Hydrology & Hydrogeological Study

For Proposed RE-Hybrid Park at Khavda, District Kutch, Gujarat

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(Sudhir Kumar)
Scientist G and PI

LIST OF ABBREVIATIONS

AOI	Area of Interest
ALOS PALSAR	Advanced Land Observing Satellite-1 Phased Array type L-band Synthetic Aperture Radar
amsl	above mean sea level
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
IMD	Indian Meteorological Department
IDF	Intensity-Duration-Frequency Curves
CPHEEO	Central Public Health & Environmental Engineering Organisation
CN	Curve Number
CGWB	Central Groundwater Board
DEM	Digital Elevation Model
GIPCL	Gujarat Industries Power Company Limited
LULC	Land Use/Land Cover
NRCS	Natural Resources Conservation Service
RE	Renewable Energy
RWH	Rainwater Harvesting
RUSLE	Revised Universal Soil Loss Equation
SCS	Soil Conservation Service
SDR	Sediment Delivery Ratio
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System

SUMMARY

The hybrid renewable energy park having capacity to generate around 30,000 megawatt (MW) solar and wind power combined have been proposed at Khavda village in Kutch district of Gujarat. The assessment of hydrogeological study is required to ascertain the safety of the park in the future extreme events of climate as well as various natural hazards. The sustainable stormwater management and flood risk management measures are needed within a catchment. Therefore, the hydrology and hydrogeological investigations have been carried out in the proposed RE-Hybrid Park at Khavda (District Kutch, Gujarat). Primary and secondary data have been used from different sources to study the project site. The rational method has been used for peak runoff potential estimations and computed design stormwater drain capacity. The volume of surface runoff and soil loss from the GIPCL project block have been estimated using SCS-CN method and RUSLE, respectively. The total sediment yield received from the project area is also estimated using the sediment delivery ratio method. The detail investigations have been carried out to assess the groundwater potential (quantity and quality), surface water availability and estimated water requirement for different uses in the proposed project site. In addition, flooding and runoff zones have been identified and their estimates were computed from project site. It is clear that site is constructed as independent zone and not having any catchment from the upstream directions, which can contribute to flooding in the park site. Rainwater harvesting and water management strategies have been devised based on the field conditions. Finally, it is recommended that proper provision of regular operation and maintenance of the stormwater drainage system in the park.

TABLE OF CONTENTS

1 INTRODUCTION 1
1.1 Background 1
1.2 Objectives 2
1.3 Significance of the study 2
2 STUDY AREA 4
2.1 Location 4
2.2 Topography 6
2.3 Climate 7
2.4 Drainage 9
2.5 Soils 9
2.6 Geology and Hydrogeology 10
2.7 Landuse / Land Cover (LULC) 11
2.8 Flora and Fauna 12
2.9 Eco sensitive areas 13
3 NATURAL HAZARDS AND RISKS ASSESMENT 16
3.1 Earthquake Hazard 16
3.1.1 Earthquake / Fault line in and surrounding area 17
3.1.2 Gujarat Hazard Risk Zonation 18
3.2 Tsunami Hazard 19
3.3 Cyclone Hazard 20
3.4 Volcanic Risk Assessment 22
3.5 Flood Risk Assessment 22
4 MATERIAL AND METHODOLOGY 24
4.1 Data used 24
4.2 Methodology 24
4.2.1 Statistical analysis of rainfall 24
4.2.2 Intensity-Duration-Frequency Curves 25
4.2.3 Runoff Estimation 26
4.2.4 Soil Erosion 28
4.2.5 Sediment Yield 30
4.2.6 Risk assessment 30
4.2.7 Water availability and its requirement estimation 30
4.2.8 Storm-water management and rainwater harvesting 30
5 FIELD INVESTIGATIONS 31

6 LAND USE / LAND COVER 35
6.1 LULC before establishment of RE Park 35
6.2 LULC after establishment of RE Park 37
7 SOIL TYPE 39
8 METEOROLOGICAL ANALYSIS 40
8.1 Statistical analysis of rainfall data 40
8.2 Derivation of IDF Curves 43
9 WATERSHED ANALYSIS 44
9.1 Digital Elevation Model 44
9.1.1 Procedure for DEM preparation 44
9.1.2 Distribution of land in different elevation ranges 46
9.2 Slope Analysis 47
9.3 Stream network delineation 48
10 RUNOFF POTENTIAL 50
10.1 Runoff volume 50
10.2 Peak Runoff potential 51
11 FLOOD RISK ASSESSMENT 54
11.1 Flooding risk due to streams/channels 55
11.2 Flood risk from nearby water bodies 56
11.3 Flood risk due to rainfall 58
12 SOIL EROSION ASSESSMENT 59
12.1 Estimation of Soil Erosion 59
12.1 Estimation of Sediment Deposition 62
13 GROUNDWATER ASSESSMENT 63
13.1 Groundwater Conditions 63
13.2 Groundwater Quality 66
13.3 Resistivity survey 68
14 FRESH WATER AVAILABILITY 72
14.1 Groundwater regime in nearby area 73
14.2 Surface water availability 73
14.3 Fresh water from desalination of groundwater 74
15 ESTIMATION OF WATER EQUIREMENT 77
15.1 Water requirement for human consumption 77
15.2 Water requirement for cleaning of solar panels 77
15.3 Total water requirement during O&M stage 78
16 RAIN WATER HARVESTING 79

16.1 Components of RWH System 79
16.2 Rainwater Harvesting Plan 81
16.3 Rainwater Harvesting Structures 83
16.4 Rainwater Recharge to Groundwater 83
17 WATER MANAGEMENT 85
18 SUMMARY AND CONCLUSIONS 87
19 RECOMMENDATIONS 95
Limitations of the study 95

LIST OF FIGURES

Figure 1: Location of the proposed RE Park of GIPCL.....4
Figure 2: GIPCL Project site on SoI toposheet 5
Figure 3: GIPCL Project site on Landsat-8 imagery 6
Figure 4: General topography of the Kutch area 7
Figure 5: Climatic chart of Bhuj District.....8
Figure 6: Drainage map of Gujarat 9
Figure 7: Geological map of the Kutch District.....10
Figure 8: LULC map of the Great Rann of Kutch.....11
Figure 9: Location of Kutch Biosphere Reserve (KBR) 14
Figure 10: Eco-sensitive areas around the RE Park 15
Figure 11: Earthquake Zonation map of Gujarat 16
Figure 12: Seismotectonic features in Gujarat 17
Figure 13: Gujarat Earthquake Hazard Risk Zonation 18
Figure 14: Gujarat Tsunami Hazard Risk Zonation Map 20
Figure 15: Gujarat Cyclone hazard risk zones 21
Figure 16: Gujarat Flood hazard risk zones 23
Figure 17: Topographical conditions at the proposed project site 31
Figure 18: Sparse vegetation (Bunny grass) and Acacia trees.....32
Figure 19: Streams / Channels in the AOI.....33
Figure 20: Streams dissecting though the elevated areas 33
Figure 21: Clayey soil in low lying areas 34
Figure 22: Saline Groundwater in the proposed project site 34
Figure 23: Inter-connected drains between GIPCL project site 34
Figure 24: LULC Map of GIPCL RE Park area 36
Figure 25: Dry stream channel/gullies observed in the field 37
Figure 26: Annual maximum daily rainfall and total rainfall.....40
Figure 27: Monthly rainfall in the site (1901 to 2018) 41
Figure 28: Maximum daily rainfall observed in different seasons 42
Figure 29: IDF curves for different return periods.....43
Figure 30: DEM of the GIPCL RE Park area 44
Figure 31: DEM - terrain colour intensity map 45
Figure 32: Cumulative areal distributions with elevation 47
Figure 33: Slope map of the GIPCL RE Park area.....47

Figure 34: Watershed boundaries and drainage network of the site 48
Figure 35: Variation of monthly rainfall and runoff in the site 51
Figure 36: Longest path streams in the catchment area of the site..... 52
Figure 37: Proposed project sites for different agencies 56
Figure 38: Streams extracted using DEM based on contours survey data .. 57
Figure 39: Streams extracted from a) ALOS PALSAR & b) ASTER DEMs 58
Figure 40: Thematic input database used for soil erosion estimation 60
Figure 41: Average annual soil erosion from the project area 61
Figure 42: Depth to water level in the project site area 64
Figure 43: Water Table map of the project site area 65
Figure 44: TDS variation in the GIPCL RE Park area 67
Figure 45: Wenner's Configuration for resistivity measurement 68
Figure 46: Location map of resistivity measurement sites 69
Figure 47: Apparent Resistivity with depth at various locations 71
Figure 48: Proximity of fresh water source GIPCL RE Park area..... 72
Figure 49: Bandi River vis-à-vis RE Park 74
Figure 50: Storm water management and rainwater harvesting plan 86
Figure 51: Tentative Design of the Bund..... 86

LIST OF TABLES

Table 1: Salient features of the 30-GW renewable energy park 1
Table 2: Climatological data of IMD Station, Bhuj 8
Table 3: AMC conditions and the related curve number (CN) 27
Table 4: The vegetation cover factor C for the study area 30
Table 5: LULC statistics of the study area 35
Table 6: Land use pattern of project area of GIPCL 38
Table 7: Monthly statistics of average daily rainfall (mm) 41
Table 8: Top ten wettest day 41
Table 9: IDF curve statistics for the site 43
Table 10: Areal distribution with elevation in study area as per DEM 46
Table 11: Runoff estimation by SCS-CN method 50
Table 12: Estimated time of concentration (t_c) 52
Table 13: Estimated rainfall intensity as per time of concentration (t_c) 53
Table 14: Peak runoff potential for 50 and 100 year return periods 53
Table 15: Different classes of soil erosion in the project area 61
Table 16: Groundwater levels observed in GIPCL project area 63
Table 17: Water quality of groundwater in the project site area 66
Table 18: Apparent resistivity measured at various locations 71
Table 19: Runoff coefficients for various surfaces 80
Table 20: Annual RWH potential for GIPCL RE Park Area 81
Table 21: Number of rainy days & rainfall intensity in Kutch area 82
Table 22: Maximum daily RWH potential 82

1 INTRODUCTION

1.1 Background

A hybrid renewable energy park, having electricity generation capacity of around 30,000 megawatt (MW) from solar and wind energy, is coming up near village Khavda in Kutch district of Gujarat. The project will avoid emission of five crore tonnes of carbon dioxide annually. The salient features of the project are given in ***Table 1***:

Table 1: Salient features of the 30-GW renewable energy park

Largest of its kind in the world: The 30-GW renewable energy park at Kutch, Gujarat is billed as the largest of its kind in the world.

GOI vision: The project is in line with the Government of India's vision to install 175 GW of renewable energy capacity by the year 2022 and is of national importance.

The park will have two zones: Spread over 72, 600 ha of land, the first will be a 49,600-hectare hybrid park zone, accommodating wind and solar power plants of 24,800 MW capacity; and second will be an exclusive wind power zone spread over 23,000 hectares.

Location of the project: The project site is located close to the Indo-Pak border between Khavda village and Vighakot.

Hybrid Park: It will be located 6 km from the International border.

Exclusive Wind Park: It will be located 1-6 km from the International border.

Distance from Indo-Pak border: The project will come up around 25 km away from Khavda (the last point accessible by the civilians in the area).

Allocation of the Project:

Hybrid Park Zone:

(a) Adani Green Energy Ltd (19,000 Ha; 9,500 MW)

(b) Sarjan Realities Ltd (Suzlon, 9,500 Ha; 4,750 MW)

(c) NTPC Ltd (9,500 Ha; 4,750 MW)

(d) Gujarat Industries Power Company Ltd (4,750 Ha; 2,375 MW)

(e) Gujarat State Electricity Corporation (6,650 Ha; 3,325 MW).

