Chapter-1

Coastal urbanization: an introduction

1.1. Introduction

The urbanized areas of the coastal plain of Medinipur littoral tract, West Bengal are selected for exploration of their urban growth rate as well as pattern, demographic status, exposure to various type of coastal hazards and related risks. Moreover, the understanding of environmental conflict is arising due to uncontrolled sprawling of urban areas over the wetlands, sand dunes, lowlands and shore fringes, and possible adjustments with emerging impacts of coastal chaos due to climate variability at present are also be assessed. The urban areas like Digha, Contai in the Kanthi (Contai) coastal plain and Haldia township area in the Hugli-Haldi estuarine floodplain are considered for the above study. The sensitive groundwater aquifers, saline and brackish water wetlands, sand dune habitat and low-lying alluvial plain, and tidal drainage systems of the littoral tract have limitation to support the uncontrolled sprawling and overuse of local resources by the urban centres. The areas of urban centres have emerged during 1958 (Contai), 1990 (Digha) and 1997 (Haldia) in the littoral tract (BADP, 2014; LUDCP, 2015; Mukhopadhyay, 2015; Duari, 2019) to fulfil the functions like residential and trade centre development, expanding resort centres for coastal tourism processes, and expansion of port area development with emerging institutional hubs under the coastal district of Purba Medinipur of West Bengal. Among the three different sites of urban areas, Haldia township and Digha under the Digha-Sankarpur Development Authority (DSDA) are located along the estuary and the Bay of Bengal shore fringes and on the other hand Contai municipality town is expanding over the platforms of coastal sand dune ridge and coastal plain lowlands slightly away from the recent shore fringes (about 10 km inland from the sea-shore) of the Bay of Bengal.

Heavy downpours during cyclone landfalls in the coastal plain areas (Thomalla & Schmuck, 2004; Sahoo & Bhaskaran, 2018a) liable to saltwater floodings due to storm surges and tidal waves mainly during the Highest Astronomical Tide (HAT) phase of monsoon months (Chittibabu et al., 2004; Machineni et al., 2019; Mukherjee et al., 2019). The wetlands, lowlands, sand dune habitats and agricultural lands are occupying for urban sprawling (Jelgersma et al., 1993; Aber et al., 2012). The urban areas are liable to vulnerabilities of coastal hazards due to over-extraction of groundwater and contamination of the groundwater aquifer for human consumption and salt water penetration (Bhattacharya et al., 2012; Krishan et al., 2015). The shoreline retreat due to erosion by advancing sea is also responsible for the inland penetration of salt waters (Gornitz, 1991; Hazra et al., 2001) in Digha and Haldia. The intensive urban infrastructural developments violate the wetland act, Coastal Regulation Zone (CRZ) rule and forest act in many areas to maintain the environmental quality, increased problems related to susceptible coastal hazards and disparity in resource sharing problems among stakeholders of the coastal zones at present (Philcox et al., 2010; Berkes, 2009).

As per the 2011 Census, the urban centres hold a large size of population 44403 (Digha), 92226 (Contai) and 200827 (Haldia) and within the area of 67.04 km², 14.35 km², and 99.97 km² respectively in Digha, Contai and Haldia over the coastal zones. Remote sensing and Geographic Information System (GIS) techniques are used to evaluate the temporal and spatial growth of the individual urban centres of the region and also to estimate the rate of the land conversions and resource uses by such sprawling in the sensitive coastal environments (Xian & Crane, 2005; Fan et al., 2009; Shaw & Das, 2018). Population pressures are estimated through the primary and secondary data to note the changing pattern of the population with time and space due to ever-increasing growth and occupational structures of the urban people.

The Intergovernmental Panel on Climate Change (IPCC) in its working report (UNEP, 2002; Cazenave & Cozannet, 2014; Allen et al., 2019; Harms, 2019) predicted about the areas of Indian coastal urbanization in the scenario of the global warming, induced sea-level rise impacts. Thus, in the above context of assessment, the urban centres of Digha and Haldia of the shore fringes of the northern Bay of Bengal are prone to repeated attack of cyclone landfalls (Ali et al., 2007; Hoarau et al., 2012) and saltwater inundations (Chand et al., 2012; Gayathri et al., 2016; Nalakurthi et al., 2018) with time. Gradual alterations and degradation of sand dunes and wetlands (Namboothri et al., 2008; Jana & Paul, 2019), drainage control measures (Rahman et al., 2007; Naik et al., 2013; Bandyopadhyay et al., 2014) and over extractions of groundwater (Maity et al., 2017, 2018), as well as the emerging problems of urban wastes treatment and their dumping (Arceivala & Asolekar, 2006; Sharholy et al., 2008; Chattopadhyay et al., 2009) will create the additional threats to the uncontrolled sprawling of urban areas of the coastal zones in the near future (Rahman et al., 2010; Franci et al., 2015).

The GIS database on water quality, air quality, groundwater status, waste dumping sites and their existing management techniques, land use alterations and weather parameters (rainfall, temperatures) are prepared with the help of satellite images and of other collected secondary sources of data from municipality offices, DSDA, district-level census and West Bengal Pollution Control Board (WBPCB), Central Ground Water Board (CGWB) report and India Meteorological Department (IMD) for analysis in the present work.

Finally, on the basis of findings of the above results, various recommendations are suggested to adjust with ever-increasing problems of urbanizations in the low-lying coastal belts for their sustenance under sea level rising threats and related climate variability of the tropics.

1.2. Description of the study area within the Medinipur littoral tract

The supralittoral zones of the Bay of Bengal and the Hugli estuary region occupy the coastal fringes of Purba Medinipur district, West Bengal (Fig. 1.1). Haldia municipality town is located on the supralittoral tract of the Hugli-Haldi estuarine floodplain surface. This area extended within the coordinates of 22°00'52.98" N – 22°08'35.76" N and 88°01'24.93" E – 88°11‘49.95" E with the areal coverage of 99.97 km² (Fig. 1.1).

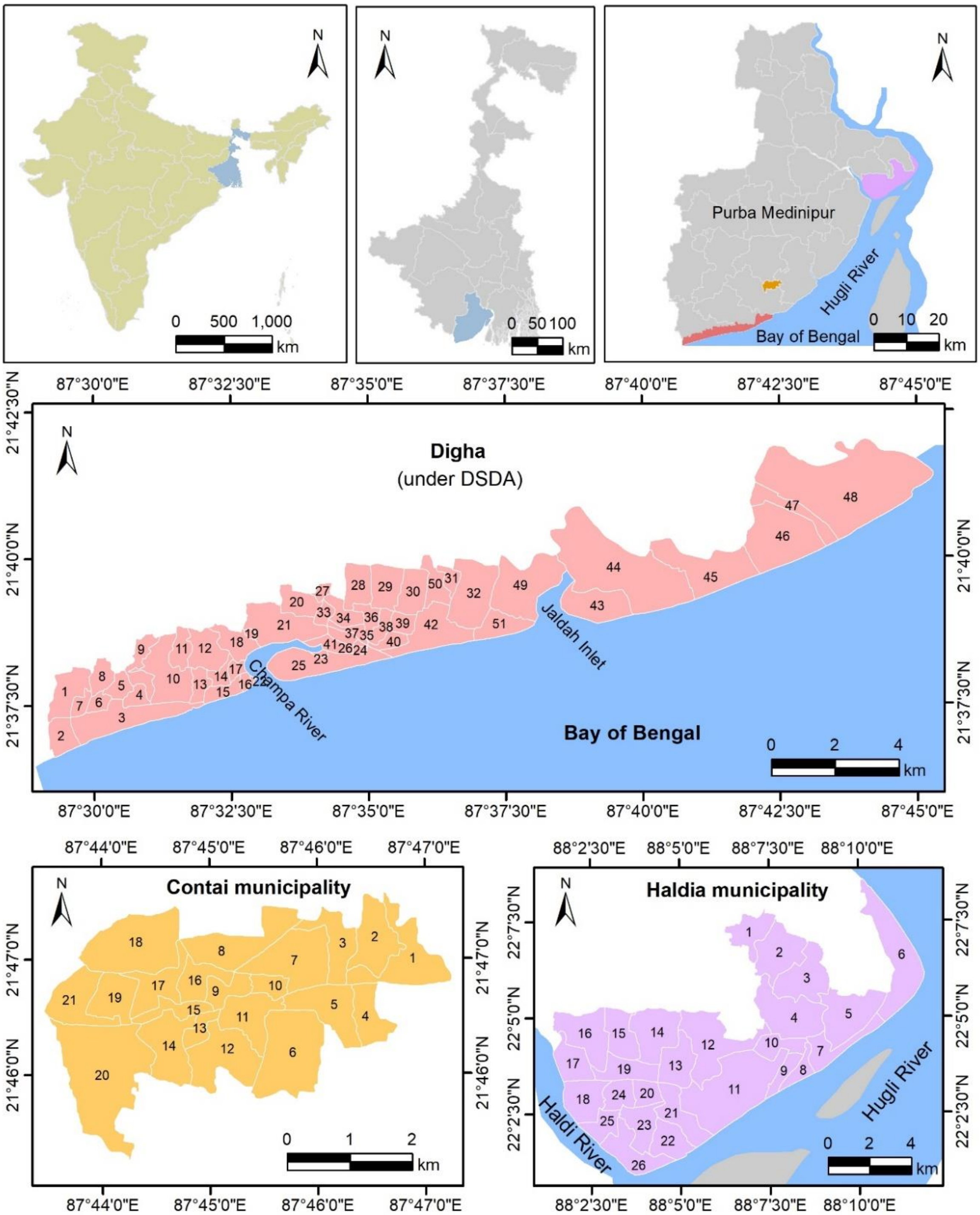

Fig. 1.1: Location of the coastal urban centres of the study areas.

