

Final Report

Impact of Tsunami on Kalpasar Dam, Assessment of Sea Level Rise due to Climate Change and Inundation in Gulf Post Construction of Dam.

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NCCR

राष्ट्रीय तटीय अनुसंधान केन्द्र

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1. Introduction

Coastal zones are attracting people and industries due to the availability of ample resources and ethical beauty. Hence, huge population and developmental pressures have been building in the coastal areas for the last four decades. It was reported that more than half of the world's population lives within 60 km of shoreline (UN, 1992). Urbanization and the rapid growth of coastal cities have been a dominant population trend over the last decades, leading to the development of numerous mega cities in all coastal regions around the world. The ratio of people living in coastal zones compared to available coastal lands further indicates that there is a higher tendency for people to live in coastal areas than inland.

However, the developments for the needs of the growing population is inevitable and need of the hour. Hence, the development of the Kalpasar Dam to ensure the fresh water supply in the region plays a major role. The safety of the infrastructure and sustainable development need to be taken care of. Hence, the current work is the scientific assessment to understand the implications of sea level change, tsunami impact, and post-construction inundation. Such evaluations will help to develop the infrastructure against the future adversaries of such hazards.

2. Scope of Study

The scope of work includes carrying out the following activities that lead to the outcomes and deliverables listed in respective activity (Table 1).

Table 1 scope of the study is to achieve the outcomes and deliverables from the three activities

<i>S.No</i>	<i>Activity</i>	<i>Outcome</i>	<i>Deliverables (Documents: Hard and Soft)</i>
1. Impact of Tsunami on Kalpasar Dam.			
1	Estimation of Design Parameters for Proposed Dam and inundation areas in Gulf of Khambhat due to Tsunami in Arabian Sea.	<ul style="list-style-type: none"> (1) Review of existing studies of NGRI and identify additional parameters and possible sources that can have impact on Gulf of Khambhat(INCOIS). (2) Numerical modeling of the tsunami wave propagation following the additional sources megacitiesand parameters(INCOIS). (3) Estimation of the water levels for design of Dam and determining height of the dam crest(INCOIS). (4) Quantifying the run-up heights and inundation distances in the Gulf of Khambhat for pre and post Dam scenario cases (INCOIS). 	(1) A report on Design Parameters and Impact of Tsunami in Gulf of Khambhat due to construction of Kalpasar Dam.
2. Assessment of Sea-level Rise due to Climate Change			
1	Estimation of possible Sea level rise at dam location during the life of Dam through various methods and suggest suitable values for Design of Dam.	<ul style="list-style-type: none"> (1) Review of existing studies of NIO (IITM, INCOIS). (2) Estimation of Sea level Rise using available satellite/Tidal observations and assess the associated uncertainties (INCOIS). (3) Numerical Model of Sea Level Rise under various climate change scenario's during the life of Dam (IITM). (4) Suggest suitable Sea Level Rise values for Design of Dam and Spillway (IITM, INCOIS). 	(1) A report on estimates of Sea Level Rise at Dam location during the life of Dam (IITM, INCOIS).

3. Seaside Inundation in Gulf post-construction of Dam			
1	Estimation of Inundation areas and villages along the coast in Gulf of Khambhat due to rising in water levels post-construction of Dam.	(1) Identify the inundation areas and villages in the Gulf of Khambhat due to an increase in water levels after the construction of Dam (INCOIS). (2) Provide the contours at 0.5m intervals in the inundation areas and buffer areas that will help in identifying possible locations of Flood protection structures in low-lying areas by NCCR along the coast (INCOIS).	(1) A report on inundation areas and villages in the Gulf of Khambhat after construction of Kalpasar Dam. (2) Contours at 1m interval in the inundation areas

3. Study Area

The study area is part of the Gujarat coast in the Gulf of Khambhat in the Arabian Sea (Figure 1). The proposed Kalpasar dam is situated in the upper streams of the Gulf of Khambhat. This area is historically known as the Gulf of Cambey. The Gulf of Khambhat is about 200 km (120 mi) long, about 20 km (12 mi) wide in the north and up to 70 km (43 mi) wide in the south. Major rivers draining Gujarat are the Narmada, Tapti, Mahi and the Sabarmati, forming estuaries in the Gulf (https://en.wikipedia.org/wiki/Gulf_of_Khambhat).

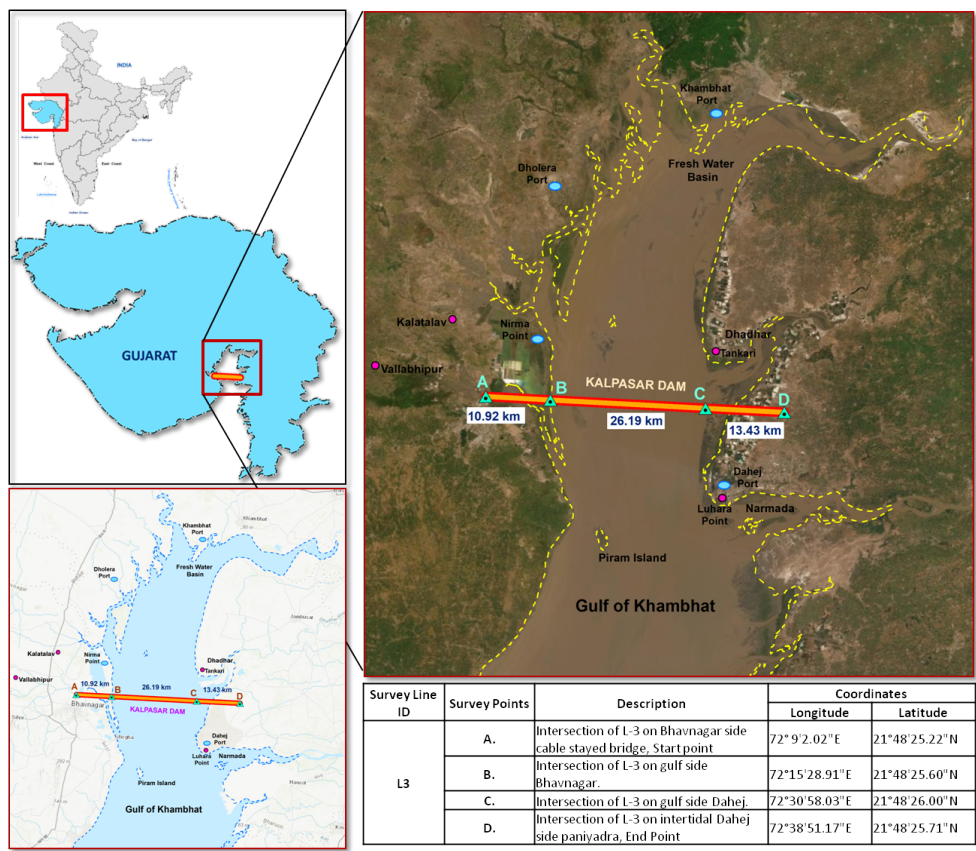


Figure 1. Map showing the location of the study area.

