 storyline and scenario family describes a very heterogeneous world especially consider the impacts of climate change and translate those impacts on the water sector. Fig. **12** shows separately the waterlogging condition with climate change and sea level rise and with improvement interventions and adaptation. It shows that waterlogging condition is varied in 2030 and 2050 for different conditions and also with improvements and adaptation. Waterlogging covers 54% area of the city if no adaptation or improvement measures are taken. On the other hand, 29% waterlogging condition is reduced if improvements for the drainage system are implemented.

It is interesting that KCC is not subject to direct flooding from her surrounding rivers in the core parts of the city, but the low-lying areas situated on the western and southern part of the city floods due to the rain and tidal effects during monsoon season. Improper operation and maintenance of natural canals and man-made drains, blockage in the existing drains, absence of integrated network comprising secondary and side drains, haphazard expansion of the settlements which obstructs the natural drainage system, uncontrolled and haphazard disposal of solid waste into the drainage system and siltation in drainage channels with consequent reduction of discharge capacity are the main reasons for waterlogging in the city [7]. Waterlogging situation is directly observed in different parts of the city from the fields and validated with the waterlogging situation for 2020 (Fig. **12**) during the month of July and August 2020 which are shown in Figure 13. In some areas, the inundation of the waterlogging is worse than the modelled situation. Overall, where the drainage density is low having low capacity the inundation level of the waterlogging is severe in ward-27, ward-28, and ward-30 of Khulna City. The reverse scenario for inundation level is observed where the drainage density is high with higher capacity [9]. It is obvious from the analysis that where amount of waterbody (in area) is larger, less waterlogging is observed (Fig. **8**b). It is surprising that in the core part of the city, a severe waterlogging is observed despite having high drainage density. In a catchment with having large amount of waterbodies, severe water logging is observed (Fig. **8**a and Figure 13). These waterbodies are not directly connected to the rainwater surface runoff and the capacity of the waterbodies are low.

Climate experts predict that by 2050, rising sea levels will submerge some 17 percent of the nation's land and displace about 20 million people [23]. It is now proven that climate change impact is observing in Bangladesh and will be exacerbated in the future if there is taken enough mitigation and adaptation measures. Fig. (a) shows the inundation based on conceptual sea level rise at different heights. If 0.25m sea level is risen, 5% area of the city will be inundated which accounts for 4% agricultural land and residential 0.47 (Table 1). Agricultural lands here are mostly ditches and water retention areas. When 0.50m sea level is considered 9% area will be inundated that account for 6% agriculture and residential will be increased to 1%. If 0.75m is considered as sea level rise, 13% land will be inundated which encompasses 8% agriculture and residential 2.5%. When 1m sea level rise is taken, 18% land will be inundated that will account for 10% agriculture and 5% residential. With the increase of sea level rise, significant percentage of residential building is started to inundate Fig. (b). When the lower sea level rise is considered, there will have less impacts on the built environment.