The Contai municipality town is widely extended over the coastal sand dune ridge and Holocene tidal basin of the supralittoral track with an area of 14.35 km² which is extending within the coordinates of 21°45'15.14"N – 21°47'33.84" N and 87°43'27.69" E – 87°47'15.05" E (Fig. 1.1). However, the shore fringe resort town of Digha (Fig. 1.1) is located and extended over the shore parallel sand dunes and beach ridges fringed with the Bay of Bengal and separated by Digha estuary and Jaldah estuary into three coastal plain sectors (Digha sector, Sankarpur-Tajpur sector, and Mandarmani sector). In the Mandarmani coastal sector, the tourism site of Mandarmani actually located at the Dadanpatrabar mouza, however, the actual Mandarmani mouza is located in the mouth of Jaldah inlet. The Digha area is extended within the coordinates of 21°36'34.43" N – 21°41'54.13" N and 87°29'06.02" E – 87°45'18.84" E with the area of 67.04 km². The littoral or intertidal fringes can produce impacts over the supralittoral tracts (above the intertidal littoral fringes) during tidal waves, cyclone surges and during the seasonal high sea levels (June to November) along the region.

1.2.1. Geology

As per the Geological Quadrant map, the entire Purba Medinipur district is originated with the composition six different types of geological formations (Fig. 1.2) during the Late Pleistocene to Late Holocene period (Table 1.1). Among these, most of the areas formed with the Panskura formation during the Middle Holocene period with the composition of fine sand, silt and clay type of materials. The Haldia urban centre is situated within the areas of Panskura formation. The parallel dune ridges were formed as recent dune sand deposit during the Late Holocene period with the composition of semi-compact medium-grained grey sands, over which the main urban areas of Contai and Digha is situated. Some part of the Contai town area is also extended over the Panskura formation. Some part of the Digha urban centre is situated over the Basudebpur formation made up by dark grey to black clay with mudflats deposited during the Middle – Late Holocene period. At the shorefront area, the Late Holocene Beach formation made up by very fine, white to grey sands mixed with clay. The Sijua formation of Late Pleistocene to Early Holocene period with the composition of sand, sandy loam, silt and silty clay with impregnation of caliche nodules have existed in the south-western part of the district. Also, the Kasai formation was formed during the Late Holocene period with the composition of unoxidised sand and silt in the palaeo and recent river courses (Kasai, Rupnarayan, Rasulpur and Subarnarekha) and their surroundings (Jana & Paul, 2018).

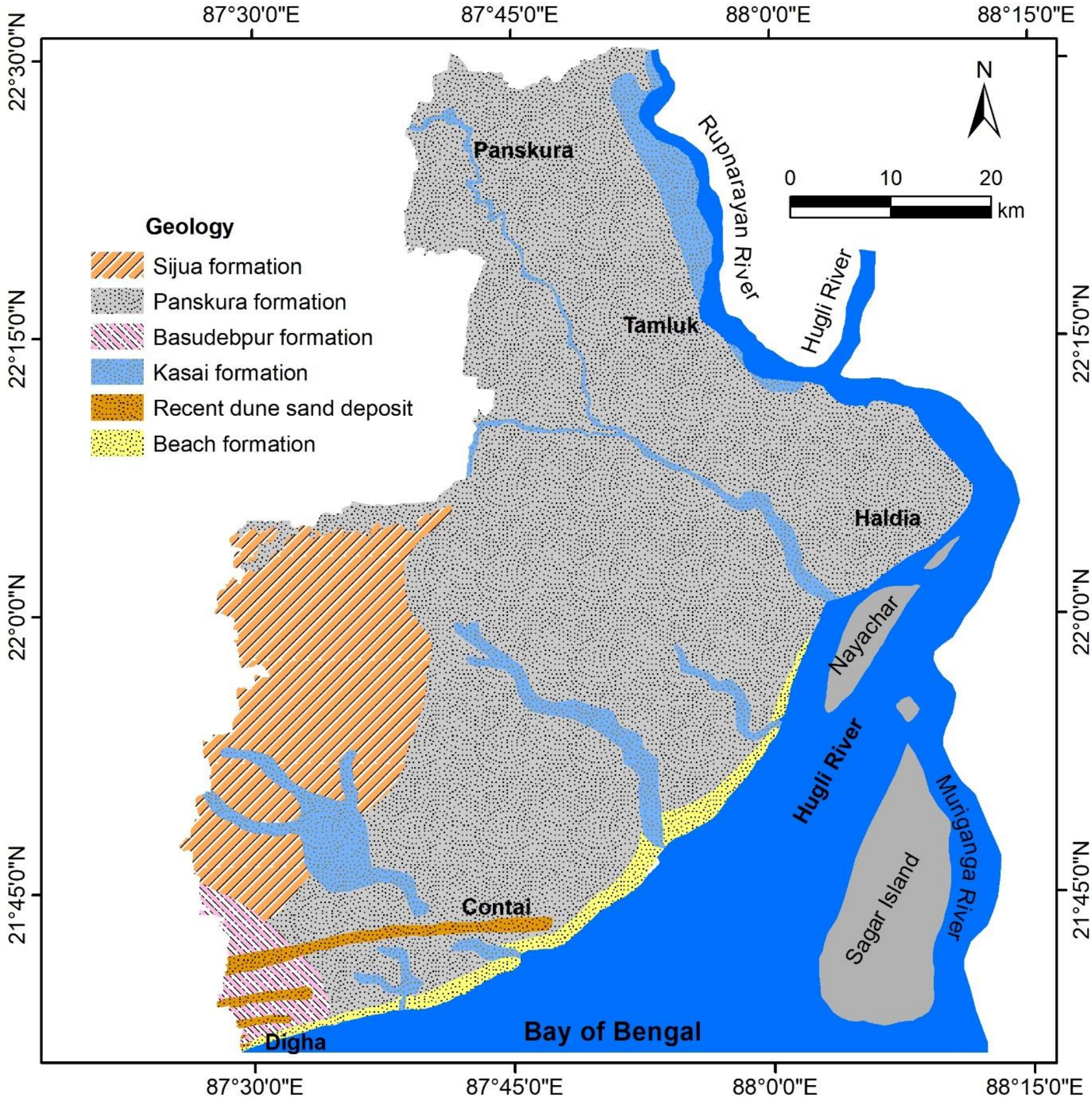

Fig. 1.2: Geological formations of the Purba Medinipur district (South-eastern Coastal Plain of West Bengal).

The coastal plain is occupied by younger and unconsolidated alluviums of Holocene to recent deposit along the fringe areas of the Bay of Bengal. The Holocene to Late Holocene beach ridges and sand dunes separated with palaeo tidal basins are extended over the coastal plain of Contai and Digha. Haldia region is made up of estuarine floodplain alluviums during the Late Holocene to Late Pleistocene period (Niyogi, 1975; Paul, 2002; Chakrabarti, 2005). Recent to sun-recent deposits of tidal flats, beaches and bars, sand dunes and swampy tracts are found on the emerged and submerged surfaces of the region. Channel fringe tidal flats and backwater wetlands are deposited and filled with mud and finer sand or silt in places of tidal influences.

Table 1.1: Period of geological formations with material compositions within the Purba Medinipur district based on Quaternary geological map of GSI.

Period	Geological formation	Materials
Late Holocene	Beach formation	Very fine, white to grey sands mixed with clay
	Recent dune sand deposits	Medium grained grey sands, semi-compact, occasionally with vegetal growth
	Kasai formation	Sand and silts (unoxidised)
Middle to Late Holocene	Basudebpur formation	Dark grey to black clay with mud flats
Middle Holocene	Panskura formation	Fine sand, silt, clay
Late Pleistocene to Early Holocene	Sijua formation	Sand, sandy loam, silt and silty clay with impregnation of caliche nodules

1.2.2. Geomorphology

With the help of Google Earth image and other existing sources of literature, the 17 micro-level geomorphological features are explored for the entire Purba Medinipur district (Fig. 1.3). According to the areal extents of the geomorphic features the ancient tidal deposit, lagoonal deposit, palaeo channel with levee, basinal deposit of Rupnarayan and Kasai system, Holocene fluvial deposit, ancient delta of Subarnarekha system, Holocene tidal deposit, levee deposit of Rupnarayan system and beach ridge with sand dune are extended with the areal extent of 768.58 km², 671.74 km², 514.02 km², 465.70 km², 347.44 km², 283.90 km², 245.60 km², 187.38 km², and 136.17 km², respectively (Table 1.2). The other morphological features remained within the areal coverage of 92.39 km² to 2.96 km² (Table 1.2).

Within the selected three urban centres, the beach ridges and sand dunes are the only topographic highs or significant relief in the lowland areas of Contai coastal plain. The sandy platforms of the ancient shorelines and modern shoreline support a special habitat of the coast dominated by Cashewnut trees, Pandanus bushes, scrubs and long-rooted tussock forming grasses with specific herbs for their composition of coastal alluviums (sandy) and presence of subsurface moistures (Paul & Bandyopadhyay, 1987; Das, 2014a; Das & Das, 2014; Barman et al., 2015). These sandy tracts also act as good reservoirs of freshwater resource to support the unique vegetation covers and available nutrient sources at the interface of saltwater (Beatley et al., 2002; Pal et al., 2002; Defeo et al., 2009). The topographic unit was densely covered by vegetation before the expansion of settlements and acted as good and stable buffer against the storm surges and tidal waves in the region (Paul, 2002).

