Indian Committee on Large Dams
Young Engineers Forum

INTERNATIONAL
DAM SAFETY CONFERENCE

Dam Rehabilitation & Improvement Project

Central Water Commission

Energy Infrastructure Risk against Flood in a Changing Climate: A Case Study

Presented by
Dr. Viraj Loliyana
Secretary - INCOLD YPF &
CEO, FAMS Design Solution

FAMS®

Contents

- Objectives of Case Study for Solar Energy Infrastructure Investment
- Adopted Methodology
- Data Sources
- Modelling and Simulation Scenarios
- Historical Analytics
- Future Analytics for RCP 4.5 and RCP 8.0 Scenarios
- Outcomes and Recommendations
- Proposed Methodology for Obtaining Risk Curve
- Opportunities for evaluation Hydropower and Renewable Energy Infrastructure Projects in India considering changing climate

Study Site:
Solar Power Energy Plant, Mexico

Client: Insurance Company, Spain

- About US $13 million Private Investment
  - Revenue per day about US $100,000-115,000
  - Operational Expense per day about US $ 10,000-15,000
- Due to Flood event (60 Years of Return Period event) in 2017, about 96 hours (about 4 Days) of flood inundation observed at site
  - 15 days operational cycle hampered
  - Revenue loss + Operational expense
- In 2020, 47 years of return period event occurred, about 70 hours (about 3 days) of flood inundation observed at site
  - 15 days operational cycle hampered
  - Revenue loss + Operational expense

Objectives of Case Study

1) Collection of **territorial data**; digital elevation model, detailed maps, etc.
2) Compilation of **hydrological data and climatic phenomena** to be analyzed in the flood study
3) Generation of the hydrological model and hydraulic model using **two-dimensional hydraulic modeling programs**,
4) Treatment of simulation results in order to obtain:
   - **Surfaces or extent of flooding**
   - **Classification / discretization by ranges of the most important hydraulic variables**
   - **Classification of the levels of danger of the resulting flood phenomenon**
   - **Establishment of risk classification and assessment criteria**
   - **Crossing of the coverage of results with the coverage of territorial information to define a distribution of risks and to be able to proceed with their valuation**
5) Generation final of **graphic documentation and conclusions**
6) Analysis of **trends, anomalies, Precipitation Max., Probable (PMP), in terms of intensity, magnitude and return periods**, in graphic, numerical, parametric and statistical format **that helps to economically quantify industrial losses, business interruption, etc.**

Sr. No.	Deliverables	Outcomes	Data Requirement
1	Spatio-temporal analysis of rainfall data • Rainfall parameter analysis • Discharge parameter analysis	• Rainfall Frequency • Flood Frequency 2, 5, 10, 25, 50, 100, 200 and 500 years of return period	• Rainfall data of raingauge stations for a period of 20-30 years or whatever available • Weather data of weather stations for a period of 20-30 years or whatever available • Discharge data of gauge discharge stations for a period of 20-30 years or whatever available
2	Rainfall Runoff modelling (HEC-HMS) for computation basin lag, time of concentration, travel time at sub-basin scale • Rainfall-Runoff (Hydrological) modelling and simulation • Calibration of model using historical data • Validation of model using historical data • Predictions of Calibrated model using Future RCP 4.5 and 8.5 Scenarios	• Basin Lag • Time of concentration • Travel time • Flow hydrograph • Free catchment rainfall-runoff analysis	• All data mentioned in Item No. 1 • River channel & its major tributary shape file or CAD file • Upstream Dams releases for a period of 20 years if available
3	**Hydrodynamic modelling (HEC-RAS) for river reaches for computation of flood levels at Site** • **Hydrodynamic modelling and simulation** • **Calibration of model using historical flood events** • **Validation of model using historical flood events** • **Predictions of Calibrated model using Future RCP 4.5 and 8.5 Scenarios**	At Site Location • Discharge hydrograph • Stage (Water Level) hydrograph • Comparison with observed data at gauge- discharge sites • Rating curve	• All data mentioned in Item No. 1 • River Geometry Data (cross-sections, Hydraulic Structures, Bridges, etc.) for River and its tributaries whatever available • Water Level data of gauge discharge stations for a period of 20-30 years or whatever available

Adopted Methodology

Data Collection from various Sources

Trend Anomalies of Rainfall for Historical and Future RCP 4.5 & 8.5

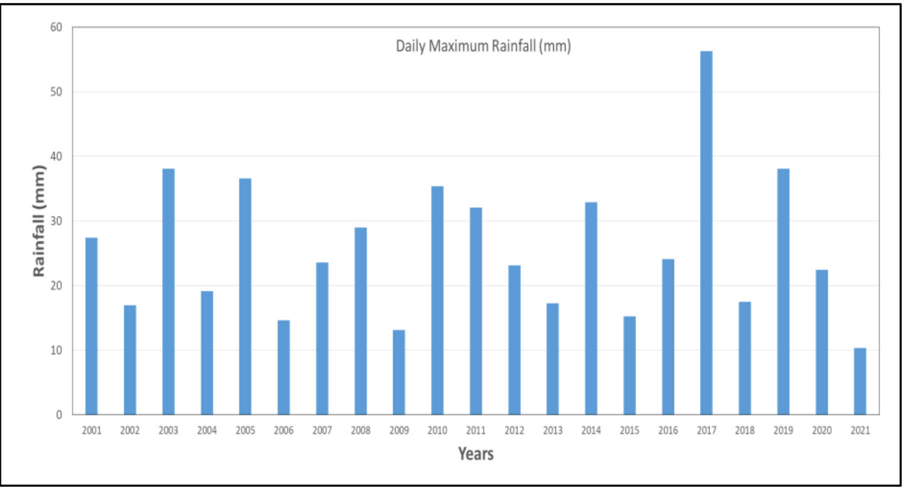
Frequency Analysis for Estimation of Intensity-Duration-Frequency Curve for various Return Period

Running the Hydrological model HEC-HMS for getting inflow, lag time, travel time at the site

Running HEC-RAS 2D model for getting Flood Inundation Depth, Flood Arrival time, Flood Depth at location for various return periods (Historical and Future)

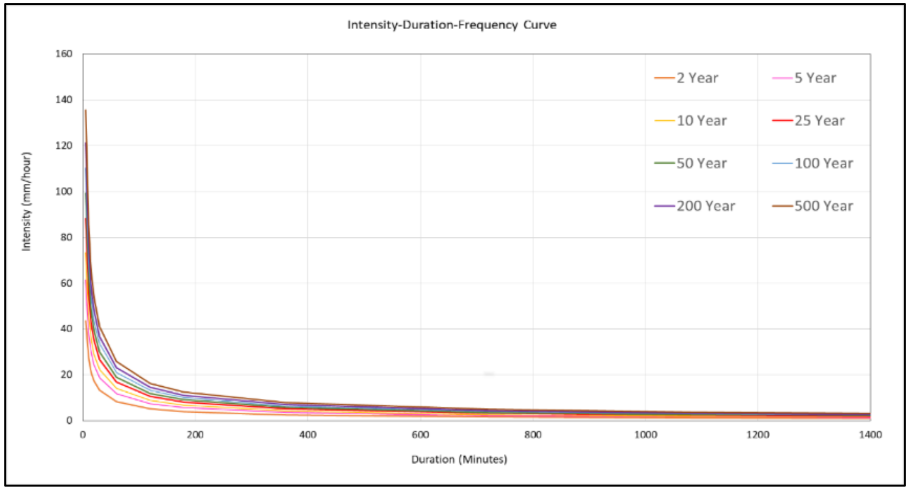
TOOLS:

- Rainfall Variability Analysis of Historical and Future RCP 4.5 and 6.0 Scenarios using **Programming Scripts**
- Two-dimensional hydraulic modeling programs, **HEC-RAS (2D)** and hydrological modeling, **HEC-HMS**, models
- GIS for the treatment of data in **QGIS**, results and generation of graphic documentation of the analysis