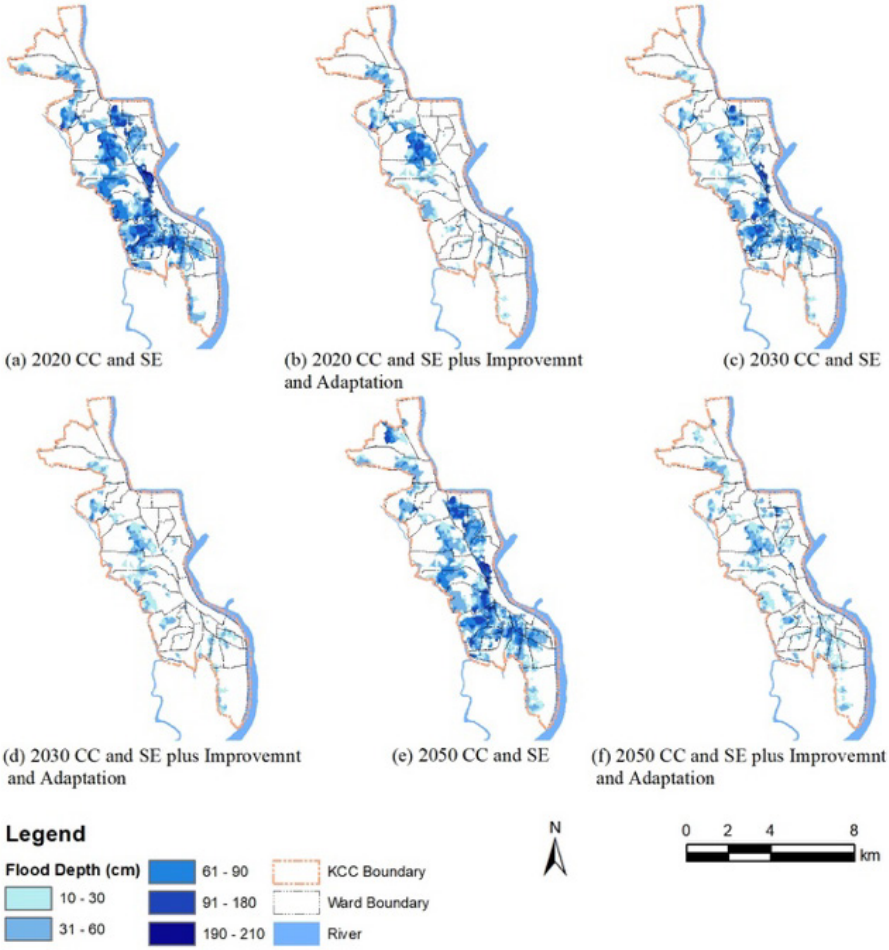



**Fig. 12. (a) Waterlogging scenario for 2020 under climate change and sea level rise**
**(b) Waterlogging scenario for 2020 under climate change and sea level rise with improvement and adaptation**
**(c) Waterlogging scenario for 2030 under climate change and sea level rise**
**(d) Waterlogging scenario for 2030 under climate change and sea level rise with improvement and adaptation**
**(e) Waterlogging scenario for 2050 under climate change and sea level rise**
**(f) Waterlogging scenario for 2050 under climate change and sea level rise with improvement and adaptation.**
Data Source: Authors, 2020 based on [8]

**Table 1. Type of land use to be impacted at sea level.**

| Type of Land Use | Percentage of Land Uses under different sea level rise (MSL) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Up to 0.25m | 0.50m | 0.75m | 1m | 1.5m | > 1.5m | Total |
| Agriculture | 3.74 | 2.4 | 2.15 | 1.43 | 1.14 | 1.59 | 12.45 |
| Residential | 0.47 | 0.7 | 1.37 | 2.6 | 8.42 | 31.77 | 45.33 |
| Waterbody | 0.57 | 0.28 | 0.42 | 0.63 | 1.4 | 4.97 | 8.27 |
| Education and Research | 0.02 | 0.02 | 0.02 | 0.05 | 0.19 | 2.6 | 2.89 |
| Mixed Use | 0.01 | 0.01 | 0.05 | 0.08 | 0.31 | 2.77 | 3.23 |
| Transportation | 0.1 | 0.11 | 0.17 | 0.3 | 1.17 | 10.35 | 12.21 |
| Commercial | 0 | 0.01 | 0.02 | 0.02 | 0.07 | 2.19 | 2.31 |
| Others | 0 | 0.04 | 0.14 | 0.35 | 1.33 | 11.43 | 13.31 |
| Total | 4.92 | 3.57 | 4.33 | 5.46 | 14.04 | 67.67 | 100 |

Data source: Analysis based on [8], [17]