4. Data Used

The current study is conducted using satellite and observation data from different sources. The list of data used in the current study is provided in Table 2.

Table 2. List of data used in the study

Data/Parameter	Location	Resolution	Period
Sea Level Change and extreme water level calculations	Tide gauge data: Veraval, Adani-Hazira and Bhavnagar	NA	Based on availability
	Altimeter data	250m	1993 to 2020
ALTM Topography	~2 km from coastline of the study area	5m	NA
Carto-DTM	Beyond ALTM coverage	10m	NA
SRTM	Beyond Carto-DTM	30m	NA
Bathymetry	Gulf of Khambhat	NCCR data of Kalpasar Project Available data at INCOIS	

NA: not applicable

5. Methodology

5.1. Impact of Tsunami on Kalpasar Dam

The objective of the tsunami modeling exercise is to study the effect of the tsunami on the proposed Kalpasar dam (study area) in the Gulf of Khambhat, considering Pre-Construction and Post-Construction Dam scenarios.

The possible tsunami-genic source locations that can affect the study area are from Makran subduction zone in the North-West Indian Ocean (NWIO), as shown in Figure2. Furthermore, based on Historical Seismicity (ISC-GEM, USGS, IMD) and Mapped Fault / Liniments published (GSI), seven source zones are considered in the Arabian sea, including the Makran subduction zone, as shown in Figure2. The source parameters for simulating tsunami are carefully selected for the listed source zones in Table 3, including the 1945 event and one hypothetical worst-case earthquake scenario considering M9.0 off Makran subduction zone.

Table 3. Earthquake Source characteristics of Source Zones considered

S.No	Source Zone (SZ)	Mmax (obs)	Mmax (considered)	Focal Depth (km)	Strike (preferred)	Dip (preferred)	Length (km)	Predominant Type of Faulting
1	Makran Subduction Zone – West (SZ1)	--	8.8	20	260	7	291	Thrust
2	Makran Subduction Zone – East (SZ2)	8.1	8.1	15	246	7	150	Thrust
3	Makran Subduction Zone – NE (SZ3)	--	9.0	20	255	7	366	Thrust (Hypothetical)
4	Kuch Rift Basin (SZ4)	7.8	8.0	20	80 (R)	50	166	Reverse
5	Saurashtra Horst (SZ5)	5.9	6.3	12	325 (D), 60(S)	70	25	Strike slip
6	Son-Narmada-Tapi Basin (SZ6)	6.2	6.5	15	270	55	25	Oblique (SS+R)
7	Deccan Traps Province (SZ7)	6.3	6.5	8	180	60	30	Strike slip

Earthquake source parameters of the 8.1Mw Makran earthquake of 1945 and 9.0 Mw Worst-Case (Hypothetical) Scenario and five more earthquakes spread across seven source zones, have been proposed to use in order to model the expected inundation and run-up heights at water levels for the design of Dam determine the height of the dam crest as well quantifying the run-up heights and inundation distances in the Gulf of Khambhat for pre and post Dam scenario cases. TUNAMI N2 model was set up using the best available bathymetry and topography data as listed in Table 2 to assess the potential tsunami risk. The details of source parameters, data sources and model parameters for the earthquake scenarios are described in Tables 3, 4 & 5. It may also be noted that the model has been set up and proposed to run independently at INCOIS with the source parameters used by NGRI, as listed in Table 5.

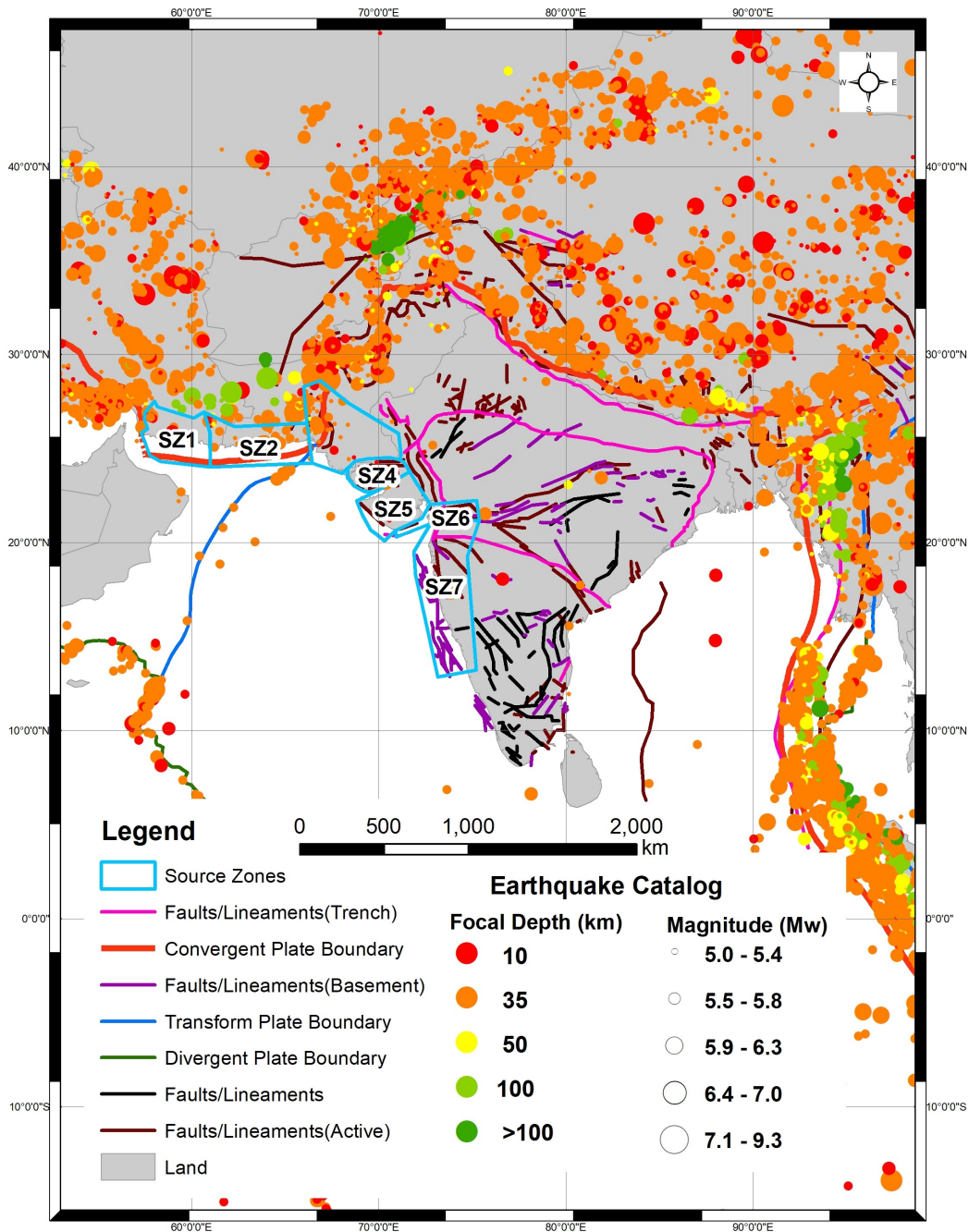


Figure 2 Source Zones considered based on Historical Seismicity and Fault/Liniments in the North-West Indian Ocean (NWIO)