Daily maximum rainfall

Duration (hr)	Rainfall Intensity (mm/hr) for Return Period T							
Duration (hr)	Rainfall Intensity (mm/hr) for Return Period T							
	2	5	10	25	50	100	200	500
1	8.33	11.73	13.98	16.83	18.94	21.04	23.13	25.88
2	5.25	7.39	8.81	10.60	11.93	13.25	14.57	16.31
3	4.00	5.64	6.72	8.09	9.11	10.11	11.12	12.44
6	2.52	3.55	4.24	5.10	5.74	6.37	7.00	7.84
12	1.59	2.24	2.67	3.21	3.61	4.01	4.41	4.94



IDF Curves

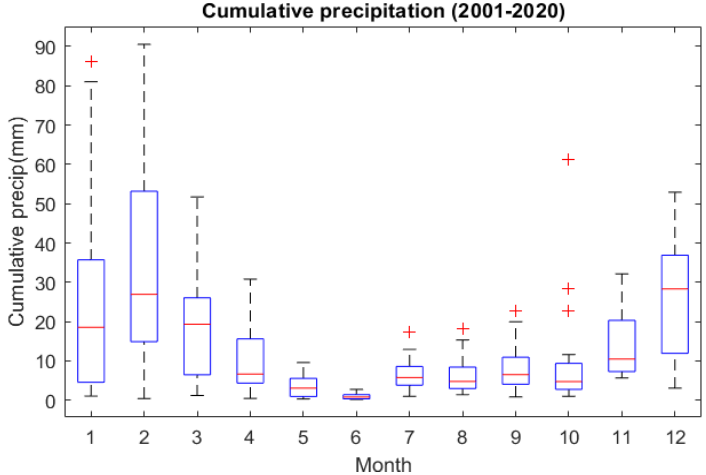
Indian Committee on Large Dams
Young Engineers Forum

INTERNATIONAL DAM SAFETY CONFERENCE

Dam Rehabilitation & Improvement Project

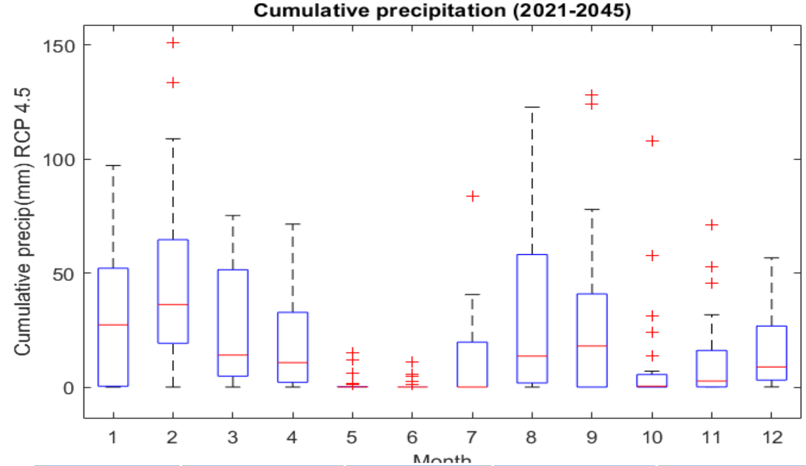
Central Water Commission

Historical Trend Anomalies of Rainfall



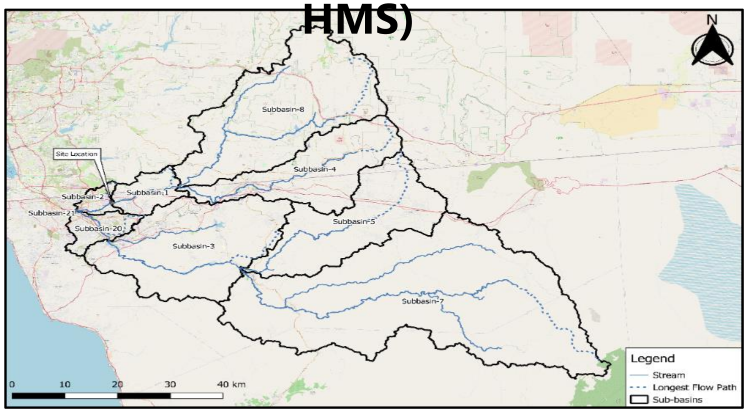
Month	Mean	Min	Max	Trend
1	25.99	1.04	86.28	0.98
2	33.53	0.43	90.57	-1.22
3	19.22	1.19	51.72	0.38
4	10.49	0.47	30.81	0.06
5	3.53	0.32	9.60	0.13
6	0.98	0.19	2.75	0.05
7	6.45	0.99	17.29	0.08
8	6.38	1.39	18.25	0.04
9	8.01	0.86	22.69	-0.004
10	9.54	0.98	61.30	0.18
11	14.10	5.66	32.13	-0.01
12	26.44	3.06	52.91	0.15

Future Trend Anomalies of Rainfall



Month	Mean	Min	Max	Trend
1	32.23	0	97.20	-0.010
2	47.02	0	151.10	1.07
3	25.69	0	75.30	0.53
4	19.27	0	71.51	-0.23
5	1.63	0	14.85	-0.0002
6	0.95	0	10.78	0
7	9.26	0	83.54	0
8	29.44	0	122.79	0.003
9	29.57	0	128.01	-0.82
10	9.84	0	107.80	0.002
11	12.87	0	71.05	-0.18
12	15.52	0.036	56.68	0.49

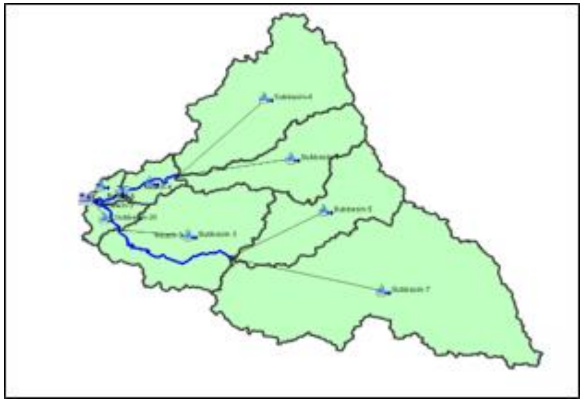
Hydrological Modelling (HEC-HMS)



Subbasin	Area (sq km)	Longest Flow Path (Km)	Longest Flow Path Slope	Basin Slope		Reach	Length (km)	Slope
Subbasin-1	1633.80	25.645	0.035	0.359		Reach-3	37.613	0.005
Subbasin-2	513.390	17.903	0.025	0.110		Reach-2	13.949	0.003
Subbasin-3	656.820	25.201	0.018	0.186		Reach-4	17.774	0.006
Subbasin-4	807.500	0.183	0.033	0.126		Reach-5	9.490	0.004
Subbasin-5	433.640	52.930	0.017	0.252		Reach-1	0.139	0.007
Subbasin-6	105.450	71.051	0.017	0.187				
Subbasin-7	91.338	68.979	0.014	0.148				
Subbasin-8	42.385	123.343	0.012	0.188				
Subbasin-9	0.010	80.298	0.022	0.270				

Sub Basin	CN
B1	86.9
B2	88.6
B3	88.0
B4	87.8
B5	88.8
B6	86.4
B7	88.3
B8	86.4
B9	87.2