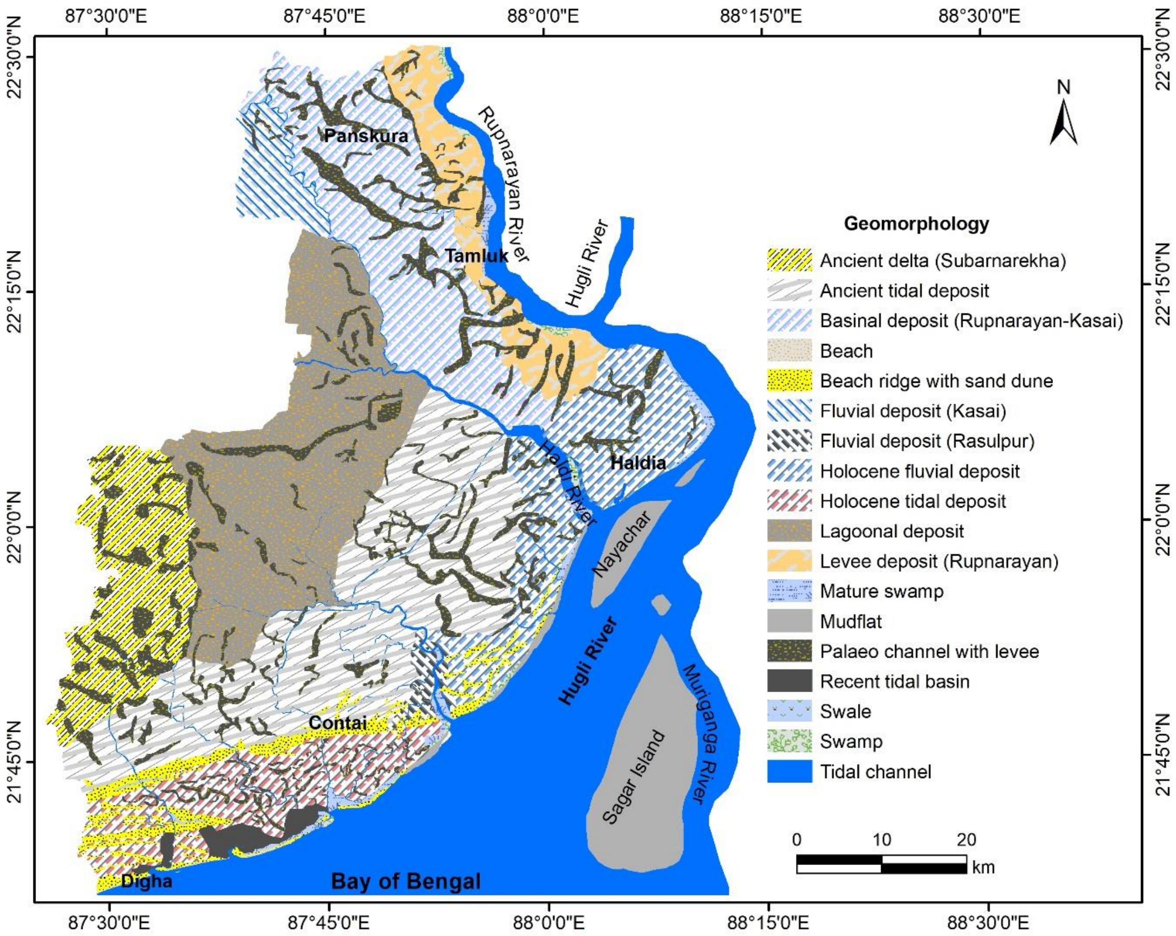

Fig. 1.3: Geomorphological diversities in Purba Medinipur district with the study areas.

Table 1.2: Different types of geomorphological features and their aerial extent within the Purba Medinipur district.

Geomorphic features	Area (km^2)
Ancient delta (Subarnarekha)	283.90
Ancient tidal deposit	768.58
Basinal deposit (Rupnarayan-Kasai)	465.70
Beach	2.96
Beach ridge with sand dune	136.17
Fluvial deposit (Kasai)	92.39
Fluvial deposit (Rasulpur)	33.49
Holocene fluvial deposit	347.44
Holocene tidal deposit	245.60
Lagoonal deposit	671.74
Levee deposit (Rupnarayan)	187.38
Mature swamp	43.72
Mudflat	12.79
Palaeo channel with levee	514.02
Recent tidal deposit	38.67
Swale	3.18
Swamp	15.78
Tidal channel	63.12

The coastal plain with tidal and fluvial deposits remain as topographic low and modified after repeated flood deposits of Subarnarekha, Kaliaghai, Kasai, Haldi and Rasulpur rivers of the region. They are susceptible to inundation by heavy rain during the occurrences of coastal floods.

The coastal wetlands with tidal spill basins and drainage channels are indicating as very low-lying surface immediately behind the shore fringe sand dunes and connected with the open marine environments by tidal channels or tidal inlets. They are flooded twice daily by the rising tides and dissected with tidal creeks to support the colony of halophytic grasslands and mangroves. The wetlands act as a buffer and good flood reservoir of advanced seawater during the seasonal high level of the sea (June-November) in the coastal belts.

1.2.3. Drainage

The major rivers of the Purba Medinipur district are Rupnarayan, Hugli, Kasai, Haldi, Rasulpur, and Champa (Fig. 1.4). Moreover, the coastal plain of Purba Medinipur district is

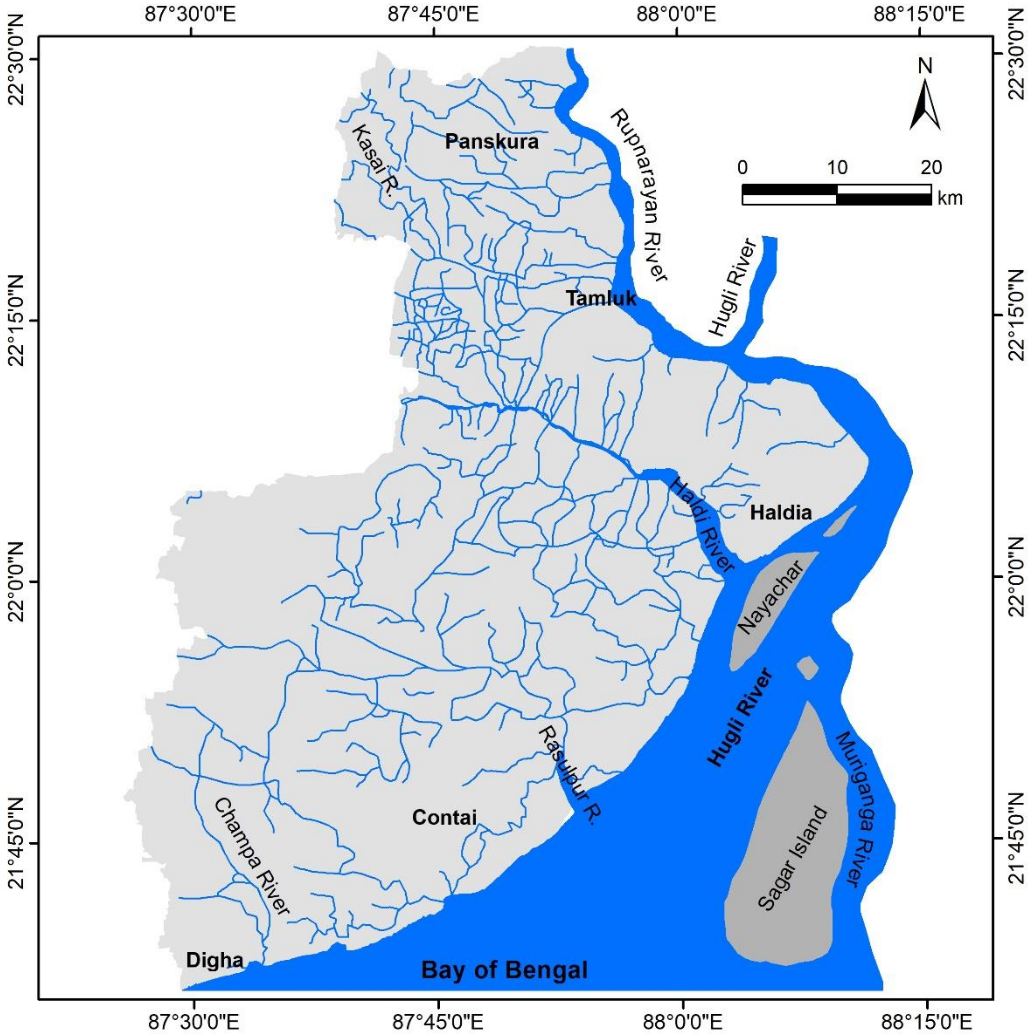

Fig. 1.4: Drainage systems of the Purba Medinipur district with location of study areas.

separated into different segments by a number of drainage channels like Jatra Nullah, Champa river, Jaldah estuary, Pichaboni estuary, Rasulpur river, Talpati channel and Haldi estuary. The coastal segments remain as basins in-between consecutive tidal rivers towards the shore fringes. Most of the channels are dissected by Hijili tidal canal and Odisha coast canal at shore parallel locations (Rudra, 2018; Duari, 2019). The tidal prism, active siltation process and spilling tides into the basins are controlled by the activity of drainage channels in the low-lying coasts. The loss of tidal drainage may produce extensive salt flats in the expanse of mangrove wetlands of the coastal belt. They also act as run-off channels during monsoon rains to support the mangrove habitats of the coast.