Exclusive Wind Park Zone: The entire 23,000 Ha of land has been allotted to Solar Energy Corporation of India (SECI).

Time: The estimated time for the completion of the project is five years.

Gujarat Industries Power Company Limited (GIPCL) commissioned National Institute of Hydrology (NIH) Roorkee to conduct a hydrology and hydrogeological study for the proposed Renewable Energy (RE)-hybrid park site in Khavda at District Kutch, Gujarat. This study requires the hydrology and hydrogeological estimates based on the base line analysis, catchment characteristics, identification of water bodies, meteorological analysis, extreme events of rainfall, peak runoff and extreme flood risk, earthquake and tsunami risk, area drainage study, stormwater drains/culverts design, impact of Land Use/Land Cover (LULC) change, soil erosion and sediment yield, water availability (surface, groundwater and imported source) rainwater harvesting and water management study in the site and plan the RE-hybrid park for solar and wind plant design suitably to account for this consideration.

1.2 Objectives

The general objective of this study is to investigate the hydrology & hydrogeology of the proposed RE-Hybrid Park at Khavda (District Kutch, Gujarat).

Specific Objectives of the study are:

i) To assess the rainfall variability and estimate the design rainfall of the different return periods using IDF curves for the proposed RE-Hybrid park site.
ii) To assess the natural hazards and risks due to earthquake, tsunami, cyclone, volcanic and flood risk in the study region.
iii) To compute the runoff potential and soil erosion from of the project site.
iv) To assess the water availability and water requirement in the project area.
v) To suggest the stormwater management and rainwater harvesting system in the park site.

1.3 Significance of the study

The study investigates the RE-Hybrid Park feasibility and identify the natural hazards and risks associated with in the park site based on hydrology and

hydrogeological investigations. Further, the study aims to contribute to the feasibility and improved performance of the stormwater management and rainwater harvesting plan through the implementation of appropriate water management strategies in the catchment area of the park site. The catchment response in terms of stormwater and peak rate of runoff are required for efficient and sustainable stormwater management during extreme events of climatic conditions in the study area.

2 STUDY AREA

2.1 Location

The site lies in the seasonal salt marsh area in the Great Rann of Kutch of Kutch District, Gujarat, India (***Figure 1***). The site is located in the North Western part (Un-surveyed land near village Khavda, Tehsil: Bhuj) of Kutch District in the Great Rann of Kutch, Gujarat.

Kutch district is fairly well connected by rail and road. The National High Way (NH 8A) connects Kandla with Ahmedabad. Nearest airport is at Bhuj, which is connected with Ahmedabad airport.

The study area is located between geographic coordinates 69°34'5.329" to 69°38'20.829" East Longitudes and 24°00'29.002" to 24°07' 24.235" North Latitudes. In the UTM coordinate system the area lies in Zone 42N, and lies between 557764.97m to 564975.22m Easting and 2655253.88m to 2668024.76m Northing. The GIPCL site is divided into two parts by Khavda – Vighakot Road, *Block-1* lies in the north of road and has an area of 3,693ha and *Block-2* lies south of the road and has an area of 1,057ha.

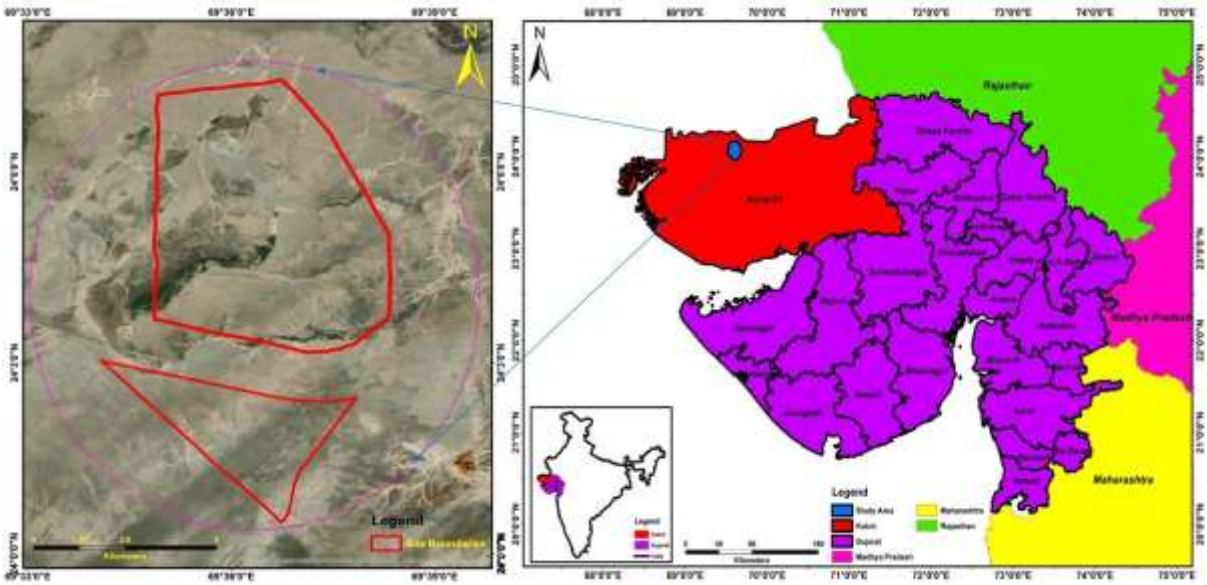

Figure 1: Location of the proposed RE Park of GIPCL

Project site is located around 12 to 15 km in south / southwest direction of International border with Pakistan. The area is heavily patrolled by Border

Security Forces (BSF) and the Indian Army conducts exercises here to acclimatize its troops to this harsh terrain.

Project site area lies in Survey of India toposheet 40E/12 (G4V12). The location and 5 km buffer zone around the project site is shown in ***Figure 2***.

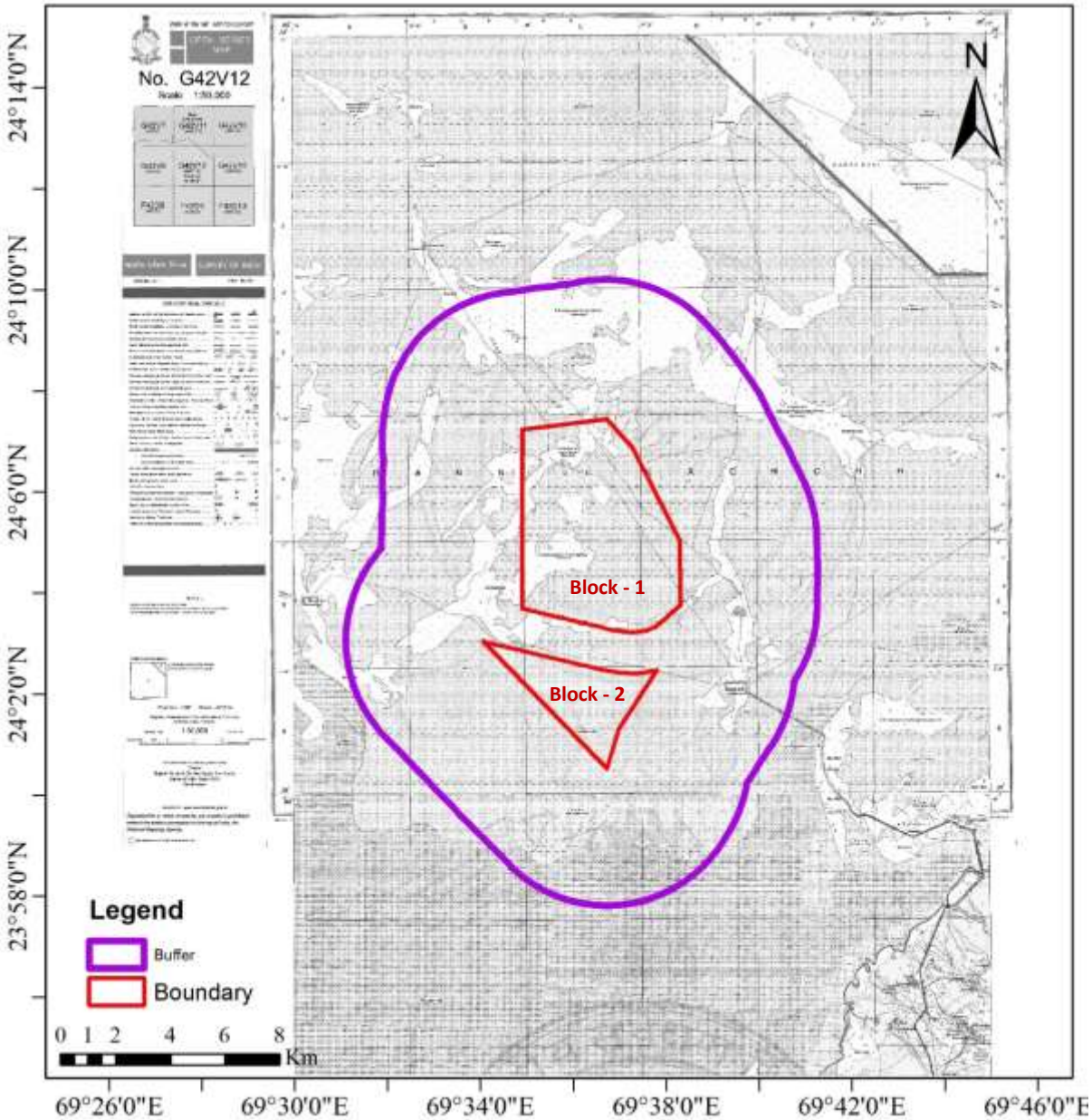

Figure 2: GIPCL Project site on SoI toposheet

The location and 5 km buffer zone around the project site on Landsat 8 imagery is shown in ***Figure 3***.

