6 LAND USE / LAND COVER

Land use is the description of how people utilize the land for the socio-economic activities. Land use maps play a significant role in planning, management and monitoring programs at local, regional and national levels. For ensuring sustainable development, it is necessary to monitor the ongoing process on LULC patterns and any upcoming changes within the surrounding area.

6.1 LULC before establishment of RE Park

The study area falls in Rann of Kutch, Gujarat. The Rann of Kutch is a large area of salt marshes that span the border between India and Pakistan. The Rann of Kutch is divided into two parts, the Great Rann and the Little Rann.

Trees are rare except on the bets which rise above the flood zone. The non-native tree *Prosopis juliflora* has become established on the bets, and its seed pods provide year-round food for the wild asses.

The predominant land use of this site is barren land (also called Rann) with scanty vegetation of arid grassland ecosystem called as ***Banni grasslands***. The total area covered by the Grass and Open Scrubs is approximately 17% of the total study area and remaining Rann (Salt Waste-Dry) area. There is no settlement/ habitat within the study area. Areal statistics of the LULC is presented in ***Table 5.***

Table 5: LULC statistics of the study area

SN	Class	Area (ha)	% area
1	Grass	16	0.34
2	Grass and Open Scrub	801	16.86
3	Rann (Salt Waste-Dry)	3894	81.98
4	Sarbela Bet	39	0.82
	Total	**4750**	**100.00**

Present landuse in the study area and its buffer is shown in ***Figure 24.*** The landuse map has been prepared using SoI toposheet and remote sensing imagery.

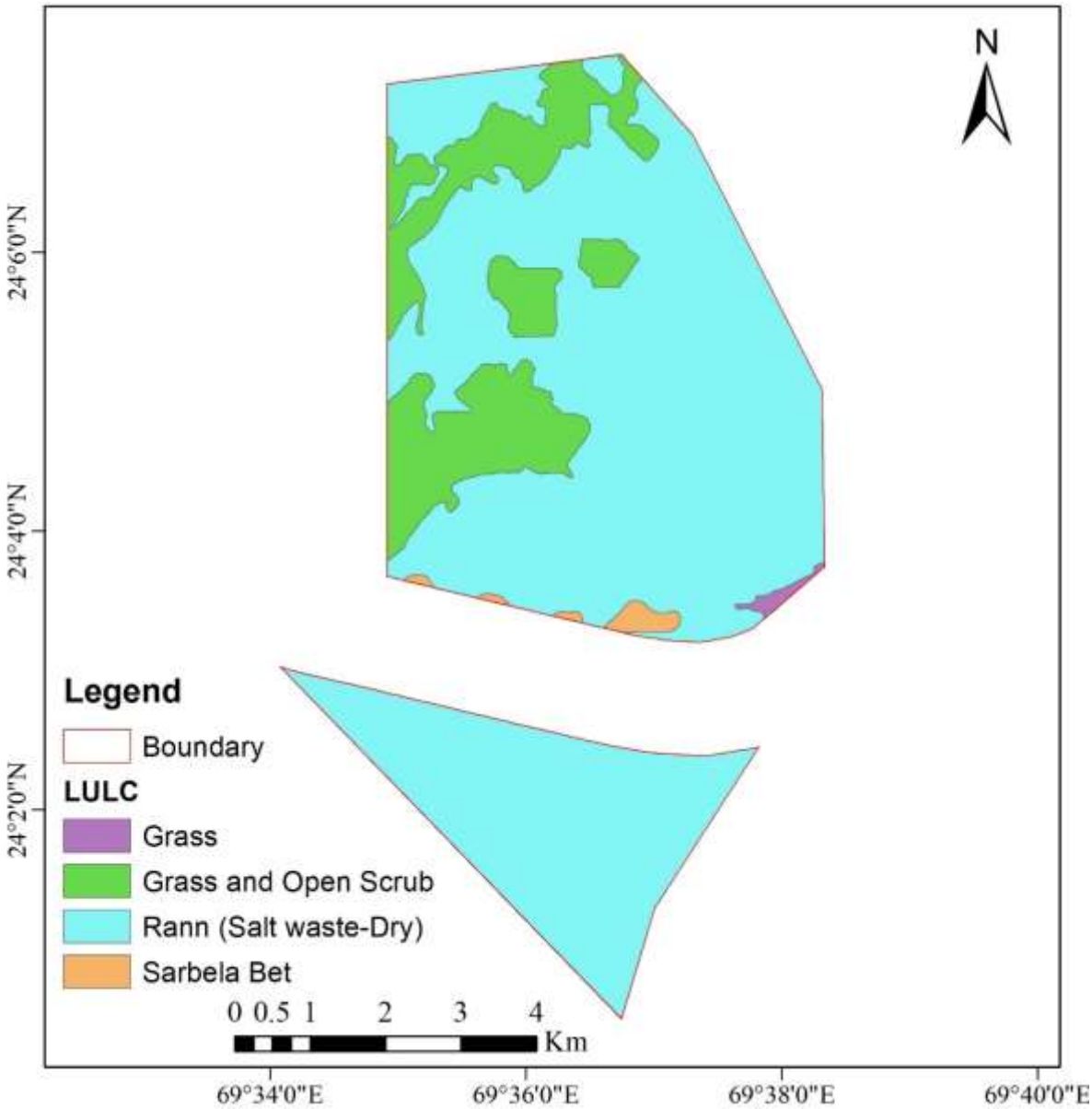


Figure 24: LULC Map of GIPCL RE Park area

Rann receives an average rainfall of 35 cm per year. The region does not have any perennial river and the development of drainage is poor. Only seasonal rivulets, originating from the central highland, drain the rain water of Kutch region through the Rann. The streams flowing to the north of the highland and disappearing in the vast expanse of the GRK are Nara, Panjarwati, Chhari, Bhukhi, Tramdo, Kaila, Pur and Kaswali. The drainages of Bhamban, Kankavati, Machchhu, Godhra and Umai from the southern fringe, Saraswati and Rupan from eastern fringe and Banas from northern fringe debouch into the LRK. Therefore, inundation in LRK is mainly by tidal waters from the Gulf

of Kutch with major contribution from surface runoff from various inland rivers draining the adjoining region.

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 2nd or 3rd order non-perennial streams which appears to have existed for atleast few decades. No drainage is marked even on 1:50,000 toposheet of SoI. Some of the dry streams observed in the field have depth upto 1 to 1.5 feet and width of 3-4 feet (***Figure 25***).

Figure 25: Dry stream channel/gullies observed in the field

6.2 LULC after establishment of RE Park

As per the planning for establishment of RE Park by GIPCL, the expected LULC has been estimated. GIPCL is planning to install 6,527,000 solar panels of 540 W with dimensions of 2x1 m. The RE Park is proposed to be divided into 24 plots with each plot having solar power generation of 100 MW. The land use after setting up of RE Park, is expected to be as given in ***Table 6***, it is estimated that the area under infrastructure (workshop, administrative building etc.) may be only 2 ha with 1.50 ha building and paved area and remaining 0.50 ha as open space with green belt.

Table 6: Land use pattern of project area of GIPCL

Sr. No	Activity	Existing (ha)	After completion of Solar Park (ha)
1	Total area disturbed	0.0	1,998
2	Infrastructure (workshop, administrative building etc.)	0.0	2
3	Area covered by Solar Panels	0.0	1,330
4	Paved area due to construction of Roads (20% of Solar Panel area)	0.0	266
5	Open Area (30 % of solar panel area)	0.0	400
6	Undisturbed area	4,750	2,752

7 SOIL TYPE

From hydrological point of view, soil study is carried out to determine its texture and infiltration characteristics.

The soil of the study area is uniform in nature and based on visual inspection it seems to be very fine silt clay varying in colour from yellow, yellowish Brown to back in colour at different locations. Mostly the soils are silt and clays and their mixtures in different proportions. Few pockets / lenses of silt, silty - clayey sands are also observed. In most of the area, salt encrustations have formed due to evaporation of water from the surface.

Dark brown silty clay with fine to very fine sand windblown particles size can be observed on Bet Zones.

The field permeability has been tested at one location in the study area by M/s Unique Engineering Services, Gandhidham and have reported that the permeability varies from 5.44 X 10^{-2} to 6.25 X 10^{-2} cm/hr. The permeability value is quite low and may not allow the vertical infiltration of water into the ground.

Stratification observed typically comprises of very soft saturated silty clays of low to high plasticity near ground level followed by soil of same character but with soft and stiff consistency towards greater depths. The soils within generally considered founding depths are highly compressible with very low to low shear strength. The consistency of clayey soils below 15 m depth is stiff to very stiff and hard towards higher depth. Mostly the soils are silty clay but few pockets / lenses of silt, silty - clayey sands are also observed. Soil characteristics are given in ***Appendix-A***.

8 METEOROLOGICAL ANALYSIS

The daily gridded rainfall data for 118 years (1901 to 2018) for the site region (0.25°x0.25°) was collected from Indian Meteorological Department (IMD). The data was analysed statistically and it has been found that the site received average annual rainfall 348.9 mm with minimum of 1.2 mm in the year 1987 and maximum 948.9 mm in the year 1961. Annual maximum daily rainfall and Total annual rainfall data for the period 1901 to 2018 is shown in ***Figure 26***. Further analysis indicates that a rainfall event of 339.4 mm occurred in month of May 1999. As this event is a single event of this intensity, the same was ignored in further analysis.

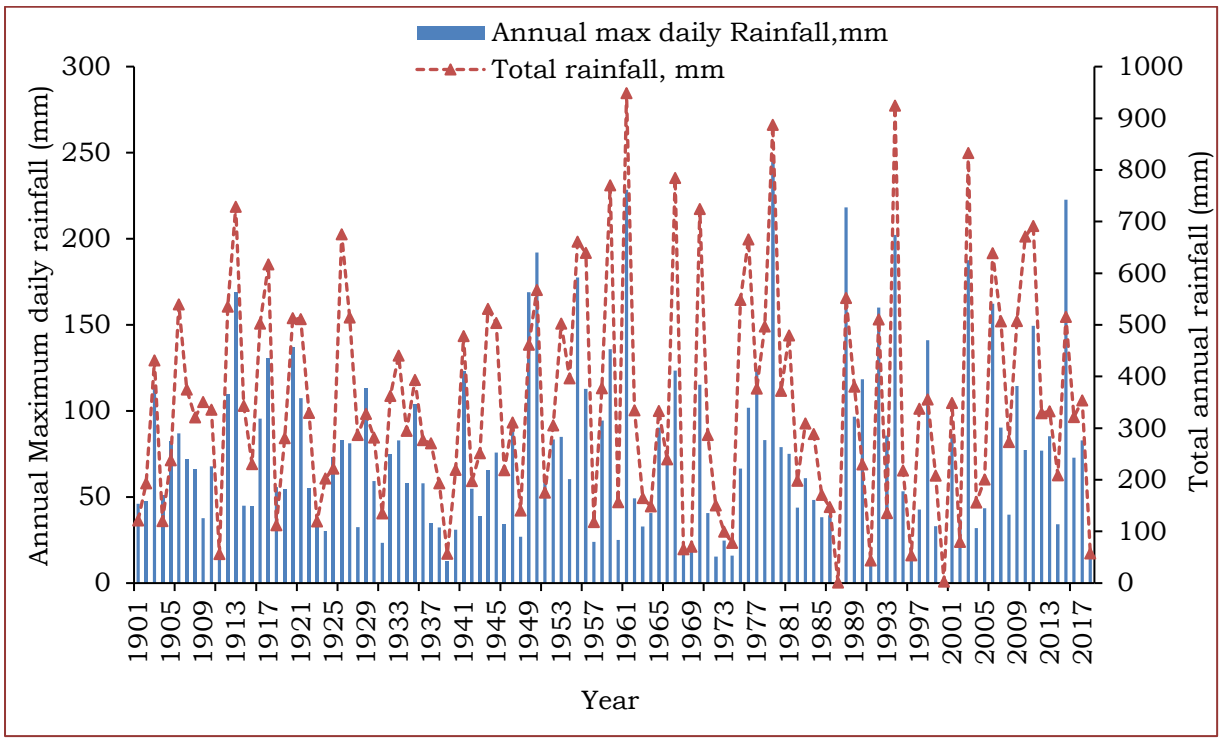


Figure 26: Annual maximum daily rainfall and total rainfall.

8.1 Statistical analysis of rainfall data

The monthly average daily rainfall statistics (1901 to 2018) observed at the site is presented in ***Table 7*** and ***Figure 27***. Also, Standard Deviation (SD) of the monthly and average annual rainfall for the site is presented in ***Table 7***. The top ten wettest days (i.e., extreme events of rainfall) for the proposed study site are listed in ***Table 8***. Seasonal analysis of the rainfall was carried out on

basis of IMD seasonal classes (i.e., winter, summer, monsoon and autumn) (***Figure 28***).

Table 7: Monthly statistics of average daily rainfall (mm)

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.9	2.0	0.7	0.6	1.2	36.0	142.8	93.2	57.6	8.9	4.1	1.0
SD	3.1	6.0	3.6	2.2	3.8	51.0	140.4	110.3	98.4	28.2	15.8	4.7

Table 8: Top ten wettest day

Year	Month	Top ten wettest day, mm
1979	Aug	246.7
1961	Sep	228.4
2015	Jul	222.6
1988	Jul	218.2
1994	Sep	202.2
1950	Jul	192.1
2003	Jul	187.5
1955	Sep	177.6
1913	Jul	169.1
1949	Jul	168.9

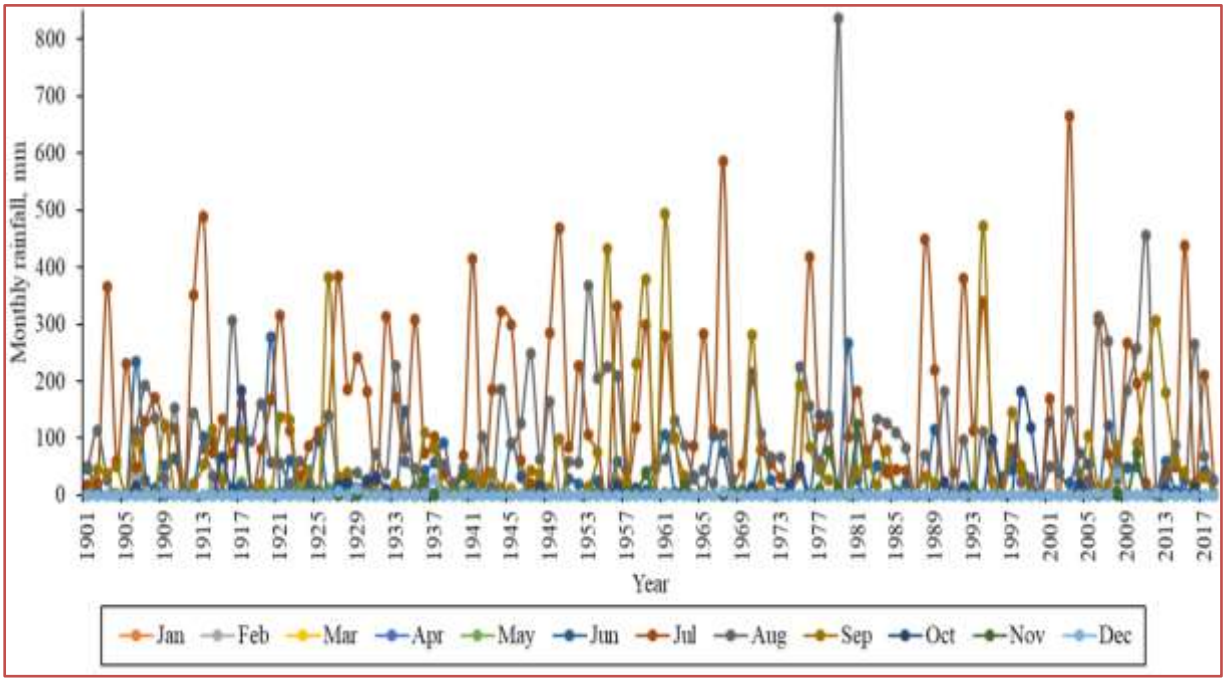


Figure 27: Monthly rainfall in the site (1901 to 2018)

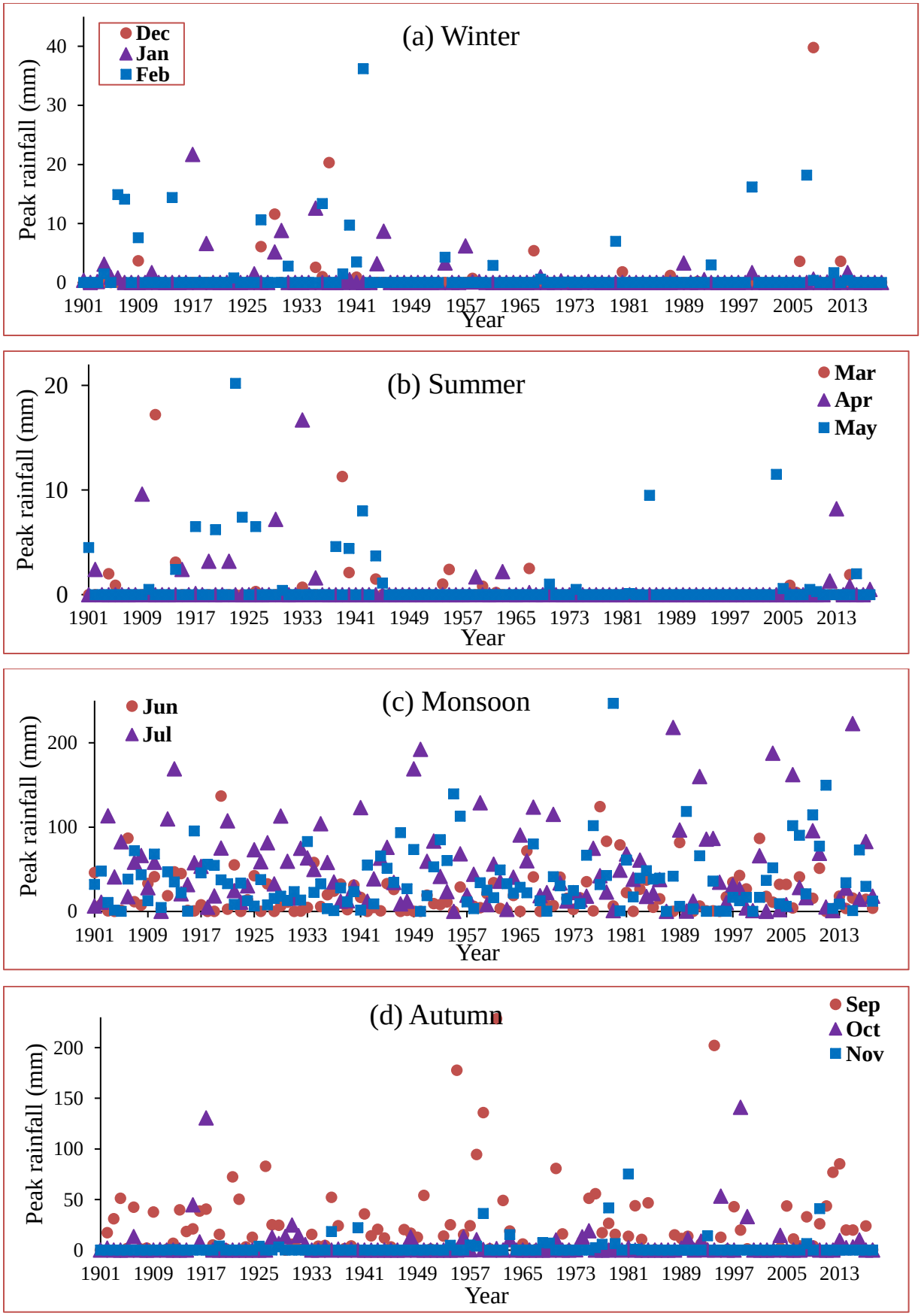


Figure 28: Maximum daily rainfall observed in different seasons

8.2 Derivation of IDF Curves

An IDF curve is a mathematical function that relates the rainfall intensity with its duration and frequency of occurrence. These curves are commonly used in hydrology for assessing rainfall events, classifying climatic regimes, to deriving design storms and assisting in designing drainage systems, etc. The deriving procedure of IDF curves, however, requires long-term historical rainfall observations, whereas lack of fine-timescale rainfall records (e.g. sub-daily) often results in less reliable IDF curves.

The IDF curve parameters have been computed for different duration of storms of different return periods from IMD rainfall gridded dataset (***Table 9 & Figure 29)***. Based on field conditions, suitable return period with rainfall intensity can be selected for design of the storm-water management system. IDF parameters indicate that the maximum rainfall intensity of 88.8 mm/hr can be expected for a storm of one hour for 100 years return period.

Table 9: IDF curve statistics for the site

Duration	Return Period / Rainfall intensity (mm/hr)					
	2 yr.	5 yr.	10 yr.	25 yr.	50 yr.	100 yr.
1 hr.	22.5	40.1	52.1	67.1	78.0	88.8
2 hr.	14.2	25.3	32.8	42.3	49.2	55.9
3 hr.	10.8	19.3	25.0	32.3	37.5	42.7
4 hr.	8.9	15.9	20.7	26.6	31.0	35.2
6 hr.	6.8	12.2	15.8	20.3	23.6	26.9
8 hr.	5.6	10.0	13.0	16.8	19.5	22.2
10 hr.	4.9	8.6	11.2	14.5	16.8	19.1
12 hr.	4.3	7.7	9.9	12.8	14.9	16.9
24 hr.	2.7	4.8	6.3	8.1	9.4	10.7

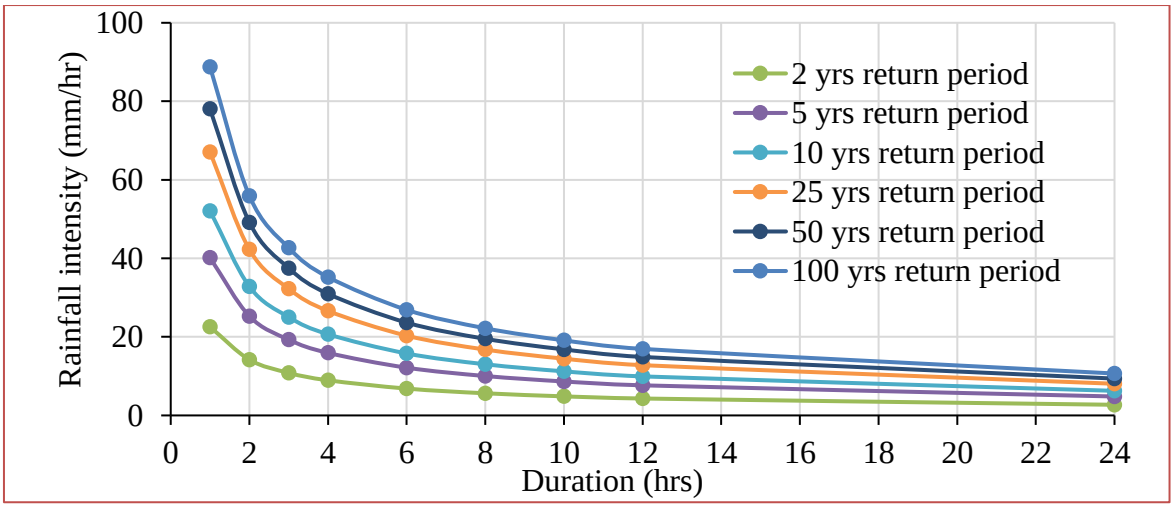


Figure 29: IDF curves for different return periods

9 WATERSHED ANALYSIS

9.1 Digital Elevation Model

Digital Elevation Model (DEM) is the digital representation (digital map) of the ground elevation data in meters. In the present study, the projection and datum WGS-84 UTM (meters) have been used for geo-referencing of all maps. Contour map of the RE Park area with contour interval of 0.5 m has been provided by GIPCL has been used (***Appendix – B***). Geographic geo-referencing points extracted from the toposheet and the map based on recent topographic survey and geo-reference point given by GIPCL have been used.