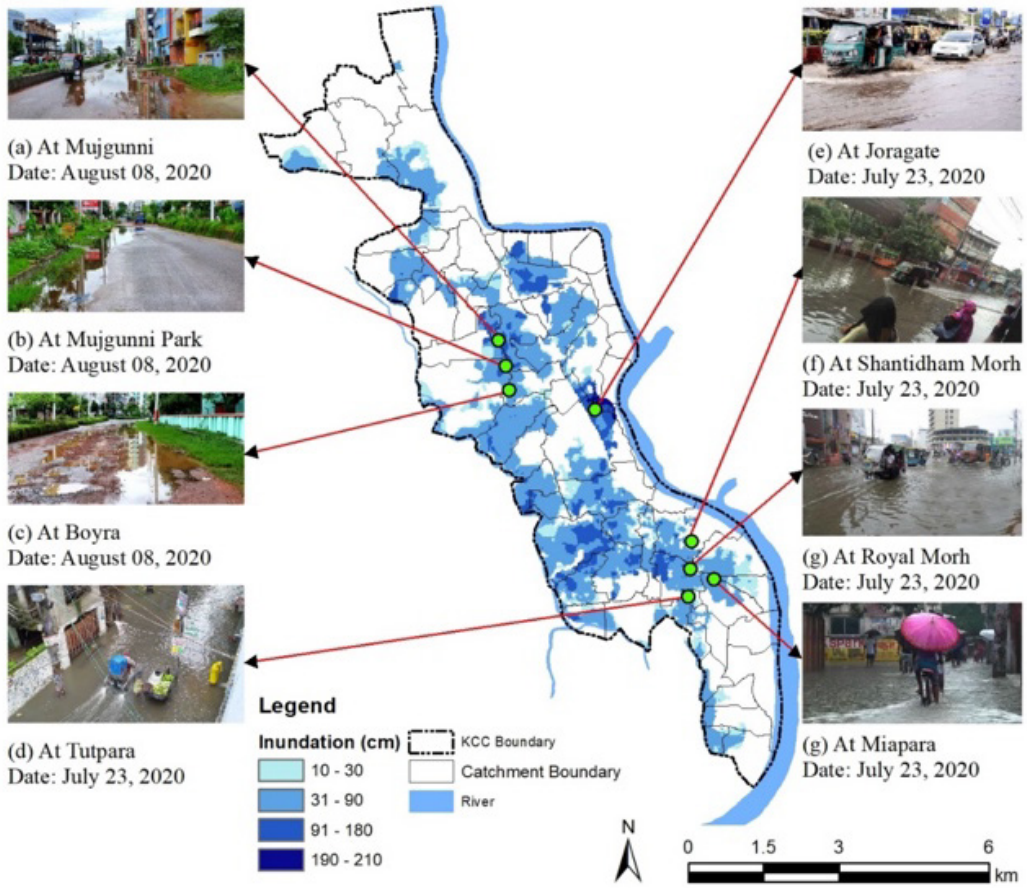



**Fig. 13. Waterlogging situation during the months of July and August 2020.**
Source: Field Survey, 2020

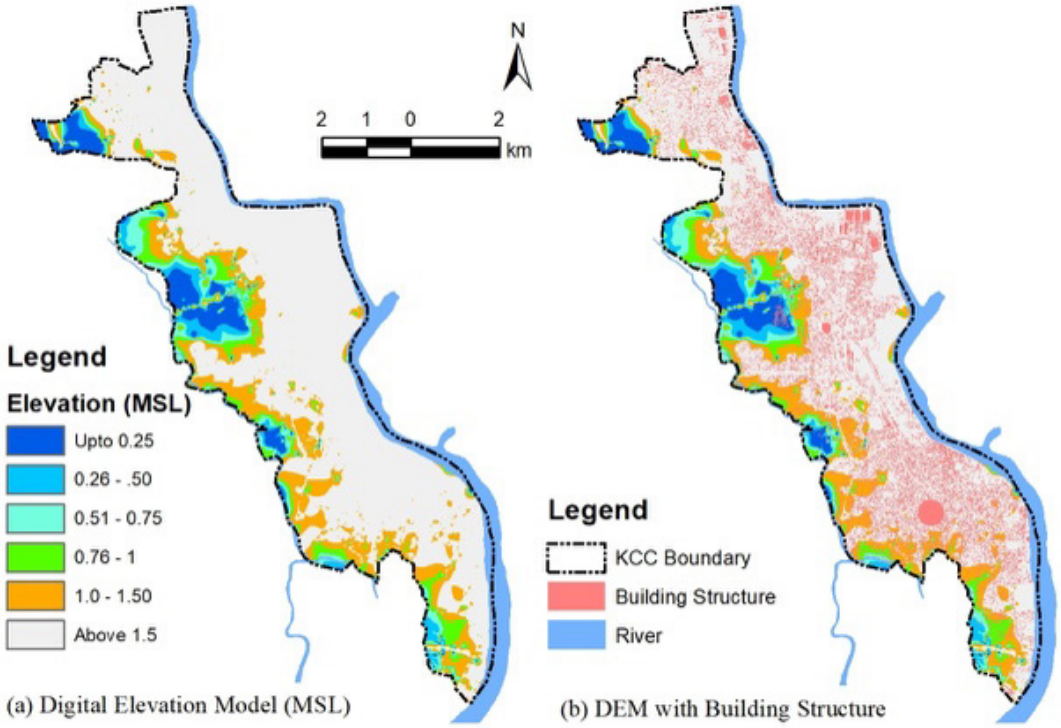



**Fig. 14. (a) Conceptual inundation under sea level rise (b) Conceptual inundation under sea level rise with building structure.**
Data Source: Authors, 2020

### 5.4 Opportunities in Building the Climate Resilient City Focusing on Nature Based Solutions (NBS)

Nature Based Solution are often terms as ecosystem-based adaptation (EbA), urban green infrastructure (UGI) and ecosystem services (ESS). All these related concepts are has become a prominent issue now-a-days and researchers are trying to create evidence by applying the concept. From the results stated above together with water management both ground and surface water, adaptation with the changing climates, etc. Khulna has a huge scope of applying NBS against the climate induced hazards and its impacts on the city level. There are many status quo gaps and challenges to be overcome for building the climate resilient city which include the social, economic, physical, environmental and technological aspects. In this research, physical and environmental aspects are explored and examined to find out the weakness against the strengths of the city. Nature based climate proofing aspects are explored through analysis and how these could be implemented to build a climate resilient city is discussed below.

(a) Green spaces help to uptake and permeate water through Soil, decreasing runoff rates which subsequently reduces the pressure on the existing drainage system. The high retention capacity of vegetation makes it important for mitigating floods and managing urban storm water. Khulna once renowned for its green resources but in recent times the city is losing its greeneries very rapidly. Urban green space is very important because of its ability to make the land permeable. And rapid destruction of green planting is giving a negative impact on soil. The amount of existing urban green space is 377.11 acre. Recently, KDA proposed to develop about 872.26 acre urban open space [13]. From the land use and land cover analysis, it is shown that about 52% of the city covers open field (agricultural land) and greeneries in 2019. Agricultural land is treated as the sources of retention for surface runoff. Moreover, the city corporation authority and KDA can enact a mandatory 'urban Greening policy' for the conservation and enhancement of urban greening and urban forestry in Khulna City.