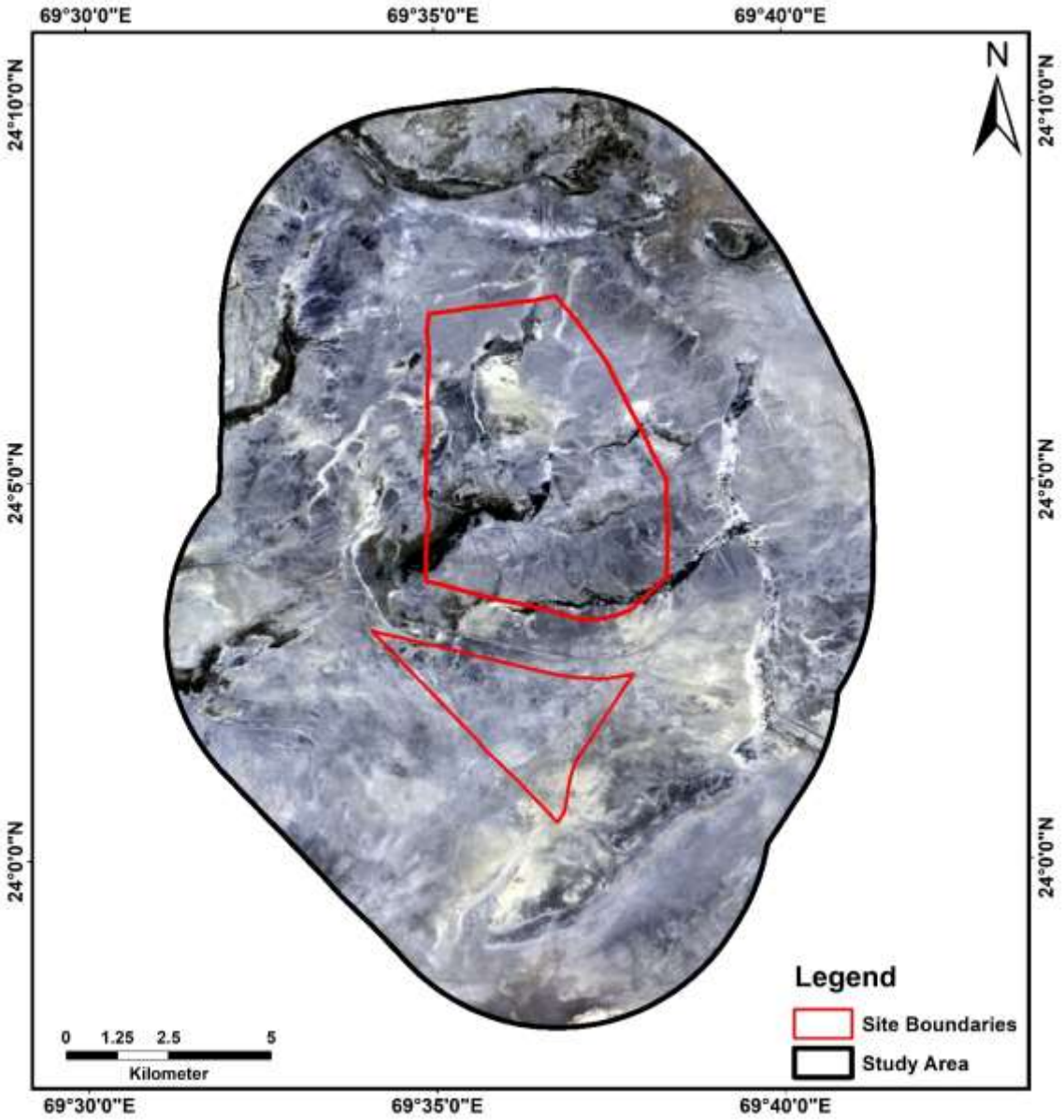

Figure 3: GIPCL Project site on Landsat-8 imagery

2.2 Topography

The topography of Kutch area comprises an array of hills and depressions (***Figure 4***). Elevated lands are occupied by Mesozoic and Tertiary rocks, whereas the residual depressions or low-lying regions consist of Quaternary sediment successions marked alluvial river terraces in the rocky mainland and the mud-flats and salt pans in the Great and Little Rann's and Banni Plains

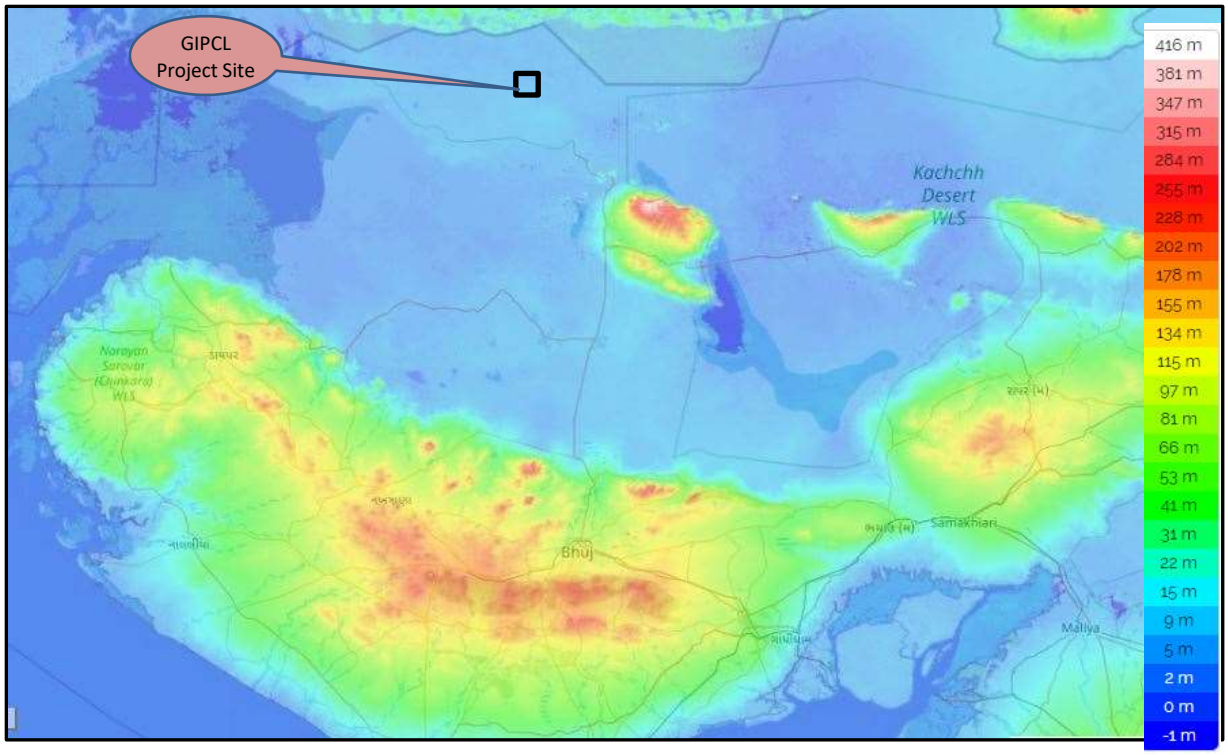

Figure 4: General topography of the Kutch area

In the project site area, the surface is generally flat and very close to sea level with elevation <10m. There are areas of higher ground, known as ***Bets*** or ***Medaks***, which lie two to three meters or more above the general ground level. Trees and shrubs grow on the bets, and they provide refuges for wildlife during the annual floods.

2.3 Climate

The study area experiences extreme climatic conditions characterized by its aridity, low rainfall and extreme temperatures. Mean maximum temperature ranges between 26.7°C during January to about 39.5°C during May and the mean minimum temperatures vary between 9°C during January and 27°C during June. The relative humidity in Kutch varies between 43.5% during March and 77% during August. The wind velocity in the district varies from about 124 km/d during November and 375 km/d during June. The potential Evapo-transpiration, calculated using Penman's method varies between 3.4 mm/d during December and 9.2 mm/d during May (CGWB, 2013). Long-term average annual rainfall for Bhuj IMD station is 378.2 mm. Climate data of Bhuj district is shown in ***Figure 5***.

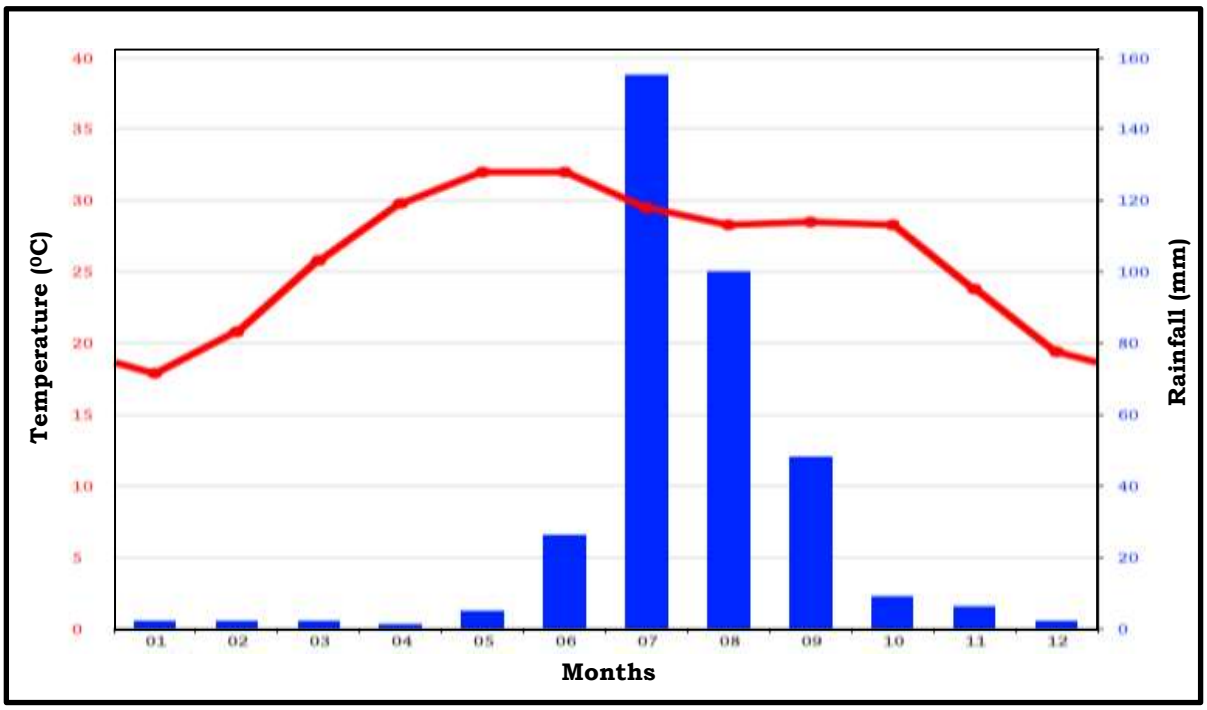

Figure 5: Climatic chart of Bhuj District

Most of the rainfall (about 345 mm) is received during south-west monsoon between June and September. The number of rainy days varies between 20 and 30 or even less and coefficient of variation of rainfall is normally between 30 and 70%. The climatological data for IMD station Bhuj is given in ***Table 2***.

Table 2: Climatological data of IMD Station, Bhuj

Month	Max. Temp	Min. Temp	RH	Wind Speed	Sunshine	Solar Radiation	ET_0	Rainfall
	(°C)	(°C)	(%)	(Km/d)	(Hrs)	(MJ/m²/d)	(mm/d)	(mm)
Jan	26.7	9.0	47.0	138.2	8.9	16.7	3.6	2.0
Feb	29.8	12.0	45.5	149.0	9.5	19.5	4.5	1.1
Mar	34.9	17.6	43.5	177.7	10.1	22.8	6.2	2.9
Apr	38.7	22.1	44.5	217.2	10.8	25.6	7.9	0.7
May	39.5	25.2	53.5	330.3	11.4	27.1	9.2	1.7
Jun	37.1	27.0	65.0	375.2	8.7	23.1	7.7	33.9
Jul	33.6	26.2	75.0	346.5	5.3	17.9	5.4	136.3
Aug	32.5	25.2	77.0	307.0	5.4	17.6	4.9	120.7
Sep	33.7	23.8	70.5	229.8	7.9	20.2	5.4	54.2
Oct	35.9	20.6	52.5	141.8	9.6	20.4	5.3	15.4
Nov	32.4	15.5	48.0	123.9	9.3	17.6	4.1	7.7
Dec	28.1	10.5	49.0	131.0	8.9	15.9	3.4	1.6
Total	-	-	-	-	-	-	-	378.2
Average	*33.6*	*19.6*	*55.9*	*222.3*	*8.8*	*20.4*	*5.6*	-

2.4 Drainage

Many rivers originating in Rajasthan and Gujarat flow into the Rann of Kutch, including the Luni, Bhuki, Bharud, Nara, Kharod, Banas, Saraswati, Rupen, Bambhan and Machchhu. Kori Creek and Sir Creek, tidal creeks which are part of the Indus River Delta, are located at the western end of the Great Rann of Kutch (***Figure 6***) (*After* Chamyal et al. 2003).