Basin Delineation Parameters



HEC-HMS Model Schematics

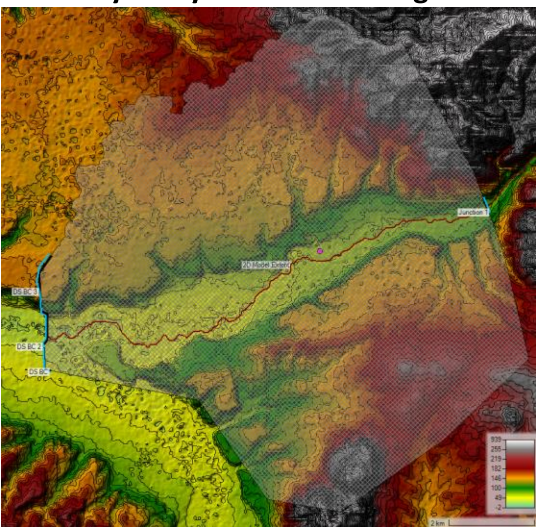
Reach	Length (km)	L (m)	Slope	Time of concentration (T_c) (min)	Time of concentration (T_c) (hr)	Lag Time (T_L) (min)	Lag Time (T_L) (hr)
Reach-3	37.61317	37613.17	0.00492	502.31	8.3718	301.386	5.0231
Reach-2	13.94921	13949.21	0.0033	272.92	4.5487	163.754	2.7292
Reach-4	17.77449	17774.49	0.00596	261.96	4.3660	157.178	2.6196
Reach-5	9.49007	9490.07	0.00379	192.35	3.2058	115.409	1.9235
Reach-1	0.13919	139.19	0.00718	5.83	0.0971	3.495	0.0583

Time of concentration calculation: Reach

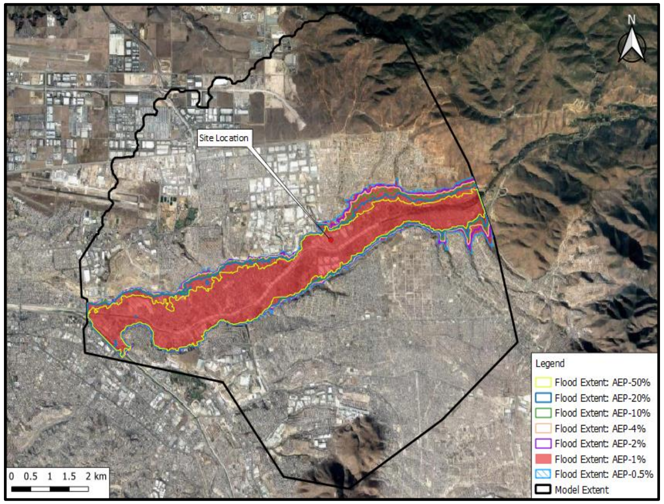
Time of concentration calculation: Sub-Basin

Subbasin	Lfp (Km)	Lfp (m)	Lfslope	Time of concentration (T_c) (min)	Time of concentration (T_c) (hr)	Lag Time (T_L) (min)	Lag Time (T_L) (hr)
Subbasin-1	25.645	25645.45	0.03465	176.41	2.94	105.845	1.76
Subbasin-2	17.903	17903.37	0.02536	150.84	2.51	90.506	1.51
Subbasin-3	25.201	25200.76	0.01798	224.06	3.73	134.435	2.24
Subbasin-4	0.183	182.89	0.03281	4.00	0.07	2.403	0.04
Subbasin-5	52.930	52929.96	0.01676	407.63	6.79	244.581	4.08
Subbasin-6	71.051	71050.88	0.01721	506.17	8.44	303.704	5.06
Subbasin-7	68.979	68979.35	0.01398	535.99	8.93	321.596	5.36
Subbasin-8	123.343	123342.74	0.01193	891.29	14.85	534.771	8.91
Subbasin-9	80.29838	80298.38	0.02176	508.15	8.47	304.890	5.08