5.2. Assessment of Sea-level Rise due to Climate Change

Oceans play a central role in regulating the Earth's climate by the uptake and redistribution of heat. Oceans have absorbed over 93% of the excess heat in the climate

system due to warming caused by human (anthropogenic) activities and have contributed to a rise in the global mean sea level (Church et al., 2011; Fox-Kemper et al., 2021). The recent Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC AR6) and Special Report on Ocean and Cryosphere in a Changing Climate (SROCC) assessed that the ocean warming is virtually certain, and there is high confidence that the rate of global mean sea-level rise has increased. As the climate has warmed, the sea-level rise has risen at an average rate of 1.7 (1.5–1.9) mm year⁻¹ between 1901 and 2010 (Church and White 2011), and the rate of global sea-level rise has accelerated in the recent decades.

Anthropogenic sea-level rise poses challenges to coastal areas globally. The reliable estimates of regional sea-level changes are critical for assessing the potential impacts of climate change along coastlines. The regional relative sea-level rise is influenced by multiple physical processes that vary both in space and time and can lead to large regional departures from the global mean. Long-term sea-level trend estimates using tide gauge observations, available along the coasts of India and the rim of the eastern Bay of Bengal, show a rate of regional sea-level rise of about 1.06-1.75 mm yr⁻¹ during 1874-2004 (Unnikrishnan et al., 2006; Unnikrishnan and Shankar, 2007). The regional sea-level rise in the Indian Ocean, based on satellite observations for the period 1993-2020, is estimated to be 3.5 mm yr⁻¹ (Swapna et al., 2020).

5.2.1. Estimation of Sea Level Trend

The method adopted for estimation of sea level trend is to use high-resolution satellite altimetry data (resolution ~ 0.25 km) along with the tide-gauge locations where the correlation between tide-gauge data and satellite data is above 0.5, within a circle of radius 100 km centered to each tide gauge station. The trend in mean sea level pertaining to four stations Mumbai, Adani Port, Bhavnagar-I, Veraval and Okha, was calculated and presented in the results section.

5.2.2. Projected change in mean sea level along the west coast of India

The Indian Ocean has warmed faster than the global average (Fox-Kemper et al., 2021). As a result, the relative sea level will continue to rise in the 21st century. The IPCC Sixth Assessment Report (IPCC AR6) projections utilize a new range of scenarios known as the Shared Socio-economic Pathways (SSPs) (O'Neill et al., 2017) introduced in the Coupled Model Intercomparison Project Phase 6 (CMIP6). The SSPs provide pathways including global radiative forcing levels for the different socio-economic pathways. The sea-level projections described here are based on a 'mitigation scenario' (SSP2-4.5, in which the anthropogenic emission leading to radiative forcing is limited to 4.5 Wm⁻² in the year 2100), which is a midrange scenario between the higher (SSP5-8.5) and lower (SSP1-2.6) scenarios. The median projections of sea level from a multi-model mean of CMIP6 models used for preparing the IPCC AR6 report were used for assessing the projected sea-level rise along the west coast of India. The mean sea level values under SSP2-4.5 scenarios for 2050 and 2100 at selected tide-gauge locations along the west coast of India were calculated.

5.2.3. Limitations

The satellite altimetry derived sea surface height over the open ocean has been widely used, extending sea level measurements into coastal zones and decreasing spatial and temporal scales. This approach calls for the integration of the altimetric measurements with in-situ observations and models to mitigate the limitations of altimetric sampling. The Gulf of Khambhat is one of the highly energetic macro-tidal regimes of the north-eastern Arabian Sea. There is a lack of long-term in-situ datasets on hydrodynamic parameters in this area. The stations Bhavnagar and Adani Port do not have continuous long time-series tide gauge measurements to validate the satellite measurements. The method adopted here is to use high-resolution satellite altimetry data (resolution ~ 0.25 km) along with the tide-gauge locations where the correlation between tide-gauge data and satellite data is above 0.5, within a circle of radius of 100 km centered to each tide gauge station. GIA corrections are not included in the satellite sea-level data. Continuous

monitoring of sea level along the coastal regions is needed to have a reliable assessment of sea-level rise.

5.3. Seaside inundation in the Gulf post-construction of a dam

The high-resolution topographic and bathymetry data listed in Table 1 are used to generate the blended data product. The weighted optimal interpolation technique merged the different datasets into a single blended dataset. This data is being used for tsunami inundation modeling. Besides, the probable water spread assessment after the dam was carried out. NCCR provided the bund locations were overlaid on the topographic data and it was understood that the dam intersects with a maximum of 7 m elevation. Hence, we assumed the maximum water level in the dam is 6m. The villages and important landmarks inundated by the dam water spread were assessed based on the open-source and available data at INCOIS. A 0.5-meter interval elevation contours were also generated using the DEMs.

Further, the Village boundary data provided by NCCR was used to estimate the elevation levels of each village. The village boundaries intersect with elevation data were performed to understand each village's elevation level from MSL. The percentage of village administrative boundaries falling under 5, 6 and 7 m elevation were calculated. Since the tsunami inundation was significantly less, the exposure of villages with respect to elevation was estimated.

6. Results

6.1. Impact of Tsunami on Kalpasar Dam

The Tsunami Modeling was carried out for those earthquake locations covering seven source zones listed in Table 3. Model TSUNAMI N2 (ICMAM 2005, ICMAM 2009, TIME Project, Imamura, 1995) is used in a nested mode for propagation results in Grid A, Grid B & Grid C as well as inundation results in Grid D, as shown in figure 3. The model time step is taken as 1 sec according to CFL criteria to avoid the model blow-ups and output written for every 1 min with a total simulation time of 15 hours.