1.2.4. Climate

The marine influences are observed in the tropical hot and humid climate of the region. The monsoon months extend from June to November and they produce the maximum percentage of annual rainfall in every year particularly during arrival and retreating phases. Formation of depressions and cyclones in the northern Bay of Bengal produce some amount of rainfall at the beginning and at the end of monsoon season in the coastal belt. The remaining months from December to May behave as a dry condition in the region. Depending on the IMD

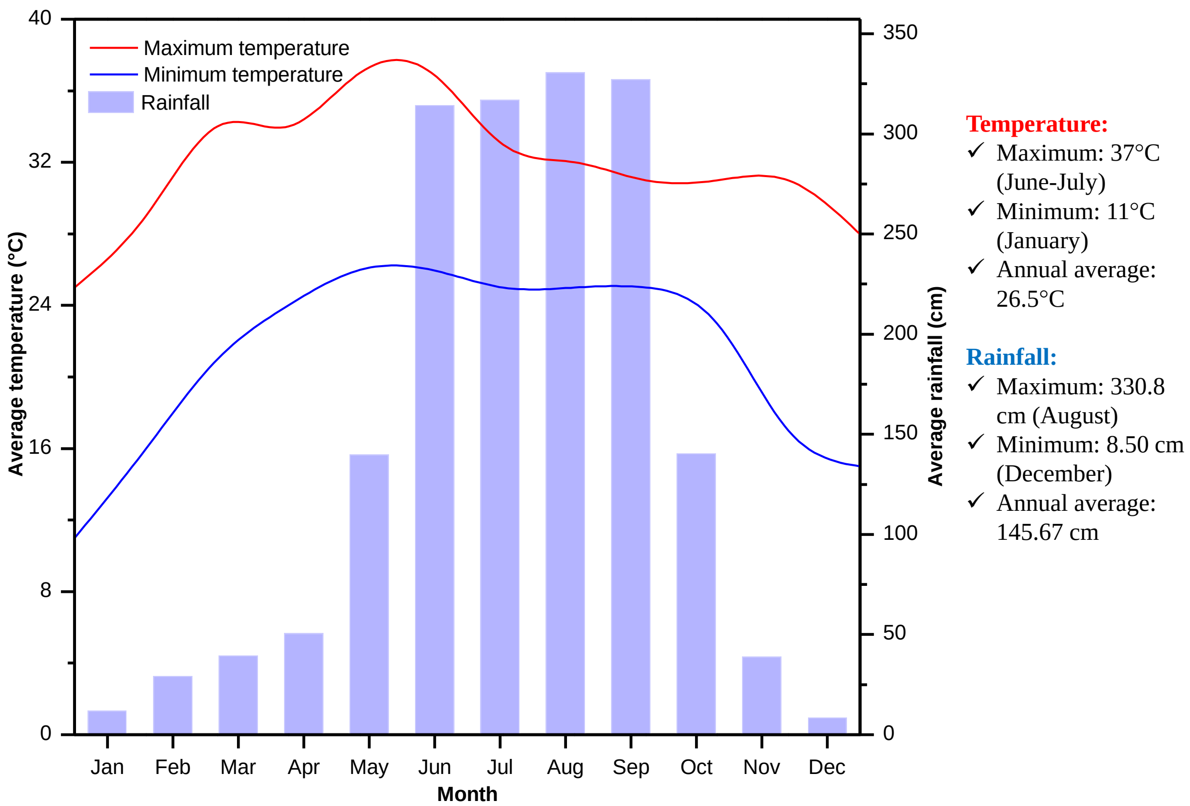

Fig. 1.5: Month-wise variation of average rainfall and temperatures during 1949 – 2017 of the Purba Medinipur district.

data during 1949 – 2017, the maximum rainfall observed in August and lowest in December with rainfall of 330.8 cm and 8.50 cm, respectively, whereas, the annual average is 145.67 cm (Fig. 1.5).

The temperature in the hot summer months (April to May) is minimized with the occurrences of sea breezes and norwesters. During this period the wind-driven current transports huge sediment load along the seashores. The maximum and minimum temperature resulted respectively as 37°C (June-July) and 11°C with the annual average temperature of 26.5°C (Fig. 1.5).

The high magnitude cyclones (over 170 km/hr wind speed) and their landfalls generate damaging impacts over the settlements of the coastal plain up to 10 km inland from the shoreline (Sahoo & Bhaskaran, 2018b).

1.2.5. Soil

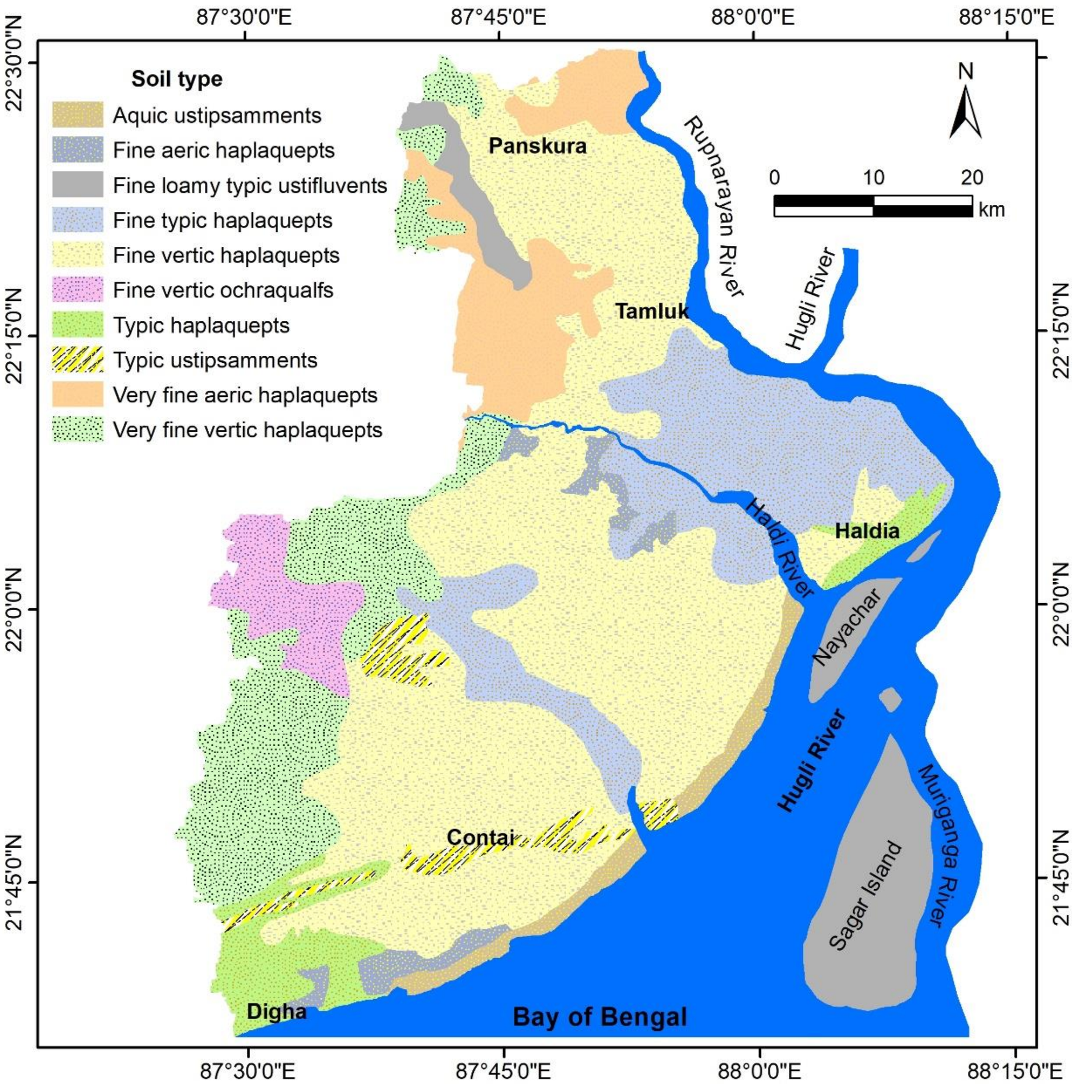

Fig. 1.6: Diversity in soil types of Purba Medinipur district with location of study areas.

Within the entire Purba Medinipur district ten major diversified soil types have been found based on the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP). Most of the areas (1777.08 km²) remain under the fine vertic haplaquepts type of soil (Fig. 1.6; Table 1.3). The other nine soil types with taxonomic name, their material composition and hydrological characteristics, and the spatial extents are also assessed (Fig. 1.6; Table 1.3).

Table 1.3: Soil types of Purba Medinipur district.