9.1.1 Procedure for DEM preparation

ARC-GIS software has been used for preparation of the DEM. The contours in shape file have been interpolated to obtain digital elevations of the equally sized grid cells. Size of a grid cell is 5 m × 5 m.

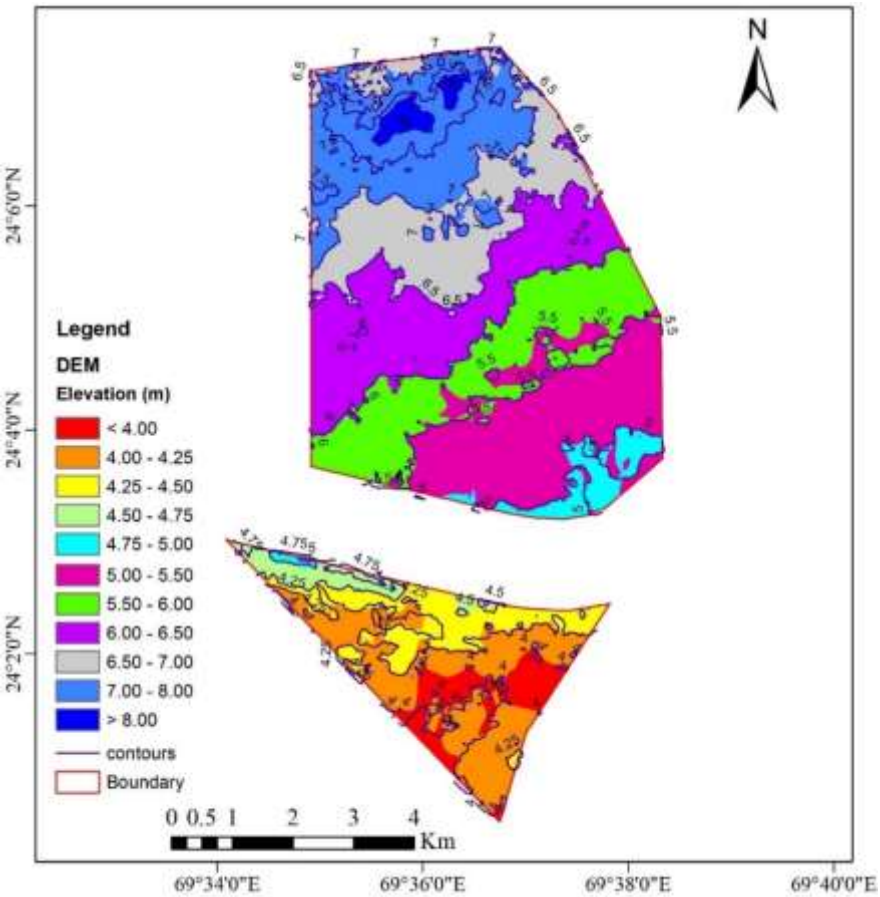


Figure 30: DEM of the GIPCL RE Park area

The DEM of the area within boundary of GIPCL RE Park area is shown as contour zoning map in ***Figure 30***. Variation in elevation from 3.85m to 8.75m is depicted through different colours. It is also shown as single colour intensity map in ***Figure 31*** in which terrain and natural drainage can be clearly identified.

Northern part of the project site area is higher in elevation than the southern part. Some of the higher land area are characterized with some patches of scanty vegetation (grassland).

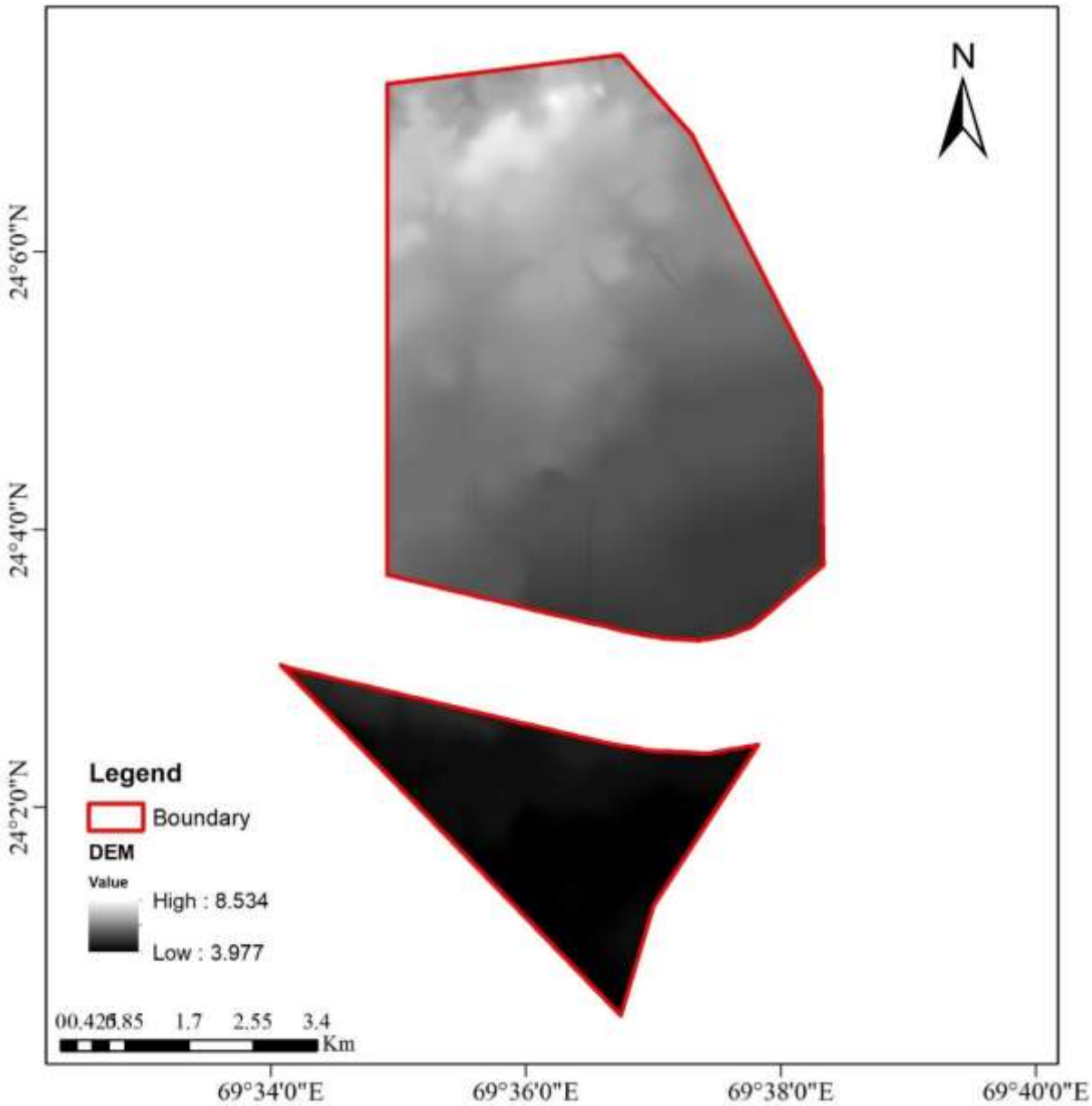


Figure 31: DEM - terrain colour intensity map

9.1.2 Distribution of land in different elevation ranges

The DEM has been used to compute the area (within project boundaries) between different elevation ranges. ***Table 10*** shows distribution of area from 3.85 m to 8.75 m elevation. The DEM computes number of pixels in each interval. DEM pixel size is 25 m^2 (5 m × 5 m). Approximately 2360 ha (50%) of the land area lies below 5.8 m elevation from msl.

Figure 32 is graphical depiction of the cumulative area distribution up to different elevation in the area. The graph suggests that the land is gradually sloping. This information derived from DEM study can be used to arrive at cost effective levels at which different plant components should be finally located.

Table 10: Areal distribution with elevation in study area as per DEM

S.N.	Elevation (m)	Pixel Count	Area (m^2)	Area (ha)	Area (%)	Cumulative Area (ha)	Cumulative Area (%)
1	<4.00	71242	1781048	178.10	3.75	178.10	3.75
2	4.00-4.25	201503	5037584	503.76	10.61	681.86	14.36
3	4.25-4.50	108985	2724623	272.46	5.74	954.33	20.09
4	4.50-4.75	36524	913107	91.31	1.92	1045.64	22.01
5	4.75-5.00	67231	1680783	168.08	3.54	1213.71	25.55
6	5.00-5.25	147150	3678754	367.88	7.74	1581.59	33.30
7	5.25-5.50	161280	4031999	403.20	8.49	1984.79	41.79
8	5.50-5.75	148824	3720601	372.06	7.83	2356.85	49.62
9	5.75-6.00	107044	2676088	267.61	5.63	2624.46	55.25
10	6.00-6.25	178458	4461453	446.15	9.39	3070.60	64.64
11	6.25-6.50	112898	2822442	282.24	5.94	3352.85	70.59
12	6.50-6.75	129013	3225320	322.53	6.79	3675.38	77.38
13	6.75-7.00	130092	3252295	325.23	6.85	4000.61	84.22
14	7.00-7.25	122934	3073351	307.34	6.47	4307.94	90.69
15	7.25-7.50	80589	2014714	201.47	4.24	4509.42	94.94
16	7.50-7.75	54048	1351195	135.12	2.84	4644.54	97.78
17	7.75-8.00	20140	503491	50.35	1.06	4694.88	98.84
18	8.00-8.25	20430	510753	51.08	1.08	4745.96	99.91
19	8.25-8.50	1453	36333	3.63	0.08	4749.59	99.99
20	8.50-8.75	163	4067	0.41	0.01	4750.00	100.00
			Total	**4750.00**	**100.00**		**100.00**

Note: Pixel size (DEM Cell size) =5 m × 5 m

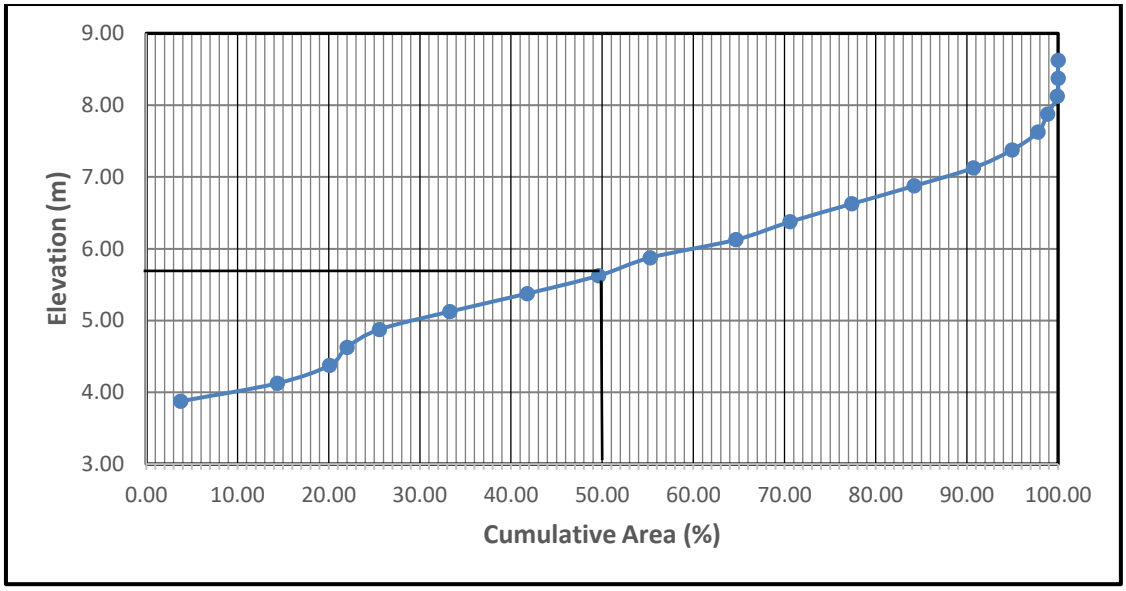


Figure 32: Cumulative areal distributions with elevation

9.2 Slope Analysis

Further, a slope map for the site was also developed (***Figure 33***) to ensure that areas with steep slope (i.e. > 4%) may be earmarked as keep out areas in the plant design. In the proposed site, all the area comes within 4% slope range (***Figure 33***).

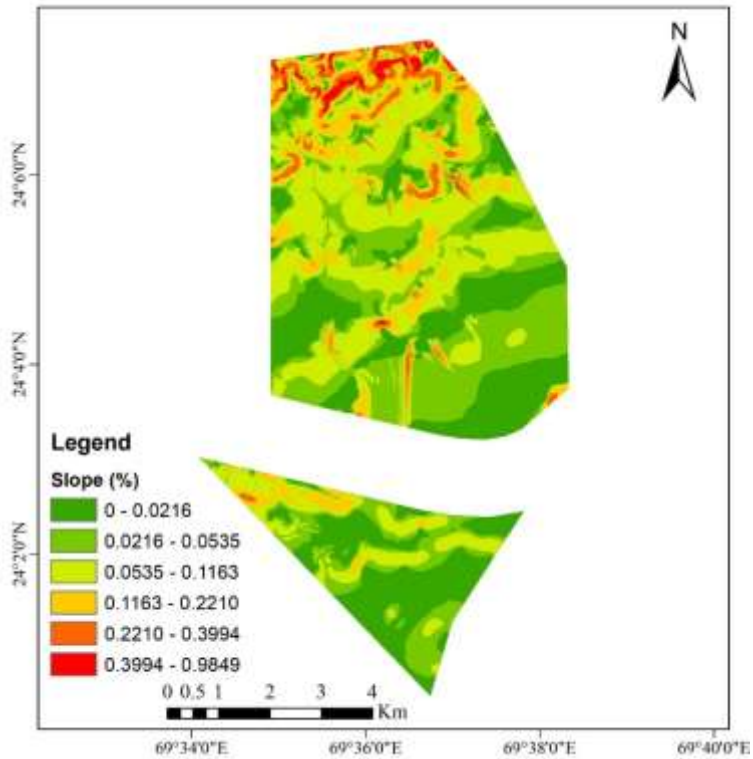


Figure 33: Slope map of the GIPCL RE Park area

9.3 Stream network delineation

Using the DEM, surface depressions on the land surface have been first delineated. The streams in the AOI were then mapped and the watershed boundary was delineated with the elevation points in the AOI (***Figure 34***). The delineated streams were used to identify the outlets points, which were further used to delineate the watersheds inside the lease area. There are eight sub-watersheds found in the project area which drains outside the project area.

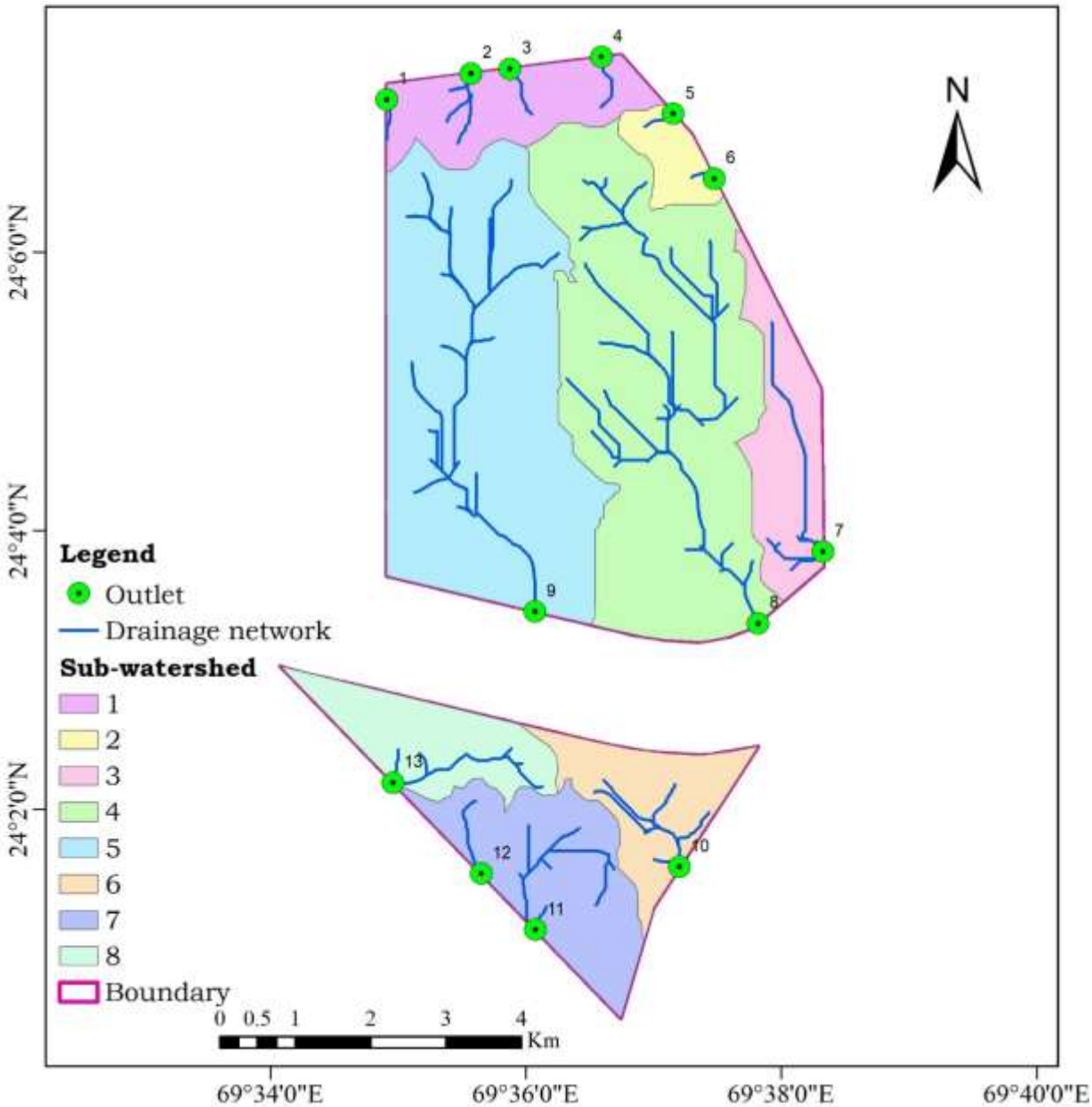


Figure 34: Watershed boundaries and drainage network of the site

There are very small streams and catchment found in the northern side of the project area. Therefore, surface runoff coming from these small catchments can be routed along the project boundary to a common outlet at proper place ***(Figure 34)***. Therefore, these watersheds have been merged together and considered single watershed where suitable water conservation measures can be taken.

The ***Figure 34*** shows that in Block-1 no stream enters in the RE Park, whereas 2 small first order streams enter the Block-2 from the northern side. The stream which is passing through Block-1 is observed dry from last 20-25 years based on the satellite images.

10 RUNOFF POTENTIAL

10.1 Runoff volume

In the present study, surface runoff (mm) has been estimated using SCS-CN method. The CN_{II} was obtained for the project area considering Soil Hydrologic Group-C and desert soils/waste land under poor hydrologic conditions. The $CN(I)_I$, and CN(III) values were determined using Eqn. (8 and 9) associated with AMC-I, and AMC-III conditions, respectively. Further, weighted CN value was estimated considering LULC characteristics and respective areas of classes using eqn. 10. The values of CN(I), CN(II) and CN(III) are computed to be 71.25, 85 and 93 for project site, respectively. Further, maximum potential surface retention capacity (*S*) has been determined using Eqn. 2.7 for the respective AMC conditions. Using Eqn. 6, the surface runoff from the GIPCL project site has been calculated in terms of depth of runoff in mm over a period of 1901 to 2018. The average annual surface runoff was estimated to be 52.58 mm and runoff coefficient (i.e. runoff/rainfall) of 0.15.

The volumetric runoff (m^3) from the entire project site is estimated by multiplying runoff depth (mm) with project area. The surface runoff from Block-1 and Block-2 have been estimated 1.9 Mm^3 and 0.6 Mm^3, respectively. The total average annual runoff from the project site is estimated 2.5 Mm^3. The volumetric average annual runoff estimation from the project area is presented in ***Table 11***. Also, the monthly runoff received from the project area is presented in ***Annexure-F***. The maximum monthly runoff was occurred in the month of August (i.e. 458.59 mm) from the project area. The variation in the average monthly rainfall and runoff from the project (1901 to 2018) is shown in the ***Figure 35***.

Table 11: Runoff estimation by SCS-CN method

SN	Site	Annual rainfall mm	Runoff (mm)	Area (ha)	Runoff (m^3)	Runoff (Mm^3)
1	Block-1	348.9	52.58	3693	1941779	1.9
2	Block-2			1057	555771	0.6
			Total	**4750**	**2497550**	**2.5**

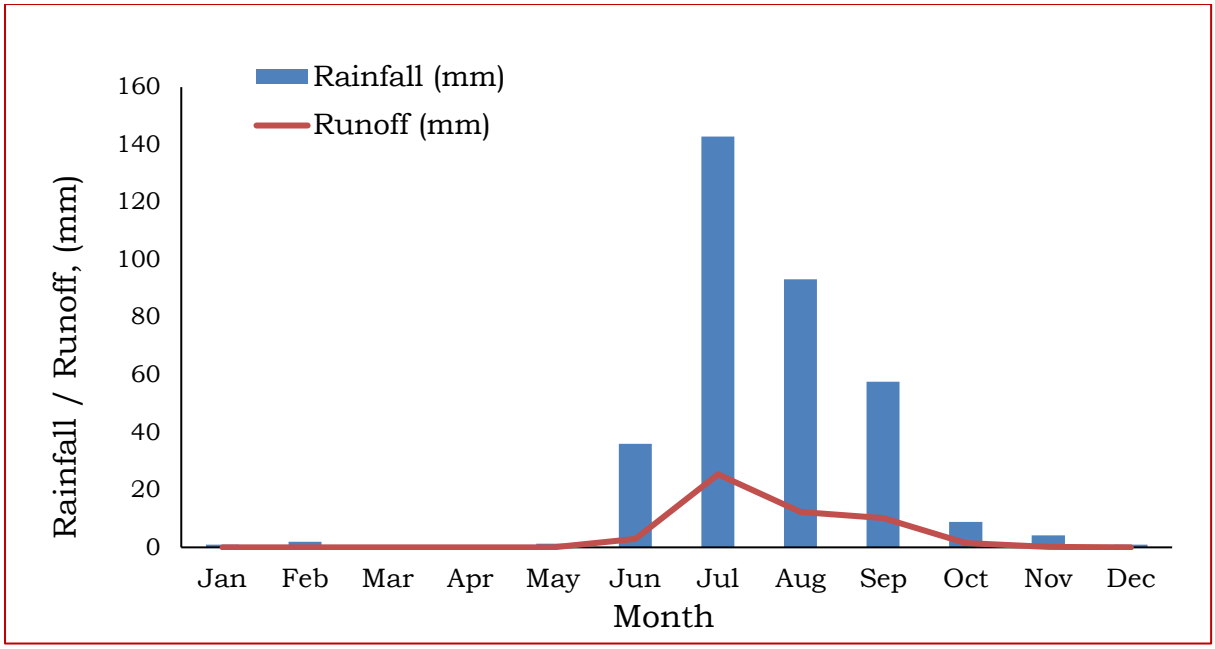


Figure 35: Variation of monthly rainfall and runoff in the site

10.2 Peak Runoff potential

The Rational method has been used to estimate the peak runoff potential based on runoff coefficient, design rainfall intensity and catchment area of AOI. In this computation, the runoff coefficient for rural watershed is takes as 0.31 (C=0.11+0.05+0.10+0.05) for the proposed site (***Appendix-C***) (Thomason, 2019). **Figure 36** shows the outlets for flow of water from the watershed. In the sub-watershed-1, runoff coming from small streams can be routed to common outlet where suitable water conservation measures can be taken (**Figure 36**).