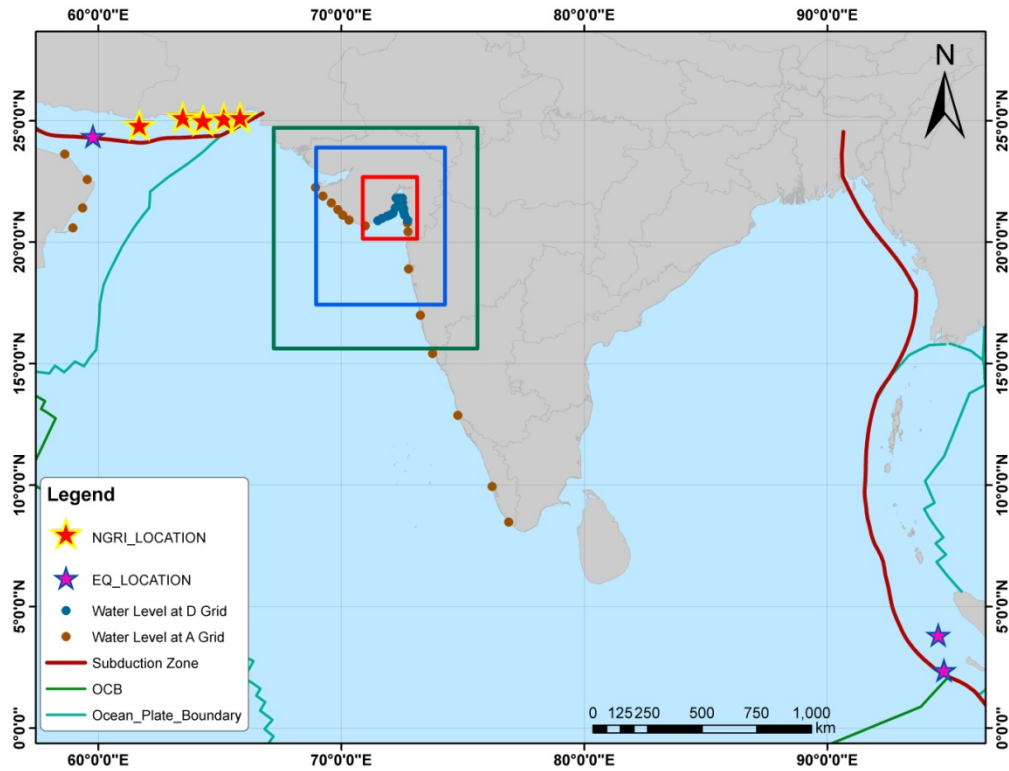


Figure 3. The extents of Grids A, B, C & D used in the model setup

For open ocean bathymetry grids – Grid A, Grid B & Grid C, GEBCO 30 arc second data was used to prepare the grids with different resolutions of 81 arc seconds, 27 arc seconds, 9 arc seconds. For the Gulf of Khambhat, ALTM data & Carto-DTM data were used to prepare Grid D with a resolution of 3 arc seconds for all simulated scenarios. The Open Ocean Propagation run was done using GEBCO 30 arc second data. The extents and topobathymetry setup of Grids A, B, C & D used in the model are listed in Table 4 and shown in Figure-3.

Table 4. Details of the grid dimensions used in the model

Model Grids	Lower left Long/Lat (°)	Upper right Long/Lat (°)	Grid Nos (Horizontal)	Grid Nos (Vertical)	Spatial Resloution (°)
GRID-A (Linear)	50.14031483 8.06120543	76.66781483 29.79620543	1180	0967	0.0225
GRID-B (Linear)	67.24781483 15.60620543	75.66281483 24.67370543	1123	1210	0.0075
GRID-C	69.07281483	74.31531483	2098	2590	0.0025

(Linear)	17.43120543	23.90370543			
GRID-D	70.85614816	73.08614816	2677	3124	0.0008333
(Non-linear)	20.10703876	22.70953876			

6.1.1. Scenarios proposed to Simulate

The earthquakes with source parameters are carefully selected, covering all eight source zones – SZ1, SZ2, SZ3, SZ4, SZ5, SZ6, SZ7 and SZ8 as listed in Table3, in total Seven scenarios considered to simulate. The following are the five earthquake source locations with the rupture running northwards/eastwards from the actual/hypothetical epicenter covering SZ1, SZ2, and SZ3 listed in Table5. The scenarios considering the source zones SZ-5 & SZ-6 simulated for magnitude 6.5 as per earthquake source characteristics are listed in Table 3.

Scenarios –5 set : Earthquake source parameters as listed in Table 5 covering source zones SZ1, SZ2 and SZ3

Table 5. Earthquake source parameters considered (SZ1, SZ2 & SZ3)

SOURCE PARAMETERS	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Longitude (Degrees)	63.48 0	64.313	65.169	61.684	65.832
Latitude (Degrees)	25.150	25.024	25.110	24.829	25.151
Strike (Degrees)	246	246	255	260	255
Dip (Degrees)	7	7	7	7	7
Rake (Degrees)	90	90	90	90	90
Depth (km)	15	20	20	20	20
Slip (m)	7	7	7	8	11
Length (km)	150	183	231	291	366
Width (km)	70	92	115	145	183
Magnitude (Mw)	8.1	8.4	8.6	8.8	9

6.1.2. Tsunami Inundation observed

All Tsunami simulations covering Source Zones SZ1, SZ2, SZ3, SZ4, SZ5, SZ6 and SZ7 were simulated and processed to obtain results in pre and post scenarios of DAM

construction. The five earthquake source locations spread across the three source zones (SZ1, SZ2 & SZ3) mentioned in Figure 3 were used as the scenarios for the tsunami modeling.

Tsunami simulation Results were extracted in A-grid and D-grid for the locations shown in Figure 3. From Open Ocean Propagation Simulations (TFF-CUDA 2011, TFF Compute Envi), the estimated travel times for the area of study - Gulf of Khambhat from Makran is about 2 to 3 hours.

The results of the maximum wave amplitudes for the various stations, including the locations near the proposed dam, are provided in Table 6.

Table 6. Results for Maximum wave amplitudes in D-grid were extracted for the various stations from five scenarios

Stations	Location		Estimated Maximum Wave Amplitudes (m)									
			Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	Lon	Lat	Without dam	With dam	Without dam	With dam	Without dam	With dam	Without dam	With dam	Without dam	With dam
L3-E	72.52	21.81	0.11	0.21	0.17	0.33	0.22	0.43	0.26	0.51	0.46	0.92
K1	72.31	21.81	0.11	0.21	0.16	0.33	0.21	0.43	0.26	0.51	0.46	0.91
K2	72.36	21.81	0.10	0.20	0.16	0.31	0.21	0.40	0.25	0.46	0.44	0.83
K3	72.41	21.81	0.10	0.18	0.15	0.28	0.19	0.36	0.25	0.46	0.43	0.83
K4	72.47	21.81	0.10	0.19	0.16	0.31	0.21	0.41	0.25	0.47	0.45	0.87
Luvara	72.52	21.63	0.15	0.15	0.21	0.22	0.28	0.28	0.32	0.32	0.64	0.64
Piram bet	72.36	21.57	0.26	0.28	0.28	0.29	0.34	0.34	0.37	0.37	0.81	0.81
Alang	72.23	21.41	0.23	0.23	0.26	0.26	0.33	0.33	0.38	0.38	0.71	0.71
Bhagva	72.57	21.37	0.20	0.20	0.33	0.33	0.43	0.43	0.43	0.43	0.91	0.91
Dandi	72.57	21.25	0.32	0.32	0.44	0.44	0.55	0.55	0.51	0.51	1.11	1.11
Jhanjmar	72.13	21.19	0.54	0.54	0.68	0.68	0.82	0.82	0.67	0.67	1.29	1.29
kotada	72.00	21.12	0.71	0.71	1.04	1.04	0.86	0.86	0.84	0.84	1.69	1.69
Hajira	72.60	21.11	0.38	0.38	0.43	0.43	0.51	0.51	0.41	0.41	0.83	0.83
Sathra	71.88	21.06	0.57	0.57	0.70	0.70	0.89	0.89	0.85	0.85	1.69	1.69
Chanch	71.67	20.97	0.39	0.39	0.48	0.48	0.67	0.67	0.81	0.81	1.42	1.42
Navasari	72.73	20.90	0.23	0.23	0.32	0.32	0.37	0.37	0.40	0.40	0.80	0.80
Bherai	71.51	20.89	0.33	0.33	0.43	0.43	0.53	0.53	0.70	0.70	1.21	1.21