(b) Urban Blue Space both is the most important physical, aesthetic landscape, indispensable elements and possesses importance in urban quality of life. They are environmental — and sometimes historic-ecological — assets of great importance for any city. But unfortunately, there is no clear plan for preserving the existing water bodies in the city development plan. But the positive aspect is that the city is surrounded by rivers and crisscrossed by many canals. Inside the city there are 5% area covers waterbody. Numbers of waterbody (more than 1000) represents significant but do not function significantly due to reducing the capacity of the waterbodies which calls for the need of digging out. On the other hand, existing waterbodies preservation techniques (viz. ecosystem services) or policy must be enacted by the development authority. It is found from the land use and land cover analysis over the 14 years since 2005 that amount of waterbody increased to 14% from 7%. Though it is happening due to shrimp culture, socio-economic factors, etc., still it is beneficial for the city thinking of the environmental aspects.

(c) The roof garden is a good way to enhance buildings in urban areas through landscape design, which can transform the obsolete areas into a valuable area that provides ecological and economic services. For instance, the most suitable structures of rooftop gardens are structures with a flat roof (concreate building). Total number of concreate structure of the Khulna city under residential use is around 27000 which covers the total area of 635 acres. Roof gardening is started everywhere in Bangladesh and Khulna is well ahead in this regard. If we consider 25% residential building under rooftop garden, 160 acres greeneries will be added to the existing 377acres greeneries, which is expected to create positive impacts on the environment. If we consider more residential buildings under rooftop gardening, there will have more positive impacts.