Further, total drainage area of the project site is 4750 ha and design rainfall intensity based on time of concentration (t_c) have been considered. Estimation of t_c for various sub-watersheds is given in ***Table 12***. Rainfall intensity estimated as per t_c is given for different return periods (***Table 13)***. The runoff estimation for the GIPCL site is presented in ***Table 14***.

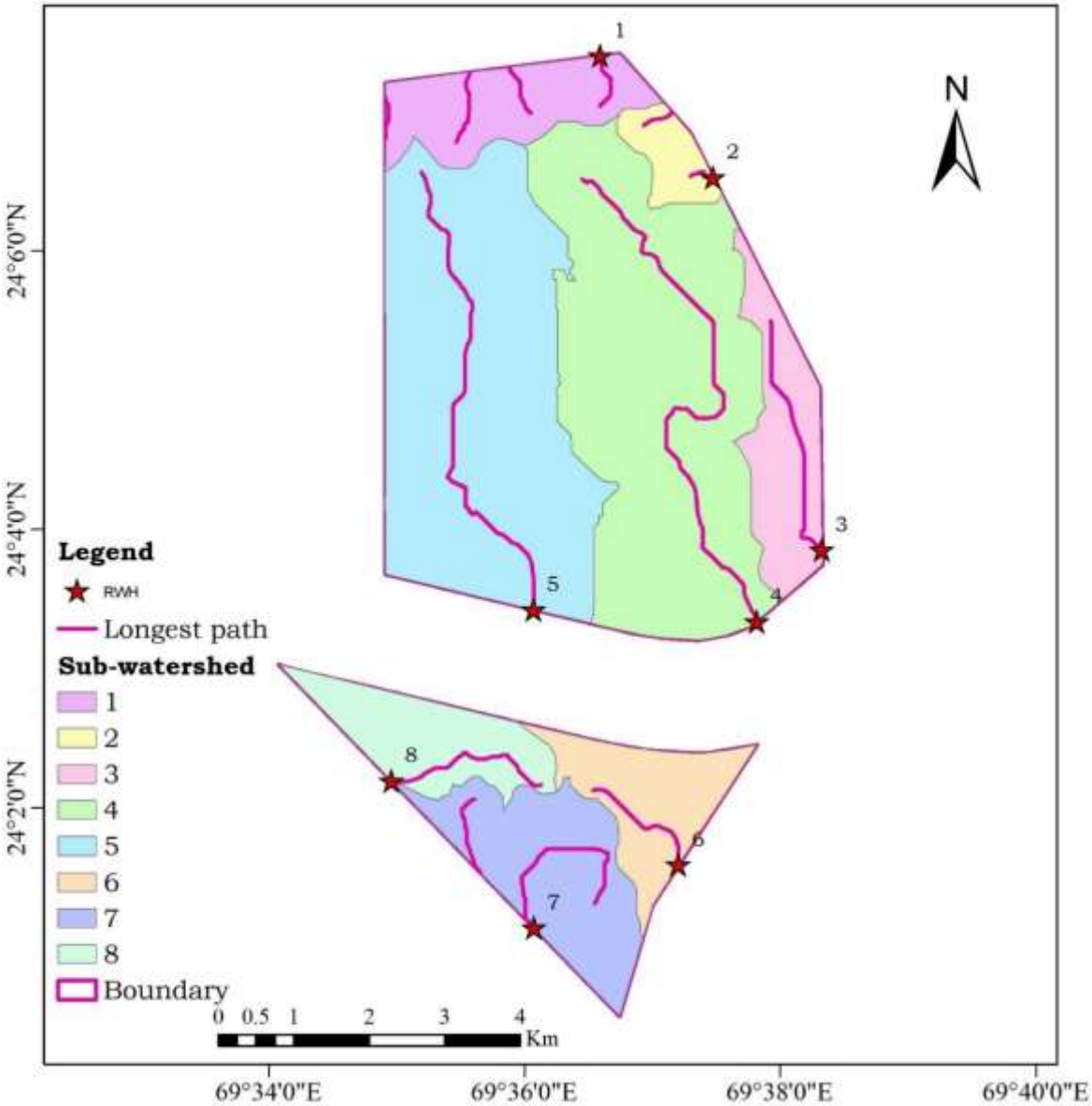


Figure 36: Longest path streams in the catchment area of the site

Table 12: Estimated time of concentration (t_c)

Sub-watershed	Longest Stream length (m)	Av. Slope (%)	t_c (min)	t_c (hr)*
	Block-1			
1	799.80	0.08	53.03	0.88
2	384.13	0.02	47.61	0.79
3	3364.56	0.03	235.14	3.92
4	8071.23	0.03	480.88	8.01
5	6809.05	0.04	369.92	6.17
	Block-2			
6	1761.87	0.015	182.73	3.05
7	2789.25	0.001	838.83	13.98
8	2374.01	0.008	292.68	4.88

Note: * The t_c is high due to flat land (slope <1%) and merging of some of the sub-watersheds

Table 13: Estimated rainfall intensity as per time of concentration (t_c)

Sub-watershed	Duration (t_c) (hr)	Return Period / Rainfall intensity (mm/hr)	
		50 yr.	100 yr.
Block-1			
1	0.88	84.99	96.68
2	0.79	91.33	103.89
3	3.92	31.39	35.71
4	8.01	19.50	22.18
5	6.17	23.20	26.39
Block-2			
6	3.05	37.11	42.21
7	13.98	13.45	15.30
8	4.88	27.13	30.86

The peak runoff potential of each sub-watershed from a rainfall of 50 and 100 years return period is estimated and presented in ***Table 14.*** It is understood from the ***Table 14*** that from a precipitation of 50 and 100 year return period may have potential to generate surface runoff, which may vary from 5.2 m^3/s to 28.7 m^3/s and 5.9 m^3/s to 32.6 m^3/s, respectively.

Table 14: Peak runoff potential for 50 and 100 year return periods

Sub-watershed	**Runoff coefficient**	**Return Period / Rainfall intensity (mm/hr)**		**Area**	**Peak runoff (m^3/s)**	
	C	**50 yr**	**100 yr**	**(ha)**	**50 yr**	**100 yr**
Block-1						
1	0.31	84.99	96.68	332.2	24.3	27.7
2	0.31	91.33	103.89	107.9	8.5	9.7
3	0.31	31.39	35.71	318.2	8.6	9.8
4	0.31	19.50	22.18	1499.0	25.2	28.6
5	0.31	23.20	26.39	1435.2	28.7	32.6
Block-2						
6	0.31	37.1	42.2	300.2	9.6	10.9
7	0.31	13.4	15.3	450.6	5.2	5.9
8	0.31	27.1	30.9	306.2	7.2	8.1

The engineering measures should be decided on the basis of each sub-watersheds runoff potential (volume and peak rate of runoff potential). The study results indicate that project area will be prone to temporary water impoundment during peak rainfall. However, appropriate arrangement of drainage structures will not create impounding in the project area.

11 FLOOD RISK ASSESSMENT

A Flood Risk Assessment (FRA) is an assessment of the risk of flooding from all flooding mechanisms, the identification of flood mitigation measures and should provide advice on actions to be taken before and during a flood.

The sources of water which may produce floods in the present case include: (a) Surface water, (b) Artificial water (burst water mains, canals or reservoirs), (c) Rivers, streams or watercourses, (d) Sewers and drains, (e) High groundwater or saturated vadose zone and (f) Flooding of low-lying coastal regions due to sea level rise.

For each of the sources of water, different flood hydraulic intensities occur. Floods can also occur because of a combination of sources of flooding, such as high groundwater and an inadequate surface water drainage system. The topography, hydrogeology and physical attributes of the existing or proposed development need to be considered. A flood risk assessment should be an evaluation of the flood risk and the consequences and impact and vulnerability.

Numerous Gullies and temporary streams are passing through study area. These gullies are temporary and flows during only monsoon season and there are some major streams which are in existence for a very long time (but non-perennial in nature). Previous satellite images also confirm the presence of some streams.

This should be considered in design of infrastructure of earthen bunds, storm water drainage for smooth passage of water if possible.

Gullies are formed by increased surface runoff which acts as a cutting agent. The size of gullies depends on the surface runoff generated from the nearby area. The main physical factors effecting the rate and amount of surface run-off generation are precipitation, topography, soil properties and vegetative cover.

Surface water risk includes risk from flooding of streams / channels and flooding due to rainfall.

11.1 Flooding risk due to streams/channels

There are no major dams/streams in the project site (***Figure 34***). Kutch Disaster Management Plans 2017-18 indicates that River flooding is a not major hazard faced by the district. All the river systems in the Rann of Kutch district are very low flooding, as captured in the Vulnerability Atlas. No major flood event record is available from the study area. Some of the areas in the southern part of the district faces flooding, primarily due to heavy rain and drainage issues.

The proposed site for RE-Hybrid Park is mostly located over a flat terrain except for few patches of undulating land (***Figure 33***). This is also clearly observed in the Google Earth Image (***Figure 37***). There are few topographical low-lying areas in some portion of the site and rest of the portions of the site is located more or less on the plain grounds. The topographical high lands of the site are mainly acting as the runoff zones wherein there will not be any impoundment of storm water during rainy days. Whereas, the topographical low lands may have temporary storm water impoundments during high intensity rainfall. A network of streams has developed, which will drain the water from the AOI.

Drainage map derived from GIPCL provided survey data indicates that slope, in general, is gentle and it is in five directions in the Block-1 and in two directions in the Block-2 (***Figure 34***).

Course of channels/streams varies depending on the upstream catchment area and slope. As far as the AOI is concerned, the historical data reveals that the south, south-eastern, north-eastern, north and north-western part of the Block-1 of GIPCL only shows changes in the temporary streams/gullies whereas rest of the area does not show any change. While in Block-2, eastern and western part of the block show some changes in drainage network

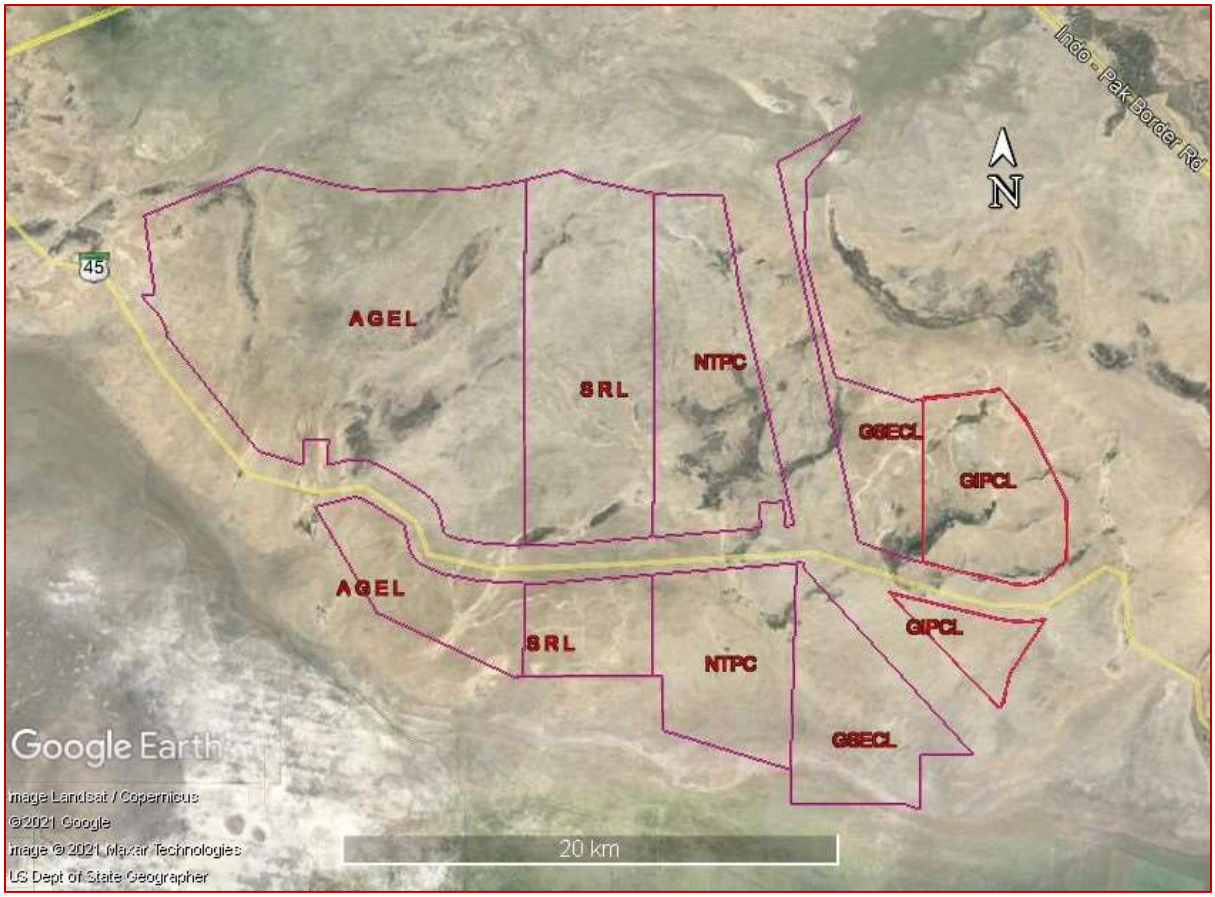


Figure 37: Proposed project sites for different agencies

11.2 Flood risk from nearby water bodies

The study of google earth images and ASTER DEM of the area shows that there is no surface water inflow into the GIPCL lease area. Moreover, the water bodies lying towards east and south have never shown any advancement towards the lease area over 35 years of satellite data available (1995 to 2000). Therefore, there is no risk from nearby water bodies to the GIPCL project site (***Figure 38***). Based on contour survey data provided by GIPCL, a 5m DEM has been generated and streams are extracted for the project area. It is found that all the streams and tributary of channels/streams are flowing away from the GIPCL site (***Figure 38***).

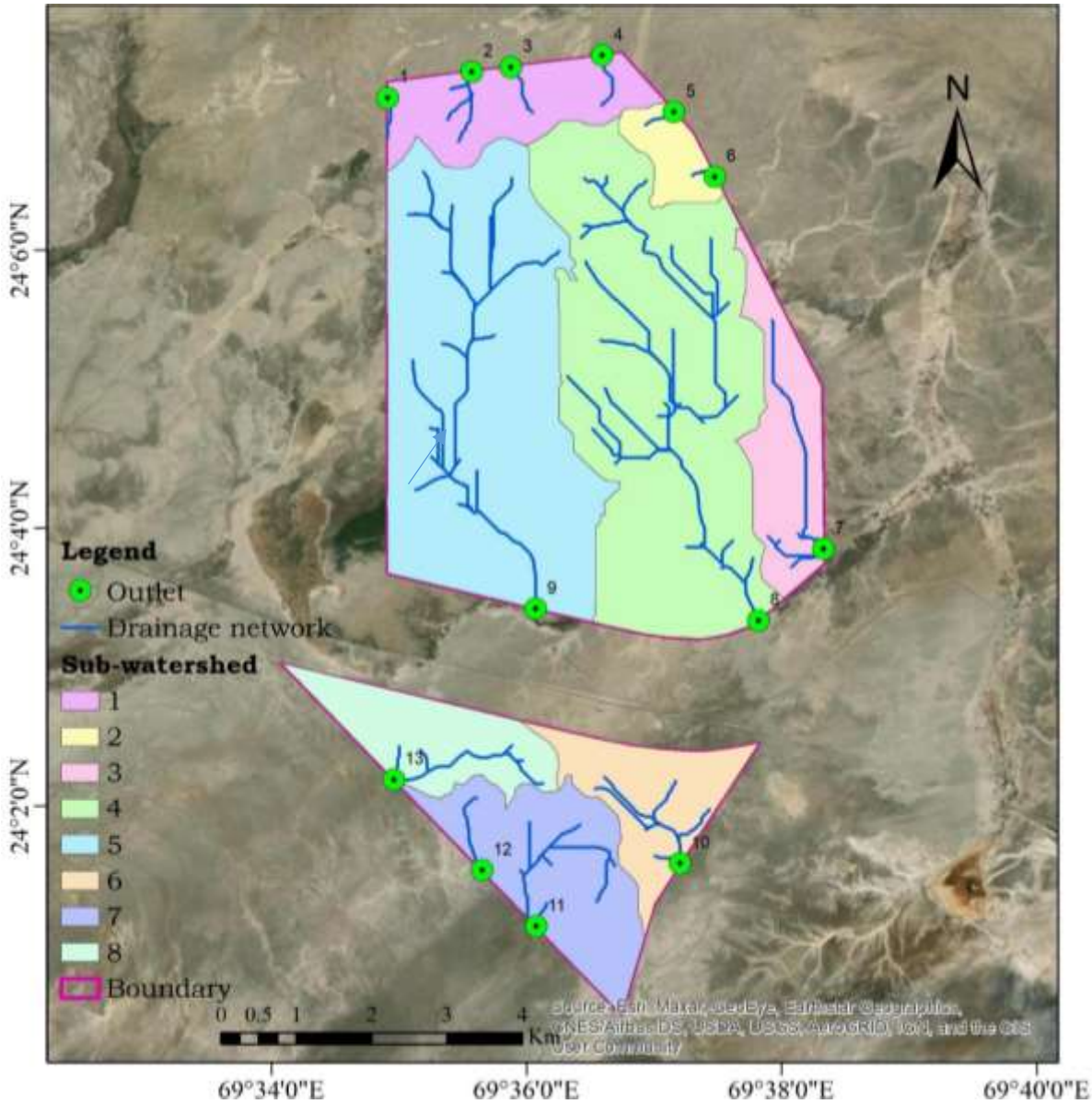
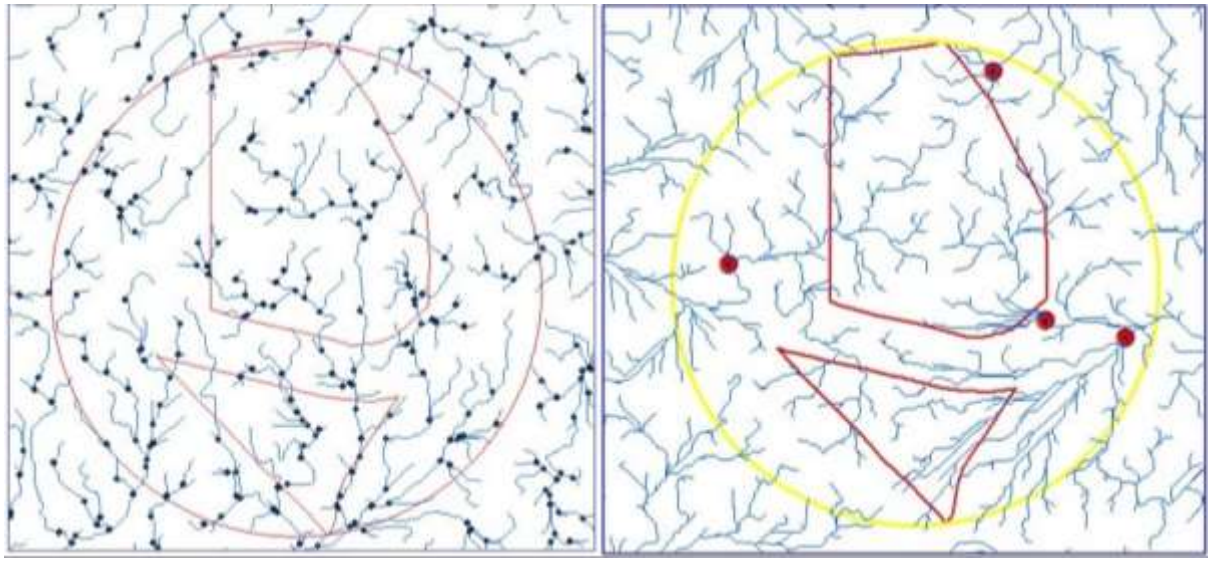


Figure 38: Streams extracted using DEM based on contours survey data

This was further confirmed with drainage generated from ALOS PALSAR (12.5 m resolution) and ASTER (30 m resolution) DEM (***Figure 39***).

The stream network was delineated using lower value of accumulation derived from ALOS PALSAR and ASTER DEM. The reduction in pixel value increased the stream density and very small stream were detected in the AOI (***Figure 39***). Since, the elevation difference of the site significantly lesser than vertical accuracy of these DEMs (15 to 20 m with 90% confidence level), we consider only main streams delineated from DEM (5m resolution) based on GIPCL contour survey data. Further to verify the existence of drainage network on site physical survey was also carried out.



(a) (b)

Figure 39: Streams extracted from a) ALOS PALSAR & b) ASTER DEMs

Superimposition of the contour maps on the available satellite images of the previous years, indicates that the High Flood Level in the Rann of Kutch had reached to the elevation of 2.4 m to 2.7 m above mean sea level (amsl) during the earlier year of 1984 and 1992. While comparing the images of the recent years of 2019 and 2020, it is seen that the water level stays near the elevation of approx. 1.5 m. The minimum elevation in the RE Park is 3.88 m amsl.

From the field investigations, historical satellite images and the interpreted stream lines for the past years has revealed that the site is not in major flood risk zone.

11.3 Flood risk due to rainfall

As per the rainfall data available, the site has received maximum rainfall of 339.8 mm during May 1999. This event was related to *Very Severe Cyclonic Storm* (intensity of T-5.5) developed in Arabian Sea which had hit the Kutch area of Gujarat. Most intense cyclones that hit west coast on India including Gujarat during 1970 to 2021 are listed in ***Appendix-D***. Risk assessment due to rainfall has been already assessed and discussed in the runoff potential estimation *Chapter 10*.

12 SOIL EROSION ASSESSMENT

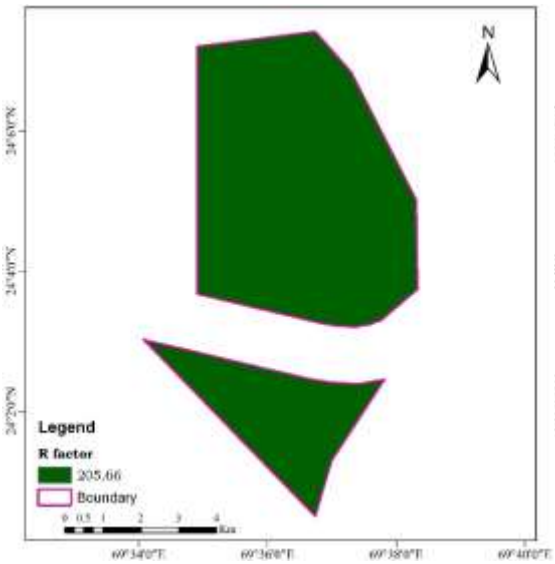
Soil erosion is an important economic and environmental concern throughout the world. Soil erosion is a complex process that is related to soil properties, topography, land cover, and human activities. In order to assess soil erosion risk and conserve soil and water soil resources, soil erosion modeling has been carried out at the watershed scale in the project area. This study estimated soil erosion using Revised Universal Soil Loss Equation (RUSLE) in a Geographic Information System (GIS) platform. This study will be an important input for identification and prioritization of critical areas for soil erosion control measures/practices in the project area.