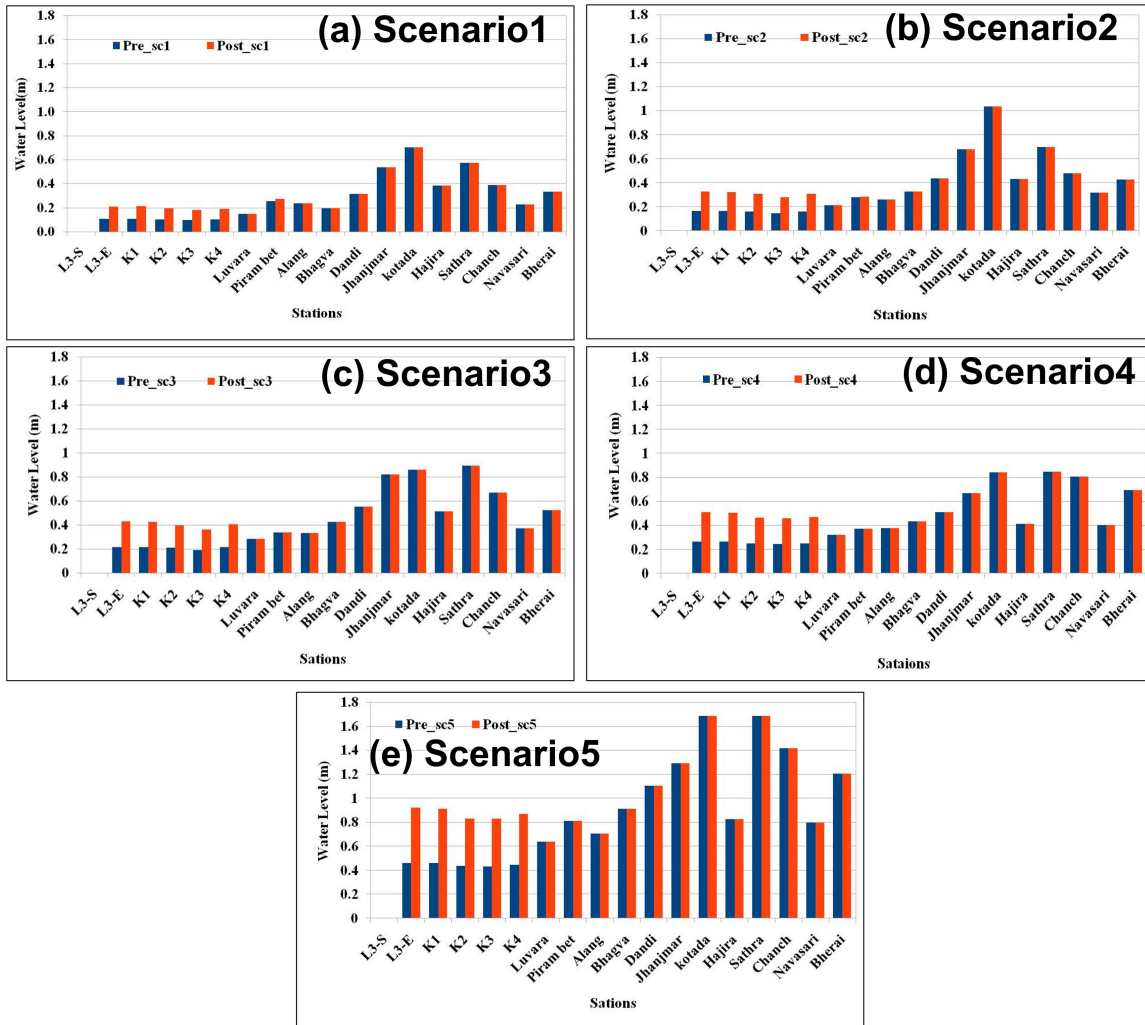


Figure 4. Bar diagram of resultant tsunami wave amplitudes measured at different stations, including locations (L3, K1 to K4) near a proposed dam without a dam and with a dam by five scenarios simulated

From the results extracted from all scenarios, it is clear that the change in wave amplitudes were observed at DAM locations (L3-E, K1, K2, K3 & K4) only in Pre-DAM construction and Post DAM construction due to the DAM presence. The minor changes in the tsunami wave amplitudes were observed with and without a dam in all the scenarios (Table 6 and Figure 4)

For source zones, SZ5 and SZ6 Scenarios simulated with magnitude 6.5, and there is no inundation observed / no difference noted in Pre DAM construction and Post DAM construction. As well, the results of the tsunami inundation study for Pre DAM

construction (Figure 5) and Post DAM construction (Figure 6) are provided in the maps below for the scenarios listed in Table 5 for comparison and consistency check