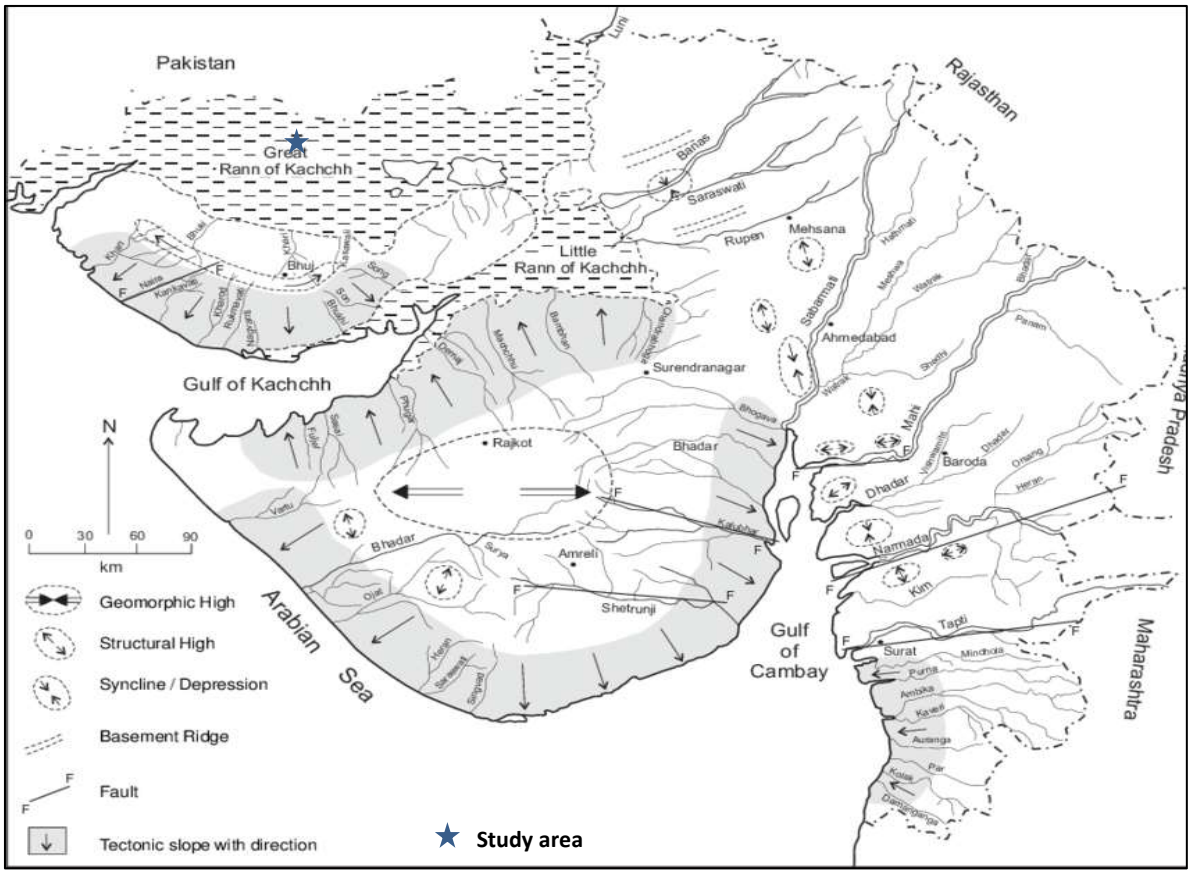

Figure 6: Drainage map of Gujarat

In the project site area, there is no major river. There are numerous Gullies and temporary streams which passes through the study area. These gullies are temporary and flows only during the monsoon season. There are some bigger non-perennial streams which appears to have existed for at least few decades.

2.5 Soils

The project site of GIPCL comes under Rann physiographic zone and comprises marshy land and salt/mud flats. The soils of the Kutch district are

broadly grouped into four types, i.e., shallow black soils, residual sandy soils, coastal alluvial soils and desert soils. The study area is mainly comprises of desert soils and has salinity problem. These soils are fairly deep and light grey in colour. The texture is sandy to sandy loam with silty clay loam in some areas. The salt content is very high with the sodium chloride as the dominant salt (CGWB, 2013). The soil belongs to 'Group A' type soil based on U.S. Soil Conservation Service (SCS) classification.

The two Ranns of Kutch have the soils which are formed as a result of the geological processes of Pleistocene age. The alluvial deposits due to the river system flowing through the area have subsequently been overlain by the aeolian deposits. These soils are fairly deep, light grey in colour. The texture is sandy to sandy loam with silty clay loam in some areas. The salt content is very high with the sodium chloride as the dominant salt. The profile study reveals the presence of sufficient amount of gypsum throughout the profile.

2.6 Geology and Hydrogeology

Sedimentary rocks of marine and non-marine origin formed under different environmental conditions during middle Jurassic to Recent period occur in the Kutch district besides volcanic and intrusive rocks (Deccan Trap) of middle Cretaceous to lower Eocene (***Figure 7***) (*after* Biswas, 1963).

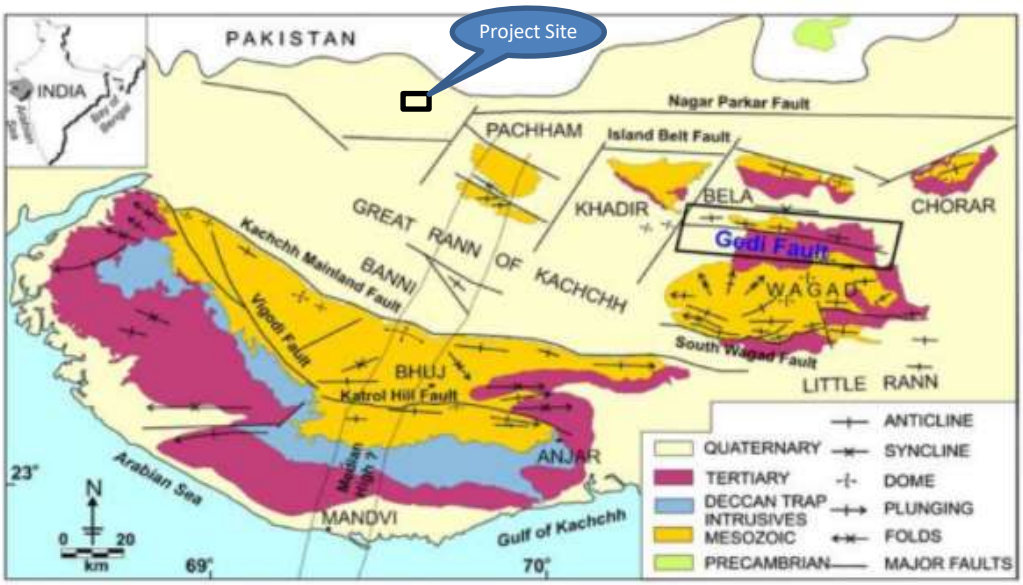

Figure 7: Geological map of the Kutch District

The geological formations in Kutch district can be grouped as:

a) Mesozoic formations

b) Deccan trap (Hard rock) as aquifer

c) Tertiary formations

d) Quaternary sediments

In the study area, the alluvium (Quaternary sediments) comprising of brown loam, kankars, silt, clay, sand and gravel. Groundwater table lies at a depth of 2-5 m below the ground surface.

2.7 Landuse / Land Cover (LULC)

Rann of Kutch, Gujarat, which is a large area of salt marshes near the border between India and Pakistan. The predominant land use of this site is barren land with scanty vegetation of arid grassland ecosystem (***Figure 8***).

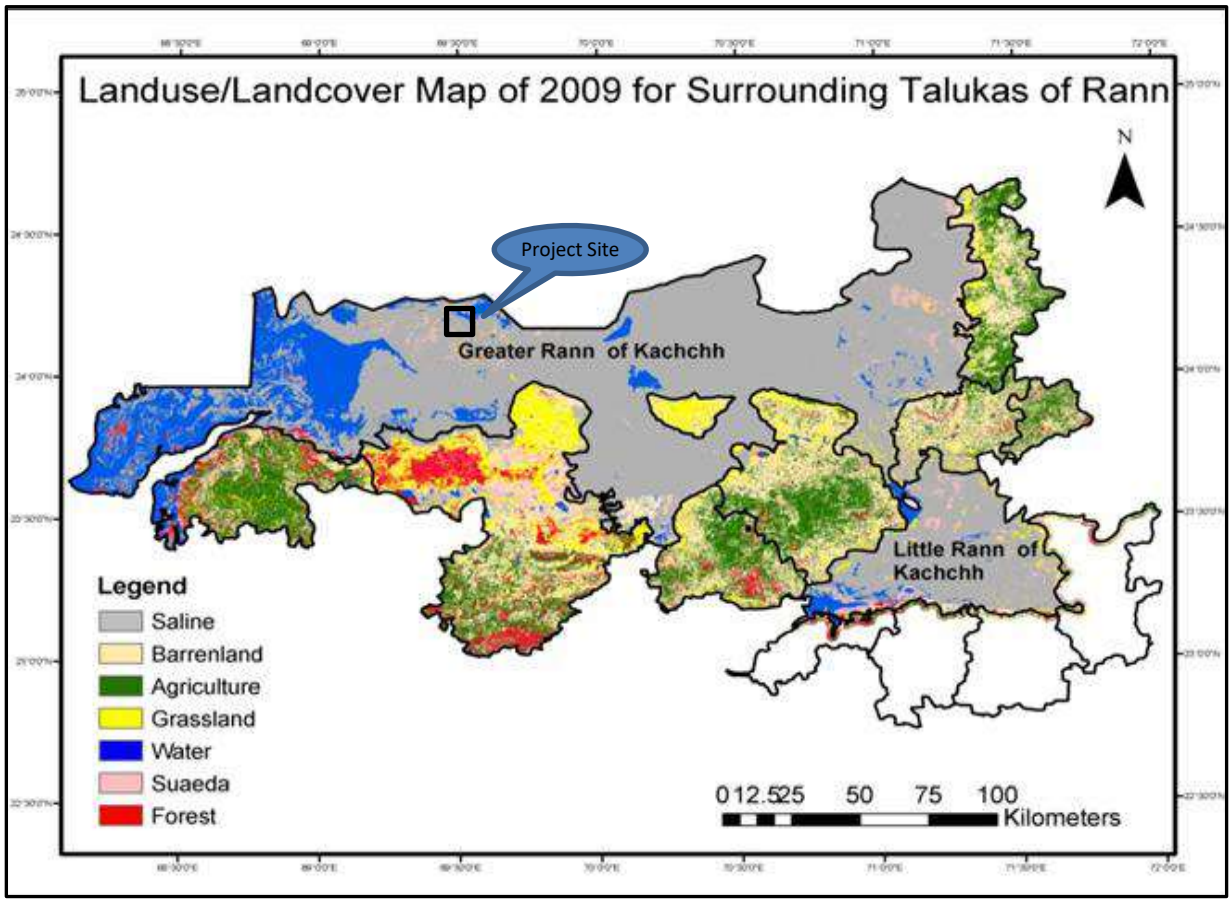

Figure 8: LULC map of the Great Rann of Kutch

The shrubs are present almost everywhere within the study area. The total area covered by the scrubs is approximately 12% of the total study area which covers dried drainage, Bet and remaining Rann area. Road network is not present within the Rann however there is a single major road and very few minor roads present in Bet areas which covers approximately 0.03% of total study area.

There is no settlement/habitat within the study area however there are few built-up spaces primarily meant for security purposes. Salt pan activities along with its supporting water channels and Bunds are seen in the southern part of the study area which covers around 0.81%. Remaining areas is mostly mud/tidal flats.