For soil erosion estimation, USLE and its derivatives, Revised USLE (RUSLE) is the most widely used empirical models because of their minimal data and computation requirements (e.g. Merritt et al., 2003). The USLE and RUSLE models estimate average annual gross erosion as a function of rainfall energy.

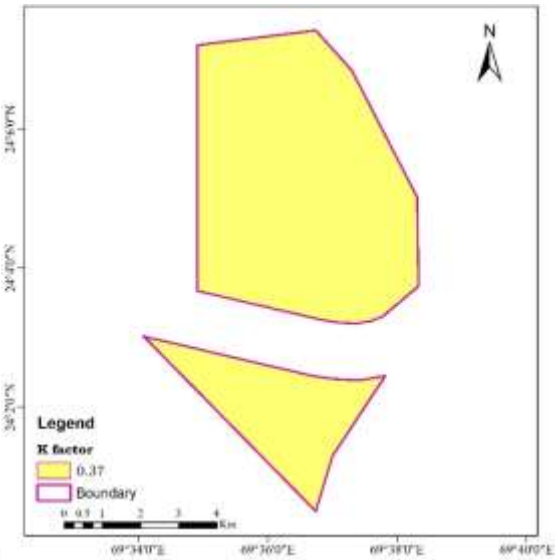
12.1 Estimation of Soil Erosion

The average annual soil loss map of the GIPCL project area was prepared using RUSLE method. The values for the factors R, K, LS, C and P are computed for different grids based on the DEM and database available from literature survey. The detail methodology adopted for the computation of each of these factors is presented in *Chapter 4, section 4.2.4*.

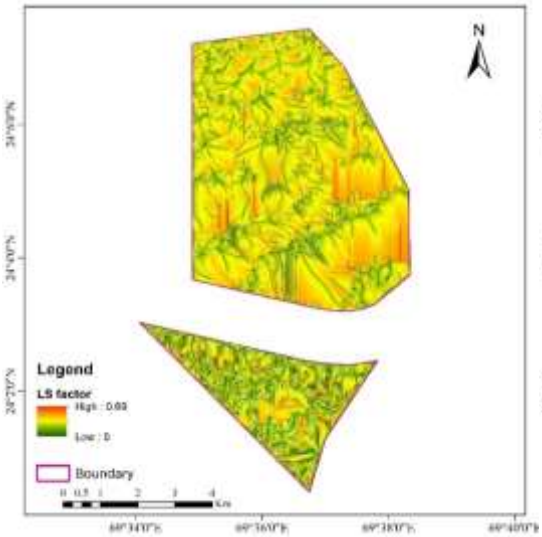
The USLE parameters, i.e., R,K,LS,C,P maps (***Figure 40***) were integrated in ArcGIS using raster calculator to derive the composite map of soil erosion potential (***Figure 41***). Maps depicting gross amount of soil erosion from different descretized cells of the project areas were computed by multiplication of the erosion potential map produced by integration of RKLSCP maps. The net erosion estimated on a cell basis for the project area was grouped into the following scales of priority: *Slight* (0 to 5 t ha^{-1} y^{-1}), *Moderate* (5 to 10 t ha^{-1} y^{-1}), *High* (10 to 20 t ha^{-1} y^{-1}), *Very High* (20 to 40 t ha^{-1} y^{-1}) and *Severe* (> 40 to t ha^{-1} y^{-1}) erosion classes as per the guidelines suggested by Singh et al. (1992) for Indian conditions ***(Table 13)***.



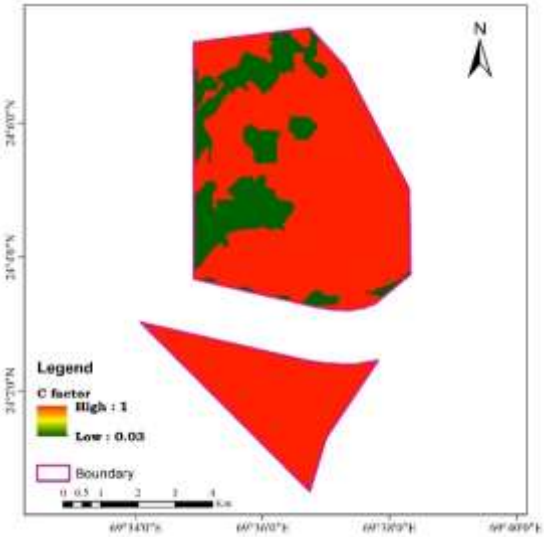
a) R factor map



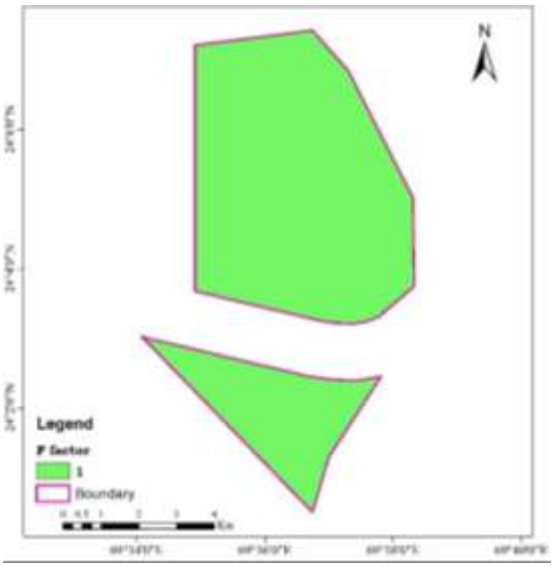
b) K factor map



c) LS factor map



d) C factor map



e) P factor map

Figure 40: Thematic input database used for soil erosion estimation

Results indicated that 55% area is under moderate erosion class, whereas 32.87% area falls under the slight class erosion zone (***Table 15***). ***Figure 41*** clearly indicates that treatment of soil conservation with the help of runoff potential will be a key factor for excellent watershed management.

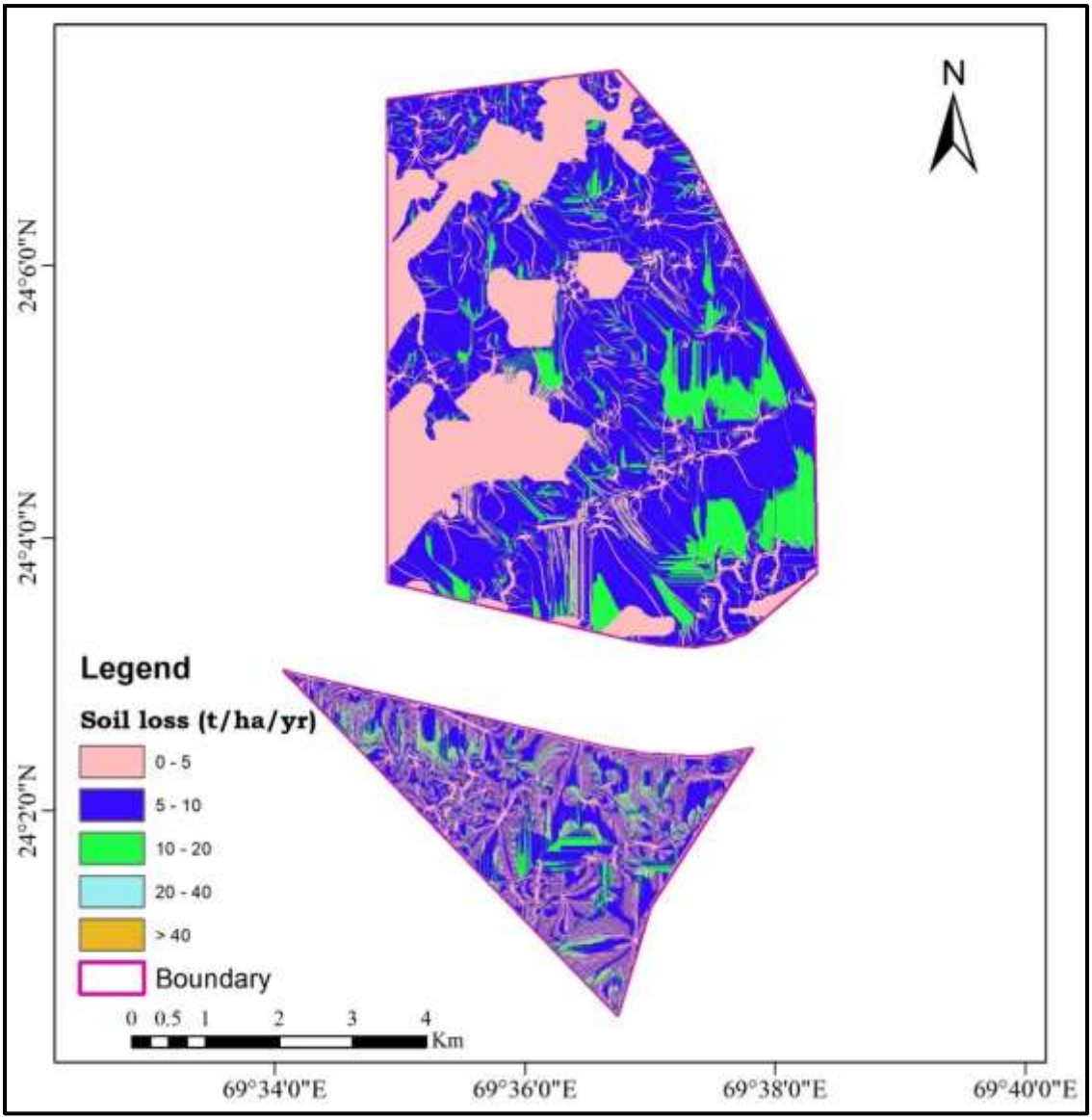


Figure 41: Average annual soil erosion from the project area

Table 15: Different classes of soil erosion in the project area

SN	Net Erosion ($t\ ha^{-1}\ y^{-1}$)	% area	Severity
1	0-5	32.87	Slight
2	5-10	55.13	Moderate
3	10-20	11.38	High
4	20-40	0.53	Very High
5	> 40	0.08	Severe

Area covered by moderate, high, very high and severe erosion zones taken together found to be 67% and can be termed as critical erosion prone areas requiring immediate attention from soil conservation point of view.

12.1 Estimation of Sediment Deposition

The average annual soil loss within watershed was found to be 9.96 t ha^{-1} y^{-1}. The information shown in **Figure 41** could be utilized for identification of the sediment source areas of the watersheds. Gross soil erosion is estimated to be 47,316 tonnes. Based on gross soil erosion and sediment delivery ratio, the sediment yield is estimated to be 10,410 tonnes.

Depending upon priority levels, the watershed area should be treated with suitable vegetative and structural measures. Remedial measures are needed in high runoff potential zones to minimize the surface runoff and soil erosion in the watersheds. The suitable catchment treatment measures (i.e. engineering and biological measures) such as contour bunds, terraces, pasture development, afforestation and gully control structures can be adopted based on the severity of erosion in the watershed according to the soil, climatic and topographical conditions (Das 2008).

13 GROUNDWATER ASSESSMENT

Ground water regime monitoring in Kutch district is carried out by CGWB four times a year i.e., during January, May, August and November through 48 National Hydrograph Network Stations (NHNS). But unfortunately, no monitoring is being done even by CGWB in the Great Rann of Kutch.

13.1 Groundwater Conditions

For determining the groundwater conditions, 28 bore wells were constructed by M/s GIPCL through M/s Unique Engineering Services, Gandhinagar. Groundwater was encountered from 2.00m to 4.50m depth below ground level during the month of December 2020. Depth to water table and water table position is given in ***Table 16.***

Table 16: Groundwater levels observed in GIPCL project area

SN	Well No.	Northing	Easting	Ground Elevation	Well Depth	Depth to Water Table	Water Table
		m	m	m amsl	m bgl	m bgl	a msl
1	BH-1	2659249	558986	4.70	50	2.20	2.50
2	BH-2	2658766	560446	4.25	30	2.20	2.05
3	BH-4	2658420	563002	4.21	50	2.20	1.99
4	BH-5	2658086	559888	4.29	50	2.00	2.29
5	BH-6	2657351	561330	3.99	30	1.90	2.09
6	BH-7	2656232	562087	4.10	50	2.20	2.10
7	BH-9	2661383	559525	5.83	50	4.50	1.33
8	BH-10	2661089	560920	5.21	50	4.00	1.21
9	BH-11	2660618	562465	5.24	30	4.20	1.04
10	BH-12	2661281	564073	4.86	50	4.50	0.35
11	BH-13	2662474	559509	6.26	30	3.90	2.36
12	BH-14	2662677	561075	7.12	50	4.40	2.72
13	BH-15	2662004	562554	5.43	50	4.30	1.13
14	BH-16	2662169	564254	5.06	50	4.30	0.76
15	BH-17	2663596	559482	6.19	50	3.00	3.19
16	BH-18	2663906	560804	6.14	50	3.50	2.64
17	BH-19	2663576	562593	5.87	50	4.30	1.57
18	BH-20	2663509	564159	5.51	50	4.40	1.11
19	BH-21	2664999	559688	6.60	50	3.50	3.10
20	BH-22	2665252	561390	6.90	30	4.40	2.50
21	BH-23	2664879	562834	6.30	30	4.30	2.00
22	BH-24	2664666	563996	6.05	50	4.40	1.65

SN	Well No.	Northing	Easting	Ground Elevation	Well Depth	Depth to Water Table	Water Table
		m	m	m amsl	m bgl	m bgl	a msl
23	BH-25	2665989	559725	7.39	30	4.40	2.98
24	BH-26	2666558	561205	7.74	50	4.00	3.74
25	BH-27	2666128	562981	6.77	50	4.30	2.47
26	BH-28	2667219	559649	7.83	35	3.30	4.53
27	BH-29	2667619	560896	6.90	30	3.00	3.90
28	BH-30	2667442	562307	7.07	50	4.30	2.77

Depth to water level map and Groundwater flow direction maps are shown in ***Figure 42*** and ***Figure 43***.

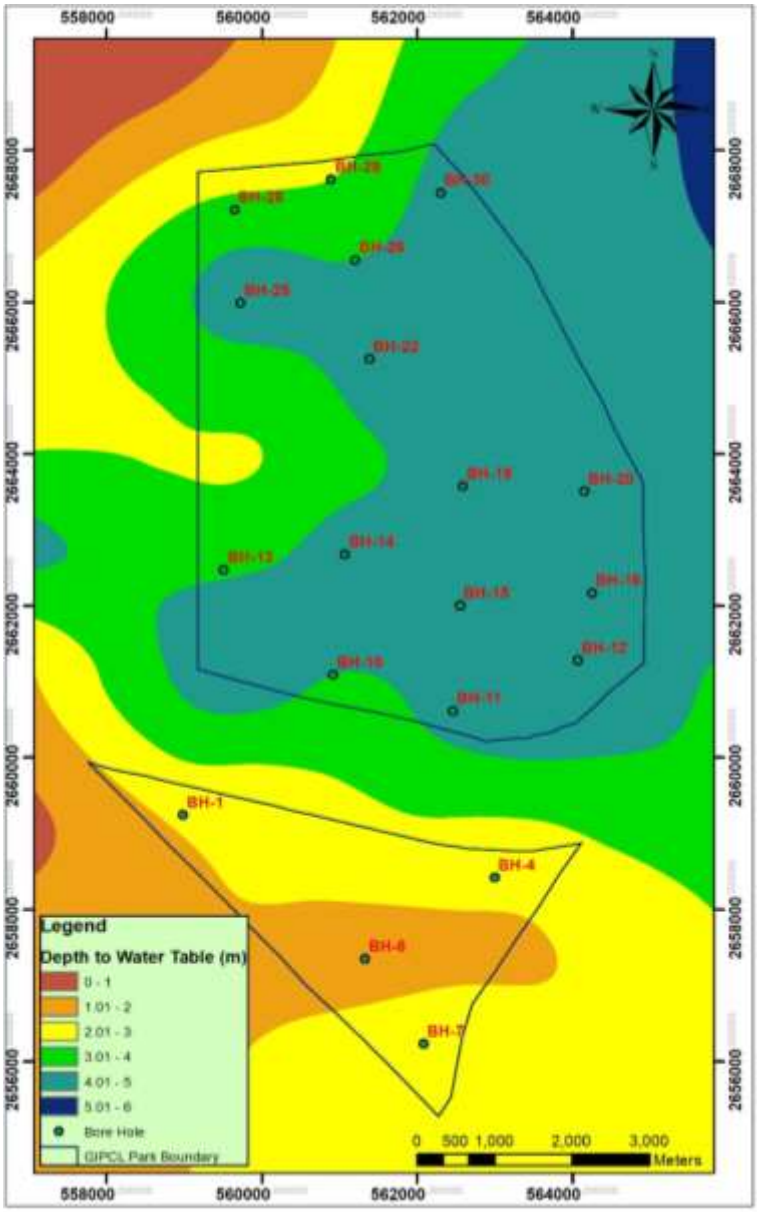


Figure 42: Depth to water level in the project site area

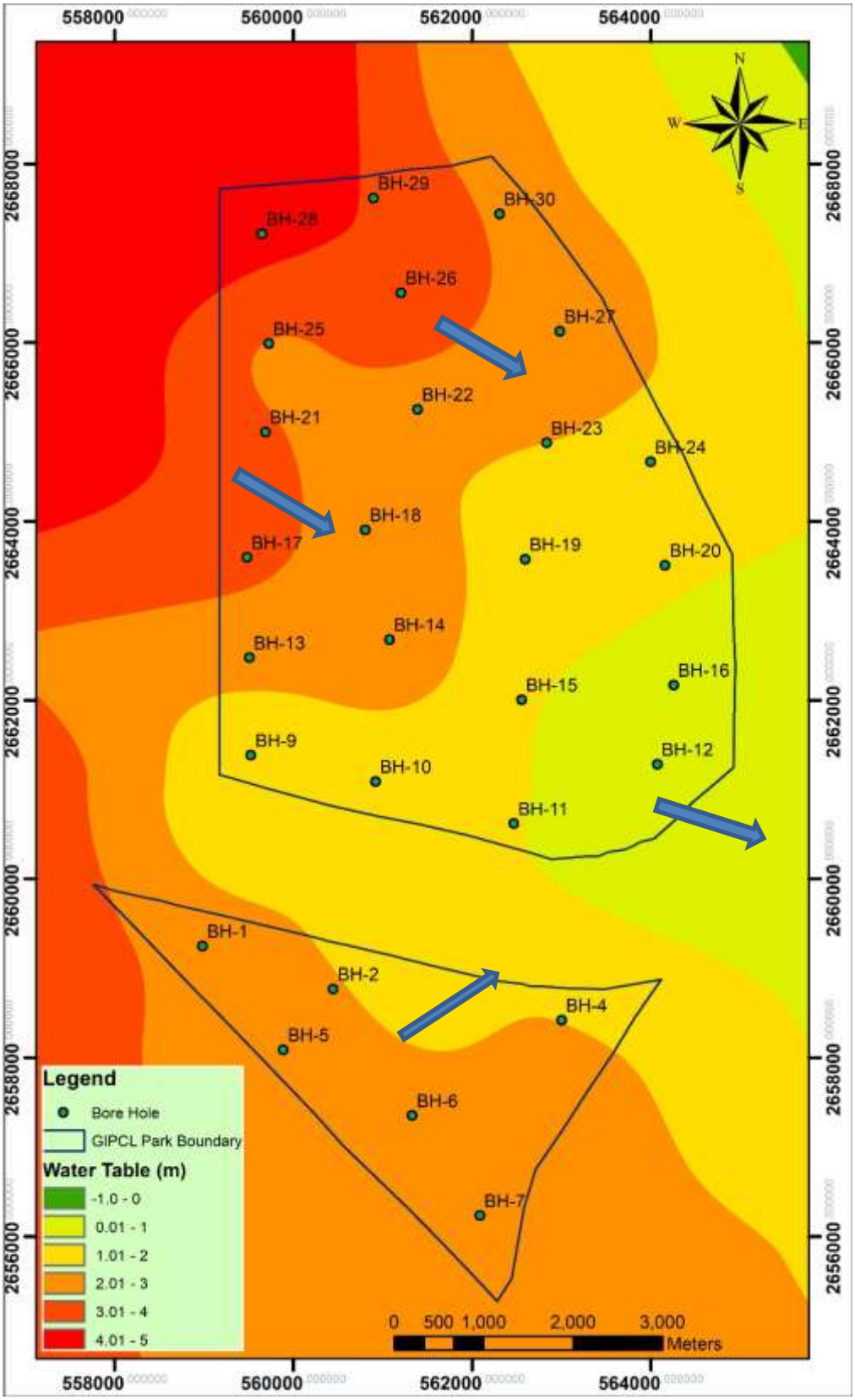


Figure 43: Water Table map of the project site area

(Blue arrows indicate general groundwater flow direction)

The Rann is reported to be flooded seasonally during the monsoon rains. During the Monsoon the western part of Great Rann is inundated by sea water which reaches as Far East as Kuar bet and Pachchham Island and foot hills of Kalo Dungar. Major part of the area is flooded annually due to rainwater and discharge from the rivulets and stream draining from the Kutch Mainland and Banni plains. It is also influenced by the intertidal creeks. Hence the area is an eco-sensitive zone showing predominantly marine influence. Owing the impervious nature of the Rann Clays, it takes several months to become dry again. The low-lying portion of the Rann remains permanent wet with salt encrustation layer.

13.2 Groundwater Quality

The quality of ground water in the area has been determined in 19 borewells drilled. Groundwater in the area is very saline with TDS in the range of 99,000 mg/L to 108,000 mg/L (***Table 17***).

Table 17: Water quality of groundwater in the project site area

Sr. No.	Bore Hole	pH	TDS (mg/L)	Nitrate (mg/L)	Sulphate (mg/L)
1	BH-1	6.81	108,520	7	2,181
2	BH-4	6.72	107,321	5	2,262
3	BH-6	7.00	108,521	5	4,032
4	BH-7	6.62	107,852	7	3,528
5	BH-10	7.05	102,641	5	2,632
6	BH-11	6.71	107,493	8	2,305
7	BH-12	6.92	105,241	5	3,064
8	BH-13	6.81	103,210	6	3,236
9	BH-14	6.53	108,361	8	2,218
10	BH-15	6.61	105,211	5	2,205
11	BH-16	6.52	105,923	6	2,854
12	BH-19	6.58	106,852	7	2,157
13	BH-20	6.55	103,794	5	3,125
14	BH-22	6.82	99,871	6	2,987
15	BH-25	7.01	106,194	8	2,635
16	BH-26	6.73	107,932	7	2,197
17	BH-28	6.65	108,126	6	2,152
18	BH-29	6.59	107,623	7	2,105
19	BH-30	7.02	106,321	10	2,595

TDS distribution in the area is shown in the ***Figure 44***. The data indicates high TDS and Sulphate values. Nitrates are low and are within acceptable limits.