Taxonomic name	Description	Area (km^2)
Aquic ustipsamments	Very deep, moderately well drained, sandy soils occurring on gently sloping dunes in coastal plain with sandy surface, severe erosion and strong salinity	93.89
Fine aerichaplaquepts	very deep, poorly/imperfectly drained, fine soil occurring on level to nearly level marshes in coastal plain with clayey surface and moderate flooding and salinity Associated with deep, well drained sandy soils	87.82
Fine loamy typic ustifluvents	Very deep moderately well drained, fine loamy soils occurring on very gently sloping floodplain in loamy surface, moderate erosion and moderate flooding Associated with very deep, well drained sandy soils	58.48
Fine typichaplaquepts	very deep, poorly drained, fine soils occurring on nearly level to gently sloping coastal plain with clayey surface, moderate flooding and slight to moderate salinity (limited extent) Associated with very deep, poorly drained, fine cracking soils	630.69
Fine vertichaplaquepts	very deep, poorly drained, fine cracking soils occurring on nearly level to very gently sloping coastal plain with clayey surface, moderate flooding and moderate salinity (moderate extent) Associated with deep, poorly drained, file soils	1777.08
Fine verticochraqualfs	very deep, poorly drained, fine cracking soils occurring on level to nearly level low-lying alluvial plain with clayey surface Associated with very deep, imperfectly drained, fine soils	135.12
Typichaplaquepts	Very deep, poorly/imperfectly drained, fine soils occurring on level to nearly level marshes in coastal plain with clayey surface, moderate flooding and salinity Associated with very deep, well drained, sandy soils	190.74
Typicustipsamments	very deep, well drained, sandy soils occurring on moderately sloping coastal plain with sandy surface severe erosion and slight salinity	102.41
Very fine aerichaplaquepts	Very deep, poorly drained, fine soils occurring on level to nearly level low-lying alluvial plain with clayey surface and severe flooding Associated with very deep, moderately well drained, fine loamy soils	282.17
Very fine vertichaplaquepts	very deep, very poorly drained, fine cracking soils occurring on level to nearly level low-lying alluvial plain with clayey surface Associated with very deep, poorly drained, fine soils	538.73

The coastal belt of this study area is characterised by sandy alluviums, loamy soils and clayey soils of saline environment. Sandy alluviums are mostly distributed in the beach ridges and sand dunes, and loamy soils exhibit the productive lands of estuarine floodplain towards the east. However, the clayey alluvium dominates over the lowland basins and wetlands of the coast which support the vegetative growth in salt-affected areas. Fluvio-marine deposits have produced a large tract of loamy soils in the coastal plains, and this tract is acting as productive agricultural land.

1.2.6. Land use and land cover

The Land Use and Land Cover (LULC) classification of the Purba Medinipur district shows the six main classes (Fig. 1.7). Most of the area (46.41%) to the total land is used for the agricultural practices (Table 1.4). About 33.06% area remain under the vegetation cover, along

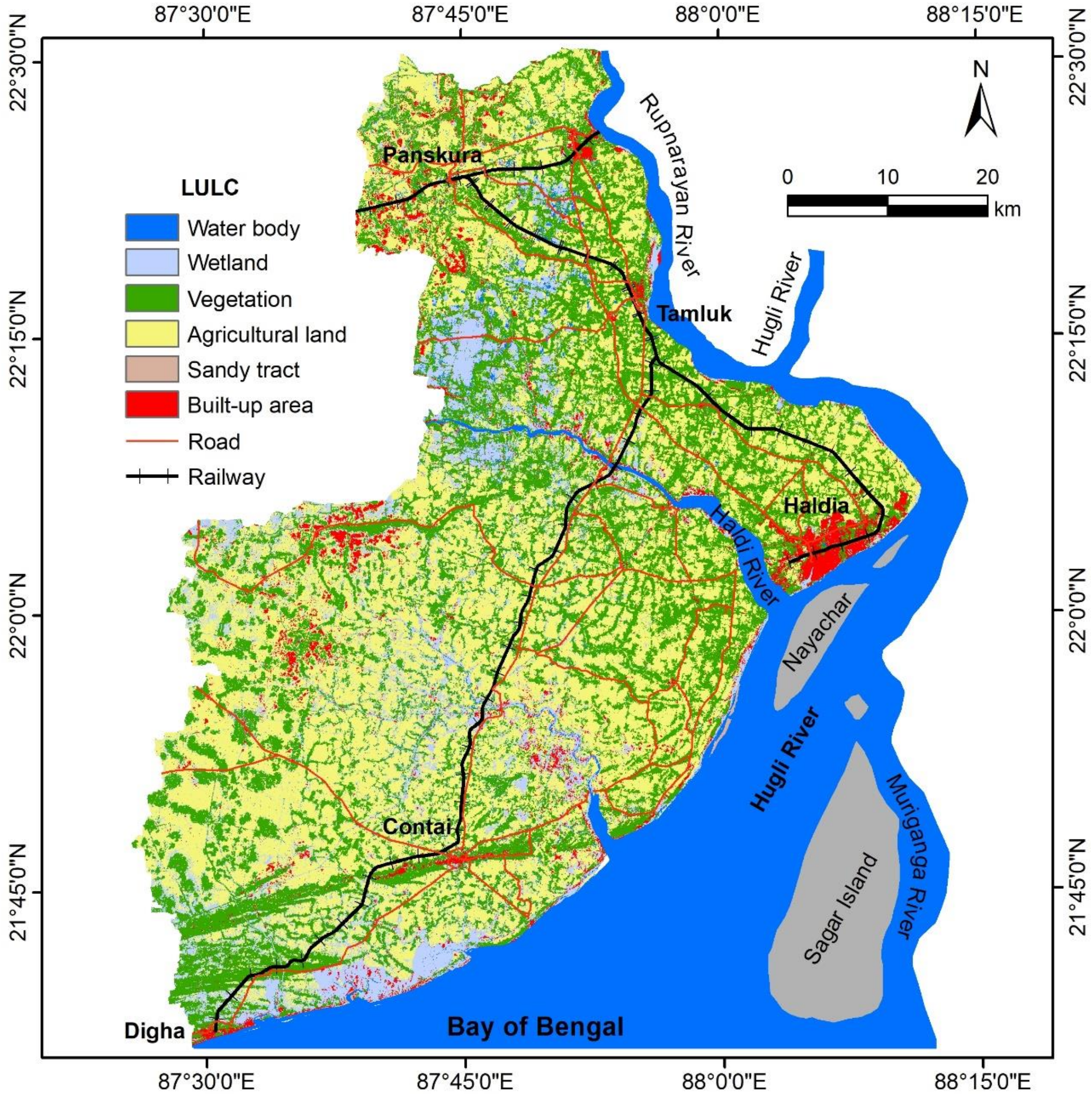

Fig. 1.7: Land use and land cover types of the coastal zones (littoral tracts) within Purba Medinipur district.

with the other land uses of wetlands (12.27%), water bodies (3%), built-up area (5.05%) and sandy tract (0.20%). Here, in the wetland class, the areas of fisheries and other natural low-lying areas are considered, whereas, only the ponds and river water parts are considered under the water bodies. The significant level of the built-up area observed in the urban and municipality areas of Haldia, Contai, Digha, Panskura, Mecheda, Egra, Tamluk and in the areas of Patashpur-Amarshi.

Table 1.4: Diversity in land use and land cover types of Purba Medinipur district.

Land use and land cover types	Area (%)
Water body	3.00
Vegetation	33.06
Agriculture	46.41
Sandy tract	0.20
Built-up	5.05
Wetland	12.27

1.3. Background of the urban centres

The urban centres of Digha, Contai and Haldia have remained under the diverse physical and socio-economic settings. In the physical point of view, the geology, physiography, drainage and natural landscape are the major driving factor responsible for the initiation of the urban centre as well as the trend of urban growth in the present global changes. Moreover, the socio-economic structures and life-supporting occupational structures are also liable to greater expansion of the urban centres.

The Digha urban centre under the DSDA lies in the shorefront part of the Bay of Bengal in the Purba Medinipur district, West Bengal. The area is situated within the part of Digha and Ramnagar police station under the Contai subdivision. The western part of the area is located along the border of West Bengal and Odisha (LUDCP, 2015). The area consists of sand, silt and clay type of materials to form the beach, dune and interdune swale landscape (Fig. 1.6; Table 1.3). The beach ridge and sand dune are elevated part of the land which gradually lowered towards the interior lowlands. The tidal inlets and channels dissect the entire area into three main coastal segments such as Digha, Sankarpur-Tajpur, and Mandarmani. The occurrences of the severe cyclone (at least one in every alternate year) and Sea Level Rise (SLR) promoting the coastal erosion and associated shoreline retreat. Therefore, the erosion protection structure constructed along with the shorefront areas. The dune belt lies almost parallel to the present shoreline with varied width and height in place to place. With the introduction of mass-tourism, the natural dune landscape and dune vegetation are intensively degraded with the construction of tourism infrastructures. The population and number of tourist are gradually increasing in recent time.

The Contai is a municipality town in the Purba Medinipur district of West Bengal. The area existed over the wide and extensive elevated dune ridge and its surrounding swale landscape. That area remains about 10 km away from the recent shoreline. Presently, the Contai municipality is the 2nd most populous municipality with 92226 populations within the 14.35 km² area. The greater magnitude of dune degradation, landscape alteration and vegetation destruction are most significant in association with the expansion of urban infrastructures. The over-extraction subsurface and groundwater are responsible for gradual depletion of the water table in that area. In the eastern part of the area (Uttar Darua), the further expansion of the settlement as well as the urban infrastructures is not observed with due effects from the saline water encroached into the groundwater table. Moreover, in the recent period, the settlements are mostly constructed in the low-lying areas after landfilling processes.

The Haldia municipality town established based on the port-industrial activities over the estuarine floodplain surface. Most of the urban areas expanded over the natural levee of Hugli and Haldi rivers also over the low-lying areas. The lowland filling is intensively adopted for the preparations of the suitable land for urban infrastructural development. Moreover, wetland and agricultural land are degrading due to industrial effluents and pollutants. The massive growth of population and urban infrastructure in the risk-prone estuarine environment is promoting vulnerability in this area. Recently, the new accrue area of Haldia municipality and extended Haldia planning area's urban infrastructure have been planned and implemented in the low-lying area which is liable to more vulnerable (PLMLS, 2015; LU&DCP, 2015).