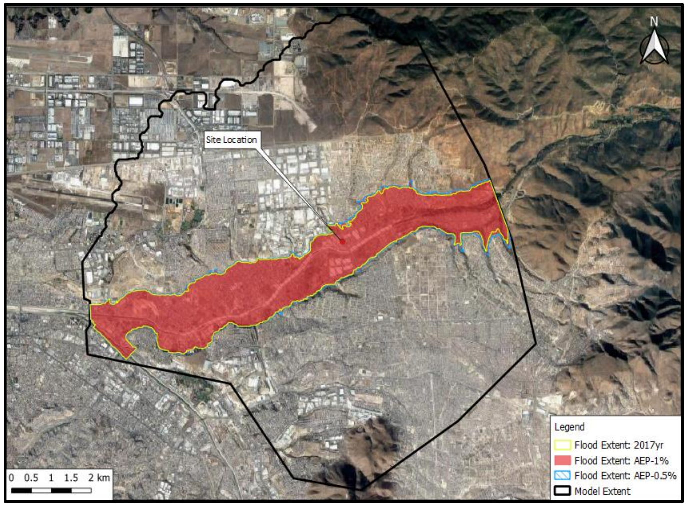
Hydrodynamic Modelling



HEC-RAS 2D Model Schematics



Flood extent all AEP's

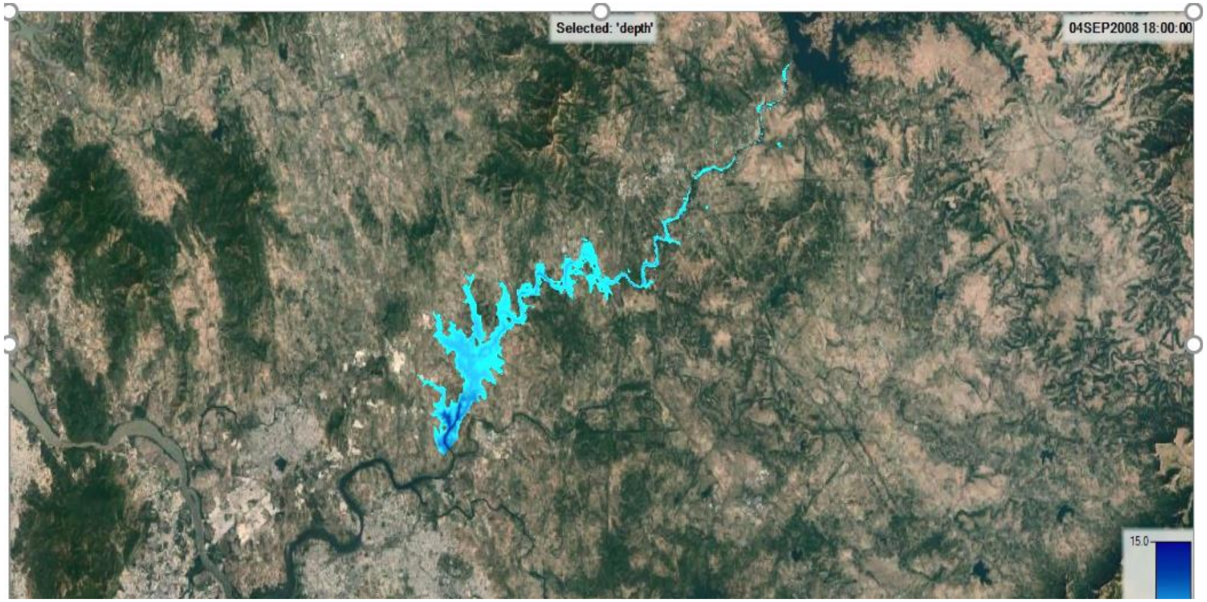


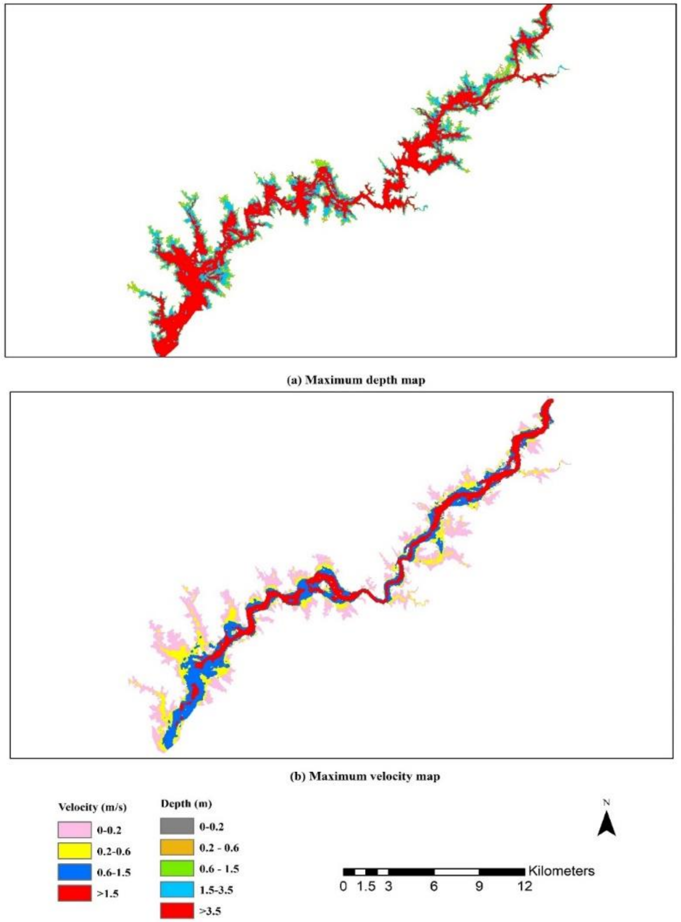
Flood extent historical Events

Return Period (year)	AEP (%)	Rainfall (24-Hr) (mm)	Max Depth (m)	Duration of Inundation (hr)
2	50	24.02	-	-
5	20	33.84	-	-
10	10	40.34	9.897	66
25	4	48.55	13.190	80
50	2	54.64	15.497	89
100	1	60.69	17.675	98
200	0.5	66.71	19.753	107

Historical Event (Yr)	Rainfall (24-Hr) (mm)	Max Depth (m)	Duration Of Inundation (hr)
2017	56.23	15.98	91.5
2020	50.77	11.89	67

Flood Inundation Simulation





(a) Maximum depth map

(b) Maximum velocity map

Historical & Future Predictions Assessment

Return Period (Year)	AEP (%)	Max. depth (m)	Precipitation Depth (mm)	Number of Events (days)			Duration of Inundation (hrs)		
				Historical	RCP 4.5	RCP 8.5	Historical	RCP 4.5	RCP 8.5
2	50	-	24.02	7	16	17	0	0	0
5	20	-	33.84	3	8	11	0	0	0
10	10	9.897	40.34	0	5	7	0	327.6705	459.3104
25	4	13.19	48.55	0	4	1	0	317.6838	79.73353
50	2	15.497	54.64	1	2	2	0	176.5508	176.2525
100	1	17.675	60.69	0	3	2	0	292.4718	195.0639
200	0.5	19.753	66.71	0	0	0	0	0	0

Year	AEP %						
	50	20	10	4	2	1	0.5
2005	1	0	0	0	0	0	0
2006	0	0	1	0	0	0	0
2007	0	0	1	0	0	0	0
2008	0	0	0	0	0	0	0
2009	2	0	0	0	0	0	0
2010	1	0	1	0	0	0	0
2011	2	0	1	0	0	0	0
2012	1	0	0	0	0	0	0
2013	2	1	0	0	0	0	0
2014	1	0	1	0	0	0	0
2015	1	0	0	0	0	0	0
2016	1	0	2	0	0	0	0
2017	2	0	1	0	0	0	0
2018	1	0	0	0	0	0	0
2019	0	0	0	0	0	0	0
2020	1	0	1	0	0	0	0

Year wise total events (Historic period 2005-2020)

RCP 8.5 IPCC Scenario: Prediction Assessment

Year	AEP %						
	50	20	10	4	2	1	0.5
2021	2	0	0	0	0	0	0
2022	0	0	1	0	0	0	0
2023	1	1	1	0	1	0	0
2024	3	0	2	0	0	0	0
2025	0	0	0	0	0	0	0
2026	2	0	0	0	0	0	0
2027	1	0	0	0	0	0	0
2028	0	1	0	0	0	0	0
2029	3	1	0	0	0	0	0
2030	1	2	0	0	0	0	0
2031	0	0	0	0	0	0	0
2032	0	1	0	0	0	0	0
2033	0	0	0	0	0	0	0
2034	0	0	0	0	0	0	0
2035	0	0	0	0	0	0	0
2036	1	0	0	0	0	1	0
2037	0	0	1	0	0	0	0
2038	1	1	0	0	0	0	0
2039	0	0	0	0	0	0	0
2040	0	0	0	0	0	1	0
2041	0	1	0	0	0	0	0
2042	1	0	0	0	1	0	0
2043	0	2	1	0	0	0	0
2044	0	0	0	0	0	0	0
2045	1	1	1	1	0	0	0

Year wise total events
(Future RCP 8.5 period 2021-2045)

Year	AEP %						
	50	20	10	4	2	1	0.5
2021	0	0	0	0	0	0	0
2022	0	0	12.2021	0	0	0	0
2023	0	0	12.1902	0	16.3682	0	0
2024	0	0	10.8849	0	0	0	0
2025	0	0	0	0	0	0	0
2026	0	0	0	0	0	0	0
2027	0	0	0	0	0	0	0
2028	0	0	0	0	0	0	0
2029	0	0	0	0	0	0	0
2030	0	0	0	0	0	0	0
2031	0	0	0	0	0	0	0
2032	0	0	0	0	0	0	0
2033	0	0	0	0	0	0	0
2034	0	0	0	0	0	0	0
2035	0	0	0	0	0	0	0
2036	0	0	0	0	0	19.753	0
2037	0	0	11.2142	0	0	0	0
2038	0	0	0	0	0	0	0
2039	0	0	0	0	0	0	0
2040	0	0	0	0	0	19.3374	0
2041	0	0	0	0	0	0	0
2042	0	0	0	0	16.3682	0	0
2043	0	0	10.2263	0	0	0	0
2044	0	0	0	0	0	0	0
2045	0	0	11.8728	14.8049	0	0	0

Year wise depth of inundation (m)
(Future RCP 8.5 period 2021-2045)

Year	AEP %						
	50	20	10	4	2	1	0.5
2021	0	0	0	0	0	0	0
2022	0	0	66.88504	0	0	0	0
2023	0	0	66.83979	0	89.11816	0	0
2024	0	0	66.20521	0	0	0	0
2025	0	0	0	0	0	0	0
2026	0	0	0	0	0	0	0
2027	0	0	0	0	0	0	0
2028	0	0	0	0	0	0	0
2029	0	0	0	0	0	0	0
2030	0	0	0	0	0	0	0
2031	0	0	0	0	0	0	0
2032	0	0	0	0	0	0	0
2033	0	0	0	0	0	0	0
2034	0	0	0	0	0	0	0
2035	0	0	0	0	0	0	0
2036	0	0	0	0	0	98.12023	0
2037	0	0	66.57209	0	0	0	0
2038	0	0	0	0	0	0	0
2039	0	0	0	0	0	0	0
2040	0	0	0	0	0	98.94939	0
2041	0	0	0	0	0	0	0
2042	0	0	0	0	89.25639	0	0
2043	0	0	66.98987	0	0	0	0
2044	0	0	0	0	0	0	0
2045	0	0	66.34981	80.20852	0	0	0

Year wise duration of inundation (hr)
(Future RCP 8.5 period 2021-2045)