(d) Rainwater harvesting can be considered as a probable solution of the drinking water crisis in this salinity prone areas. The main limitation of this option is no availability of rainwater around the year. A study shows that Khulna, during the entire year, the rain falls for 95 days, which is one-fourth of the year and collects up to 1809.4mm of precipitation. So, it can be widely used as a supplementary source of rainwater is properly stored in the rainy season. It is already an established culture to harvest rainwater in this region. But in the urban areas, it is long way to go. But rainwater harvesting has begun and increasing with time as the advocacy from different levels at different stakeholders is going on. Many NGOs have already working at the community level to harness the rainwater during monsoon. More advocacy for the adoption of rainwater would certainly lead to a reduction of problems related to water shortage in a monsoon-prone country like Bangladesh and reducing waterlogging during rainy season.

(e) Groundwater is the major source to satisfy the water demand of Khulna City. Despite the easy availability of groundwater, Khulna is facing acute water shortages as a result of improper water management, highly dependent on the groundwater rather than surface water and groundwater pollution. These events are making the Khulna city more vulnerable to climate change and urban flooding. Soil permeability is one of the main components of groundwater recharge. The present condition of the permeable soil is moderate, but it is decreasing with each passing year. The amount of permeable soil area in a city or a region influences the infiltration rate and the groundwater recharge of the area. The more permeable area the more possibility of water infiltration to the ground which will help to enrich the aquifer of the city below as well as help Khulna city become more water resilient. Analysing permeable and non-permeable data

it is found that the total area of permeable and non-permeable land is 33 sq.km and 13 sq.km of the city respectively. Building setbacks should be mandatorily kept permeable to increase the percentage of permeable soil that will also increase the greeneries.

(f) Modern cities like Khulna usually have mostly impervious surface and very minimal percentage area is permeable ground cover. In Khulna City, about 34% of all surfaces in the city areas are impervious, which is shown in Figure 11. This impervious soil is supposed to be the main cause of excessive storm water runoff, which leads to low water quality as well. Urban agriculture could be a way to deal with this problem by preserving the high value agricultural land. Urban agriculture (UA) presents an alternative use for modern cities that has not been given adequate consideration as a method of addressing storm water mitigation and other urban environmental concerns. Existing 12% agricultural land, which are mostly hinterland should be preserved for rendering services from many aspects.

(g) As watersheds become developed, rainwater quickly runs off paved surfaces such as roofs, parking lots and driveways increasing flooding while picking up and carrying pollutants into storm drains and surface waters. By reducing storm water runoff, rain gardens effectively change these trends. While an individual rain garden may seem like a small contribution, collectively they produce substantial environmental benefits. If we see the land-use dynamics of Khulna city, the potential spots that's are most suitable for rain garden based on their suitable location for rain garden. Because the rain garden should be in a public area that can be seen by members of your community. Most likely this area will be located on a commercial, industrial or institutional property, so storm water management regulations will have to be taken into consideration and professionals and researchers will be needed to assess the site.

## 6. CONCLUSION

Khulna City is the most important economic hub in the southern part of Bangladesh connected through rivers, road and railway networks and it is gaining its importance with times. At the same time, climate change leads to extreme calamities and sea level rise together is making the city vulnerable and the infrastructure at risk. Among them, flood and waterlogging are worsening the city. Waterlogging is happening due to drainage congestion, decreasing of waterbodies and their capacities, lack of drainage connectivity and capacity, etc., which is severe compared to impact of sea level rise. Sea level rise impacts on the hinterland (agriculture) which are normally retains waterbody all through the year. The city has 52% open field and greeneries and 14% waterbodies. Many studies show that SLR is expected to have serious impacts on the city. It is seen from the analysis that 0.50m SLR will start to cause 1% inundation of the residential inundation. It proves that city has capacity to absorb the impacts without significant impacts on the built-up areas due to its topographical, hydrological, and physiographical factors. If improvement and adaptation measures are taken, there will have less impacts in terms of the extent and magnitude of waterlogging. It is proven from the study that waterlogging covers 54% area of the city if no adaptation or improvement measures are taken. On the other hand, 29% waterlogging condition is reduced if improvements for the drainage system are implemented. These gaps and challenges need to be addressed proper way to build climate resilient city through exploring, creating and implementing the opportunities to keep the pace with future growth. It is proven in many cities that nature-based solution can contribute much in tackling the problems. In this regard, Khulna has a lot of opportunities to adopt nature based solutions. Furthermore, adaptation with improvement will play important role in minimizing the impacts of the future events.

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