1.4. Literature review

It is widely accepted that the coastal zones around the world are coming under threat concerning the population pressure and increasing hydrometeorological hazards (Leroy, 2006; Shamsuddoha & Chowdhury, 2007; Rahman & Rahman, 2015a). With such effects, the coastal habitat and ecosystems are degrading and become more and more vulnerable. The extending urbanization in the coastal areas remain under threat and it will be more fragile and vulnerable in time perspective (Turner at al., 1996; Brown et al., 2013; Senapati & Gupta, 2014). In the present context of the intensities, frequency and magnitude of SLR and other hydrometeorological hazards and disasters in the coastal areas, particularly in the Indian coasts as well as in the tropical coasts, the coastal areas of south and south-east Asia like Bangladesh, India, Myanmar, Thailand are exposed to severely vulnerable (Krishnamurthy, 2008; Hoque et al., 2016; Hu et al., 2018). In these regions, more than 75 % of total population are living within the coastal zone (Vernberg & Vernberg, 2001; Small & Nicholls, 2003; McGranahan et al., 2007) depending on the plenty of resources and livelihood options (Francisco, 2008; Bunce et al., 2010; Hussain, 2013). The flourishing urban infrastructural development and population growth mostly over the soft sedimentary landscape creating a boomerang effect to the coastal society after degrading the entire natural setup (Creel, 2003; Bulleri & Chapman, 2010; Rahman & Rahman, 2015b).

In the Indian coastal areas, the mega-cities like Mumbai, Kolkata and Chennai are recently devastated by rainwater flooding (Kamini et al., 2006; Nath et al., 2008; Gupta, 2007; Rumbach, 2014; Jameson & Baud, 2016; Selvaraj et al., 2016). Basically, the unplanned urban infrastructural development leading to the urban sewerage and water-logging problem which intensified during the storm rainfall (Mowla & Islam, 2013; Rahman & Rahman, 2015b; Pervin et al., 2019). In West Bengal, the coastal areas of Purba Medinipur district are situated over the littoral deposition of soft sedimentary surface (Duari, 2019). The sand dune and estuarine floodplain and natural levees in the transitional zones of land and sea are more elevated than the interior coastal areas. The suitable land as well as the low-lying surfaces have been modified and already occupied by the anthropogenic activities. Further expansion of anthropogenic activities become viable for the entire coastal environment.

In the littoral tract of Purba Medinipur district, particularly in the shorefront areas of Digha-Mandarmani coastal stretch, the shoreline protection measures have been adopted (Maiti & Bhattacharya, 2009; Jana & Bhattacharya, 2013). However, the other areas of the urban centres are not considered for implementation of the protection measures in the coastal belt. Moreover, the protective sea wall structures are producing the impacts related to reflecting scour on the unconsolidated sediments of the sea beaches, and for which the beach lowering process is still continuing in Digha Sankarpur and Mandarmani areas at present (Van Rijn, 2011; Mandal et al., 2013a). In spite of the carefully accepted laws and regulations, the anthropogenic pressure and landscape degradations continued to increase ignoring the laws and regulations by the bureaucratic developers by constructing illegal structural units (Sharma, 2011; Mitra et al., 2013). Since the 1990s, the population pressure and growth of urbanization in the coastal areas have intensified and recognized as a severe problem with due effects from socio-economic development (Lakshmi & Rajagopalan, 2000; Burak et al., 2004; Long et al., 2009). Although the Integrated Coastal Zone Management (ICZM) scheme has taken, it rarely implemented due to lack of coordination between the regulating authorities and stakeholders (Post & Lundin, 1996; Ramachandran, 1999; Ramesh & Vel, 2011). Illegal constructions are encouraged for generating amenities and easy income opportunity on illegal proceedings which promoting further environment degradation (Mandal et al., 2013b; Ganguly & Bagri, 2014; Baitalik & Majumder, 2018). Therefore, the goal of the sustainable development to protect the environment for present as well as the future generation by controlling our present stage of development at certain level is somehow impossible to achieve (Cicin-Sain, 1993; Sum & Hills, 1998; Sathaye et al., 2006; Ray et al., 2019). However, it is the prior duty as an academician and researcher to find out the level of development and degradation to minimize the problems and way of long-term survival in upcoming global environmental concern.

The alterations of landscape and LULC changes are promoting the degradation of natural ecosystems and habitats (Abdullah et al., 2019; Das & Das, 2019; Kantamaneni et al., 2019). Most of the sand dunes and wetlands are converted into profitable land use. The urban infrastructure is gradually built over the sand dunes and wetlands, respectively after dune cutting and wetland filling (Kunte & Wagle, 1994; Middleton, 1999; Jana & Paul, 2018). Moreover, the natural wetlands are somehow altered into fisheries (Mahapatra et al., 2014; Finkl & Makowski, 2017). Therefore, the natural habitat of the floral and faunal species have been endangered with time (Naskar & Mandal, 1999; Chakraborty, 2011; Chakraborty, 2013). The agricultural land is also converted into built-up areas (Nanda, 2001; Ojha & Chakrabarty, 2018). With due effects, the environment quality has deteriorated in tremendous form. The urban-industrial untreated waste materials are directly mixed with the coastal water and in the coastal environment (Kaly, 2004; Dixit, 2014; Krishna et al., 2017) which further leading to environment degradation (Sarkar et al., 2007). In the present scenario of the population growth and anthropogenic activities, people cannot able to minimize and someway control their daily life and activities (Rahman, 1993; Faulkner, 2001; Streatfield, 2003; Miah et al., 2010; Dandapath & Mondal, 2013). So, they are compelled to adjust the nature of degradation, and such kind of tendency promotes rapid urban expansion and environmental degradation.

The required habitable space is squeezing and more compact urban infrastructures are growing up. The huge extraction of groundwater allows the saline seawater to encroach into the groundwater aquifers (Pareek et al., 2006; Basack et al., 2014; Maity et al., 2017). The over-extraction is also liable to regional and local land subsidence (Galloway & Burbey, 2011; Bhattacharya, 2013; Erban et al., 2014). The ambient air quality and air temperature are gradually increasing due to industrial pollutants, gasses and somehow for the congested building environment (Guldmann, 1979; de Magalhaes Rios et al., 2009; McDonald et al., 2019). Therefore, in respect to the spatial (lateral and vertical space) and temporal context, the man-environment conflict is tremendously increased (Burgess et al., 1988; Chambers, 1994; Fabos, 2019).

Lots of research had been done in such perspective around the world (Wohlwill, 1982; Le Tixerant et al., 2011; Mukhopadhyay et al., 2012a; Mondal, 2014; Ghosh & Shetty, 2017; Pereira et al., 2019). Different coastal zone management policies have also been adopted to the long-term survival of mankind in a sustainable manner. However, the coastal zone is vulnerable due to rudeness and unscientific activities and still, it is a challenge to save the human being and adjust to the fragile environment. Therefore, the assessment of risks and vulnerability of the different landscape and fragile coastal areas, particularly the densely populated urban areas is to be required in an urgent basis (Revi, 2008; Elliott et al., 2019; Viero et al., 2019). Also, finding out the best suitable and easy ways which can minimize the risks and future vulnerability of the coastal society.

1.5. Problems of the urban centres

There are many emerging problems in the coastal urban centres at present. The population pressure, land use conversion, saltwater inundation, shoreline erosion and effects of cyclone landfalls, uncontrolled growth of the urban infrastructure on the wetland fringes and CRZ rule violations are responsible for such emerging problems in the urban areas of the coastal belts. The Contai municipality town is situated over the dune ridge surface. The urban centre is located about 10 km inland area of beach ridge surface positions from the current shoreline of Digha. Contai urban area has expanded on the beach ridge surface, on the lowlands and also on the wetlands areas of Kanthi coastal plain. The inland coastal plain urban centre is growing as administrative centre, residential complex and market complex over the expanding horizons of the landscapes. Whereas, the Haldia municipality area exists over the estuarine floodplain surface at the confluence of the river Hugli and Haldi with expanding urban activities based on the port facilities, industries, market complex and residential areas. Therefore, the urban centres are suffering from multiple problems related to environmental sensitivity of the coast and climate change processes over the coastal belt of the region. The problems are highlighted bellow in the next section;

- Higher rate of population growth and urban expansion in the littoral coastal area after degrading the natural landscape setup of dune ridge, wetlands and low-lying areas.
- LULC change and anthropogenic activities leading to ecosystem degradation associated with degradation and conversion of natural habitat, industrial-urban waste and pollutants.

- Construction of building through wetland filling over the low-lying areas can create sewage problem and water-logging which can be intensified with the recent trend of SLR, severe cyclonic rainfall and tidal bore.
- Huge extraction of groundwater can extend the problem of saline water encroachment into the groundwater table.
- Mass-tourism and associated urban infrastructure development degrading the natural landscape of the coastal habitats.
- Violation of the CRZ rules.

1.6. Objectives

As per the problems of the three urban centres (Digha, Contai and Haldia), the following objectives are set to fulfil the entire research.