RCP 4.5 IPCC Scenario: Prediction Assessment

Year	AEP %						
	50	20	10	4	2	1	0.5
2021	1	1	0	0	0	0	0
2022	1	1	1	0	0	0	0
2023	1	0	0	0	1	0	0
2024	0	0	0	0	0	1	0
2025	1	0	0	0	0	0	0
2026	1	0	2	0	0	0	0
2027	1	1	0	0	0	1	0
2028	2	0	0	0	0	0	0
2029	1	1	0	1	0	0	0
2030	0	0	0	0	0	0	0
2031	0	0	0	0	0	0	0
2032	1	0	0	0	0	0	0
2033	2	0	0	0	0	0	0
2034	0	0	0	0	0	0	0
2035	1	1	0	0	0	0	0
2036	0	0	0	0	0	0	0
2037	1	1	0	0	1	0	0
2038	0	0	0	0	0	0	0
2039	1	1	0	0	0	0	0
2040	1	0	0	0	0	0	0
2041	0	0	0	0	0	0	0
2042	0	0	1	0	0	0	0
2043	0	1	0	0	0	0	0
2044	1	0	0	0	0	0	0
2045	1	0	0	0	0	0	0

Year wise total events
(Future RCP 4.5 period 2021-2045)

Year	AEP %						
	50	20	10	4	2	1	0.5
2021	0	0	0	0	0	0	0
2022	0	0	9.8791	0	0	0	0
2023	0	0	0	0	15.3413	0	0
2024	0	0	0	0	0	17.5661	0
2025	0	0	0	0	0	0	0
2026	0	0	9.8282	0	0	0	0
2027	0	0	0	0	0	17.5148	0
2028	0	0	0	0	0	0	0
2029	0	0	0	13.0088	0	0	0
2030	0	0	0	0	0	0	0
2031	0	0	0	13.1076	0	0	0
2032	0	0	9.7977	0	0	17.5743	0
2033	0	0	0	0	0	0	0
2034	0	0	0	0	15.2812	0	0
2035	0	0	0	0	0	0	0
2036	0	0	0	0	0	0	0
2037	0	0	9.7721	0	0.0000	0	0
2038	0	0	0	0	0	0	0
2039	0	0	0	0	0	0	0
2040	0	0	0	0	0	0	0
2041	0	0	0	0	0	0	0
2042	0	0	9.8585	13.0457	0	0	0
2043	0	0	0	0	0	0	0
2044	0	0	0	13.0530	0	0	0
2045	0	0	0	0	0	0	0

Year wise depth of inundation (m)
(Future RCP 4.5 period 2021-2045)

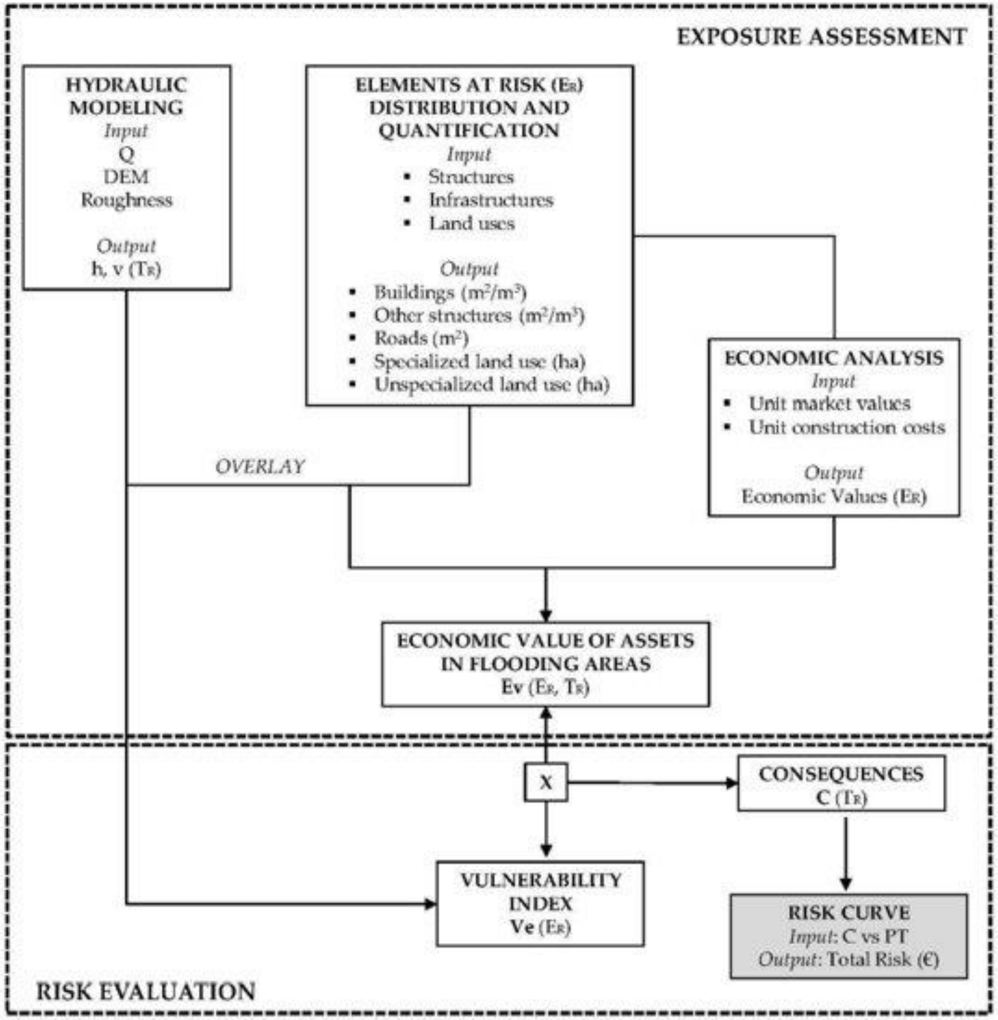
Year	AEP %						
	50	20	10	4	2	1	0.5
2021	0	0	0	0	0	0	0
2022	0	0	65.8806	0	0	0	0
2023	0	0	0	0	88.3927	0	0
2024	0	0	0	0	0	97.5499	0
2025	0	0	0	0	0	0	0
2026	0	0	65.5413	0	0	0	0
2027	0	0	0	0	0	97.3381	0
2028	0	0	0	0	0	0	0
2029	0	0	0	79.2297	0	0	0
2030	0	0	0	0	0	0	0
2031	0	0	0	79.6498	0	0	0
2032	0	0	65.3380	0	0	97.5838	0
2033	0	0	0	0	0	0	0
2034	0	0	0	0	88.1581	0	0
2035	0	0	0	0	0	0	0
2036	0	0	0	0	0	0	0
2037	0	0	65.1671	0	0.0000	0	0
2038	0	0	0	0	0	0	0
2039	0	0	0	0	0	0	0
2040	0	0	0	0	0	0	0
2041	0	0	0	0	0	0	0
2042	0	0	65.7436	79.3865	0	0	0
2043	0	0	0	0	0	0	0
2044	0	0	0	79.4178	0	0	0
2045	0	0	0	0	0	0	0

Year wise duration of inundation (hr)
(Future RCP 4.5 period 2021-2045)

Our Recommendations

- The Mexico site has a **very big catchment** (basin) which drains at the site location.
- The site at Tijuana, Mexico is inside the floodplain. A floodplain or flood plain or bottomlands is an area of land adjacent to a river which stretches from the banks of its channel to the base of the enclosing valley walls, and which experiences flooding during periods of high discharge.
- High flood banks can cause any runoff generate from the upstream basin to be contained in this area unless the banks also flood.
- The elevation of side banks is quite high as compared to the site location.
- **During heavy floods the floodplain should get inundated completely. The most severe flood event was observed in the year 2017 when the site received more than 56.23 mm in 24 hours.**
- **Any rainfall above 60 year return period, i.e., 55 mm in 24 hours resulted in the flooding of this site.**
- **Since the site is in the floodplain, any flood event during full moon nights can also result into backflow of sea water and longer inundation periods.**
- The **only advantage at this site is that the rainfall rate remained low in the past 30 years.**
- In the projected scenario, t**he site remains fairly at risk, as the frequency of higher rainfall intensity is expected to rise.**