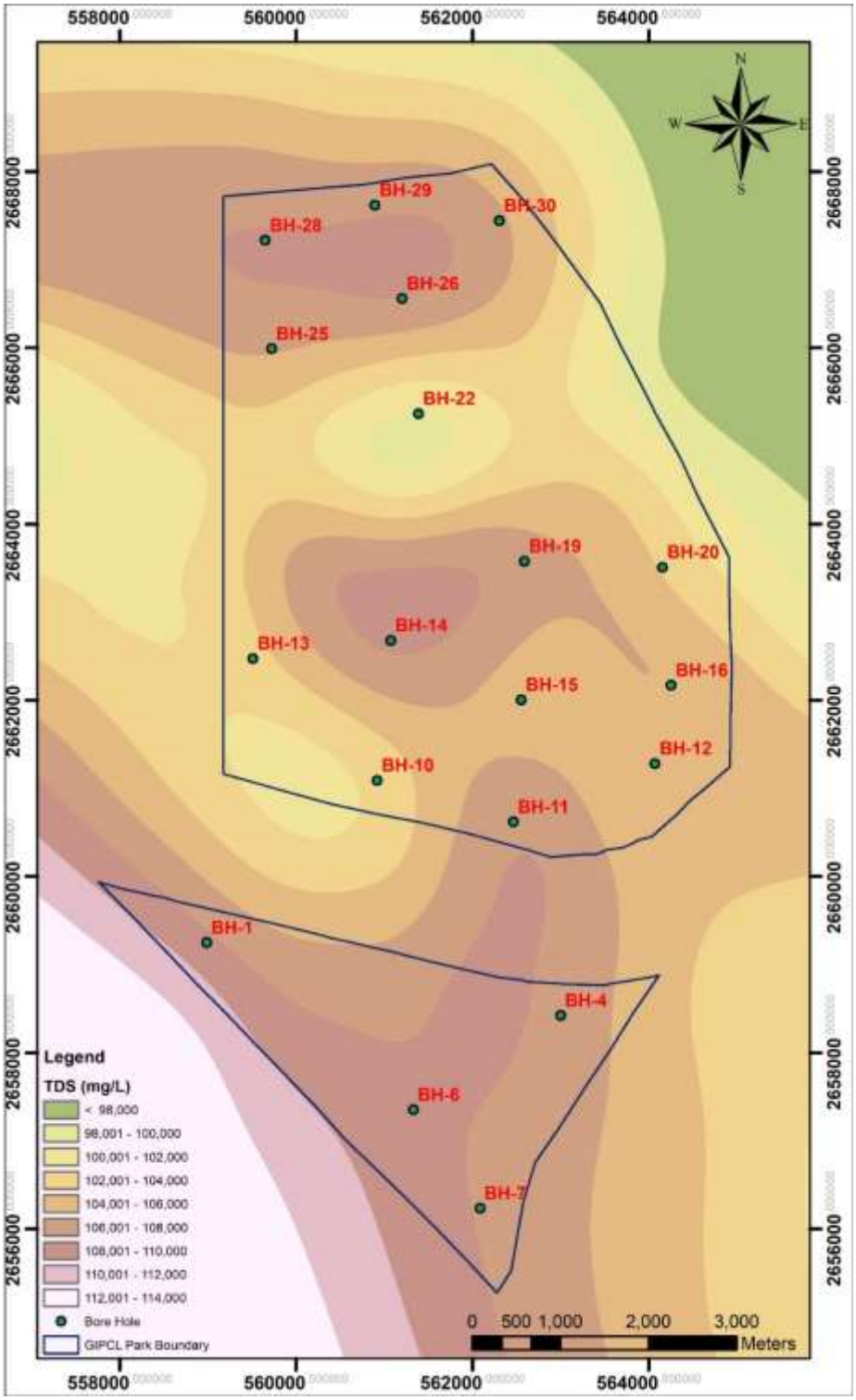


Figure 44: TDS variation in the GIPCL RE Park area

13.3 Resistivity survey

Geophysical survey is ground-based physical sensing techniques used for mapping of subsurface geology. One of the geophysical methods used in the study was surface electrical resistivity to measure the physical properties of the subsurface, along with the anomalies in those properties.

Resistivity surveys have proven to be one of the most useful geophysical techniques in groundwater investigation. In Resistivity method, a known electrical current (I) is sent into the ground through a pair of electrodes (current electrodes) and the potential (V) developed due to this current is measured across two other pair of electrodes (potential electrodes).

The survey was carried out by M/s Unique Engineering Services, Gandhidham using Wenner's configuration of electrodes.

In Wenner's Configuration four electrodes A, B, M, and N are placed at the surface of the ground along a straight symmetrically about a point O. The observation point in such a way that the distance between AM = MN =NB = a, where 'a' is called electrode separation (***Figure 45***). The current 'I' is sent generally through outer electrodes A and B and the potential difference (V) is measured between M and N. The configuration factor (K) for this array is K = 2πa and apparent resistivity, which is used for further analysis, is calculated with the formula:

$$a = KR = 2\pi aR$$

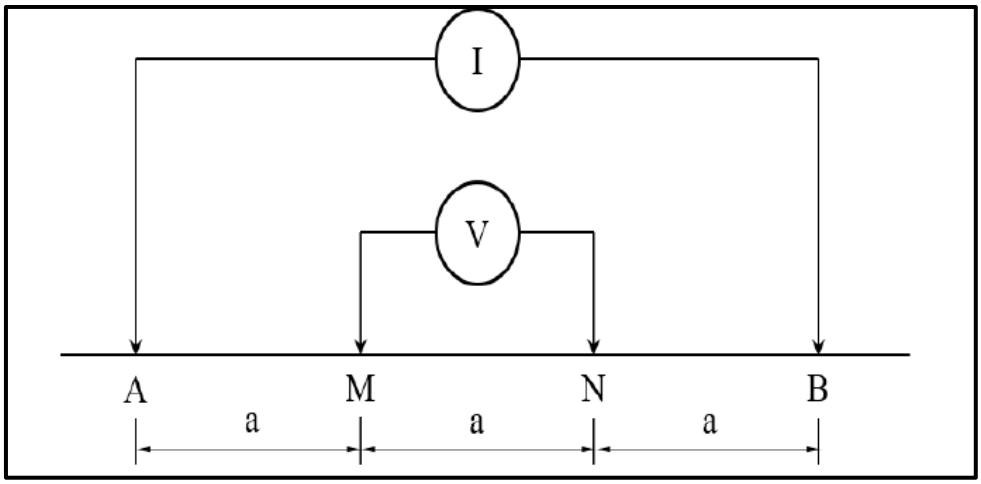


Figure 45: Wenner's Configuration for resistivity measurement

Apparent resistivity was measured at 15 locations (***Figure 46***).

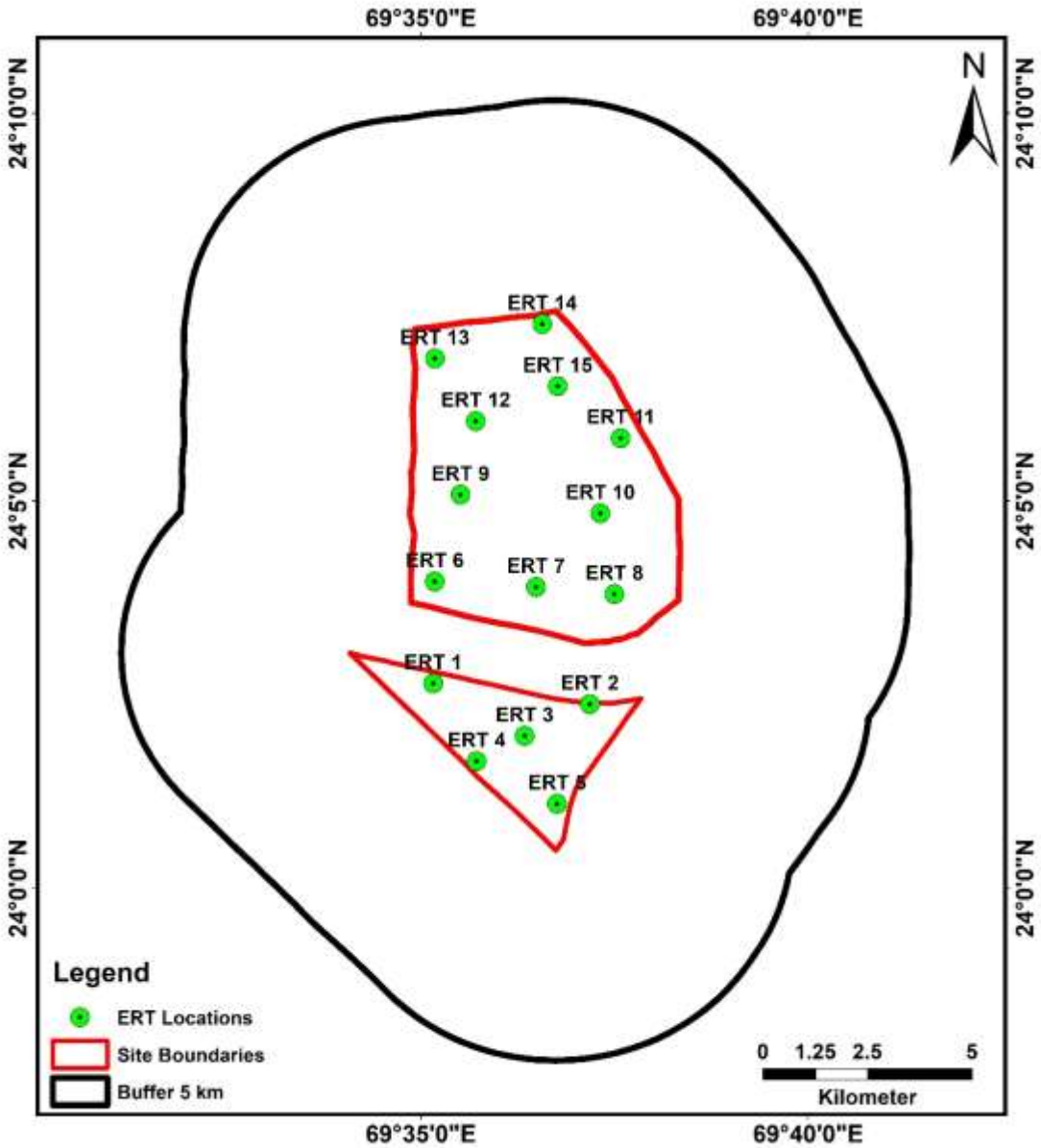
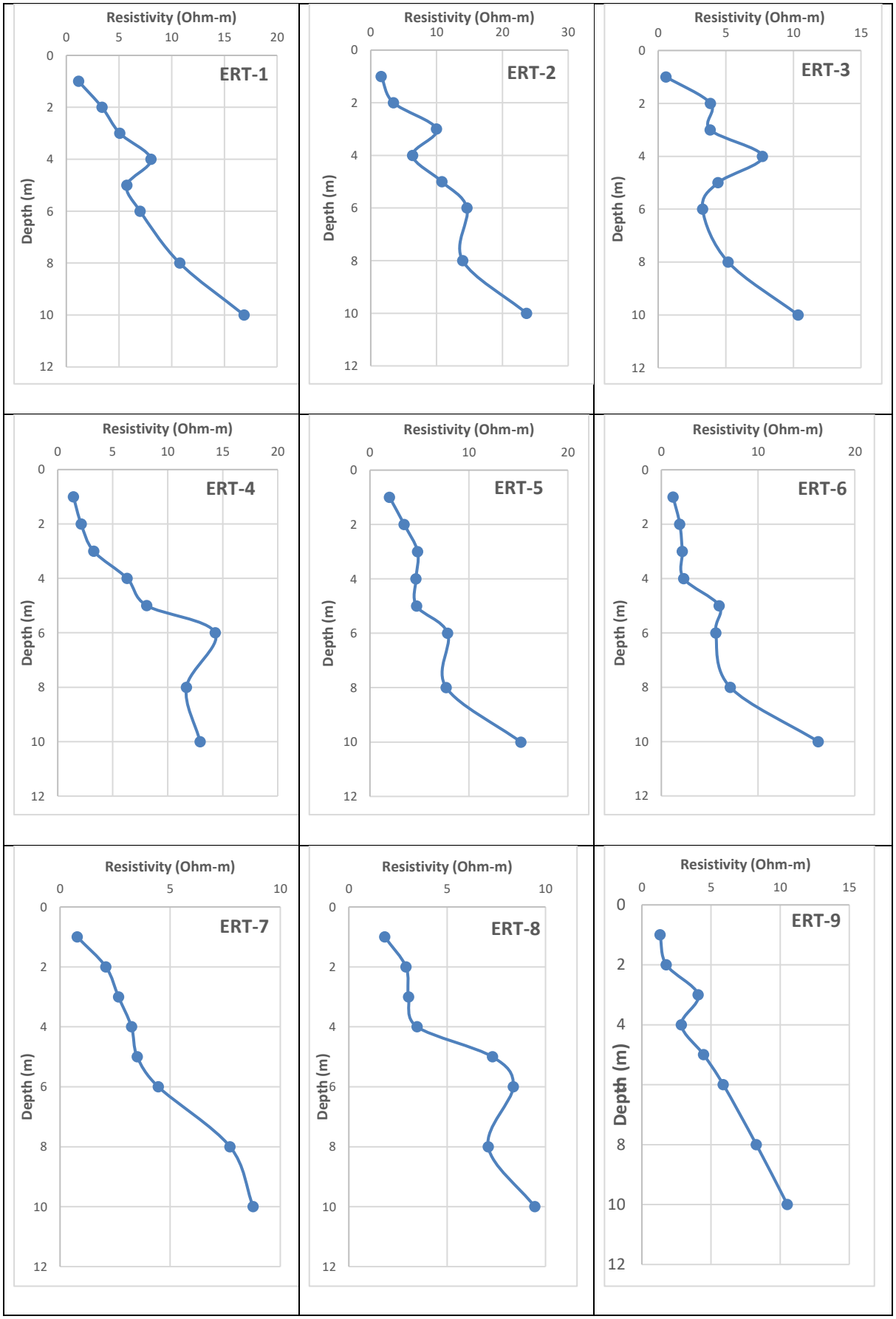


Figure 46: Location map of resistivity measurement sites

Apparent resistivity values with depth are tabulated in ***Table 18*** and are plotted in ***Figure 47***. The resistivity data shows apparent resistivity values generally lower than 10 and maximum upto 20 ohm-m, which indicates presence of clayey soils / highly saline soils/ saline water. The resistivity results match with the finding obtained from borehole drilling.


ERT-1
ERT-2
ERT-3
ERT-4
ERT-5
ERT-6
ERT-7
ERT-8
ERT-9
Resistivity (Ohm-m)
Depth (m)

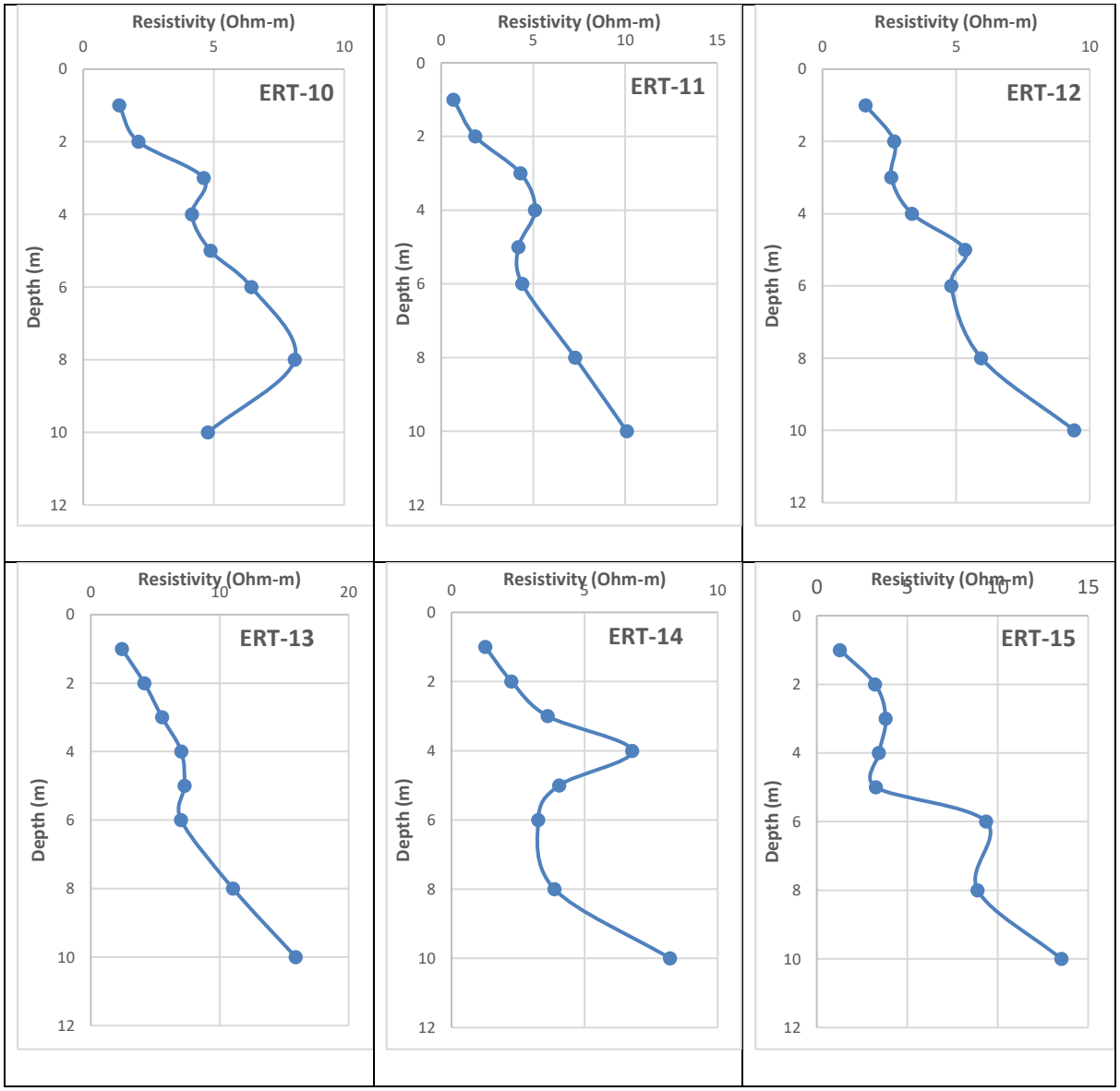


Figure 47: Apparent Resistivity with depth at various locations

Table 18: Apparent resistivity measured at various locations

No.	Latitude	Longitude	Depth (m)							
			1m	2m	3m	4m	5m	6m	8m	10m
ERT 1	24.0440	69.5860	1.161	3.390	5.075	8.024	5.741	7.003	10.757	16.870
ERT 2	24.0396	69.6197	1.604	3.453	10.009	6.359	10.816	14.618	13.974	23.672
ERT 3	24.0327	69.6056	0.589	3.870	3.850	7.716	4.422	3.289	5.177	10.352
ERT 4	24.0273	69.5953	1.425	2.127	3.266	6.308	8.097	14.316	11.699	12.943
ERT 5	24.0182	69.6126	1.982	3.465	4.821	4.656	4.720	7.860	7.716	15.252
ERT 6	24.0660	69.5863	1.214	1.916	2.168	2.318	5.985	5.636	7.125	16.226
ERT 7	24.0648	69.6081	0.779	2.080	2.653	3.242	3.503	4.458	7.716	8.765
ERT 8	24.0632	69.6250	1.828	2.906	3.035	3.475	7.304	8.360	7.087	9.456
ERT 9	24.0846	69.5918	1.318	1.769	4.072	2.859	4.469	5.890	8.281	10.524
ERT 10	24.0806	69.6219	1.376	2.114	4.613	4.166	4.877	6.437	8.105	4.775
ERT 11	24.0968	69.6263	0.669	1.857	4.312	5.102	4.202	4.401	7.276	10.085
ERT 12	24.1004	69.5951	1.613	2.689	2.576	3.349	5.341	4.825	5.944	9.425
ERT 13	24.1139	69.5863	2.410	4.147	5.528	7.025	7.265	7.003	11.033	15.896
ERT 14	24.1213	69.6094	1.268	2.253	3.610	6.792	4.045	3.261	3.870	8.215
ERT 15	24.1080	69.6128	1.277	3.226	3.812	3.443	3.267	9.359	8.897	13.525

14 FRESH WATER AVAILABILITY

As per CGWB reports, only Pachchham Island is the only fresh water source near to the buffer zone from project boundary (***Figure 48***). The Pachchham Island lies at a distance of approximately 15 km from the project boundary. Geological formations of the Pachchham Island belongs to the Tertiary System of Mesozoic Period.

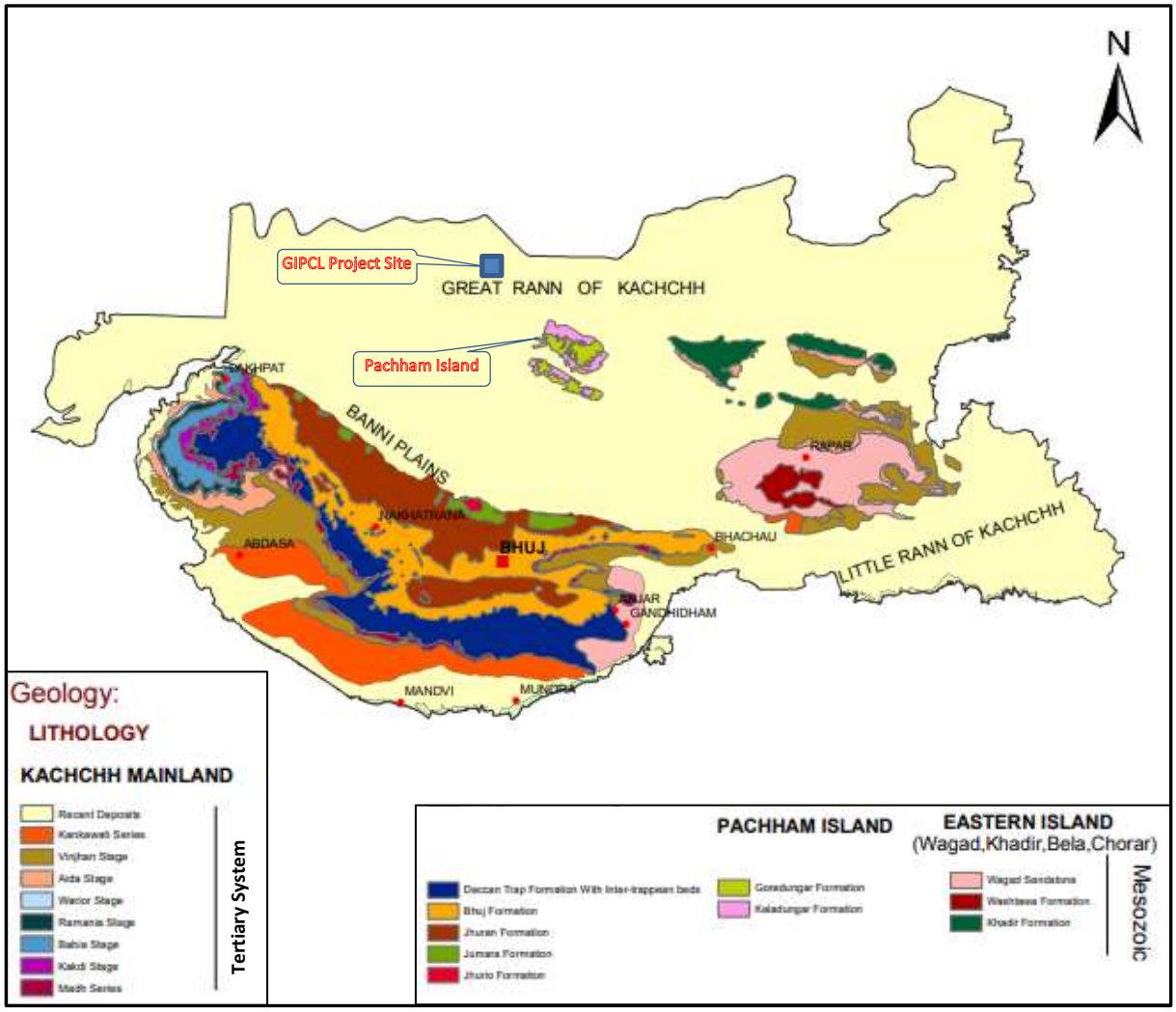


Figure 48: Proximity of fresh water source GIPCL RE Park area

The sediments belonging to Mesozoic period include both marine and non-marine sedimentary formations. The rocks of this series consist of yellow and greyish coloured sandstone, shale, and fossiliferous. Limestone and represent marine sedimentary sequence. The groundwater occurs under water table and confined conditions in the sandstone/shale sequence belonging to this group.