1. To assess the impact caused by coastal urbanization and population pressure in Medinipur littoral tract;
2. To estimate the coastal vulnerabilities arise from the cumulative effects of population pressures, and from marine forcing factors like sea-level rise, coastal floods, cyclones, and related coastal erosions;
3. To identify the urbanization-environment conflict in the sensitive coastal environment of Medinipur littoral tract; and
4. To monitor the status of CRZ rules and modification of the coast.

1.7. Data Source

The research work has been carried out based on the primary and secondary data, and their proper analysis through geospatial and statistical environment adopting different methods of analysis using models and suitable software. All the results in the form of tables and diagrams have been prepared based on the data sets mentioned in Table 1.5 and 1.6. The main aspect of this research is depending on the LULC classification and changing pattern. Satellite data in Multispectral Scanner System (MSS), Thematic Mapper (TM), and Operational Land Imager (OLI) sensors of Landsat 1, 5 and 8 satellites have been collected and used in the different purpose (Table 1.5). Moreover, Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) data are also adopted for a different purpose (Table 1.5). Other secondary data of different published maps like mouza maps and drainage map were collected from the Natural Resources Data Management System (NRDMS), Purba Medinipur; ward maps of Contai and Haldia from the respective municipalities; geological maps from

Geological Survey of India (GSI) portal; and soil maps from NBSS & LUP, Kolkata (Table 1.6).

Table 1.5: Different Satellite data used in the study.

Satellite data	Acquisition date	Path/Row; Coordinate	Purpose of use	Data source
Landsat 1 (MSS)	17/01/1973 17/01/1980	149 / 049 149 / 049	Shoreline and bankline shifting	USGS, Earth Explorer (https://earthexplorer.usgs.gov/)
Landsat 5 (TM)	06/03/1991 13/03/1991 13/02/2001 21/03/2000 09/02/2011 16/02/2011	138 / 045 139 / 045 138 / 045 139 / 045 138 / 045 139 / 045	Shoreline and bankline shifting, LULC classification, and urban sprawling	
Landsat 8 (OLI)	27/01/2018 18/01/2018	138 / 045 139 / 045		
SRTM-DEM	11/02/2000	22 N / 87 E 21 N / 87 E 22 N / 88 E 21 N / 88 E	Elevation, contour, cross profiles, water logging, Vulnerability assessment, projected channel network	

Table 1.6: Different types of maps, other secondary and primary data used in the study.

Data used	Purpose of use	Data source
Mouza map	Study area map and expansion of area	NRDMS, Purba Medinipur and DSDA
Ward map		Contai and Haldia Municipality
Geological quadrant map	Geological description; CRZ mapping	GSI (https://www.gsi.gov.in/)
Google Earth	Geomorphological description; CRZ mapping	Google Earth
Toposheet	CRZ mapping	SOI
Drainage map	Regional drainage system	NRDMS, Purba Medinipur
Soil map	Description of different soil type	NBSS & LUP (https://www.nbsslup.in/)
Climate data	Local and regional rainfall and temperature variability	IMD, Pune (www.imdpune.gov.in)
Demographic data	Demographic condition (population, literacy and worker category)	Census of India (1991, 2001, 2011)
Tide gauge data	Fluctuation of mean tidal level	PSMSL (https://www.psmsl.org/)
Cyclone data	Cyclone intensity	Cyclone eAtlas – IMD (http://14.139.191.203/ViewByParam.aspx)
Groundwater data	Groundwater depletion	CGWB (http://cgwb.gov.in/)
Water quality data	Physico-chemical quality of groundwater	WBPCB (www.wbpcb.gov.in)
Solid waste data	Type and volume of solid waste	Primary survey; Haldia municipality office
Beach width and dune elevation	Beach and dune erosion	Primary (on-field) survey
Field photo	Different type of field observation and analysis	

The climate data (temperature and rainfall) and cyclone data were collected from the IMD, Pune. Tide gauge data of four different stations (Diamond Harbour, Gangra, Haldia and Digha) were collected from the official site of the Permanent Service for Mean Sea Level (PSMSL). The groundwater data were collected from the CGWB, Kolkata. The data on the drinking water quality were collected from the WBPCB. The information and data about the solid waste were mainly collected from the primary survey and also from the Haldia municipality office (for Haldia). The CRZ map has been prepared considering the Survey of India (SOI) toposheet, geological map, Google Earth and map prepared by the National Centre for Sustainable Coastal Management (NCSCM). Moreover, the on-field primary survey was conducted in different periods to understand the nature of beach and dune erosion, and other different information about the urban landscape alteration, nature of urbanization, and urban activities with photographic evidence.

1.8. Methodology

The entire work has been done following the different methods of remote sensing and GIS techniques coupling with statistical techniques, empirical equations and modelling of data processing to achieve the results and final outcomes of the research work (Fig. 1.8).

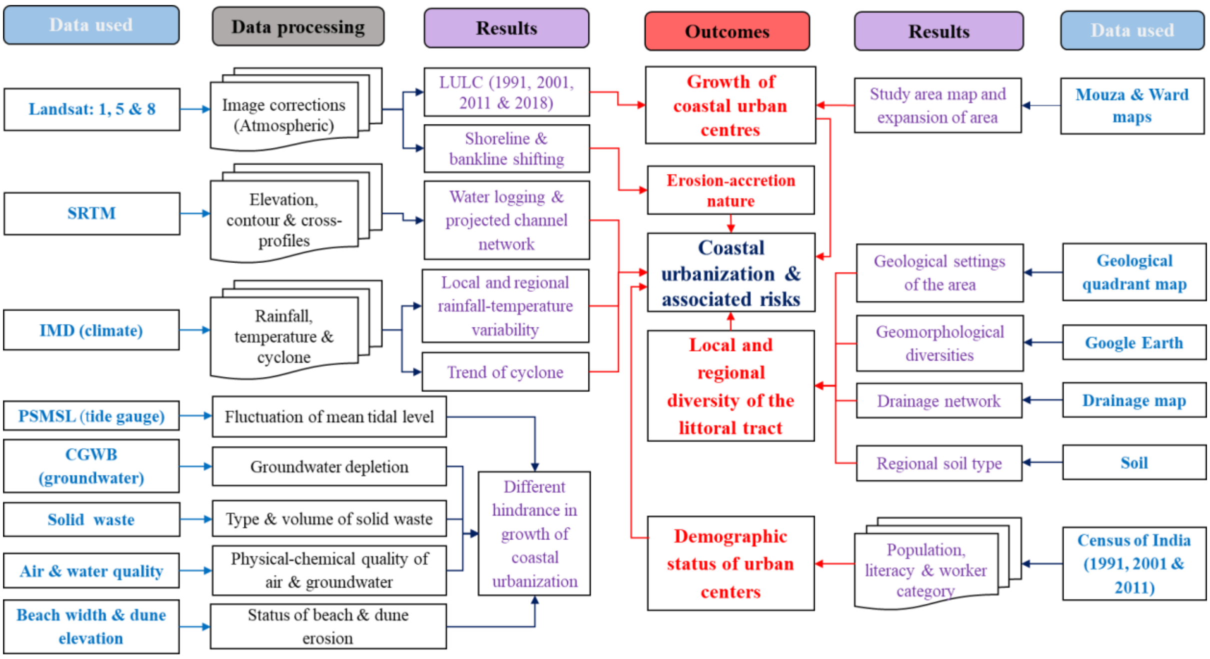

Fig. 1.8: Methodological flowchart of the study.

The methodologies have been adopted in this research regarding the local and regional diversity of the littoral tract through assessing the geology, geomorphology, drainage network and soil types; LULC classification and land use alterations; statistical analysis of census data; risk assessment of the urban centres concerning the tidal impact, water-logging and inundation, impact of cyclone hazard, and coastal erosion; the urban-environment conflicts and related vulnerability of the urban centres reflected through the water scarcity in the long-term scenario of climatic variability and status of groundwater, level of solid waste production, quality of drinking water and air, and level of safeguarding and violation of the CRZ rules.

1.8.1. LULC classification

The Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) atmospheric correction has also been done after the radiometric corrections (ENVI, 2009). The FLAASH model is used to remove or minimize the influence of atmospheric noise from the object reflectance.

The radiometric corrections of the MSS, TM and OLI sensors have been done on the satellite images of Landsat 5 and 8. In this process, the Digital Numbers (DNs) have been converted to radiance value for the Landsat 5 and 8 images respectively using the Eq. 1.1 and 1.2 (Chander et al., 2009; Markham et al., 2014; Mishra et al., 2014).

$$L_\lambda = \left(\frac{L_{MAX\lambda} - L_{MIN\lambda}}{Q_{cal\max} - Q_{cal\min}} \right) \left(Q_{cal} - Q_{cal\min} \right) + L_{MIN\lambda} \qquad (1.1)$$

where, L_λ is the spectral radiance at the sensor's aperture, Q_{cal} is the quantized calibrated pixel digital number, $Q_{cal\min}$ is the minimum quantized calibrated pixel value corresponding to $L_{MIN\lambda}$ (DN), $Q_{cal\max}$ is the minimum quantized calibrated pixel value corresponding to $L_{MAX\lambda}$ (DN), $L_{MAX\lambda}$ is the spectral at-sensor radiance that is scaled to $Q_{cal\max}$, and $L_{MIN\lambda}$ is the spectral at-sensor radiance that is scaled to $Q_{cal\min}$.

$$L_\lambda = \left(M_L \times Q_{cal} \right) + A_L \qquad (1.2)$$

where, L_λ is the spectral radiance, M_L is the radiance multiplicative scaling factor for the band, A_L is the radiance additive scaling factor for the band, and Q_{cal} is the pixel value in DN of the level 1 (L1) product image.