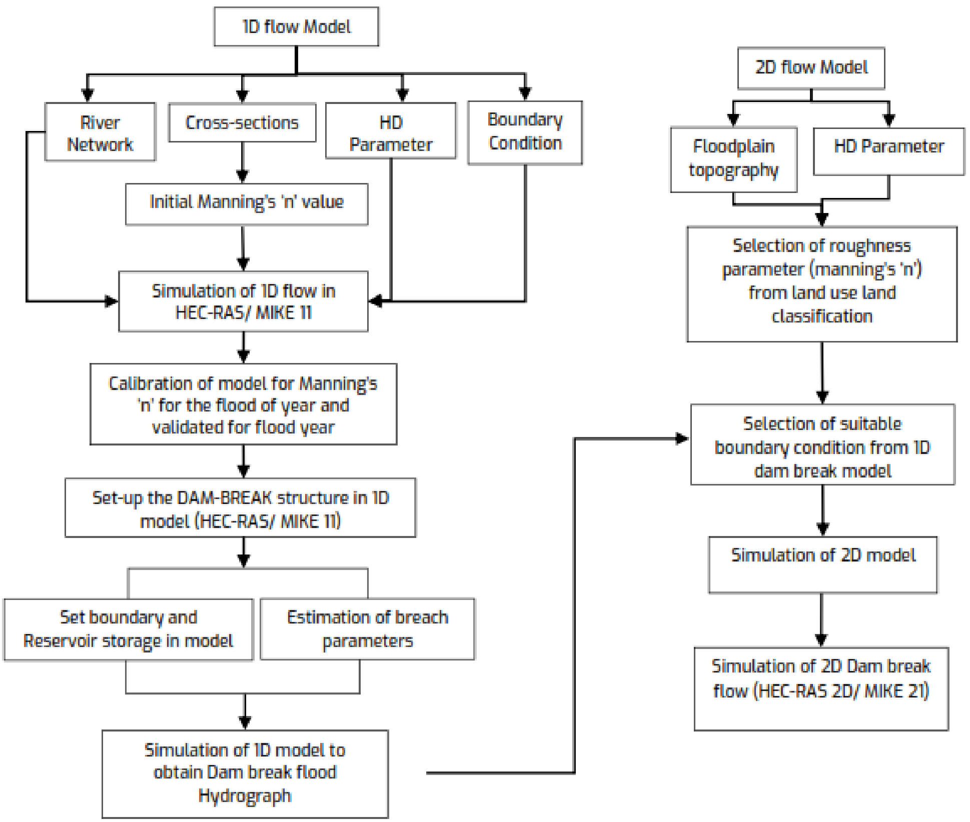
Proposed Methodology for Obtaining Risk Curve



- Quantitative assessment in terms of monetary values, of the elements at risk consequently of the associate risk, in of economic losses, is to be carried out.

- This assessment should be aimed to quantify economically tangible and direct damages due to potential flood events, which are physical damages to material and industrial damage or loss of lives.

Flood Inundation Mapping



Adopted Methodology

- **Modelling Software**
  - 1D models – HEC-RAS
  - 2D models – HEC-RAS 2D

- **Data Requirements**
  - Elevation Data (DEM. DSM, DTM)
  - Topographic and Bathymetric Data
  - Land Cover/ Use Data
  - Additional Surveys
  - Population Density
  - Hydraulic Data
  - Hydrologic Data

Flood Hazard, Risk and Vulnerability Assessment Parameters

- Flood Risk
- Flood Hazard to Flood Risk
- Management of Flood Risk
- Assessment of Flood Risk
- Risk Identification
- Hazard Identification
- Consequence Identification
- Risk Quantification
- Consequence Magnitude Estimation
- Failure Hydrographs
- Population at Risk
- Potential Loss of Life
- Economic Losses
- Risk Mitigation
- Flood Risk Reduction through Structural Measures
- Flood Risk Reduction through Non-Structural Measures
- Integrated Flood Risk Management Strategy
- Towards Risk Resilience

Indian Committee on Large Dams
Young Engineers Forum

INTERNATIONAL DAM SAFETY CONFERENCE

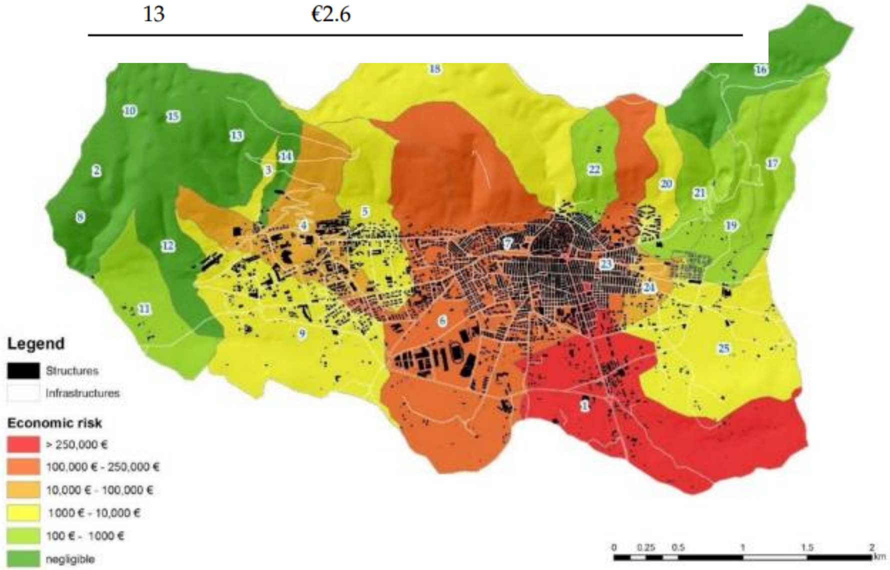
Dam Rehabilitation & Improvement Project