The semi-consolidated sandstone exposed in the lower reaches forms phreatic aquifer and is being developed locally for domestic and irrigation purposes. The dug wells tapping this aquifer ranges in depth from 10 to 24 m below ground level (m bgl) whereas the depth to water level during summer varies from 15 to 20 m bgl. Their yield varies from 50 to 175 m^3/day. The quality of groundwater is potable to slightly brackish near Rann and lower reaches while the deeper groundwater is saline.

14.1 Groundwater regime in nearby area

Hydro-Geologists of the Indian Geomatics Research Institute have carried out Well Inventory Survey to check nearby freshwater potential sites and hydrological conditions of the area.

One Artesian Well found in the valley of Kalo Dungar is constantly overflowing on the surface due to enough pressure in the aquifer. Artesian well is locally known as Samdha Vav. The coordinates of the well are 23°51'32.2"N latitude and 69°48'54.8"E longitude. Maldhari resident's uses artesian well water for drinking purpose of humans and also of animals.

The nearest fresh ground aquifer from the proposed project site is approximately 15 km in South East direction near Khavda in Pachham island. Water level in the area is around 9 m. The quality of the water is good and most of the parameter fall within permissible limits except fluoride which was found to be slightly above permissible limits.

14.2 Surface water availability

There is no perineal stream flowing through the RE Park or its 5 km buffer area. Also, there is no reservoir at 3-5 km from the plant. Nearest fresh water source is Bandi River which is located at 10-12 km south east of the RE Park area (***Figure 49***). Bandi River originates from the Kalo Dungar hills and through the Khavda village. Two small reservoirs have been created on the river and its tributary to store water.

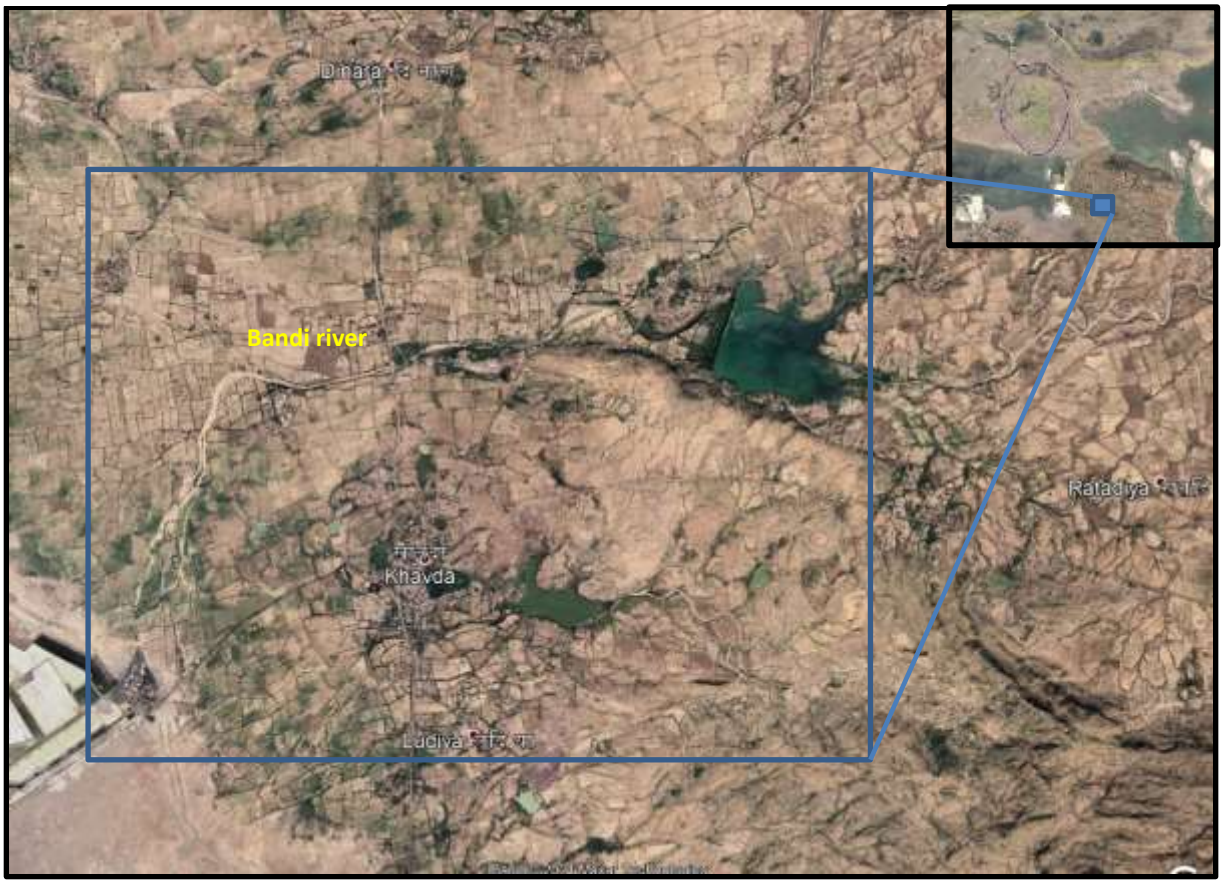


Figure 49: Bandi River vis-à-vis RE Park

As per information from the local people, Bandi river is not a perineal river and flows only during Monsoon season. The water from the river may not be enough to meet the fresh water requirement of the RE Park.

14.3 Fresh water from desalination of groundwater

The total freshwater requirement of the RE Park is 3.1 MLD or 31 or 3,000 m^3/day. As fresh surface water and groundwater are not available in the RE Park area or in the 5 km vicinity of the Park, possibility of obtaining fresh water through desalinization of saline groundwater has been explored.

Considering the recovery of 70% fresh water from saline groundwater, approximate 4.5 MLD of saline water is required.

Saline water can be pumped by installing tubewells. Location and depth of tubewells may be determined detailed geophysical / geological investigations.

As the saline groundwater is locally available, only one day storage of saline water has been considered.

Dimensions of water storage reservoirs

Total saline water to be stored = 4500 m^3

Volume = Length (L) x Width (W) x Height (H)

As the groundwater is shallow (<5 m), the maximum depth considered for the reservoir is 4.5 m.

So the area of reservoir for storage of saline water = 4500/4.5 = 1000 m^2.

Therefore, dimensions of the saline water storage reservoir = 40 X 25 X 4.5 m.

Fresh water from the desalinization plant may be transferred to the 24 plots, where the water can be stored in small tanks / ponds. Size for storing fresh water for each plot for 2 days is calculated below:

Water to be stored for days at each plot = 2 days * (3.1 MLD /24 Plots)

= 0.258 Million liter = 258 m^3

Dimension of the Pond / Tank = 8 m X 8 m X 4.5 m

Disposal of concentrate:

Brine disposal is an environmental problem that should be considered while installing a desalination plant. In most cases, the easiest way to get rid of the important brine flow is to discharge it in the sea via a brine outfall pipe. Brine concentration has a much higher density than seawater and therefore tends to fall on the sea floor near the brine outfall outlet (plume effect), creating a very salty layer which can have negative impacts on the flora and the marine life and any related human activities. To avoid the plume effect, the brine outfall should end within a strong sea current to aid mixing the brine with seawater.

There various methods available to dispose concentrate includes dispose to surface waters (in creek, tidal rivers), deep well injection, land application,

evaporation ponds and zero liquid discharge. The most suitable methods are zero liquid discharge and evaporation pond for the present study area.

The waste water or brine concentrate needs to be disposed of in a safe area to minimize the impact of the surrounding aquatic life and fauna etc. as per the guidelines.

15 ESTIMATION OF WATER EQUIREMENT

Water in the RE Park is required for human consumption, cleaning of solar panels and other miscellaneous activities.

15.1 Water requirement for human consumption

As per plan, GIPCL divided the area into 24 plots, each for generation of 100MW power. It is estimated that 15 persons will work for the maintenance of the one plot. As per Estimation of Water Requirements for drinking and domestic use, National Building Code 2016, BIS approx. 150 liters (*l*) of water is required per head per day. Considering the same value for total requirement for a single plot.

15 persons x 150 *l/d* = 2250 *l/d* water would be required.

Assuming 300 working days, maximum storage requirement of any water tank.

Domestic water requirement per year per plot = 2250 *l* x 300 days=675,000 *l*.

Total annual water requirement for 24 plots = 675,000 X 24 = 16,200,000 *l*.

Daily water requirement for Domestic usage = 16,200,000 / 365 = 44,384 *l/d.*

15.2 Water requirement for cleaning of solar panels

Water requirement for cleaning panels (and its frequency) mainly depends on the location of the installation. Roughly 9,000 to 15,000 liters (average 12,000 liters) of water is required for cleaning 1 MW power solar panels per wash. This range is huge because the location of the site and its surroundings plays a crucial role.

If the site in a very dusty (near desert) location, it may require more water to clean such panels and vice versa. Usually, the cleaning frequency may be 2 times a month.

As per plan of GIPCL 2400 MW capacity solar panels are to be in the RE Park in Rann of Kutch. Total water requirement has been calculated as:

Total annual water req. = 2400 (MW) X 12,000 (liter) X 2 (cycle/month) X 12 (months) = 691,200,000 liter = 691.2 million liter

Water requirement per day = 691,200,000 / 365 = 1,893,699 litre

The RE Park area of the GIPCL shall be divided into 24 plots of 100 MW each. Water requirement for each plot per day = 1,893,699 / 24 plots= 78,904 liter

15.3 Total water requirement during O&M stage

Total water requirement during O&M stage of the RE park shall include the requirement for domestic usage, solar panel cleaning and for other miscellaneous purposes. In the present study, water requirement for miscellaneous purposes is assumed to be 10% of the daily domestic water requirement.

Total water requirement per day per plot = 44,384+4,438+78,904

= 127,690 l/d

Total water requirement for RE Park = 127,690 X 24

= 3,064,560 l/d

= 3.1 MLD

Therefore, 3.1 MLD water is required for O&M of the GIPCL RE Park.

16 RAIN WATER HARVESTING

Rainwater harvesting (RWH), in its broadest sense, used for collecting and storing rainwater for human use from rooftops, land surfaces or rock catchments. As RWH is neither energy intensive nor labor- intensive, it can be a cost-effective alternative to other water-accruing methods. RWH is a technically feasible solution for overcoming the problem of water scarcity in cities and rural areas. Water from harvested rainfall may also infiltrate, thus recharging the aquifer. The water is stored in the aquifer, from where it can be retrieved for future use. RWH is considered a reliable solution for augmenting groundwater level to attain self-sufficiency in public distribution of water in drought-prone areas. In this context, rooftop RWH can become a popular technique to improve the storage and recharge of water. Proper recharge of harvested water can augment the ground water storage and increase the ground water level. It would also reduce the wastage of water due to surface runoff.

The application of appropriate RWH technology is important for the utilization of rainwater as a water resource. Among the various alternative technologies to augment freshwater resources, RWH and its utilization is a decentralized, environmentally sound solution, which can avoid many environmental problems often caused in conventional large-scale projects using centralized approaches. Typically, once an industrial unit is constructed, the paved surface area increases and infiltration/percolation area decreases. It has been reported that surface runoff can increase from 10% to 55% and infiltration volume can decrease from 50% to 15%. This causes two types of problems, e.g., (i) lowering of the groundwater table due to less recharges, and (ii) increase in localized flooding. If designed properly good RWH system can address both the issues.

16.1 Components of RWH System

Typically, a RWH system consists of three basic elements: the collection system, the conveyance system and the storage system.

Collection systems

Collection systems can vary from simple types within a household to bigger systems where a large catchment area contributes to an impounding reservoir from which water is either gravitated or pumped to water treatment plants.

The catchment of a water harvesting system is the surface, which directly receives the rainfall and provides water to the system. It can be a paved area like a terrace or courtyard of a building, or an unpaved area like a lawn or open ground. A roof made of Reinforced Cement Concrete (RCC), galvanized iron or corrugated sheets can also be used for water harvesting.

The runoff can be estimated by the following formula.

Runoff = Catchment Area × Runoff Coefficient for different catchment surfaces. Runoff Coefficients for various catchment surfaces are given in **Table 19**.

Table 19: Runoff coefficients for various surfaces

Type of Catchments	Runoff Coefficients
Roof Catchments Tiles Corrugated Metal sheets	0.8-0.9 0.7-0.9
Ground surface coverings: Concrete Brick pavements	0.6-0.8 0.5-0.6
Untreated Ground Catchments: Soil on slopes less than 10% Rocky natural catchments	0.0-0.3 0.2-0.5
Green Belt	0.05-0.1

Conveyance system

Conveyance system or conduits are the pipelines or drains that carry rainwater from the catchment or rooftop area to the harvesting system. Conduits can be of any material like Polyvinyl Chloride (PVC) or Galvanized Iron (GI), materials that are commonly available.

Storage Structures

Storage tanks may be constructed with respect to the shape, size and the material of construction. Rainwater may be charged into the groundwater aquifers through any suitable structures like dug wells, bore wells, recharge trenches and recharge pits.

16.2 Rainwater Harvesting Plan

The water harvesting potential of storm water is the amount of water that can be efficiently harvested from the total amount of water that is received in the form of precipitation over an area. This is influenced by catchment type and climatic conditions such as rainfall, and its pattern. Land use pattern after setting up of the solar park. As discussed above, average annual rainfall in the area is around 349 mm. The LULC after establishment of RE Park is given in **Table 6**.

Out of the total land of 4,750 ha, roof-water harvesting system can be implemented in the area under infrastructure. It can be seen from the **Table 6.** The estimated RWH potential as per estimated LULC after establishment of RE Park is given in **Table 20**.

Table 20: Annual RWH potential for GIPCL RE Park Area

LULC	Area		Average Rainfall	Runoff Coefficient	Runoff Potential
	Ha	*m^2*	*(m)*		*(m^3/yr)*
A) Infrastructure					
Building area	1.50	15000	0.349	0.75	3,926.25
Open / Green Belt	0.50	5000	0.349	0.30	523.50
Sub Total (A)					4,449.75
B) Area under Solar Park					
Area covered under solar panels	1,330	13300000	0.349	0.85	3,945,445.00
Roads / paved area	266	2660000	0.349	0.60	557,004.00
Open Area	400	4000000	0.349	0.30	418,800.00
Sub Total (B)					**4,921,249.00**
C) Total undisturbed area	2752	27520000	0.349	0.31	**2,497,164.80**
Total (A+B+C)					***7,903,087.75 =7.423 * 10^6***

Total annual RWH potential of GIPCL RE Park is estimated to be $7.906*10^6$ m^3/yr or 7.423 Mm^3.

The suitable design for RWH structure has to be prepared based on the basis of monsoon rainfall, LULC and hydrogeology of the area. The maximum rainfall observed in a day for the area is 246.7 mm (***Table 8***). It means that the average hourly rainfall intensity is approximately 10.3 mm. But, there is large variation in the rainfall intensity and number of rainy days in the area. ***Table 21*** shows the average rainfall during each rainy day in monsoon months (IMD, 2020).

Table 21: Number of rainy days & rainfall intensity in Kutch area

Month	Rainy Days	Average Rainy days	Average Rainfall (mm)	Average rain per rainy day (mm)
June	2 to 3.98	3	36.0	12.0
July	7 to 9.42	8	142.8	17.9
August	5 to 8.13	7	93.2	13.3
September	2 to 3.98	3	57.6	19.2
Annual	***22 to 28.7***	***25***	***349.0***	***14.0***

For this study daily annual monsoon rainfall of 14 mm/d has been used to calculate the volume of water generated from the RE Park per day (***Table 22***). The total water generated from the RE Park area comes out to be about $0.317*10^6$ m^3/d. The water collected from the RWH can be utilized for domestic activities, plantation and cleaning and washing etc.

Table 22: Maximum daily RWH potential

LULC	Area		Average Rainfall	Runoff Coefficient	Runoff Potential
	Ha	***m^2***	***(m/d)***		***(m^3/d)***
A) Infrastructure					
Building area	1.50	15000	0.014	0.75	157.50
Open / Green Belt	0.50	5000	0.014	0.30	21.00
Sub Total (A)					***178.50***
					B) Area under Solar Park
Area covered under solar panels	1330	13300000	0.014	0.85	158,270.00
Roads / paved area (20% of Solar Panels)	266	2660000	0.014	0.60	22,344.00
Open Area (30% of solar panel area)	400	4000000	0.014	0.30	16,800.00
Sub Total (B)					**1,97,414.0**
C) Total undisturbed area	2752	27520000	0.014	0.31	**119,436.80**
Total (A+B+C)					***317,029.30 ≈0.317 X 10^6***

16.3 Rainwater Harvesting Structures

Artificial structures can be constructed for the storage of rain water in small tanks as per the plotting of the Solar Park. This would provide every individual plot enough of freshwater for their domestic activities and gardening purpose.

As the area is water deficient, it is advisable to collect every drop of water. Therefore, it is proposed to construct RWH structures considering the storm of 2 days during monsoon season. Therefore, structures have been proposed to collect water available in 2-days, i.e., 2*0.317 =0.634 Mm^3.

Since, the groundwater is shallow in the RE Park area of GIPCL, it is proposed to construct 1 pond for each plot, so that depth of the pond may be kept above the water table.

16.4 Rainwater Recharge to Groundwater

The selection of a suitable technique for artificial recharge of ground water depends on various factors, which includes:

a) Quantum of non-committed surface runoff available.
b) Rainfall pattern
c) Land use and vegetation
d) Topography and terrain profile
e) Soil type and soil depth
f) Thickness of weathered / granular zones
g) Hydrological and hydro-geological characteristics
h) Socio-economic conditions and infrastructural facilities available
i) Environmental and ecological impacts of artificial recharge scheme proposed.

The main water bearing formation of the area is clay / silt which mostly have poor permeability.

To manage the ground water resource properly, artificial recharge to ground is recommended in the areas where groundwater table is >3m below ground level.

Due to low permeability of the soil, rain water recharge through recharge well does not seem feasible, however if any new technology is available then it should be explored on the experimental basis.

Further, due to the saline nature of the soil of Rann area the rainfall runoff may not be suitable for rainwater recharge.

17 WATER MANAGEMENT

Based on the hydrological investigations and field visit, it was found that the proposed area for RE Park of GIPCL has shallow groundwater table with desert soils. The field investigation and stream network generated based on DEM reveals that proper attention is required to be given for the selection of the proposed hybrid solar park site where the site area found normally with gentle slope so that runoff water can be dispose of safely. It has also been confirmed that the storm water from the proposed project site can be tapped and diverted to nearest RWH tank through natural streams (***Figure 50***).

Based on the hydrological assessment, it is understood that the site is selected as independent zone and not having any catchment from the upstream directions. Hence, the runoff estimations are considered only within the site boundary. Since, the historical river course lines are not protruding into the site, the chances of flood from the nearby areas into the site is very minimal. Hence, the flooding of site will take place only through the runoff generated within the site during rainy days. In order to avoid the flooding situations, a storm water management model can be planned by constructing suitable storm water drainage network system in the proposed site as well as some suitable safety measures should be taken during the installation of the hybrid power system. For example, the details of the storm water drainage network and possible location of RWH tanks/ponds are presented in the ***Figure 50***.

Depends on the local constraints, soil and water conservation engineering measures such as tanks/ponds, bunding, contour stone wall and vegetative filter strips may be constructed in the project area. In order to divert the outside runoff into the site along the margin of the site boundary a storm water drain can also be planned.

The size of the drains/bunds should be decided as per the requirement and local conditions (***Figure 51***). Water harvested shall have to be processed for desiltation before using for domestic or solar panel cleaning.

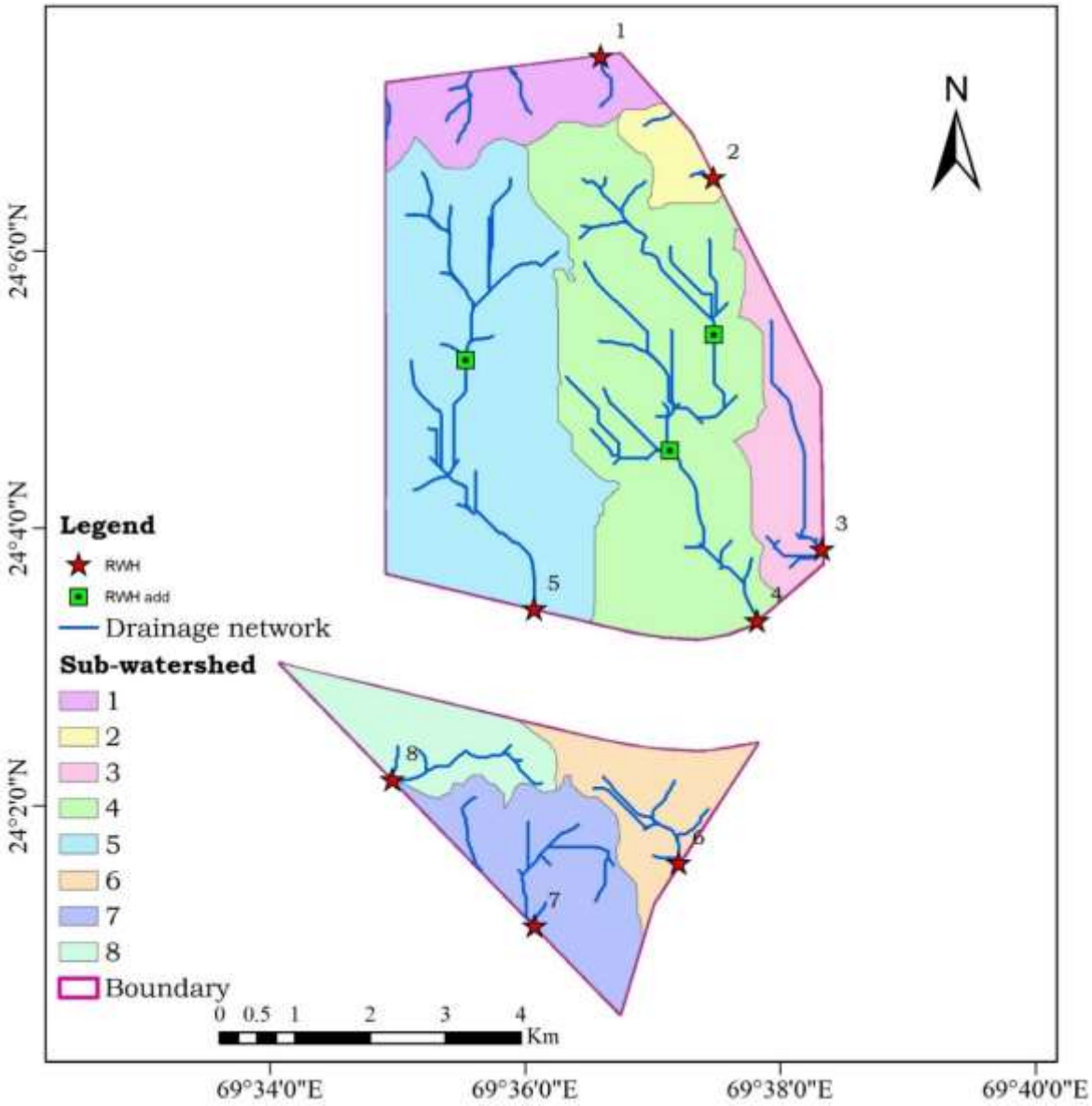


Figure 50: Storm water management and rainwater harvesting plan

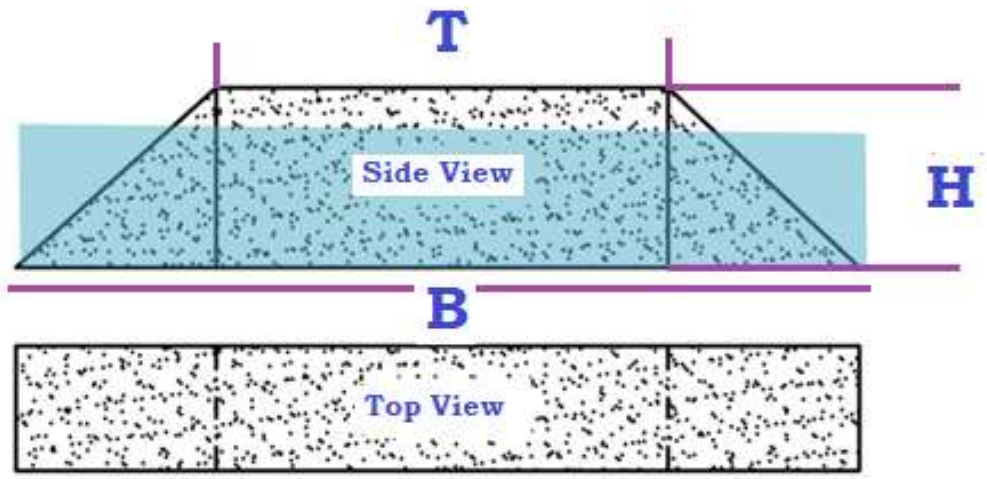


Figure 51: Tentative Design of the Bund

18 SUMMARY AND CONCLUSIONS

To study the hydrology and hydrogeology of the lease area of M/s GIPCL, various types of available data were analysed and field surveys were conducted including topography survey, well inventory etc.