2.8 Flora and Fauna

In the Rann of Kutch area, trees are rare except on the bets which rise above the flood zone. The predominant vegetation in the Rann of Kutch are grassland and thorny scrubs. Common grass species include: *Apluda aristate*, *Cymbopogon spp., Eragrostis spp., and Elionurus spp., Cenchrus spp., Pennisetum spp.* The non-native tree *Prosopis juliflora* has now established on the bets, and its seed pods provide year-round food for the wild asses.

The Rann of Kutch is home to about 50 species of mammals. They include several large herbivores, including Indian wild ass (*Equus hemionus khur*), chinkara (*Gazella bennettii*), nilgai (*Boselaphus tragocamelus*), and blackbuck (*Antilope cervicapra*), and the large predators wolf (*Canis lupus*), striped hyena (*Hyaena hyaena*), desert wildcat (*Felis lybica*), and caracal (*Felis caracal*). The Indian wild ass once had a wider distribution but is now limited to the Rann of Kutch. The nilgai and blackbuck are threatened species.

There are over 200 bird species in the Rann of Kutch, including the threatened species lesser florican (*Sypheotides indicus*) and houbara bustard (*Chlamydotis undulata*). The seasonal wetlands provide habitat for many water birds, including the demoiselle crane (*Grus virg*o) and lesser flamingo (*Phoeniconaias minor*).

Vultures temporary resting place lies 2 km North-East of project site. The Griffon Vulture (*Gyps fulvus*), also known as the *Eurasian Griffon*, a bird of prey family *Accipitridae*, is found in the area. This vulture establishes nesting colonies in areas that are undisturbed by humans and is a scavenger and feeds mostly on carcasses of dead animals.

2.9 Eco sensitive areas

Kutch is a unique kind of ecological zone demarcated as Kutch desert biotic province under desert bio geographic zone of the country (Rodgers & Panwar, 1988). It represents a distinct biological diversity and gene pool of Indian arid region (Chawla, 2004). The Rann is unique in a sense that it has the characteristics of both desert and wetland and therefore supports unique assemblages of flora and fauna. The eco region of Rann of Kutch represents the saline and marshy habitat dominated by scrub vegetation and flooded grasslands with swampy land providing shelter to diverse wildlife. The environment of Rann is cyclic in nature, where during some part of the year land remains under water and rest of period remains dry making the Rann suitable for aquatic as well as terrestrial biota.

Rann harbors rich floral and faunal diversity besides providing habitat for some important threatened wildlife including Asiatic wild Ass, Indian gazelle, blue bull, wild boar, desert cat, striped hyena, Indian wolf and caracal. The large and open wetlands of Rann are also a unique wintering and breeding ground for diverse avifauna such as Greater & Lesser Flamingo, Cranes, Falcons, Wild ducks, Ibis, Spoonbill, Pelicans, etc. Due to the presence of large number of rare and endangered fauna and flora in Rann, in year 2008 it was declared as a Kutch Biosphere Reserve (KBR) under protected area network of India (MoEF, 2010).

The present study area located in the Great Rann of Kutch (GRK). The part of GRK is an important wetland of Gujarat and flamingo city is also located in the GRK. Hence, the care should be taken to avoid adverse impact of disposal on wetland. The Great Rann of Kutch having total area of 16,780 km^2 (GUIDE, 1997). It includes Kutch Desert Wildlife Sanctuary (7505.22 km^2) and forms

part of Kutch Biosphere Reserve (12,454 km^2). It is important to note that Kutch Biosphere Reserve (KBR) includes both Great Rann and Little Rann of Kutch) (***Figure 9***).

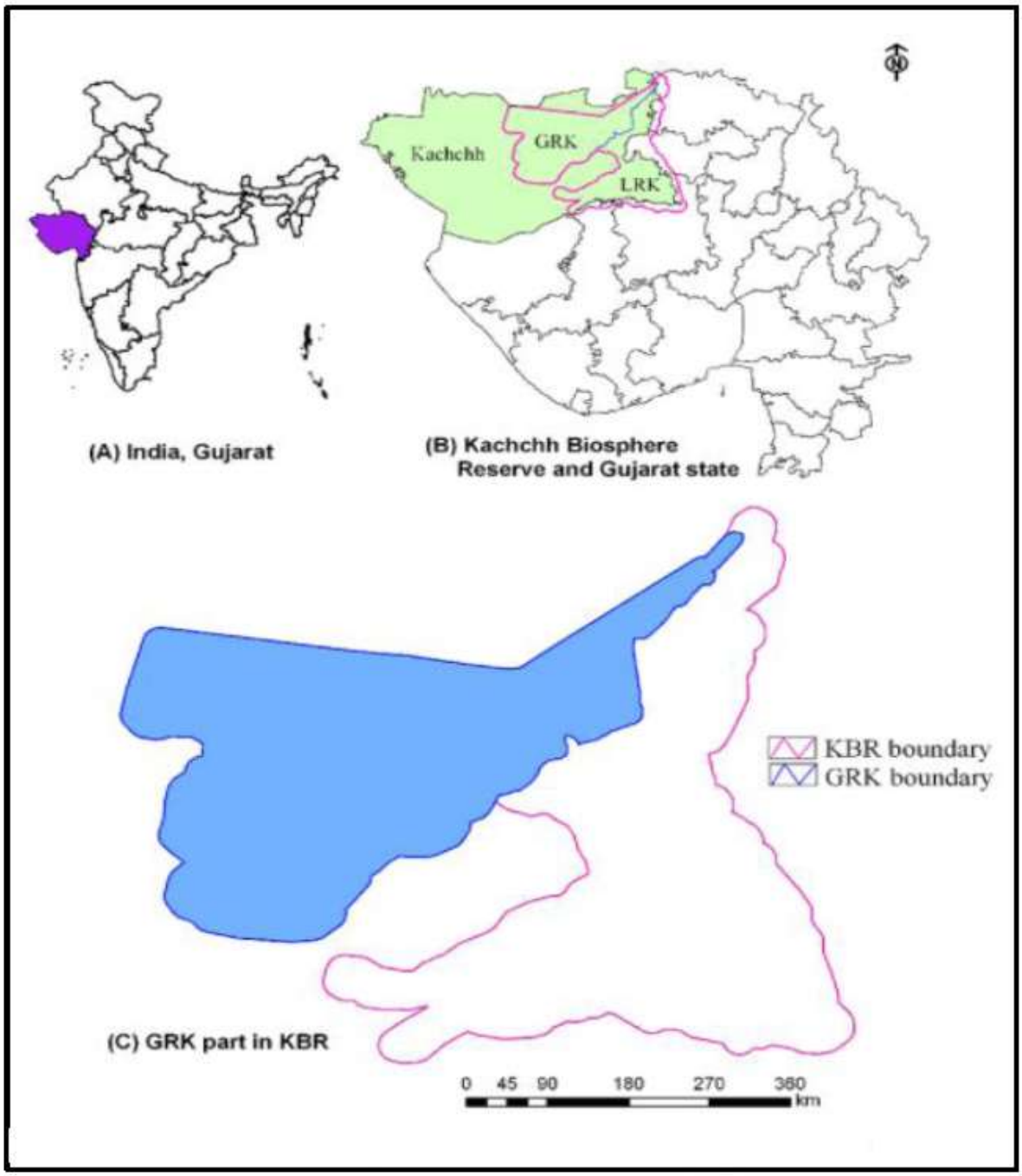

Figure 9: Location of Kutch Biosphere Reserve (KBR)

Figure 10 shows the location of GIPCL project site with reference to Kutch Biosphere Reserve (KBR), Flamingo city (the only area in India where flamingo congregate in large numbers to breed) located near Nirviri, Kala Dongar Sanctuary and Chhari-Dhandh wetland reserve (Vazeed Pasha et al., 2014).

The Chhari-Dhandh wetland reserves are located about 47 km southwest from project site. Kala Dongar sanctuary is located approximately 23 km south east of the project site. Flamingo city is situated in Great Rann of Kutch at approximately 53 km east of the GIPCL project site.

Figure 10: Eco-sensitive areas around the RE Park

3 NATURAL HAZARDS AND RISKS ASSESMENT

Natural hazards are naturally occurring physical phenomena caused either by rapid or slow onset events which can be geophysical (earthquakes, landslides, tsunamis and volcanic activity), hydrological (avalanches and floods), climatological (extreme temperatures, drought and wildfires), meteorological (cyclones and storms/wave surges) or biological (disease epidemics and insect/animal plagues).

In the present study earthquakes, tsunamis, volcanic activity, floods, and cyclones have been considered as natural hazards.

Risk is a technical concept aimed at estimation of losses in the event a disaster and the expected probability of its occurrence the probability of harmful consequences or expected losses resulting from interactions between natural hazards.

3.1 Earthquake Hazard

The site falls under seismic Zone-V, i.e., susceptible to very high higher damage risk (>MSK IX) of earth quakes and the most seismically active region of Gujarat (***Figure 11***).

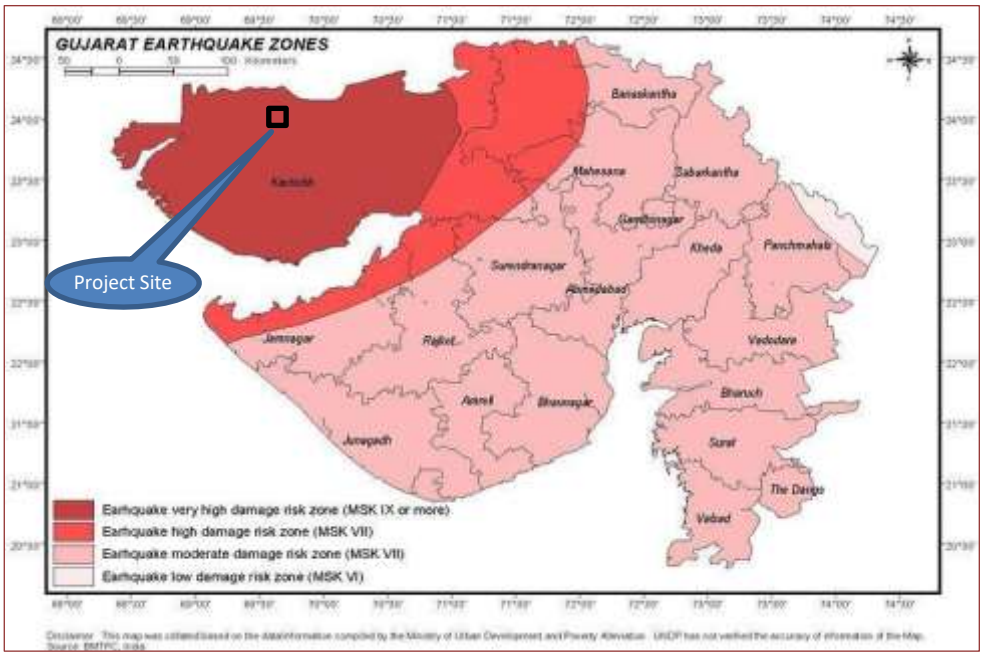

Figure 11: Earthquake Zonation map of Gujarat

The area is earthquake prone and many epicenters are located here. Major part of the district lies in very high-risk zone of seismicity, while a comparatively smaller part in the east lies in high-risk zone of seismicity.

3.1.1 Earthquake / Fault line in and surrounding area

The study area is within very close proximity or passing through 1819 Allah Bund fault based on the superimposition of the Gujarat State Disaster Management Authority (GSDMA) earthquake management plan map over the site boundary as shown in ***Figure 12***. The fault and lineaments are mainly aligned parallel/sub-parallel to the major tectonic grains.