Reflectance rescaling coefficient factor is used to convert the Top of Atmospheric (TOA) planetary reflectance of multispectral bands of the satellite data. The Eq. 1.3 is considered to switch the spectral radiance to TOA reflectance for Landsat data (NASA, 2016).

$$\rho_p = \frac{(\pi \times L_\lambda \times d^2)}{(ESUN_\lambda \times \cos\theta_s)} \qquad (1.3)$$

where, ρ_p is the unit less planetary reflectance, which is the ratio of reflected versus total power of energy (NASA, 2016); L_λ is the spectral radiance at the sensor's aperture (at satellite radiance); d is the earth-sun distance in astronomical units (provided with Landsat 8 metadata file; $ESUN_\lambda$ is the mean solar exo-atmospheric irradiances; θ_s is the solar zenith angle in degrees, which is equal to $(\theta_s = 90° - \theta_e)$, where θ_e is the sun elevation; $ESUN$ is the $(\pi \times d^2)$ $\times$ radiance maximum and reflectance maximum.

So, the Landsat 8 images are made available with band-specific rescaling factors which allow for the straight conversion from Digital Number (DN) to TOA reflectance. On the other hand, the property of the atmosphere (i.e. Disturbance on the reflectance that varies with the wavelength) should be considered in order to calculate the reflectance at the surface (Eq. 1.4) so, it is described by the land surface reflectance (ρ) (Moran et al., 1992).

$$\rho = \frac{\left\{\pi \times (L_\lambda - L_p) \times d^2\right\}}{\left[T_v \times \left\{(ESUN_\lambda \times \cos\theta_s \times T_z\right\} + E_{down}\right]} \tag{1.4}$$

where, L_p is the path radiance; T_v is the atmospheric transmittance in the viewing direction; T_z is the atmospheric transmittance in the illumination direction; E_{down} is the downwelling diffuse irradiance.

The supervised classification techniques, Spectral Angle Mapping (SAM) and Support Vector Machine (SVM) algorithm are applied in the four different Landsat images of 1991, 2001, 2011 and 2018 of the selected sites for the LULC classification (Pal & Mather, 2004, 2005; Bouaziz et al., 2017). In this study, based on the spatial coverage of the study areas, about 15 points of each class were demarcated depending on the on-field knowledge for the LULC classification. The classified images (2018) were further validated with the field verification, and the LULC classification was finally considered for this study when the classification was more than 89 per cent accurate based on the Kappa coefficient (Smits et al., 1999). Moreover, year to year LULC conversions has been estimated using conversion matrix (Li & Yeh, 2004; Deng et al., 2008).

1.8.2. Statistical analysis of census data

The mouza and ward-wise census data of 1991, 2001 and 2011 have been used for the analysis of the demographic status of the three urban sites of Digha, Contai and Haldia. In this study, the population density, the year-wise population growth rate (decadal) and population projection of 2021, educational status (literate and illiterate), and status of different working and non-working population have been analysed and cartographically represented.

The mouza and ward-wise population density are estimated as the number of population per km² area. The decadal (10 years) growth rate of population (Patra et al., 2019) computed through Eq. 1.5.

$$GR_D = \frac{P_r - P_p}{P_p} \times 100 \tag{1.5}$$

where, the decadal growth rate (GR_D) is estimated considering the recent population (P_r) and past population (P_p).

The population projection (Keyfitz, 1972) has been computed adopting the arithmetic increase method (Eq. 1.6).

$$P_n = P_o + N\overline{X} \tag{1.6}$$

where, P_n is the number of population in the projected year, P_o is the population of last decade, N is the number of decades need to project (the difference between the last year (Y_l) and the projected year (Y_p)), and $\overline{X}$ is the average number of population increase per decade. When P_i is the sum of the decadal population increase in n number of a decade (D_n). Therefore, N and $\overline{X}$ is computed as per Eq. 1.7 and 1.8, respectively.

$$N = \frac{Y_p - Y_l}{10} \tag{1.7}$$

$$\overline{X} = \frac{P_i}{D_n} \tag{1.8}$$

1.8.3. Risk assessment of the urban areas

The Digha and Haldia situated in the shorefront part of the Bay of Bengal and estuarine margin of the river Hugli. Therefore, the low-lying areas are prone to tidewater inundation. The trend (r) of increasing tide level during the period of 1948 – 2014, 1971 – 2014, 1974 – 2006, and 1977 – 2012 for the tide gauge stations of Diamond Harbour, Haldia, Gangra and Digha are analysed. Furthermore, the water-logging and inundation risk have been assessed considering the DEM-based elevation and contour pattern in association with the natural drainage network of the area. In this purpose, the cross-sectional form, and area of inundation has been demarcated considering the trend of increasing tide level and tidal bore in the Hugli estuary mouth. The low-lying areas in the Contai municipality have been demarcated those are prone to be waterlogged during the heavy rainfall. The intensity, severity and trend (r) of different cyclone events have also been assessed in and around the Bengal coast. Moreover, in such kind of tide and cyclone-prone condition, nature of shoreline and bankline erosion-accretion has been estimated considering the six different shorelines and banklines from 1973 – 2018 through the Digital Shoreline Analysis System (DSAS) model of the extension tool of ArcGIS 10.4 software.

The banklines and shorelines have been digitized from the geo-referred satellite images (Table 1.5). All the digitized banklines and shorelines have been imported in the DSAS model to estimate the nature of shifting (erosion/accretion) adopting the statistical methods of Net Shoreline Movement (NSM) and Linear Regression Rate (LRR) (Jana et al., 2014; Nassar et al., 2019). In this study, all transects have been demarcated at 100 m interval across the shoreline or banklines which are placed along the respective baselines as per the applicability. The NSM is estimated through the positional differences ($y_e - y_r$) of earliest (y_e) and recent (y_r) shoreline/bankline. However, after considering the intersect positions (distance from baseline) of n number of shoreline/bankline ($y_{1,2....n}$) with respective to time ($t_{1,2...n}$) as year, coupling with the application of linear regression equation (Eq. 1.9), the rate of shifting is estimated through LRR (Thieler et al., 2009; Mukhopadhyay et al., 2012b; Jana, 2019, 2020).

$$y = a + bx \tag{1.9}$$

where, y is the position of shoreline/bankline, a is the intercept of y, b is the rate of shifting in an independent time interval (x) between the earliest (x_e) and recent (x_r) shoreline/bankline. The a and b can be estimated through Eq. 1.10 and 1.11, respectively.

$$a = y_e - \left(\frac{y_e - y_r}{x_e - x_r}\right)x_e = y_r - \left(\frac{y_e - y_r}{x_e - x_r}\right)x_r \tag{1.10}$$

$$b = \left(\frac{y_e - y_r}{x_e - x_r}\right) \tag{1.11}$$

1.8.4. Urbanization-environment conflicts

The vulnerability has been assessed regarding the urban infrastructural development and the deteriorated environmental quality. Therefore, several problems arise in the studied urban areas like water scarcity, the volume of solid waste and pollutants, along with the level of violation of CRZ rule. For the assessment of water scarcity, the monthly and seasonal trend of temperature and rainfall has been analysed in the Origin pro 8.5 software, considering the meteorological data during 1982 – 2017 for the site of Digha and Haldia, and 1949 – 2017 for Contai. Moreover, the seasonal and long-term (1996 – 2015) trend of groundwater depletion has been assessed for the study areas, and the Inverse Distance Weighting (IDW) method of interpolation has been adopted for the mapping purpose using the ArcGIS 10.4 software. Also, the level of pollution is estimated through the collection and diagrammatic representation of primary and secondary data of solid waste, quality of groundwater and air. The CRZ map has been prepared following the CRZ rule (2011) for the Digha-Mandarmani coastal belt. In this purpose, the map layers have been digitized directly in the Google Earth image and exported in the GIS environment for the zonation and mapping. Finally, the vulnerability of the urban centres have been assessed considering the different physical variables. Such variables are zone wise average elevation, area of water-logging and inundation, wetland filling, groundwater depletion, dune degradation, area affected by salt water encroachment in to the groundwater, nature of shoreline and bankline shifting, position of sea-wall, built-up area of the urban centres etc. The zone-wise categorical risk rating scores have been assigned according to the risk rising factors. The zone-wise Coastal Vulnerability Index (CVI) has been calculated based on the square root of the product of the n number of variables divided by the total number of variables (n) as per the Eq. 1.12 (Pendleton et al., 2005; Sahana et al., 2019). The estimated CVI scores have been further standardized $(\mathrm{CVI_S})$ adopting the Eq. 1.13 (Jana, 2020). Finally, the zone-wise standardized CVI scores have been assigned in the respective zone and interpolated through the IDW method in the ArcGIS 10.4 software. Also, the CVI maps have been generated for the selected urban areas.

$$CVI = \sqrt{\frac{V_1 \times V_2 \times V_3 \times .....V_n}{n}} \tag{1.12}$$

$$CVI_S = \frac{X - X_{\min}}{X_{Max}} \tag{1.13}$$

where, V_1, V_2, V_3 and V_n are the different variables, X is the zone-wise estimated CVI scores, $X_{\min}$ is the minimum and $X_{\max}$ is the maximum CVI score among all zones.

1.8.5. Drainage plan to reduce water-logging and inundation problem

The projected drainage network has been demarcated based on the DEM of the individual sites after processed in the ArcGIS 10.4 software adopting the ArcHydro tool (Maidment & Morehouse, 2002; Gopinath et al., 2014).