Location:

- M/s GIPCL has been allocated an area of 4750 ha falling between 69°34'5.329" to 69°38'20.829" E Longitudes and 24°00'29.002" to 24°07' 24.235" N Latitudes in Great Rann of Kutch, District Kutch, Gujarat. Project Site is located around 12 to 15 km in south / southwest direction from Indo-Pak International border.
- The area is divided into 2 parts by Khavda-Vighakot road. Most of the area is mostly vast mud flats and is devoid of any major drainage system.

Topography:

- The project area is almost flat with elevation ranging from of 3.5 m to 9.0 m amsl. In general, the northern part is higher and is very gently dipping slopping towards south. The high grounds devoid of flooding are called island bets.

Climate:

- The 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.
- Long-term average annual rainfall for Bhuj IMD station is 378.2 mm. More than 95% rainfall occurs during the monsoon months of June to September. The number of rainy days varies between 20 and 30 or even less and coefficient of variation of rainfall is between 30 and 70%.

Soil properties:

- Mostly the soils are silty clay but few pockets / lenses of silt, silty - clayey sands are also observed. It is very fine silt clay varying in colour from yellow, yellowish brown to black colour at different location.
- The permeability value is quite low and allows restricted vertical infiltration of water into the ground.

Hydrogeology:

- The study area is located mostly in the Rann clay formation of Marine and Fluvio-marine origin.
- The geology is comprised of the alluvium (Quaternary sediments) comprising of brown loam, kankars, silt, clays, sand, and gravel.

LULC:

- The predominant land use of the project site is barren land (also called Rann) with scanty vegetation of arid grassland ecosystem (i.e. Banni grasslands).
- Most of the area surrounding the projects site is mud flats dry salt playa, scrubs and non-perineal seasonal drainage network. There is apparently only one road passing in between the two blocks of project site. Presence of Bet area indicates that there are few portion of the land which is above the flood level.

Flora and Fauna

- The predominant vegetation in the Rann of Kutch are grassland and thorny scrubs. Common grass species includes: *Apluda aristate*, *Cymbopogon spp., Eragrostis spp., and Elionurus spp., Cenchrus spp., Pennisetum spp.*
- Several large herbivores, including Indian wild ass 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*) are found in and around the project area.

Eco-sensitive zones:

- The project site does not have any eco-sensitive zone or wild life sanctuary.
- Project site is 47 km away from eco-sensitive zone of Chhari-Dhand and 53 km away from Flamingo City, and 23 km from Kala Dongar sanctuary. However, there is a small temporary Vulture resting area lying 2 km northeast of project site and 47 km southwest from project site.

Natural hazards and risks:

- The area is earthquake prone and many epicenters are located near project site. It falls in a seismic zone - V and is susceptible to very high higher damage risk (>MSK IX) of earth quakes.
- Allah Bund fault lies in the close vicinity of the project site.
- There is no record available on tsunami as well as no volcanic activity found in and around the project area.
- There are no rivers in Rann of Kutch, so there is no risk of flooding in the study area.

Meteorological analysis:

- The statistically analysis of rainfall (118 years) indicates that the site received average annual rainfall 348.9 mm.
- It was found that site receives extreme annual maximum daily rainfall of 246.7 mm in the month of August, 1979.
- IDF curves of the rainfall indicates that the maximum rainfall intensity of 88.8 mm/hr can be expected for a storm of one hour for 100 years return period.

Watershed analysis:

- The project site is located between the elevations 3.85 m to 8.75 m from mean sea level. Northern part of the project site area is higher in elevation than the southern part.

- The relationship between cumulative area (%) and elevation (m) of the project site suggests that the land is gradually sloping.
- Slope map indicates that all the area of the site comes within 4% slope.
- There are eight sub-watersheds found in the project area which drains outside the project area.
- There are very small streams and catchments found in the northern side of the project area. Therefore, surface runoff coming from these small catchments can be routed along the project boundary to a common outlet where suitable water conservation measures can be taken.
- In Block-1, no stream enters in the RE Park, whereas few streams enter the Block-2 from the northern side.

Runoff Potential:

- The total average annual surface runoff potential from the project site is estimated 2.5 Mm^3 (in terms of depth is 52.58 mm). The average annual surface runoff from Block-1 and Block-2 have been estimated 1.9 Mm^3 and 0.6 Mm^3, respectively.
- The maximum monthly runoff was occurred in the month of August (i.e. 458.59 mm) from the project area. This is the rare event found in the site over a period of 118 years.
- The peak runoff potential of each sub-watershed from a rainfall of 50 and 100 years return period may have potential to generate surface runoff of 5.2 m^3/s to 28.7 m^3/s and 5.9 m^3/s to 32.6 m^3/s, respectively.
- The engineering measures should be decided on the basis each sub-watersheds runoff potentials.

Flood risk analysis:

- There are no major dams/streams in the project site area. Flooding is not a major hazard faced by the District. All the river systems in the Rann of Kutch district are very low flooding, as captured in the Vulnerability Atlas. No major flood event record is available from the study area. River flooding is not a major hazard faced by the District.

- There is no risk from nearby water bodies to the GIPCL project site. It is also found that all the streams and tributary of channels/streams are flowing away from the GIPCL site.
- The High Flood Level had reached to the elevation of 2.4 m to 2.7 m during the earlier year of 1984 and 1992 in Rann of Kutch, whereas in 2019 and 2020, it was at approx. 1.5 m. On an average the flood level in Rann is 1.5 m amsl. The RE Park land has minimum elevation 3.88 m amsl. Therefore, there is no risk of flooding from external water bodies.
- The study results show project area will be prone to temporary water impoundment during peak rainfall. However, appropriate arrangement of drainage structures will not create impounding in the project area.

Soil erosion & Sediment deposition:

- The soil erosion estimated by using RUSLE indicated that 55% area is under moderate erosion class, whereas 32.87% area falls under the slight class erosion zone.
- The average annual soil loss within the site is found to be 9.96 t ha^{-1} y^{-1}, while gross soil erosion is estimated to be 47,316 tonnes and sediment yield has been found to be 10,410 tonnes.
- It is revealed that treatment of soil conservation with the help of runoff potential will be a key factor for excellent watershed management in the project areas.
- Depending upon priority levels, the watershed area should be treated with suitable vegetative and structural measures.

Groundwater assessment:

- Groundwater in the area lies at the depth of 2 to 5 m from the ground surface.
- Groundwater flow direction in Block-1 is from NW to SE. In Block-2, the flow direction is from SW to NE.
- Groundwater is highly saline with TDS of approximately 100,000 mg/l.
- No tube well exists within 5 km radius of project site.

- Rainwater recharge is not feasible at the project site due to inherent salinity and clayey soil type.
- Low values of apparent resistivity indicate presence of highly saline and conductive zones. Results of the subsurface study area confirms the presence of highly saline water at shallow depth.

Freshwater availability and Requirement:

- Pachchham Island is the nearest fresh water source near to the project boundary area and is approximately 15 km away from the site.
- There is a presence of 3 artesian wells surrounding 20 km radius of the project site namely Gainda, Khardoi and Kala Dungar.
- The water quality was found to be potable with most of the parameters falling with the permissible limits except fluoride, which was found to be slightly above permissible limit from the sample collected from Kalo Dungar well.
- Only surface water source near the RE Park area is seasonal Bandi River. Water in the river may not be sufficient to meet the fresh water requirement.
- Total daily freshwater requirement of the project is 3.1 MLD.

Rainwater harvesting potential:

- Out of the total land of 4,750 ha, about 2 ha shall be under infrastructure (workshop, administrative building etc.), 1330 ha under solar panels 266 ha under roads and pavements, 400 ha open area and 2752 ha undisturbed area.
- Total annual rainwater harvesting potential of GIPCL RE Park is estimated to be $7.907*10^6$ m^3/yr or 7.907 Mm^3.
- Average daily monsoon rainfall of 14 mm/d is used to calculate daily volume of water generated from the RE Park. The total water generated from the RE Park area comes out to be about $0.317*10^6$ m^3/d. The water collected from the rainwater harvesting can be utilized for domestic activities, plantation and cleaning and washing etc.

Rainwater harvesting structures:

- Artificial structures can be constructed for the storage of rain water in small tanks as per the plotting of the Solar Park. This would provide every individual plot enough of freshwater for their domestic activities and gardening purpose.
- As the area is water deficient, it is advisable to collect every drop of water. Therefore, it is proposed to construct rainwater harvesting structure considering the storm of 2 days during monsoon season. Therefore, structures have been proposed to collect water available in 2-days, i.e., 2*0.317 =0.634 Mm^3.
- Since, the groundwater is shallow in the RE Park area of GIPCL, it is proposed to construct 1 pond for each plot, so that depth of the pond may be kept above the water table.

Rainwater recharge to groundwater

- The main water bearing formation of the area is clay / silt which mostly have poor permeability.
- Due to low permeability of the soil, rain water recharge through recharge well does not seem feasible, however if any new technology is available then it should be explored on the experimental basis.
- To manage the ground water resource properly, artificial recharge to ground is recommended in the areas where groundwater table is >3m.
- Further, due to the saline nature of the soil of Rann area the rainfall runoff may not be suitable for rainwater recharge.

Desalinization of saline water:

- For meeting the fresh water requirement approximately 4.5 MLD saline water would be needed. The saline water can be pumped from the groundwater by installing tubewells.
- The waste water or brine concentrate needs to be disposed of in a safe area to minimize the impact of the surrounding aquatic life and fauna etc. as per the guidelines.

Water Management:

- Eight probable locations for water harvesting from sub-watersheds have been identified, where suitable water conservation structures can be constructed.
- In addition, some structures may be taken into consideration inside the project area based on local constraints.
- Water harvested shall have to be processed for desiltation before using for domestic or solar panel cleaning.

19 RECOMMENDATIONS

The following recommendations may be considered:

- Suitable storm-water drainage network may be constructed to avoid waterlogging within the park site.
- Soil & water conservation engineering measures such as tanks/ponds, bunding, contour stone wall and vegetative filter strips may be constructed in the project area.
- In order to divert the outside runoff into the site along the margin of the site boundary a storm water drain may be planned. Size of the drains/bunds should be decided as per the requirement & local conditions.
- To augment the groundwater, the rainwater harvested water may be be recharged to shallow groundwater, as it is saline in nature and is very shallow. Further the possibility of recharging the harvested water to deeper aquifers may be explored, if available.
- It is recommended that the proper provision of regular operation and maintenance should be made for the successful performance of the stormwater drainage system.
- The possibility of less saline water in deeper aquifers may be explored for desalination of water for use in RE Park.

Limitations of the study

In this study, IMD grid wise (0.25^{o}x0.25^{o}) rainfall data has been used in the absence of observed rain gauge data (i.e., long term historical) for the grid representing GIPCL site, which may result slight differences in the actual estimates of the runoff potential from the site. This has to be taken into consideration.

****

REFERENCES

Biswas, S.K. (1993) Geology of Kutch volume I, p. 1-415. K. D. Malaviya Institute of Petroleum Exploration, Dehradun.

Chowdhury, R., Alam, J.B., Das, P., Alam, M.A. (2007) Short duration rainfall estimation of Sylhet: IMD and USWB method. Journal of Indian Water Works Association. pp. 285-292.

CGWB, 2013, Groundwater Brochure, Kachchh District. Government of India

Ministry of Water Resources, Central Ground Water Board, West Central Region, Ahmedabad

CPHEEO (2019) Manual on stormwater drainage systems. Central Public Health & Environmental Engineering Organisation (CPHEEO), Ministry of Housing and Urban Affairs, Government of India. Volume-I, Part-A, Engineering Design, First Edition. http://cpheeo.gov.in/cms/manual-on-storm-water-drainage-systems---2019.php. Date of Access: 21/01/2021.

Chatterjee, S., Krishna, A.P., Sharma, A.P. (2014) Geospatial assessment of soil erosion vulnerability at watershed level in some sections of the Upper Subarnarekha river basin, Jharkhand, India. Environ Earth Sci 71, 357–374. https://doi.org/10.1007/s12665-013-2439-3

Das, G. (2008) Hydrology and Soil Conservation Engineering: Including Watershed Management. PHI Learning Pvt. Ltd, New Delhi

Haan, C.T., Barfield, B.J., Hayes, J.C.: Design Hydrology an Sedimentology for Small Catchments. London, Academic Press, Inc., 1994, 588 p. ISBN 978-0123123404

IMD, 2020, Observed rainfall variability and changes over Gujarat State. Met Monograph No.: ESSO/IMD/HS/Rainfall Variability/08(2020)/32.

Merritt, W.S., Letcher, R.A., Jakeman, A.J. (2003) A review of erosion and sediment transport models. Environmental Modeling and Software 18: 761-799. DOI: 10.101

Morgan, R.P.C. (2005) Soil Erosion and Conservation, National Soil Resources Institute, Cranfield University, https://doi.org/10.1002/9781118351475.ch22

Pandey, A., Chowdary, V.M., Mal, B.C. (2009) Sediment yield modelling of an agricultural watershed using MUSLE, Remote Sensing and GIS. Paddy Wat Environ 7(2):105-113. https://doi.org/10.1007/s10333-009-0149-y

Rai, J., Prasad, M., Prakash, N., Singh, A., Garg, S., Gupta, M., Pandey, D.K. (2016). Gymnosperm Fossil Woods from Gangta Bet, Eastern Kachchh, Western India. *Journal of the Palaeontological Society of India*. 61. 111-122.

Singh et al. (1981) Soil Loss and Prediction Research in India. Bulletin No. T-12/D9, Central Soil and Water Conservation Research Training Institute, Dehradun.

Singh, G., Babu, R., Narain, P., Bhusan, L.S., Abrol, I.P. (1992) Soil erosion rates in India. J Soil Water Conserv 47(1):97–99.

Thomason (2019) Hydraulic Design Manual. http://onlinemanuals.txdot.gov/txdotmanuals/hyd/rational_method.htm#i1108889. Date of Access: 31/01/2021.

USDA (2004) Estimation of direct run-off from storm rainfall. National Engineering Handbook: Part 630—Hydrology.

Pasha, S.V., Satish, K.V., Reddy, C.S. Rao P.V.V.P., Jha C.S. (2014) Satellite image based quantification of invasion and patch dynamics of mesquite (Prosopis juliflora) in Great Rann of Kachchh, Kachchh Biosphere Reserve, Gujarat, India. J. Earth Syst. Sci. 123(7):1481–1490.

Wikipedia (2021) https://en.wikipedia.org/wiki/Probability_distribution. Date of Access: 21/01/2021.

Williams, J.R. (1975a) Sediment routing for agricultural watersheds. Water Resource Bulletin 11: 965-974.

Williams, J.R. (1975b) Sediment-yield prediction with universal equation using runoff energy factor. In Present and prospective technology for predicting sediment yield and sources. ARS.S-40, US Gov. Print. Office, Washington, DC. 244-252.

Wischmeier, W.H., Smith, D.D. (1978) Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. Agriculture Handbook No. 537. USDA/Science and Education Administration, US. Govt. Printing Office, Washington, DC. 58pp

APPENDIX

APPENDIX – A

Soil characteristics as reported by M/s Unique Engineering Services, Gandhidham.

Bore Hole No	Depth From	Depth To	Soil Type	Soil Description
BH-1	0.00	3.00	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
	3.00	9.00	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	9.00	10.50	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with fine grained sand particles
	10.50	21.00	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	21.00	43.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
	43.50	50.50	Sandy Clay	Reddish Greyish consolidated Clayey Sand of low Plasticity mixed with little kankars in form of soft rock
BH-2	0.00	0.50	Clay (IP)	Greyish Brownish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
	0.50	6.00	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with fine grained sand particles
	6.00	12.00	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	12.00	18.10	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with fine grained sand particles
	18.10	19.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
	19.50	21.00	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	21.00	30.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
BH-4	0.00	3.00	Clay (IP)	Greyish Brownish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
	3.00	6.00	Silt (IP)	Greyish Silt of Intermediate Plasticity Mixed With Little Fine Sand & Gravel
	6.00	12.00	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
	12.00	16.50	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	16.50	19.50	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with fine grained sand particles
	19.50	39.45	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
	39.45	50.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
BH-5	0.00	1.50	Silt (IP)	Brownish Silt of Intermediate Plasticity mixed with little Fine Sand & Gravel
	1.50	10.51	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	10.51	13.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
	13.50	19.46	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	19.46	30.55	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
BH-6	0.00	0.50	Clay (LP)	Brownish Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particle
	0.50	5.90	Silt (IP)	Greyish Silt of Intermediate Plasticity mixed with little Fine Sand & Gravel
	5.90	22.50	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	22.50	30.57	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
BH-7	0.00	5.90	Clay (LP)	Brownish Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particle
	5.90	22.40	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines

Bore Hole No	Depth From	Depth To	Soil Type	Soil Description
	22.40	50.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
BH-9	0.00	8.75	Clay (LP)	Brownish greyish Silty Clay of Low Plasticity Mixed With Kankars
	8.75	13.55	Silt (LP)	Greyish brownish non-plastic clayey silt mixed with little Fines
	13.55	16.50	Silty Sand	Greyish Silty Sand with Kankars
	16.50	25.51	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	25.51	48.00	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity Mixed With Kankars
	48.00	50.00	Clay (HP)	Greyish Clay of High Plasticity Mixed With Little Gravel and Sand Particles
BH-10	0.00	0.50	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	0.50	7.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
	7.50	12.00	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particles
	12.00	15.10	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
	15.10	22.40	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	22.40	42.10	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
	42.10	50.50	Clay (HP)	Brownish Clay of High Plasticity Mixed With Little Gravel and Sand Particles
BH-11	0.00	1.40	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particle
	1.40	16.50	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	16.50	21.10	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particle
	21.10	30.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
BH-12	0.00	0.30	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particle
	0.30	2.50	Clay (HP)	Greyish Clay of High Plasticity Mixed With Little Gravel and Sand Particles
	2.50	7.50	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particle
	7.50	23.60	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	23.60	50.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
BH-13	0.00	7.40	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particle
	7.40	10.50	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	10.50	13.40	Silty Sand	Greyish Silty Sand with Kankars
	13.40	17.70	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	17.70	25.30	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particle
	25.30	30.60	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
BH-14	0.00	18.00	Silt (LP)	Brownish Greyish Non-Plastic Clayey Silt mixed with little Fines
	18.00	39.00	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Fine Grained Sand Particles
	39.00	50.50	Clay (HP)	Greyish Silty Clay of High Plasticity mixed with Fine Grained Sand Particles
BH-15	0.00	3.00	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particle
	3.00	7.45	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
	7.45	15.00	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	15.00	24.00	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particle