Impacts may occur due to excessive spillage/leakage of wastewater from broken pipeline/crack in storage tank during earthquake, which may contaminate groundwater. All type of Built-up structures are prone to damage due to any tectonic activities at Allah bund fault. Project site falls in a close proximity to a historic Allah Bund fault of 1819.

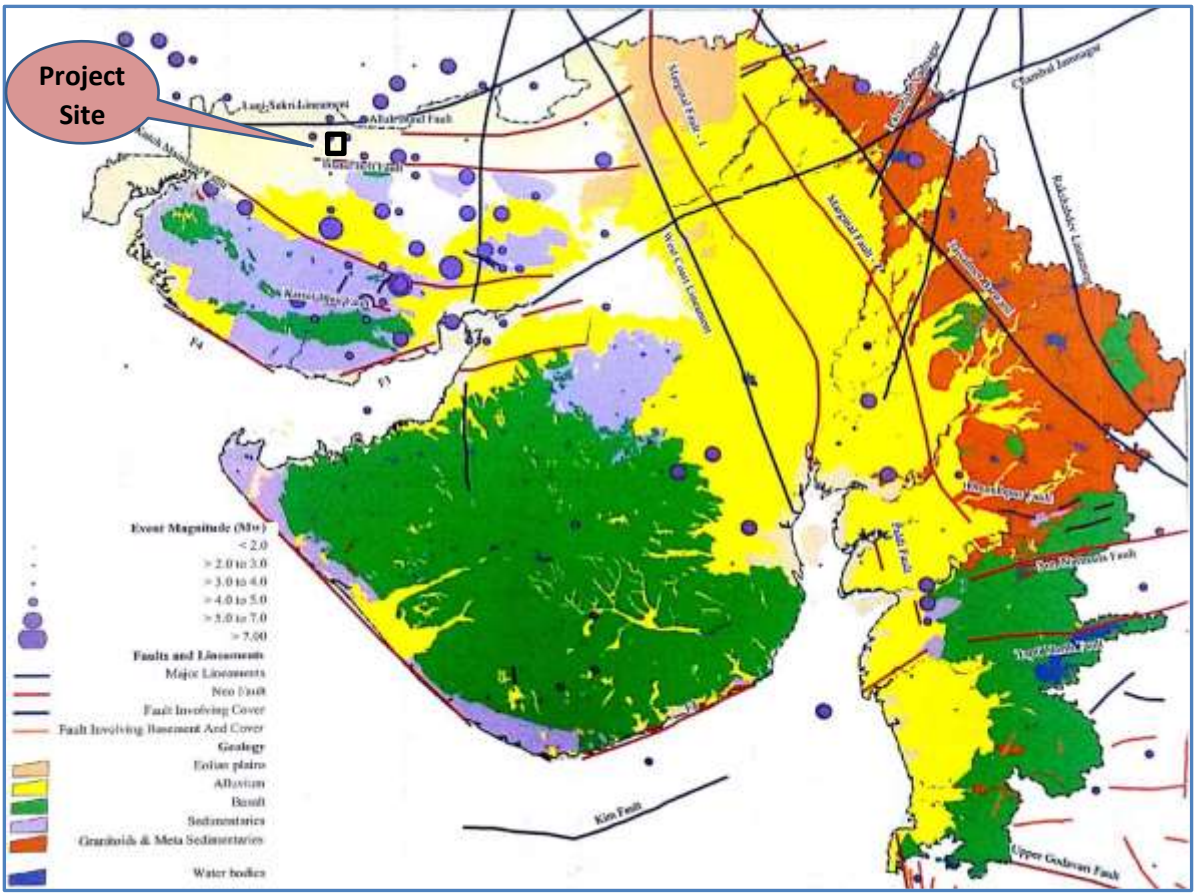

Figure 12: Seismotectonic features in Gujarat

3.1.2 Gujarat Hazard Risk Zonation

The estimated mean Taluka Peak Ground Acceleration (PGA) (in g) zonation for a 100-year return period is presented in the ***Figure 13***. This zonation is typically used for the design of critical buildings that need to have a mean design service life of 100 years.

The boundaries of key structural features emerge in this zonation map with the broad boundaries of the Cambay Graben and the eastern hilly region emerging due a mix of the influence of active faults, distance from historical events and ground amplification due to the deep alluvium within the basins.

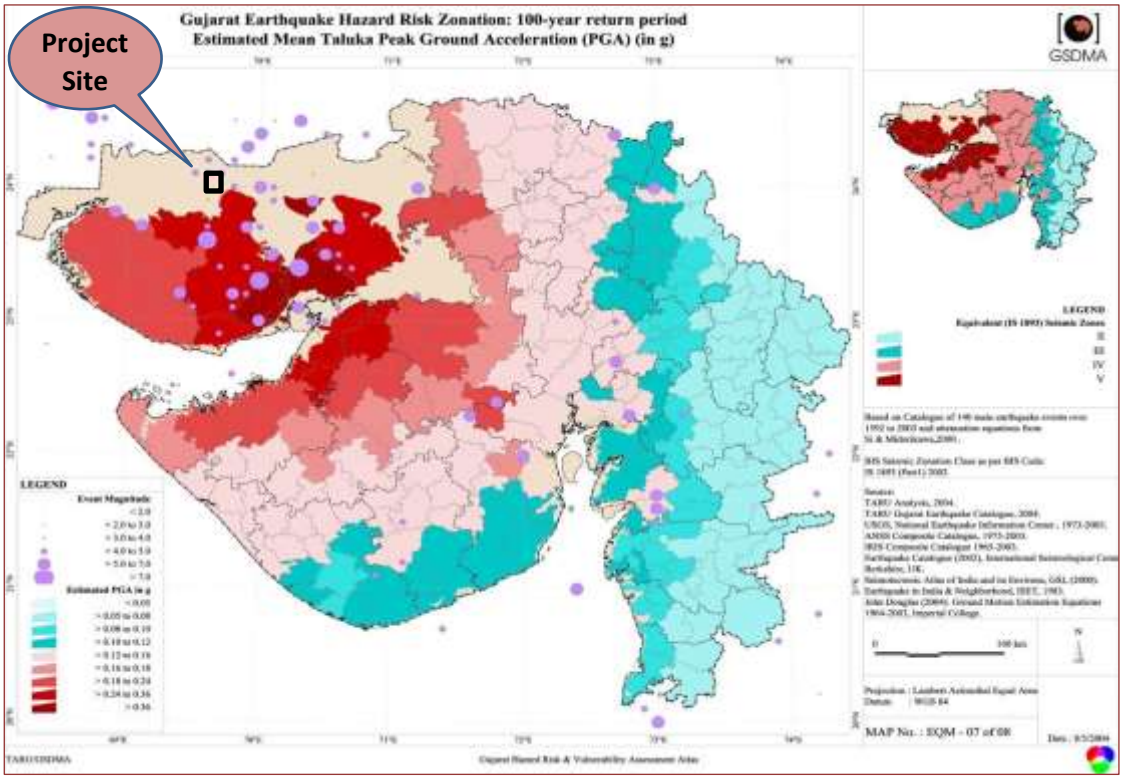

Figure 13: Gujarat Earthquake Hazard Risk Zonation

The Kutch district has two pockets of low to moderate intensity with the maximum estimated Peak Ground Acceleration (PGA) values between 0.05 to 0.10 g in units of gravity (the acceleration due to Earth's gravity, equivalent to g-force). Four moderates to very high intensity earthquake pockets are located in Kutch and north coastal Rajkot and Jamnagar districts clustered around the major events in this region.

The eastern hilly region of Gujarat consists of stable Granatoids and Basalt has relatively low estimated intensities – a departure from seismic zonation.

3.2 Tsunami Hazard

A tsunami is a series of waves most commonly caused by an earthquake under the sea floor. As tsunamis enter shallow water near land, they increase in height and can cause great loss of life and property damage.

Gujarat has no record on tsunami though number of earth quakes have been recorded in the area. During the earthquakes of 1819 and 1845 near the Rann of Kutch, there were rapid movements of water into the sea. There is no record of waves resulting from these earthquakes along the coast adjacent to the Arabian Sea, and it is unlikely that Tsunamis were generated. Further west, in the Persian Gulf, the 1945 Makran earthquake (magnitude 8.1) generated Tsunami of 12 to 15 m height. This caused a huge deluge, with considerable loss of life and property at Ormara and Pasi (now in Pakistan). The estimated height of Tsunami at Gulf of Cambay was 15 m but no report of damage is available.

Above facts indicate the coastal region of Gujarat is vulnerable to Tsunamis from great earthquakes in Makran coast. Earthquake of magnitude 7 or more in this region may be dangerous to Gujarat. It may be noted that all earthquake does not generate Tsunami.

The basics of Tsunami risk & vulnerability assessment is the record of seismic activities in the oceans & seas around the landmass for which the assessment is being done. Also, the vulnerability assessment is carried out based on tsunami run-up model for that area. Such a model for Gujarat is yet to be prepared.

In the absence of scientific data on tsunamigenic submarine earthquakes for the Arabian Sea and North Indian Ocean in the Gujarat, planning for risk assessment is done on the basis of worst-case Storm surge scenario i.e. PMS (Possible maximum Surge) at HHTL (Highest High Tide Level) to be the area

potentially exposed to tsunami impact. ***Figure 14*** shows the Gujarat tsunami hazard risk zones based on highest high tide levels.

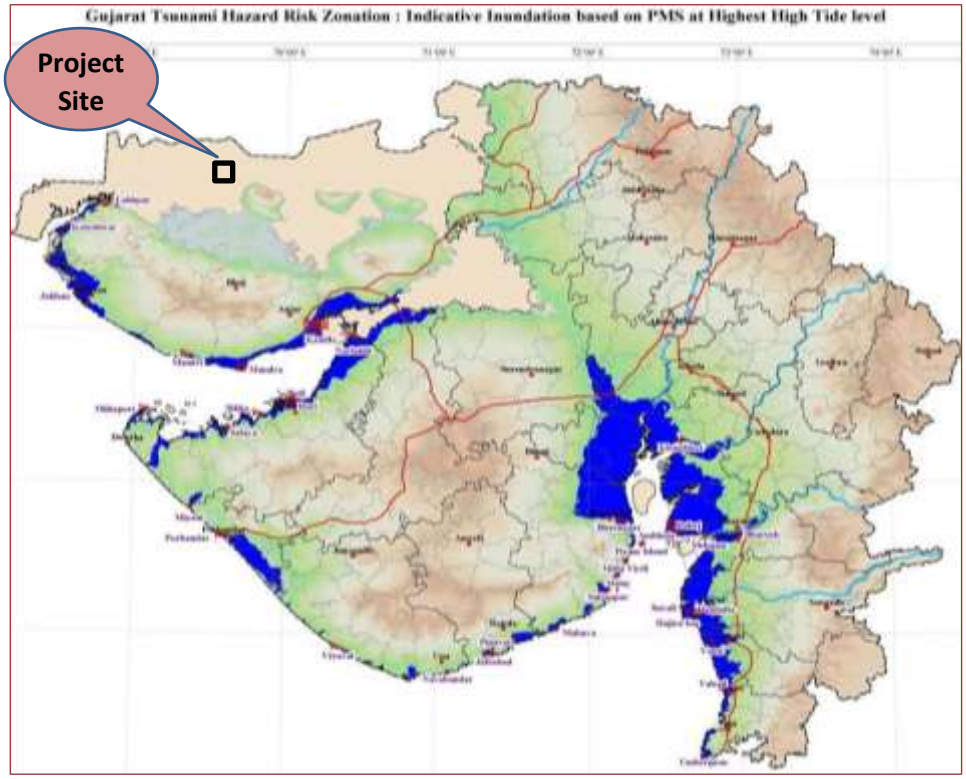

Figure 14: Gujarat Tsunami Hazard Risk Zonation Map

3.3 Cyclone Hazard

Cyclones are huge revolving storms caused by winds blowing around a central area of low atmospheric pressure. In the northern hemisphere, cyclones are called hurricanes or typhoons and their winds blow in an anti-clockwise circle. In the southern hemisphere, these tropical storms are known as cyclones, whose winds blow in a clockwise circle. Tropical cyclone is a storm system characterized by a large low-pressure center and numerous thunderstorms that produce strong winds and heavy rain. Tropical cyclones fall under the purview of warm core system of storms.