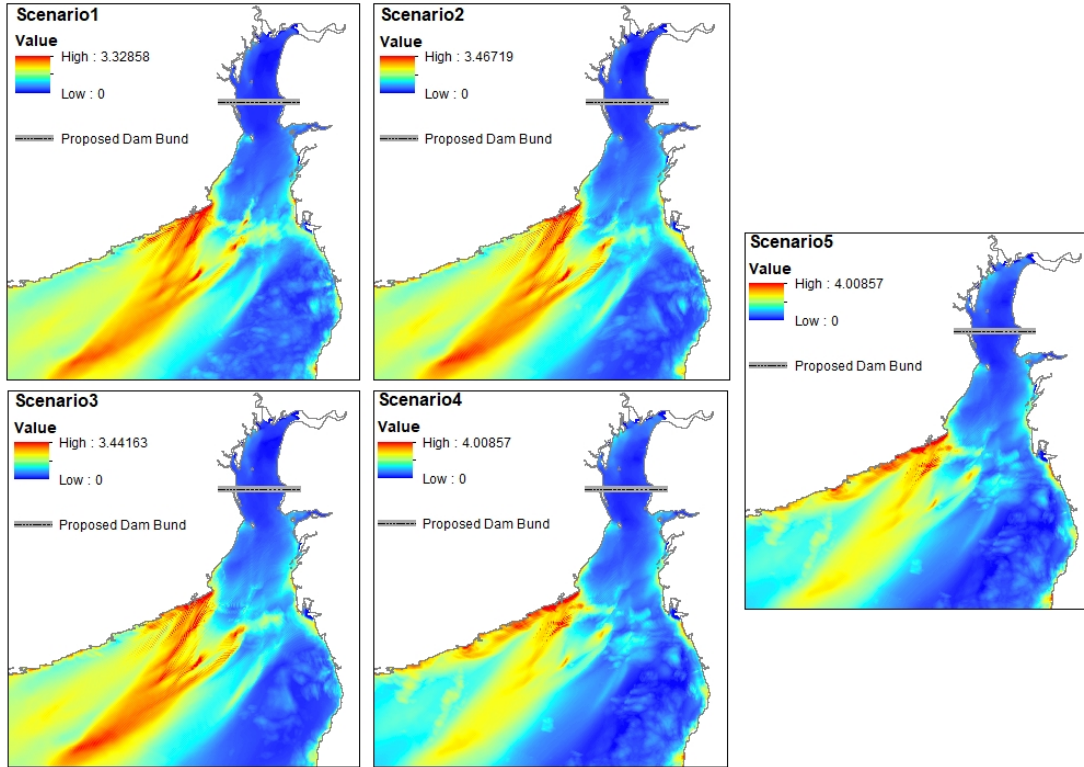


Figure 5. Tsunami Inundation results from five scenarios without a dam

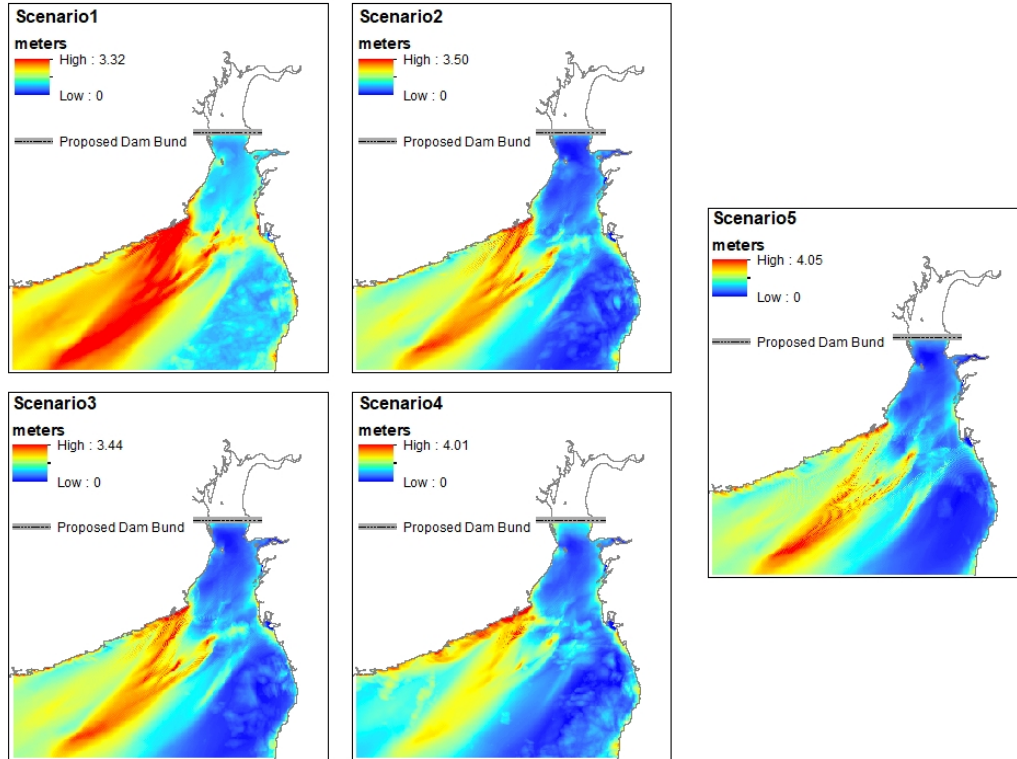


Figure 6. Tsunami inundation results from five scenarios with a dam

The inundation was not observed on land except few beach inundations in the southwestern coasts. However, the maximum wave amplitudes recorded in scenario five (Hypothetical Worst-case) were 4.01 and 4.05 m without and with a dam, respectively.

6.2. Assessment of Sea-level Rise due to Climate Change

The trend in the Mean Sea Level: The annual mean sea level trends, based on satellite observations available since 1993 for selected stations along the west coast of India, are shown in Table 7. The nearest tide gauge stations to the proposed Kalpasar Dam are Adani Port, with a mean sea level rise of 3.28 mm yr^{-1} and Bhavnagar-I with a 2.13 mm yr^{-1} .

Table 7. The trend in mean sea level (mm/y) from satellite observations at selected stations along the west coast of India.

Station	MSL Trend (mm/yr) Satellite (1993-2020)
Mumbai	3.43
Adani Port	3.28
Bhavnagar-I	2.13
Veraval	3.4
Okha	3.59

Projected change in mean sea level: The median projections of sea level from the multi-model mean of CMIP6 models used for preparing the IPCC AR6 report are used for assessing the projected sea-level rise along the west coast of India. The mean sea level values under SSP2-4.5 scenarios for 2050 and 2100 at selected tide-gauge locations along the west coast of India are presented in Table 8.

Table 8. Median projections of mean sea level rise (m) relative to 1995-2014 baseline period for 2050 and 2100 at selected stations along the west coast of India from IPCC AR6 SSP2-4.5 scenario.

Stations	Median projections of MSL rise (m) relative to 1995-2014 baseline period (IPCC AR6 projection based on SSP2-4.5 scenario)	
	2050	2100
Mumbai	0.17	0.46
Adani Port	0.18	0.52
Bhaunagar-I	0.3	0.71
Veraval	0.19	0.52
Okha	0.18	0.48

6.3. Seaside Inundation in Gulf post-construction of Dam

The seaside inundation is estimated here based on elevation levels at each village is presented below Figure 7. It was observed that a total of 373, 477 and 640 villages were recorded under elevations 5, 6 and 7m, respectively, from MSL. The percentage of the area with respect to the village's geographic area was also calculated.

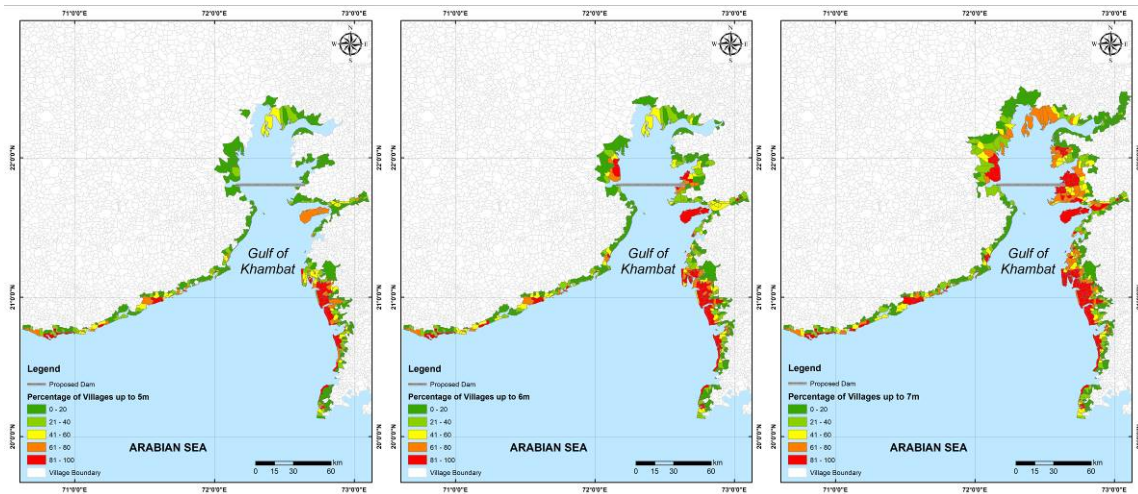


Figure 7. Elevation level of coastal villages and their percentage of areas within 5m (left), 6m (middle) and 7m(right) with respect to MSL in the adjacent coasts of the proposed Kalpasar Dam.