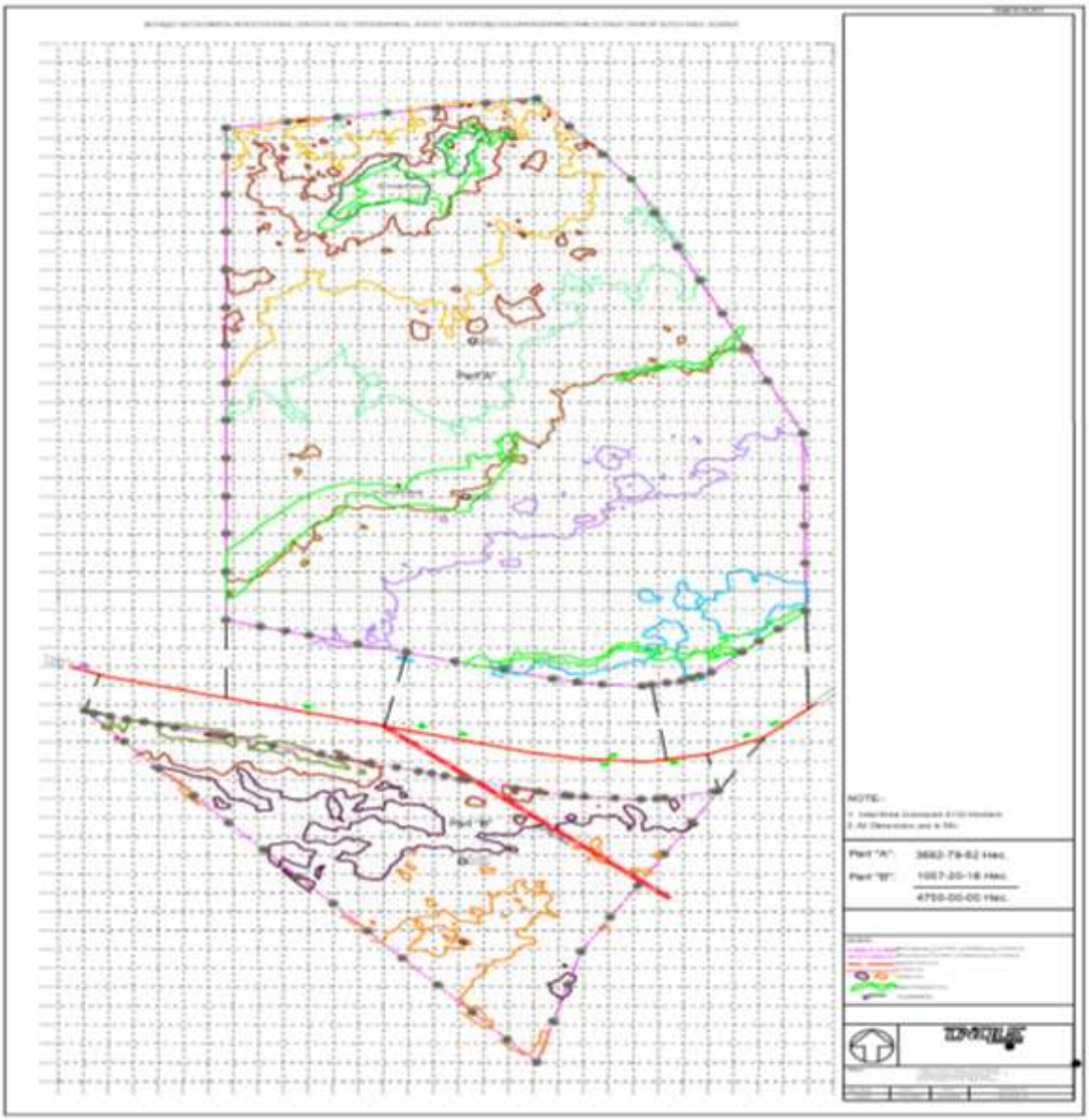
Bore Hole No	Depth From	Depth To	Soil Type	Soil Description
	24.00	50.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
BH-16	0.00	1.50	Clay (LP)	Greyish Brownish Silty Clay of Low Plasticity mixed with Little Sand Particles
	1.50	6.00	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
	6.00	15.00	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	15.00	19.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
	19.50	22.50	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	22.50	25.50	Clay (IP)	Greyish Clayey Silt of Low Plasticity mixed with little Fines and Gravel
	25.50	28.50	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	28.50	50.50	Clay (IP)	Greyish Clayey Silt of Low Plasticity mixed with little Fines and Gravel
BH-17	0.00	0.30	Clay (IP)	Brownish Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
	0.40	2.90	Clay (HP)	Greyish Clay of High Plasticity Mixed With Little Gravel and Sand Particles
	2.90	6.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
	6.50	20.70	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	20.70	34.30	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
	34.30	39.00	Clay (HP)	Greyish Consolidation Clay of High Plasticity Mixed With Little Gravel and Sand Particles
	39.00	50.45	Clay (HP)	Greyish Consolidation Clay of High Plasticity Mixed With Little Gravel and Sand Particles
BH-18	0.00	6.10	Clay (IP)	Brownish Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
	6.10	15.00	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	15.00	26.90	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particle
	26.90	41.80	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
	41.80	48.90	Clay (HP)	Greyish Clay of High Plasticity Mixed With Little Gravel and Sand Particles
	48.90	50.50	Clay (HP)	Reddish Brownish Clay of High Plasticity Mixed With Little Gravel and Sand Particles
BH-19	0.00	0.50	Silt (IP)	Greyish Silt of Intermediate Plasticity Mixed With Little Fine Sand & Gravel
	0.50	6.00	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Fine Grained Sand Particles
	6.00	10.50	Silt (LP)	Greyish Clayey Silt of Low Plasticity mixed with little Fines and Gravel
	10.50	15.00	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particles
	15.00	22.50	Silt (LP)	Greyish Clayey Silt of Low Plasticity mixed with little Fines and Gravel
	22.50	24.00	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particles
	24.00	50.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Fine Grained Sand Particles
BH-20	0.00	3.10	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particles
	3.10	5.90	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	5.90	7.50	Clay (HP)	Greyish Silty Clay of High Plasticity mixed with Fine Grained Sand Particles
	7.50	19.40	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	19.40	24.20	Clay (LP)	Greyish Silty Clay of Intermediate Plasticity mixed with Fine Grained Sand Particles

Bore Hole No	Depth From	Depth To	Soil Type	Soil Description
	24.20	50.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Fine Grained Sand Particles
BH-21	0.00	1.50	Clay (IP)	Greyish Brownish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
	1.50	6.00	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with fine grained sand particles
	6.00	7.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
	7.50	22.50	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	22.50	42.00	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
	42.00	50.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
BH-22	0.00	3.00	Clay (LP)	Greyish Brownish Silty Clay of Low Plasticity mixed with fine grained sand particles
	3.00	9.00	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
	9.00	24.00	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	24.00	30.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
BH-23	0.00	1.50	Clay (HP)	Greyish Brownish Silty Clay of High Plasticity
	1.50	4.50	Clay (IP)	Greyish Brownish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
	4.50	12.00	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	12.00	18.00	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with fine grained sand particles
	18.00	22.50	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	22.50	30.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
BH-24	0.00	6.00	Clay (LP)	Greyish Brownish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particles
	6.00	16.50	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	16.50	19.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Fine Grained Sand Particles
	19.50	24.00	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	24.00	45.00	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Fine Grained Sand Particles
	45.00	50.50	Clay (IP)	Silty Clay of Intermediate Plasticity mixed with Fine Grained Sand Particles
BH-25	0.00	4.50	Silt (IP)	Greyish Silt of Intermediate Plasticity Mixed With Little Fine Sand
	4.50	7.50	Clay (LP)	Greyish Silty Clay of Low Plasticity Mixed With Fine Grained Sand Particles
	7.50	18.00	Silt (LP)	Greyish Clayey Silt of Low Plasticity mixed with little Fines
	18.00	19.50	Clay (LP)	Greyish Silty Clay of Low Plasticity Mixed With Fine Grained Sand Particles
	19.50	22.50	Silt (LP)	Greyish Clayey Silt of Low Plasticity mixed with little Fines
	22.50	30.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity Mixed With Kankars
BH-26	0.00	6.00	Silt (IP)	Brownish Greyish Non - Plastic Silt Mixed With Little Fine Sand
	6.00	9.00	Silty Sand	Greyish Silty Sand mixed with kankars
	9.00	24.00	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	24.00	43.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity Mixed With Kankars
	43.50	50.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity Mixed With Kankars
BH-27	0.00	1.50	Clay (LP)	Greyish Silty Clay of Low Plasticity Mixed With Kankars
	1.50	6.00	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity Mixed With Kankars
	6.00	12.00	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	12.00	15.00	Clay (LP)	Greyish Silty Clay of Low Plasticity Mixed With Kankars

Bore Hole No	Depth From	Depth To	Soil Type	Soil Description
	15.00	22.50	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	22.50	28.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity Mixed With Kankars
	28.50	39.00	Clay (HP)	Greyish Silty Clay of High Plasticity Mixed With Kankars
	39.00	50.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity Mixed With Kankars
BH-28	0.00	0.60	Clay (LP)	Brownish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particle
	0.60	5.90	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with Little Sand Particles
	5.90	12.70	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	12.70	25.50	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with Fine Grained Sand Particle
	25.50	33.00	Sandy Clay	Brownish greyish Consolidated Clayey Sand of Low to Intermediate Plasticity mixed with little Gravel
	33.00	35.00	Gravel	Greyish Highly Weathered Over Consolidated Sand Stone Fragments
BH-29	0.00	4.50	Clay (IP)	Greyish Brownish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
	4.50	13.50	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	13.50	24.00	Clay (LP)	Greyish Silty Clay of Low Plasticity mixed with fine grained sand particles
	24.00	27.00	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	27.00	30.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity mixed with fine grained sand particles
BH-30	0.00	4.50	Silt (LP)	Greyish Brownish Non-Plastic Clayey Silt mixed with little Fines
	4.50	18.00	Silt (LP)	Greyish Non-Plastic Clayey Silt mixed with little Fines
	18.00	27.00	Clay (LP)	Brownish Sandy Clay of Low Plasticity Mixed With Kankars
	27.00	50.50	Clay (IP)	Greyish Silty Clay of Intermediate Plasticity Mixed With Kankars

Appendix - B

Elevation contour map of the site provided by the GIPCL



Appendix - C

Rational method runoff coefficients for rural watersheds

Watershed characteristic	Extreme	High	Normal	Low
Relief - C_r	0.28-0.35 Steep, rugged terrain with average slopes above 30%	0.20-0.28 Hilly, with average slopes of 10-30%	0.14-0.20 Rolling, with average slopes of 5-10%	**0.08-0.14** Relatively flat land, with average slopes of 0-5%
Soil infiltration - C_i	0.12-0.16 No effective soil cover; either rock or thin soil mantle of negligible infiltration capacity	0.08-0.12 Slow to take up water, clay or shallow loam soils of low infiltration capacity or poorly drained	**0.06-0.08** Normal; well drained light or medium textured soils, sandy loams	0.04-0.06 Deep sand or other soil that takes up water readily; very light, well-drained soils
Vegetal cover - C_v	0.12-0.16 No effective plant cover, bare or very sparse cover	**0.08-0.12** Poor to fair; clean cultivation, crops or poor natural cover, less than 20% of drainage area has good cover	0.06-0.08 Fair to good; about 50% of area in good grassland or woodland, not more than 50% of area in cultivated crops	0.04-0.06 Good to excellent; about 90% of drainage area in good grassland, woodland, or equivalent cover
Surface Storage - C_s	0.10-0.12 Negligible; surface depressions few and shallow, drainage ways steep and small, no marshes	**0.08-0.10** Well-defined system of small drainage ways, no ponds or marshes	0.06-0.08 Normal; considerable surface depression, e.g., storage lakes and ponds and marshes	0.04-0.06 Much surface storage, drainage system not sharply defined; large floodplain storage, large number of ponds or marshes

Note: The total runoff coefficient based on the four runoff components is C = Cr + Ci + Cv + Cs (Source: Thomason, 2019)

Appendix – D

Most Intense Cyclones hitting Indian West Coast from 1970 to 2020

S. No.	Name of Cyclone	Date and Year	Intensity (T-Number)	Observed/ Estimated Max. Wind	Damage
1	Severe Cyclonic Storm over the Arabian sea	October 19-24, 1975	N/A	97 Knots 180 Kmph	85 people died in the districts of Junagarh. Jamnagar and Rajkot of Gujarat state. This Cyclone caused considerable damage, estimated to be about Rs. 75 Crores.
2	Severe Cyclonic Storm over the Arabian sea	May 31 - June 5, 1976	N/A	90 Knots 167 Kmph	This Cyclone caused damage to property which was estimated to be about Rs. 3 Crore. 4 Burges each. Containing Rs. 5 Lakh and 6 fishing boats were swept away. Mehasana, Bhavnagar, Kaira, Panchmahal, Rajkot and Broach districts of Gujarat State were most affected areas.
3	Severe Cyclonic Storm over the Arabian sea	November 13-23, 1977	T- 5.5 (as per US satellite)	90 Knots 167 Kmph	Kerala and Lakshadweep were most affected areas due to this storm. People killed - 72. Houses damaged - 8400 and 620 fishing Vessels damaged in Kerala coast. Total loss was estimated to be about Rs 10 crores.
4	Gujarat Cyclone	November 5-13,1978	N/A	278 Kmph	Damage to Property reported.
5	Severe Cyclonic Storm over the Arabian sea	October 28 - November 3, 1981	T - 4.0 (as per US satellite)	65 Knots 120 Kmph	Junagarh, Rajkot and Jamnagar of Gujarat state were most affected areas, Total loss of damage to property was estimated to be about Rs. 52 Crores.
6	Severe Cyclonic Storm over the Arabian sea	November 4-9, 1982	N/A	N/A	Saurastra Coast of Gujarat about 45 km east of Veraval was affected very much by this storm. 507 people died and 1.5 lakh livestock perished.
7	Severe Cyclonic Storm over the Arabian sea	November 4-9, 1982	T- 4.0	50 Knots 93 Kmph	50 fishermen were reported missing in Gujarat Coast.
8	Severe Cyclonic Storm over the Arabian sea	June 17-20, 1996	T-3.5	60 Knots 111 Kmph	19 Districts of Gujarat State were affected. 33 people died. 27964 pucca houses were destroyed. Total estimated loss was Rs.1803.52 lakh.
9	Severe Cyclonic Storm over the Arabian sea	October 23-28, 1996	T-4.0	60 Knots 111 Kmph	As the system did not cross the coast no significant damage was reported.
10	Very severe Cyclonic Storm over the Arabian sea	June 4-10, 1998	T-5.0	90 Knots 167 Kmph	Gujarat & Rajasthan states were affected. Porbander of Gujarat state was the most affected area. Loss incurred due to storm was estimated to be about Rs.1855.38 Crores in Kandla. Number of lines lost 1173 and number of persons missing 1774 in Gujarat.
11	Very severe Cyclonic Storm over the Arabian sea	May 16-22, 1999	T- 5.5	55 Knots 102 Kmph	This system caused severe damage in Kutch and Jamnagar districts of Gujarat. 453 people died. In Rajasthan one person died and 5104 cattle heads perished. 5133 houses were partially damaged.

S. No.	Name of Cyclone	Date and Year	Intensity (T-Number)	Observed/ Estimated Max. Wind	Damage
12	Severe Cyclonic Storm over Arabian sea	May 5-10, 2004	3.5	Weakened over sea	Widespread damage caused at Lakshadweep. Several houses damaged due to wind, sea wave, falling of trees and floods. 16 boats reported sunk and cargo boat damaged. Sea erosion reported over Kerala and 9 people dead and 17 people missing.
13	Severe Cyclonic" Storm MUKDA" over Arabian sea	September 21-24,2006	3.5	55 Knots 102 Kmph	No damage as dissipated over the Arabian Sea.
14	Super cyclone "GONU"	01-07 June 2007	T-6.5	127 knots	The system crossed Makaran coast and hence there was no damage in India
15	Cyclonic storm "YEMYIN"	25 - 26 June 2007	T - 2.5	35 knots	The system crossed Pakistan coast and hence there was no damage in India
16	OCKHI Very Severe Cyclonic Storm	29 Nov – Dec 2017	T-3.0	155 kmph	Caused heavy rainfall along the western coast of India, particularly in Maharashtra and Gujarat
17	NILOPHER	25-31 October 2014	T – 4.0	205 kmph	Nilopher weakened into a depression on October 31, and soon after degenerated into a remnant low off coast of the Indian state of Gujarat
18	VAYU	10-17 June, 2019	T – 3.0	150 kmph	It was the strongest tropical cyclone to affect the Saurashtra Peninsula of north western India since the 1998 Gujarat cyclone.
19	Cyclone "NISAGRA"	01-04 June 2020	T – 3.5	110 kmph	Hit the coast of Maharashtra, did not cause any damage in Gujarat
20	Cyclone TAUKTAE	14-19 May 2021	T-4.0	195 kmph	The strongest tropical cyclone to make landfall in the Gujarat since the 1998 Gujarat cyclone.

Appendix-E

Runoff curve numbers for arid and semiarid rangelands (USDA 2004) [1/]

Cover description		Hydrologic soil group -			
cover type	**hydrologic condition [2/]**	**A [3/]**	**B**	**C**	**D**
Herbaceous—mixture of grass, weeds and low-growing brush, with brush the minor element	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sage-grass—sage with an understory of grass	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, paloverde, mesquite, and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

[1/] Average runoff condition, and Ia = 0.2s. For range in humid regions, use table 9–1.
[2/] Poor: <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: >70% ground cover.
[3/] Curve numbers for group A have been developed only for desert shrub.

Appendix-F

Monthly and annual average runoff (mm) estimated by SCS-CN method

Month/Year	Jun	Jul	Aug	Sep	Oct	Nov	Annual Runoff
1901	0.00	0.00	0.03	0.00	0.00	0.00	0.03
1902	0.00	0.00	12.81	0.46	0.00	0.00	13.28
1903	0.00	124.81	0.00	0.00	0.00	0.00	124.81
1904	0.00	0.05	0.00	0.00	0.00	0.00	0.05
1905	0.00	45.94	0.00	0.00	0.00	0.00	45.94
1906	30.47	0.00	10.08	10.75	0.00	0.00	51.29
1907	0.00	18.93	0.31	0.00	0.00	0.00	19.24
1908	0.00	24.65	0.00	0.00	0.00	0.00	24.65
1909	0.00	2.91	0.00	12.30	0.00	0.00	15.22
1910	0.00	5.59	10.65	0.00	0.00	0.00	16.24
1911	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1912	0.00	67.53	5.23	0.00	0.00	0.00	72.76
1913	0.00	112.24	5.67	0.00	0.00	0.00	117.91
1914	10.79	0.00	0.00	0.64	0.00	0.00	11.43
1915	0.00	4.24	0.00	0.00	1.35	0.00	5.59
1916	0.00	0.00	26.70	1.11	0.00	0.00	27.80
1917	0.00	31.70	1.54	0.00	76.51	0.00	109.75
1918	0.00	0.00	6.79	0.00	0.00	0.00	6.79
1919	0.00	0.00	13.77	0.00	0.00	0.00	13.77
1920	110.07	19.60	0.36	0.00	0.00	0.00	130.03
1921	0.00	77.80	0.00	9.72	0.00	0.00	87.51
1922	0.00	0.74	0.00	14.94	0.00	0.00	15.68
1923	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1924	0.00	4.33	0.00	0.00	0.00	0.00	4.33
1925	0.01	0.08	0.00	0.00	0.00	0.00	0.08
1926	0.00	1.70	5.55	59.88	0.00	0.00	67.13
1927	0.00	53.09	0.00	0.00	0.00	0.00	53.09
1928	0.00	4.19	0.00	0.00	0.00	0.00	4.19
1929	0.00	65.63	0.00	0.00	0.00	0.00	65.63
1930	0.00	11.08	0.00	0.00	0.00	0.00	11.08
1931	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1932	0.00	17.15	0.00	0.00	0.00	0.00	17.15
1933	0.00	25.46	33.25	0.00	0.00	0.00	58.71
1934	0.38	0.00	0.00	0.00	0.00	0.00	0.38
1935	0.00	84.30	0.00	0.00	0.00	0.00	84.30
1936	0.00	18.74	0.00	2.89	0.00	0.00	21.63
1937	0.48	0.16	0.00	1.56	0.00	0.00	2.19
1938	0.18	0.00	0.11	0.00	0.00	0.00	0.28
1939	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1940	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Month/Year	Jun	Jul	Aug	Sep	Oct	Nov	Annual Runoff
1941	0.00	135.19	0.00	0.00	0.00	0.00	135.19
1942	0.00	0.00	10.13	0.00	0.00	0.00	10.13
1943	0.00	13.60	0.00	0.00	0.00	0.00	13.60
1944	0.00	26.32	28.61	0.00	0.00	0.00	54.93
1945	0.06	28.87	0.37	0.00	0.00	0.00	29.31
1946	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1947	0.00	0.00	34.48	0.00	0.00	0.00	34.48
1948	0.00	0.00	2.58	0.00	0.00	0.00	2.58
1949	0.00	23.23	6.62	0.00	0.00	0.00	29.85
1950	0.00	221.05	0.00	8.02	0.00	0.00	229.06
1951	0.00	4.86	0.04	0.00	0.00	0.00	4.90
1952	0.00	38.69	0.00	0.00	0.00	0.00	38.69
1953	0.00	0.00	89.75	0.00	0.00	0.00	89.75
1954	0.00	0.00	42.29	0.42	0.00	0.00	42.71
1955	0.00	0.00	87.57	144.15	0.00	0.00	231.72
1956	0.00	56.53	62.21	0.00	0.00	0.00	118.74
1957	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1958	0.00	11.37	0.00	22.41	0.00	0.00	33.79
1959	0.00	41.13	0.00	124.98	0.00	0.00	166.12
1960	0.00	0.00	0.17	0.00	0.00	0.00	0.17
1961	5.44	37.05	0.00	248.25	0.00	0.00	290.74
1962	0.00	0.23	13.55	0.00	0.00	0.00	13.78
1963	0.00	0.00	0.06	0.00	0.00	0.00	0.06
1964	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1965	0.00	21.81	0.00	0.00	0.00	0.00	21.81
1966	28.27	20.30	0.00	0.00	0.00	0.00	48.57
1967	8.68	193.69	0.40	0.00	0.00	0.00	202.77
1968	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1970	0.00	69.02	10.03	66.41	0.00	0.00	145.45
1971	0.00	0.10	3.94	0.16	0.00	0.00	4.20
1972	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.26	0.00	0.00	0.00	0.26
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	30.38	11.37	0.00	0.00	41.75
1976	0.00	101.96	51.96	17.24	0.00	0.00	171.16
1977	7.91	8.36	0.53	0.00	0.00	0.00	16.80
1978	0.62	0.21	1.09	0.00	0.00	1.21	3.13
1979	0.00	0.00	458.59	0.00	0.00	0.00	458.59
1980	60.57	21.10	0.00	0.00	0.00	0.00	81.67
1981	0.00	27.23	1.27	0.00	0.00	12.76	41.26
1982	0.00	7.12	0.00	0.76	0.00	0.00	7.89
1983	0.00	5.35	0.23	0.00	0.00	0.00	5.59
1984	0.00	0.00	0.00	11.81	0.00	0.00	11.81
1985	0.00	0.00	7.44	0.00	0.00	0.00	7.44

Month/Year	Jun	Jul	Aug	Sep	Oct	Nov	Annual Runoff
1986	0.00	0.00	3.49	0.00	0.00	0.00	3.49
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.00	165.54	0.86	0.00	0.00	0.00	166.40
1989	35.85	49.35	0.00	0.00	0.00	0.00	85.19
1990	0.00	0.00	12.28	0.00	0.00	0.00	12.28
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.00	121.37	0.00	0.00	0.00	0.00	121.37
1993	0.00	0.86	0.00	0.00	0.00	0.00	0.86
1994	0.00	88.38	0.24	244.30	0.00	0.00	332.92
1995	0.00	0.15	0.00	0.00	15.84	0.00	16.00
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	0.00	0.01	0.00	17.20	0.00	0.00	17.22
1998	0.00	0.00	0.00	0.00	85.79	0.00	85.79
1999	0.00	0.00	0.00	0.00	3.64	0.00	3.64
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	39.50	26.89	0.00	0.00	0.00	0.00	66.39
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.00	169.81	2.71	0.00	0.00	0.00	172.52
2004	4.43	0.00	0.00	0.00	0.00	0.00	4.43
2005	0.00	0.00	0.00	10.02	0.00	0.00	10.02
2006	0.00	78.65	51.31	0.00	0.00	0.00	129.96
2007	8.57	0.48	48.74	0.00	0.00	0.00	57.79
2008	0.00	0.00	0.00	2.32	0.00	0.00	2.32
2009	0.00	52.00	26.71	0.00	0.00	0.00	78.70
2010	0.00	26.31	37.11	2.35	0.00	0.00	65.78
2011	0.00	0.00	147.34	32.47	0.00	0.00	179.81
2012	0.00	0.00	0.00	76.71	0.00	0.00	76.71
2013	0.42	0.00	0.00	45.67	0.00	0.00	46.08
2014	0.00	0.00	0.00	1.37	0.00	0.00	1.37
2015	0.00	239.56	0.00	0.00	0.00	0.00	239.56
2016	0.00	0.00	48.74	0.00	0.00	0.00	48.74
2017	0.00	39.00	0.00	0.00	0.00	0.00	39.00
2018	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total (mm)	352.7	2995.4	1456.9	1202.6	183.1	13.97	6204.7
MEAN (mm)	2.99	25.38	12.35	10.19	1.55	0.12	52.6
SD (mm)	12.91	47.44	46.37	37.35	10.57	1.17	76.8
Min (mm)	0.00	0.00	0.00	0.00	0.00	0.00	0.0
Max (mm)	110.07	239.56	458.59	248.25	85.79	12.76	458.6

****