Gujarat falls in the region of tropical cyclone. With the longest coast line of 1600km in the country, it is highly vulnerable to associated hazards such as floods, storm surges etc. Most of the cyclones affecting the State are generated in the Arabian Sea. They move northeast and hit the coast particularly the

southern Kutch and southern Saurashtra and the western part of Gujarat. Two cyclonic storm seasons are experienced in Gujarat: May to June (advancing southwest monsoon) and September to November (retreating monsoon). Many severe cyclones had originated in the Arabian Sea and passed through the state in last 100 years. Apart from other areas, the Gulf of Kutch and Gulf of Khambhat also witness surge as the funneling effect takes place at both the places. The eastern reach of the Gulf of Kutch is the quite vulnerable region due to its low-lying flat topography and high population density.

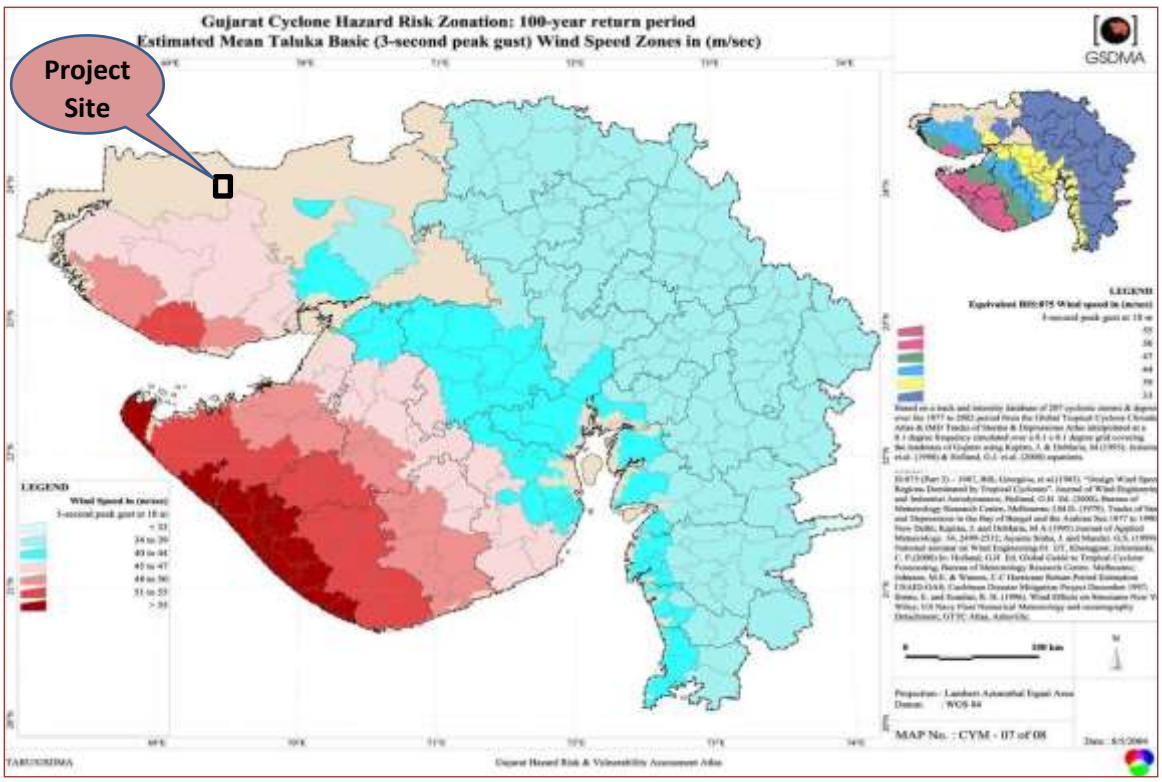

Figure 15: Gujarat Cyclone hazard risk zones

The Hazard Risk and Vulnerability Atlas prepared by GSDMA shows the Cyclone hazard zonation along with the basic wind speed at the taluka level (***Figure 15***). Over 120 cyclones originating in the Arabian Sea had passed through Gujarat over a period of 100 years. ***Figure 15*** shows a maximum wind speed class of more than 55 m/sec along the Saurashtra coast, specifically in Porbandar, Jamnagar and Junagadh districts, which are exposed to high intensity cyclonic and storm impact. The 51 to 55 m/sec class

extends further inland to cover much of Jamnagar, part of Rajkot, Junagadh and Kutch districts. The 48 to 50 m/sec class extends to most of Rajkot, part of Amreli and Jamnagar districts including Jamnagar, Rajkot cities and parts of Kutch. The 45 to 47 m/sec class covers much of Saurashtra and all of Kutch. This is followed by the 40 to 44 m/sec class that gets its swathe from Kutch through northern Saurashtra all the way to the coast of Gulf of Khambhat and southern Gujarat. The rest of the State falls into the 34 to 39 m/sec class.

3.4 Volcanic Risk Assessment

A volcano is a rupture in the crust of a planetary-mass object, such as Earth, that allows hot lava, volcanic ash, and gases to escape from a magma chamber below the surface.

In Gujarat the volcano existed at Dinodhar hills in Kutch district and a volcanic plug has been identified in rising through the sedimentary rocks. The volcano was active 500 million years ago. No new activity has been reported in recent times. The latest volcanic activity in the state of Gujarat is represented by basaltic rocks of Deccan Traps. The last activity of the Deccan trap volcanos is reported to have ceased 66 million years ago.

3.5 Flood Risk Assessment

Floods are amongst the most frequent and destructive type of disaster, causing significant damage and disrupting livelihoods throughout the world. Proper estimation of risk is challenging and requires careful consideration of a number of factors, including watershed properties such as size, topography, and land use, the types and characteristics of storms that produce rainfall and flooding in the region, and the number, location, and types of buildings and other assets that could be damaged.

Hazards associated with flooding can be divided into primary hazards that occur due to contact with water, secondary effects that occur because of the flooding, such as disruption of services, health impacts and disease, and tertiary effects such as changes in the position of river channels.

Gujarat has seen many damaging floods. Almost all major rivers in the state pas through a wide stretch of very flat terrain (often more than 50 km) before reaching the sea. These flat low lands of lower river basins are prone to flooding. Flood prone area in Gujarat (settlement wise flood frequency) is shown in ***Figure 16***.

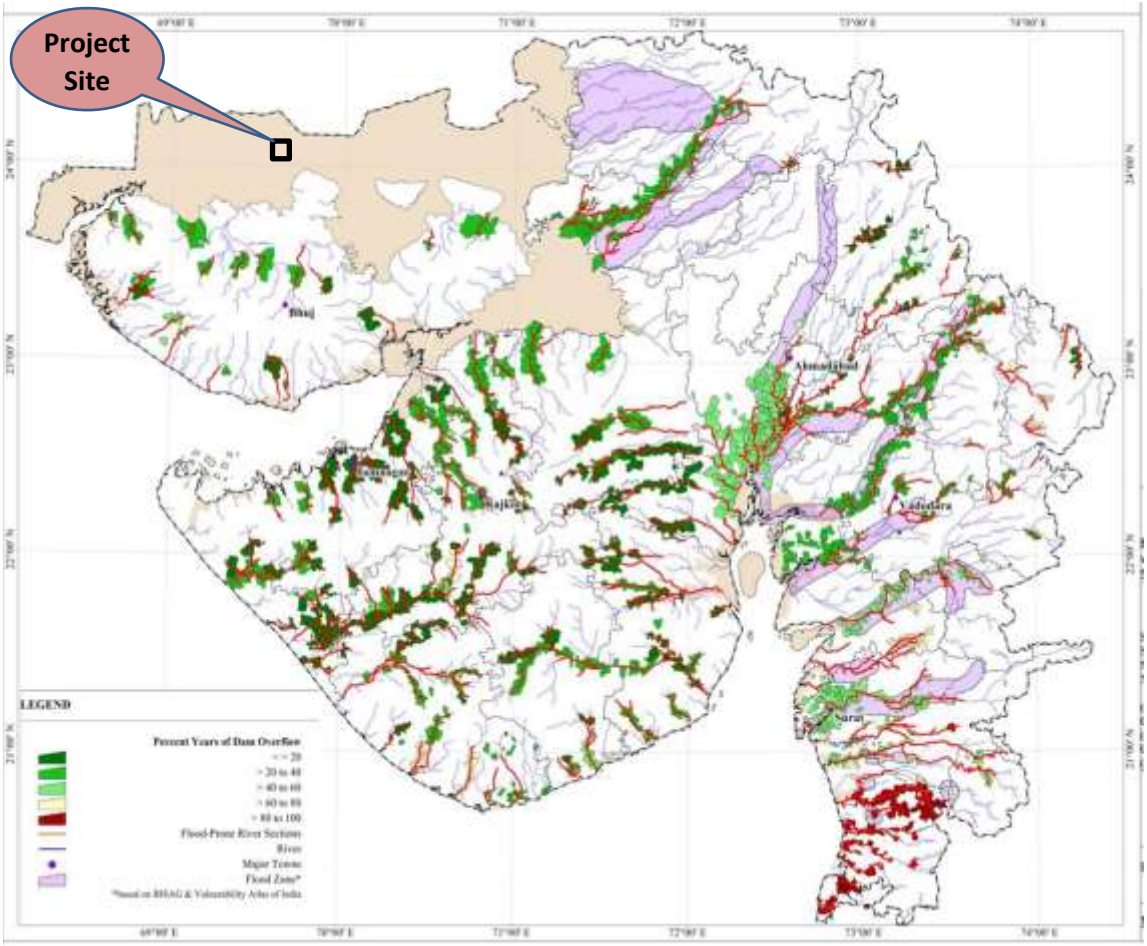

Figure 16: Gujarat Flood hazard risk zones

Because, there are no major rivers in the Rann of Kutch, so there is no risk of flooding in the study area. Further, detail study of flood risk assessment in the project area is given in *Chapter 11*.

4 MATERIAL AND METHODOLOGY

4.1 Data used

Three major inputs have been used in this study:

- *Rainfall data*: The daily gridded rainfall data (0.25°x0.25°) was obtained from the IMD (1901 to 2018) for the grid representing the study site in Khavda village in Great Rann of Kutch, Gujarat.

- *Soil and LULC*: The soil type and land cover determine runoff and absorption rates. This data was acquired from http://bhukosh.gsi.gov.in/Bhukosh/Public and Central Ground Water Board (CGWB).

- *Elevation Data*: The elevation survey data was obtained from the GIPCL. For broader understanding of area study, Google earth, ASTER (30 m) DEM from USGS earth explorer and ALOS PALSAR (12.5m) DEM (https://asf.alaska.edu/data-sets/sar-data-sets/alos-palsar/) were used.

- *Groundwater Data:* The data related with groundwater (i.e. water table, well locations, water quality, and resistivity survey data) was obtained from GIPCL.

4.2 Methodology

The methodology adopted in the present study is discussed in subsequent sections here.