The villages in the eastern bank of the Gulf of Khambhat are situated in the low elevation and recorded their maximum areas below 7m elevations. The villages with the percentage of geographic area covered under each village are listed and provided in Annexure 1.

The elevation contours of 0.5m interval were generated, and the contour map of ALTM and merged data (ALTM+SRTM) was provided in Figure 8.

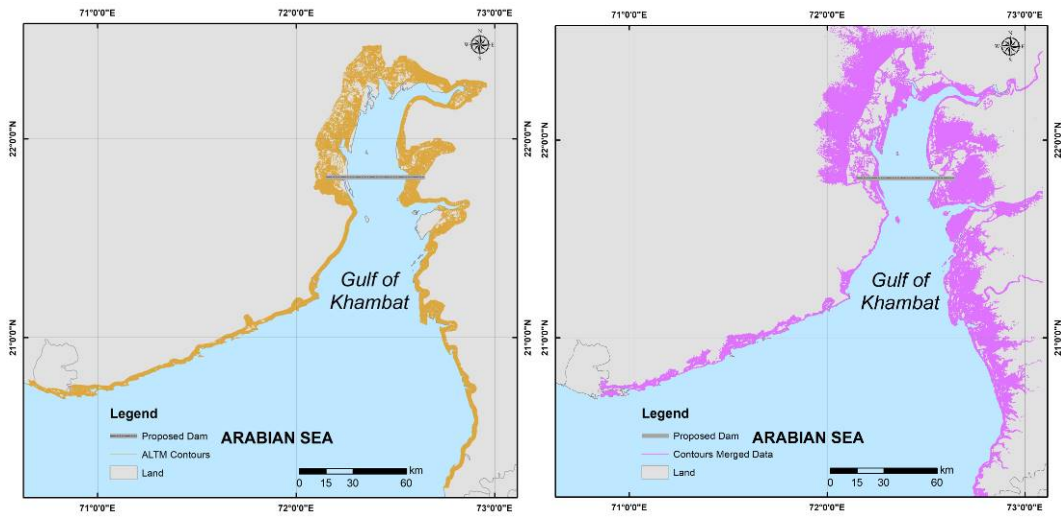


Figure 8. Contour maps of the coastal zones generated using ALTM data (left) and merged data (ALTM+SRTM) (right)

The objective was to study to assess the seaside inundation, however, the inundation due to the proposed dam water spread was also estimated. It was observed that none of the locations were recorded under the 5m water spread based on the available data. These villages/landmarks are falling in the built-up areas of the villages, hence considered to estimate the inundating habitations. Only 7 locations fall under the 6m water spread and a total of 29 habitation locations fall within the 7m of water spread inside the dam.

The DEM generated using the blended data was shown in the 3D view overlaid with 1m elevation contours, dam bund, and water spread at 5m (Figure 9).

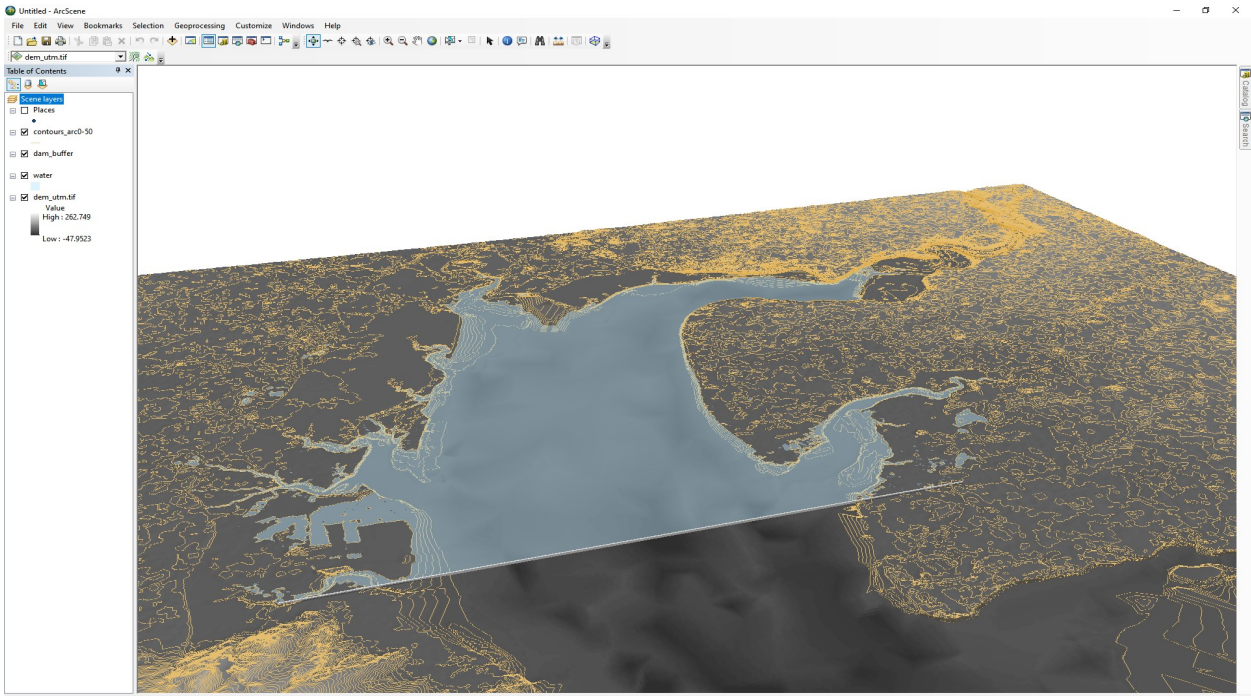


Figure 9. 3D View of the proposed Kalpasar dam area overlaid with the elevation contours and spread of water at the level of 5m

7. Deliverables

The list of deliverables of the project and the status are provided in Table 9 given below

Table 9 List of deliverable tha their status

Deliverables	Status
1. A report on Design Parameters and Impact of Tsunami in Gulf of Khambhat due to construction of Kalpasar Dam.	Covered in this report
2. A report on estimates of Sea Level Rise at Dam location during the life of Dam (IITM, INCOIS).	Covered in this report
3. A report on inundation areas and villages in the Gulf of Khambhat after construction of Kalpasar Dam.	Covered in this report
4. Contours at 1m interval in the inundation areas (ALTM-0.5m interval and merged (1m interval)	Shared by email dated 3/04/2022
5. Shapefile: villages falling up to 7m elevations, attribute contains the area and percentage in 5,6 and 7m	Shared by email dated 3/04/2022
6. Villages level elevation statistics (excel file)	Shared by email dated 3/04/2022

8. Summary

Current study focused on the assessment of the tsunami inundation, sea level trend, sea level projection and seaside inundation pertaining to the vicinity of the proposed Kalpasar Dam in the Gulf of Khambhat. The results of the current study provide vital inputs for the proposed dam development.