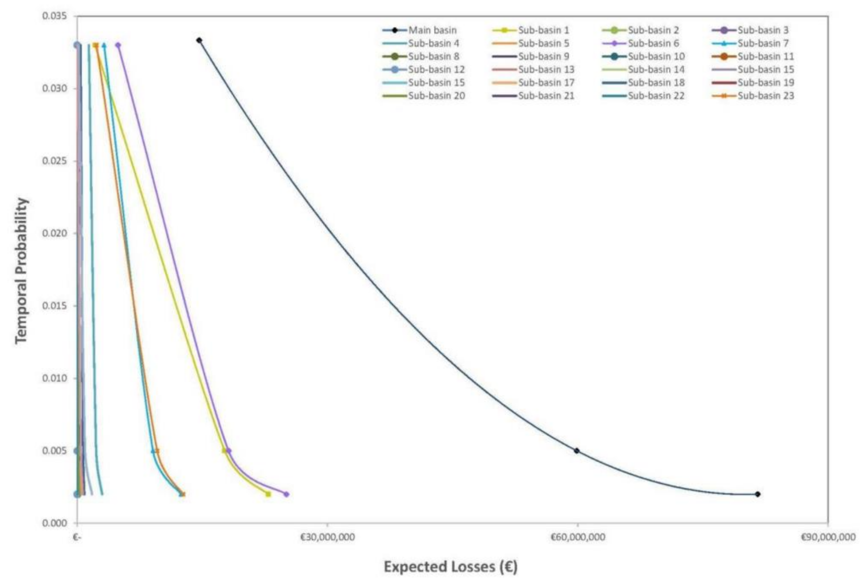
Central Water Commission

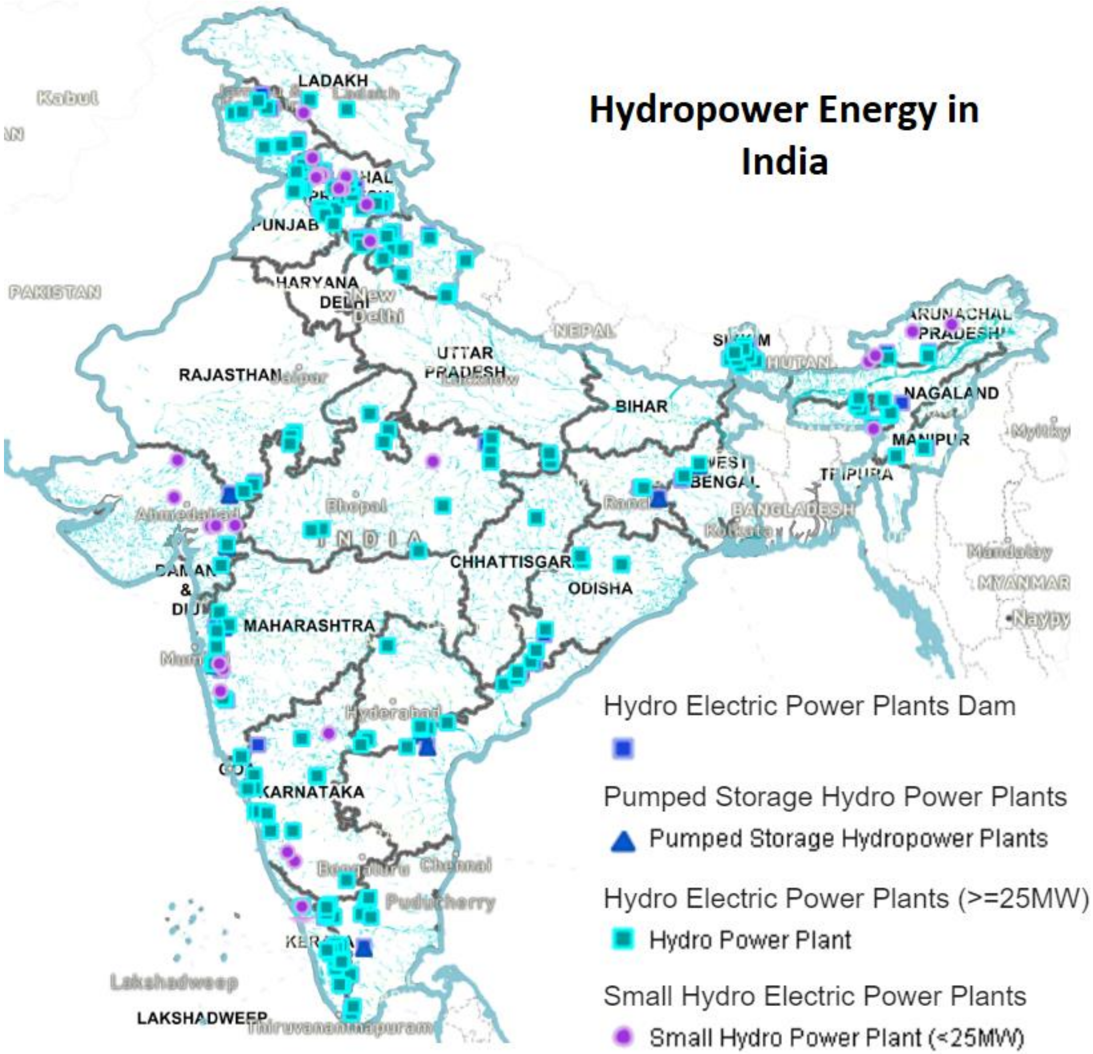
Total Risk Mapping Sub-Basin Wise for Ireland Watershed

Sub-Basins	Total Risk	Sub-Basins	Total Risk
1	€271,984	14	€ ≈ 0
2	€ ≈ 0	15	€ ≈ 0
3	€1036	16	€ ≈ 0
4	€16,031	17	€180
5	€3412	18	€5531
6	€235,335	19	€343
7	€104,698	20	€2610
8	€ ≈ 0	21	€195
9	€6513	22	€430
10	€52	23	€128,223
11	€146	24	€14,223
12	€11	25	€7792
13	€2.6		

Elements at Risk	T_R	Temporal Probability	Amount	Economic Value	Consequences	Total Economic Losses
Buildings	30	0.033	55,894 mq	€194,614,708	€13,895,661	
Other structures	30	0.033	7185 mq	€6,109,602	€694,699	
Road	30	0.033	32,020 mq	€4,002,468	€273,812	€14,880,090
Specialized land use	30	0.033	4 ha	€56,527	€9701	
Unspecialized land use	30	0.033	30 ha	€82,544	€6218	
Buildings	200	0.005	187,626 mq	€588,434,156	€57,397,781	
Other structures	200	0.005	40,472 mq	€10,577,381	€1,251,951	
Road	200	0.005	108,672 mq	€13,584,055	€1,239,335	€59,982,082
Specialized land use	200	0.005	19 ha	€265,619	€68,215	
Unspecialized land use	200	0.005	77 ha	€293,026	€24,801	
Buildings	500	0.002	228,538 mq	€717,485,846	€77,739,884	
Other structures	500	0.002	47,304 mq	€13,905,091	€1,744,504	
Road	500	0.002	137,329 mq	€17,166,171	€1,711,906	€81,326,517
Specialized land use	500	0.002	22 ha	€304,865	€94,850	
Unspecialized land use	500	0.002	89 ha	€332,429	€35,373	







Installed Power Station Capacity in India as of July 31, 2022

Sector	Hydro (MW)	Renewable (MW)
Central	15664.72	1632.30
State	27254.45	2453.31
Private	3931.00	110351.75
All India	**46850.17**	**114437.37**
Percentage	**11.59**	**28.32**

Hydroelectric power plants with ≤ 25 MW generation capacity are included in Renewable category (classified as SHP - Small Hydro Project)

The break up of renewable energy sources (RES) is:

- Solar power (57,973.78 MW)
- Wind power (40,893.33 MW)
- Biomass/Cogeneration (10,205.61 MW)
- Small hydro (4,887.90 MW)
- Waste-to-energy (476.75 MW)

Vulnerability assessment for quantification of climate change impact on Hydropower and renewable energy

Step 1: Vulnerability assessment of hydropower plants

Step 2: Evaluation of the company's exposure to climate change risk

Step 3: Measure the impact from a financial point of view

Step 4: Quantification of value of risk (VaR) of each of the assets

Step 5: Set of mitigation/resilience measures and actions to be taken

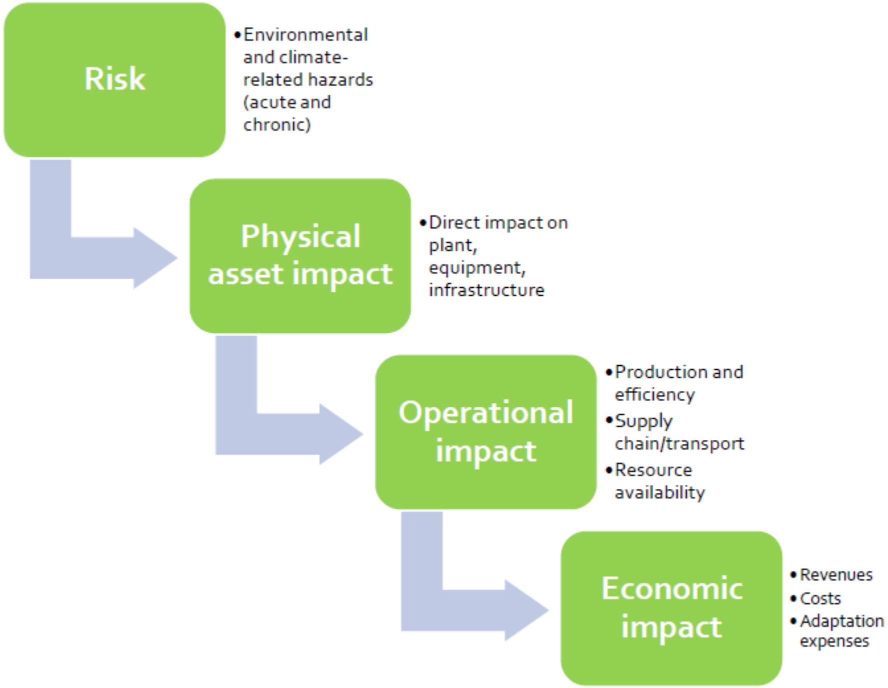
Integrating Physical Climate Risks in Infrastructure Appraisal