4.2.1 Statistical analysis of rainfall

The analysis of average annual, seasonal and monthly rainfall have been carried out using daily rainfall obtained from IMD grid for the proposed project site. Different statistics related with such as mean (μ), and standard deviation (σ) have been estimated (Eqn. 1 and 2). Also, top ten extreme rainfall events of average annual maximum daily rainfall have been computed for the site over a period of 118 years.

$$\mu = \frac{\sum x_i}{N} \qquad \text{(Eqn. 1)}$$

$$\sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{N}} \qquad \text{(Eqn. 2)}$$

Where, σ is the standard deviation; N is the size of the population; x_i is each value from the population; μ is the mean.

4.2.2 Intensity-Duration-Frequency Curves

The gridded rainfall data has been obtained from IMD (1901 to 2018) at a scale of 0.25° x0.25° latitude and longitude grids. Storm wise daily rainfall data was not available for the study site. Therefore, the annual maximum rainfall intensity derived from daily rainfall intensity has been disintegrated to hourly intensities using IMD reduction formula (Chowdhury et al. 2007) (Eqn. 3).

$$P_t = P_{24}\left(\frac{t}{24}\right)^{\frac{1}{3}} \qquad \text{(Eqn. 3)}$$

Where, P_t is the rainfall depth in mm at t-hour duration, P_{24} is the daily rainfall depth on mm and t is the duration of rainfall for which the rainfall depth is required in hours.

The Intensity-Duration-Frequency Curves (IDF) curves of the different return periods have been then derived for the proposed study site using different statistical distributions. These includes Gumbel's Extreme Value distribution (GEV), Extreme Value Type-I, Gamma, Exponential and Lognormal distributions (Wikipedia, 2021). These distributions have been applied to the rainfall data of the site and best fit distribution was identified. For example, GEV distribution is described in Eqn. 4 and 5 below:

$$x_T = \bar{x} + K_T S \qquad \text{(Eqn. 4)}$$

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\} \qquad \text{(Eqn. 5)}$$

Where x_T is the average annual daily maximum rainfall, mm; T is the return period, years, $\bar{x}$ is the mean and S is the standard deviation of annual daily maximum rainfall, mm and K_T is the frequency factor for corresponding return period T. Based on the field conditions of the site, 2 years return period can be selected for design of the stormwater drainage system (CPHEEO, 2019).

4.2.3 Runoff Estimation

Computation of runoff volume

The runoff volume from the AoI is estimated using Soil Conservation Service (SCS, now Natural Resources Conservation Service, NRCS) Curve Number (*CN*) method (NRCS, 2004). This method is popular among hydrology practitioners due to its simplicity, predictability, and stability.

$$Q = \frac{(P - 0.2 \times S)^2}{(P + 0.8 \times S)} \qquad \text{If } P \geq 0.2S$$

&

$$Q = 0 \quad \text{If } P \leq 0.2S \qquad \text{(Eqn. 6)}$$

Where Q is the runoff depth in mm; P is the event rainfall in mm and S is the potential maximum retention capacity, which is estimated from CN depends on soil and land cover conditions of the watershed (Eqn. 7).

$$S = \frac{25400}{CN} - 254 \qquad \text{(Eqn. 7)}$$

CN varies from 0 for impervious surface (minimum runoff) to 100 for concrete surface (maximum runoff). The major factors that determine CN are the Hydrologic Soil Group (HSG) type, treatment, hydrologic condition, and Antecedent Moisture Conditions (AMC). AMC is pre-storm indicator of basin wetness and soil storage availability. In CN method, three levels of AMC are used such as AMC-I for dry, AMC-II for normal and AMC-III for wet conditions. In this study, the dormant season is considered while estimating the AMC conditions based on Table 3. The CN values were estimated according to the case of AMC-I and AMC-III conditions (Mishra and Singh 2013; Subramanya et al. 2013), which are given below,

$$CN(I) = CN(II)/(2.281 - 0.0128 * CN(II)) \qquad \text{(Eqn. 8)}$$

$$CN(III) = CN(II)/(0.427 + 0.00573 * CN(II)) \qquad \text{(Eqn. 9)}$$

Where, *CN(I), CN(II)* & *CN(III)* are the curve number for AMC-I, II & III conditions, respectively.

Soils are classified into four HSG's (A, B, C, and D). A represents well drained sand or gravel, high infiltration rate, B represents moderately well drained soil, moderate infiltration rate, with fine to moderately coarse texture, C indicates slow infiltration rate, moderate to fine texture, and D represents very slow infiltration, mainly clay material, relatively impervious. In the present study, soil hydrologic group C is considered based on the infiltration characteristics of the project area.

Table 3: AMC conditions and the related curve number (CN)

AMC	Curve Number	5-Days Antecedent Rainfall (mm)	
		Growing Season	Dormant Season
I	CN(I)	<35.6	<12.7
II	CN(II)	35.6-53.3	12.7-27.9
III	CN(III)	<53.3	<27.9

For a watershed with sub-catchment areas having different land uses and soil types, a composite CN's is determined by weighting of CN values for different sub-catchments (Eqn. 10).

$$CNw = \frac{\sum Ai*CNi}{\sum Ai} \quad \text{(Eqn. 10)}$$

CN_w is the weighted average curve number; Ai is the area of respective class for i=1…n.

Finally, the runoff volume is estimated by multiplying watershed area into runoff depth.

<u>Computation of peak runoff</u>

Drains are designed based on peak rate of runoff potential, which is the flow when the entire catchment is contributing to its outlet. This will occur when the given intensity of rainfall begins instantaneously and continues until the time of concentration (t_c) (CPHEEO, 2019). Rational method has been used successfully to design storm drains size, inlets and small on-site detention catchments based on peak rate of runoff (Eqn. 11):

$$Q_p = \frac{CiA}{360} \quad \text{(Eqn. 11)}$$

Where, Q_p is the peak rate of runoff (m^3/s), C is a runoff coefficient (dimensionless), i is the average rainfall intensity equal to the t_c (mm/h) and A is the catchment area (ha). The major factors affecting the runoff coefficient are the land use, soil type and slope of the catchment area. The assumptions used in the Rational method can be referred in the CPHEEO (2019). For the study site, runoff coefficients are adopted from the ***Annexure-A***. Further, weighted runoff coefficient (C) has been estimated using following equation:

$$C = \frac{C_1 A_1 + C_2 A_2}{A_1 + A_2} \quad \text{(Eqn. 12)}$$

Where, C_1 and C_2 are runoff coefficients, and A_1 and A_2 are respective areas of paved and general ground.

Computation of time of concentration (t_c)

It is defined as "the time required for water to travel from the most hydraulically distant point in the total contributing catchment to the design outlet (CPHEEO, 2019). The t_c is generally depends on distance of a farthest point in the drainage catchment to the shape, characteristics and topography of the catchment. Typically, it is estimated using Eqn. 13:

$$t_c = 0.0195 L^{0.77} * S^{-0.385} \quad \text{(Eqn. 13)}$$

Where, L is the length of main stream (m), S is the surface/longitudinal slope (ratio).

4.2.4 Soil Erosion

The RUSLE equation is applied to estimate soil erosion within a watershed. In RUSLE can be expressed as follows (Williams, 1975a and 1975b):

$$A = R \times K \times LS \times C \times P \quad \text{(Eqn. 14)}$$

where A is the average annual soil loss (t/ha/yr), R is the rainfall erosivity factor, K is the soil erodibility factor can be obtained from soil properties; LS is the slope length and gradient factor; C is the cover management factor can be derived from land cover data and P is the erosion control practice factor.

In case of RUSLE application for soil erosion estimation, R factor for the given storm was estimated using Eqn. 15 (Singh, 1981).

R= 79+0.363*Pa (Eqn. 15)

Where, P_a represents the mean annual rainfall in mm.

Soil Erodibility Factor

Soil erodibility (K) is a function of soil horizon and soil profile parameter, which was computed based on the study of Wischmeier et al. (1978). In the present study, the K factor can be estimated using Eqn. 16:

$$K = \frac{2.1\times10^{-4}(12-OM)M^{1.14}+3.25(s-2)+2.5(p-3)}{759.4} \quad \text{(Eqn. 16)}$$

K is soil erodibility (tonnes-yr/MJ-mm), OM is percentage organic matter, p is soil permeability code, s is soil structure code and M is a function of the primary particle size fraction.

Desert soil is generally found in the project area. It is sandy to sandy loam with silt clay loam in structure. The K factor is taken as 0.37 based on literature survey (Haan et al., 1994).

Determining LS Factor

The LS factor reflects the effect of topography on soil erosion. The dimensionless LS factor has been estimated from Eqn. 17 (Morgan 2005);

$$LS = \left(\frac{flow\ accumulation \times cell\ size}{22.13}\right)^{0.2} \times \left(0.065 + 0.045\times S + 0.0065\times S^2\right) \quad \text{(Eqn. 17)}$$

where, L is the slope length in m, and S is the slope steepness in %.

The computation of the LS factor requires flow accumulation and slope steepness factor, which was computed from the DEM (5m resolution).

Estimation of C and P Factor

The factor C measures the combined effect of all the interrelated vegetative cover and management variables, which was adapted from Pandey et al. 2010. While, the P-factor reflects the impact of support practices that will reduce the amount and rate of direct runoff as well as the amount of soil erosion. The C-factors for different LULC were taken from the literature (Haan et al. 1994; Chatterjee al., 2014) (***Table 4***). Since in the study area, no major conservation practices are followed, the P factor was taken equal to 1 for all LULC types as majority of land areas have not been provided with any conservation support.

Table 4: The vegetation cover factor C for the study area

SN	Class	C-factor
1	Grass	0.03
2	Grass and Open Scrub	0.03
3	Rann (Salt Waste-Dry)	1.00
4	Sarbela Bet	0.03

4.2.5 Sediment Yield

To quantify the amount of deposition occurring, a sediment delivery ratio (SDR) has been defined as (Haan et al., 1994):

$$SDR = \frac{Y}{(Grosserosion \times Watershed\ area)} \qquad \text{(Eqn. 18)}$$

Where, Y is the sediment yield (tons). For the present study, value of SDR was taken as 0.22 (adapted from Haan et al., 1994).

4.2.6 Risk assessment

Based on the design layout provided by GIPCL, field visit, primary data analysis and literature, the proposed site have been investigated and evaluated to ascertain the flood, seismic and tsunami risk.

4.2.7 Water availability and its requirement estimation

The water available from various sources such as surface water, groundwater, imported source and fresh water after desalination have been explored and assessed in the present study. Also, the groundwater availability and its quality have also been investigated in detail. The water requirement for the proposed project for different purposes has been estimated using different data sources and the inputs received from the GIPCL.

4.2.8 Storm-water management and rainwater harvesting

The storm-water drains and storage tanks can be designed to store the rainwater, which can be used for different purposes in the site. These can be estimated by considering the design rainfall event over the catchment area of the storage tank. The storage volume has been estimated in the site where appropriate rainwater harvesting tank can be designed.

5 FIELD INVESTIGATIONS

A team of scientists along with official of GIPCL made a field visit from December 29, 2020 to Jan 01, January, 2021 to get an insight into the hydrological conditions. Some of the photographs of the area are given in ***Figure 17*** to ***Figure 23***.

(a) Flat terrain with clayey loam type of soil without any vegetation

(b) Undulating terrain due to channel erosion

Figure 17: Topographical conditions at the proposed project site

Figure 18: Sparse vegetation (Bunny grass) and Acacia trees.

Figure 19: Streams / Channels in the AOI

Figure 20: Streams dissecting though the elevated areas

Figure 21: Clayey soil in low lying areas

Figure 22: Saline Groundwater in the proposed project site

Figure 23: Inter-connected drains between GIPCL project site