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Annexure1

List of villages and their percentage of the area falling under the 5, 6 and 7 m elevation levels recorded in each coastal village between Diu and Daman

Vilalge	Percentage of coastal Village area under Elevation from MSL		
	5 meters	6 meters	7 meters
Zankhi	0.4	1.0	21.7
Bavliyari	0.0	0.7	30.6
Mingalpur	0.2	4.8	77.5
Jantran	0.0	0.0	17.5
Dahri	0.0	0.0	16.8
Velavadar	0.0	0.0	33.0
Adhelai	0.6	27.9	64.5
Malpore	0.0	0.4	63.9
Panchakada	0.0	0.0	11.7
Kava	0.0	0.0	10.9
Bhadkodara	0.0	0.0	80.1
Bhadbhid	0.0	8.5	40.7
Vad	0.0	0.0	70.9
Madafar	0.0	0.0	93.6
Panchpipla	0.0	0.0	77.2
Sindhav	0.0	0.0	77.6
Kansagar	0.0	0.0	90.7
Jashavantpar	4.1	48.5	88.1
Chandpor Bara	0.0	0.0	45.1
Nadiad	0.0	0.0	0.5
Singarna	0.0	0.0	74.4
Bakarpor Timbi	0.0	0.0	88.2
Devla	0.0	7.5	65.4
Thakore Talavdi	0.0	0.0	83.8
Sardarpura	0.0	0.0	0.0
Asanvad	0.0	0.0	89.8
Vanseta	0.0	3.4	3.2
Ganeshgadh	0.3	13.8	20.4
Kotda	3.6	65.9	94.0
Tankari	0.0	6.2	26.4
Dolia	0.0	6.1	6.5
Kundhal	3.9	10.4	32.1
Gundala	11.4	93.0	98.9

Islampore	0.0	3.0	45.0
Pursa	0.0	0.0	4.7
Khanpor Deh	0.1	19.9	35.6
Asarsa	1.2	28.1	58.0
Amod	0.0	0.0	4.0
Kapuria	0.0	1.3	50.6
Nada	0.0	42.2	77.0
Sanes	1.0	12.4	34.8
Achhod	0.3	23.1	49.6
Valipor	6.2	46.0	57.8
Denva	11.8	50.6	67.5
Mangrol	2.5	16.8	31.2
Narbad	33.3	93.3	99.2
Kalatalav	0.8	74.8	96.7
Machhasara	0.0	7.8	20.1
Buva	0.0	0.0	5.3
Khetakhatli	0.0	52.9	90.6
Savainagar	0.0	0.0	1.0
Chanchvel	0.0	31.6	64.6
Nava Madhiya	0.0	5.8	25.6
Kerwada	0.0	0.0	0.1
Kolavana	0.0	0.0	0.2
Gandhar	5.1	86.5	95.9
Juna Madhiya	0.0	29.5	64.0
Badalpura	0.0	31.9	72.4
Paldi	0.0	42.9	86.2
Muler	0.0	60.0	87.3
Ochchhan	0.0	2.9	41.7
Kardej	0.0	0.0	1.1
Keshwan	0.0	16.8	81.5
Aladar	0.5	79.1	94.5
Trankal	0.0	84.0	98.8
Bhavnagar (m Corp.)	0.5	16.9	24.4
Kalam	0.0	0.3	38.9
Ruva (part)	0.7	28.6	37.5
Paniadara	0.0	62.5	86.9
Ambhel	0.0	66.0	95.1
Limdi	0.0	62.5	94.9
Sutrel	0.0	0.0	8.8

Goladara	0.0	16.3	85.8
Vahiyal	0.0	0.0	52.7
Harinagar	1.1	85.4	97.2
Pipalia	0.0	0.0	59.4
Pakhajan	0.0	6.0	71.0
Narnavi	0.0	1.7	55.5
Sayakha	0.0	0.0	13.0
Nadarkha	0.0	0.0	52.5
Padariya	0.0	62.0	87.2
Janiadara	0.0	0.0	47.6
Akwada	0.0	5.3	20.4
Kadodara	0.0	29.9	84.1
Kothia	0.0	0.0	42.3
Nandida	0.0	0.0	63.9
Sadathala	0.0	0.0	77.2
Akhod	0.0	0.0	55.0
Sambheti	0.0	0.0	76.3
Khojbal	0.0	0.0	63.3
Avaniya	0.0	8.7	17.4
Dahej	5.7	23.8	69.2
Vav	0.0	0.0	76.5
Samatpor	0.0	0.0	79.5
Tavara	19.5	20.9	22.5
Amleshwar	0.0	0.0	10.5
Vadadla	0.1	28.7	80.1
Galenda	0.0	0.0	80.2
Atali	0.0	0.0	71.2
Jolva	1.2	33.1	79.0
Jhadeshwar	4.3	5.5	6.2
Bhensali	0.0	0.2	59.5
Bhuteshwar	0.0	0.0	0.2
Kaladara	17.9	34.1	92.7
Ghogha (ct)	1.2	18.2	32.5
Kesrol	0.0	0.0	42.9
Rahiad	2.4	15.7	74.4
Lakhigam	23.0	41.7	64.5
Bhumbhali	0.0	0.6	3.7
Govali	33.5	37.5	44.1
Borbhatha Bet	75.6	81.3	83.7

Bharuch (m)	24.7	28.0	30.2
Koliad	21.7	38.5	93.4
Suva	26.8	39.2	65.8
Bhuva	7.2	7.9	8.3
Mandvabuzarg	3.6	13.9	20.0
Maktampur (ct)	68.9	81.9	86.6
Ambheta	13.3	20.6	56.6
Govali	2.5	2.7	3.3
Vadva	31.6	34.3	38.0
Kansiya	1.9	7.0	12.6
Manad	3.7	4.3	7.8
Vengani	25.7	30.5	93.8
Jageshwar	5.5	18.9	53.5
Bhadbhut	53.2	59.3	60.3
Nava Ratanpar	0.4	2.4	9.1
Mahegam	4.4	9.2	36.2
Dashan	50.3	53.2	55.8
Verwada	46.2	46.6	48.2
Kasva	32.7	50.6	50.9
Chhapra	8.5	8.5	8.8
Luvara	6.8	16.1	41.1
Kukarwada	48.4	50.2	52.4
Borbhatha Bet	9.1	10.2	10.5
Total Number of Villages	373	477	640