Hazard	Potential variables (proxies in italics)	Notes
	Acute	
Coastal flooding	Extent, depth	Consider a range of return periods
Storm surge	Height, full curve of height over time, astronomical tide, sea level rise, extent, depth	Consider a range of return periods
Fluvial flooding	Extent, depth, velocity (if available)	Consider a range of return periods
Surface water flooding	Extent, depth, *daily max rainfall, 5-day rainfall total*	Consider a range of return periods, consider a range of probabilities, including the 90% probability (where possible)
Heatwave	*Heatwave index, daily max temperature, tropical days/nights,* sea-surface temperature	It may be possible to gather data on exceedance of temperature threshold (if known)
Wildfire	*Wildfire index*	Wildfire hazard depends on changes in temperature and rainfall
Cold events	Daily min temperature	Consider a range of probabilities, including the 10% probability (where possible)
Snowfall	*Daily min temperature, winter precipitation*	Snowfall hazard depends on changes in temperature and precipitation
Storms	Wind speed and direction	There is generally low confidence in projections of changes in wind in downscaled climate projections

Integrating Physical Climate Risks in Infrastructure Appraisal

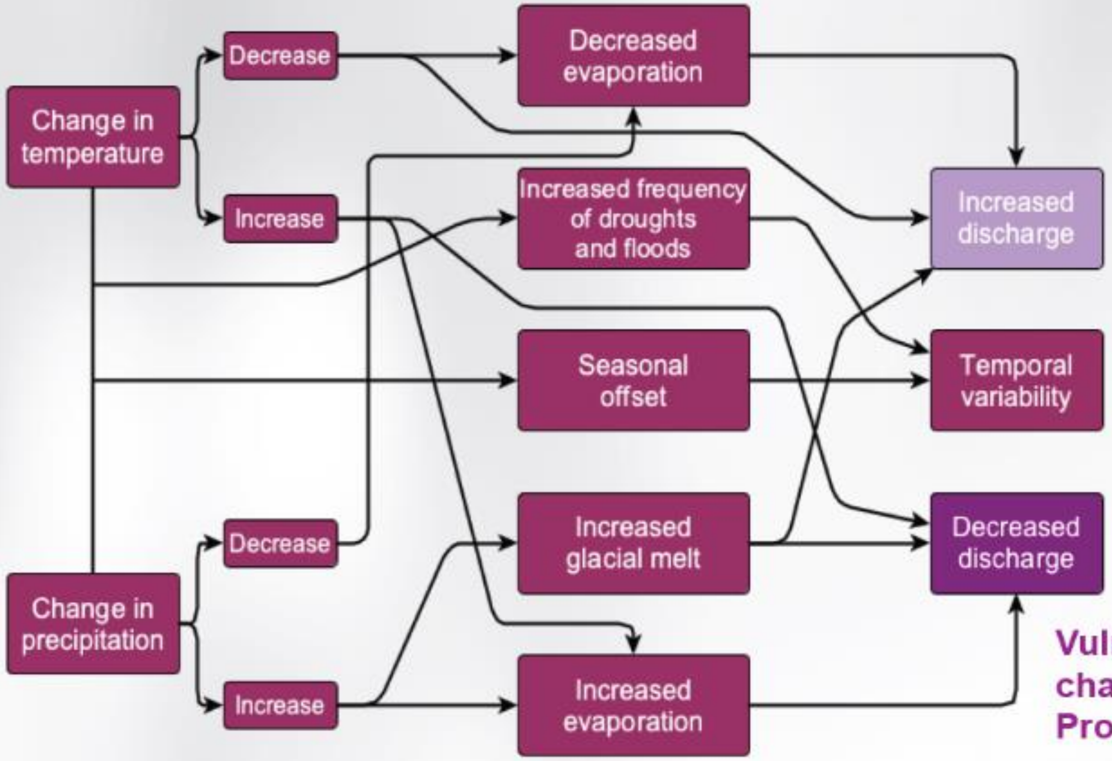
Hazard	Potential variables (proxies in italics)	Notes
	Chronic	
Drought	*Drought index* *Seasonal average* rainfall	Consider a range of drought index durations (3, 6 and 12 months) Consider a range of probabilities, including the 10% probability (where possible)
Low/high river flow	River flow or discharge rate *Seasonal average rainfall*	Consider a range of probabilities, including the 90% probability (where possible)
Change in soil moisture content	Soil moisture content *Seasonal average rainfall* *Seasonal temperature*	
Change in length/timing of growing season	*Seasonal average rainfall* *Seasonal temperature*	Consider change in timing of seasons

Climate Risk assessment for water security and energy projects



Hazard	Physical asset impact	Operational impact	Economic impact
Water scarcity			
Reduced river flow (chronic)	Reduced cooling water intake over long term	Production, efficiency; resource availability	Adaptation expenses – improved water extraction, changing pump location
Drought (acute)	Temporary loss of cooling water; more frequent reliance on emergency water supply	Production, efficiency; resource availability	Revenues – reduced power output
Heat stress			
Increased river temperature (chronic, acute)	Higher temperature of cooling water may reduce long-term condenser efficiency	Production, efficiency - slower condensation	Revenues – long term output reduction
	Used cooling water discharge stalled under obligation to protect river temperatures	Production, efficiency; shutdown	Adaptation expenses – increase used water storage capacity
Increased air temperature (chronic)	Higher temperatures may reduce long-term condenser efficiency	Production, efficiency - slower condensation	Revenues – output reductions
Heat wave (acute)	Used cooling water discharge stalled under obligation to protect river temperatures	Production, efficiency; shutdown	Adaptation expenses – increase used water storage capacity
	Higher temperature of cooling water may reduce condenser efficiency	Production, efficiency - slower condensation	Revenues – output reductions

Vulnerability assessment for quantification of climate change impact on Hydropower Production



Vulnerability Flow chart of climate change effects for Hydropower Production.

Spatio-Temporal Rainfall Variability across Upper Tapi Basin

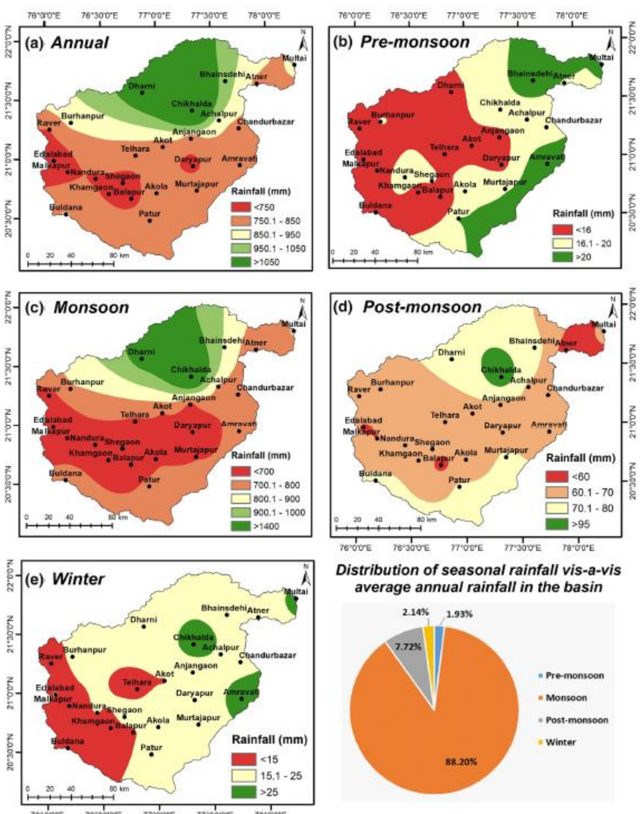
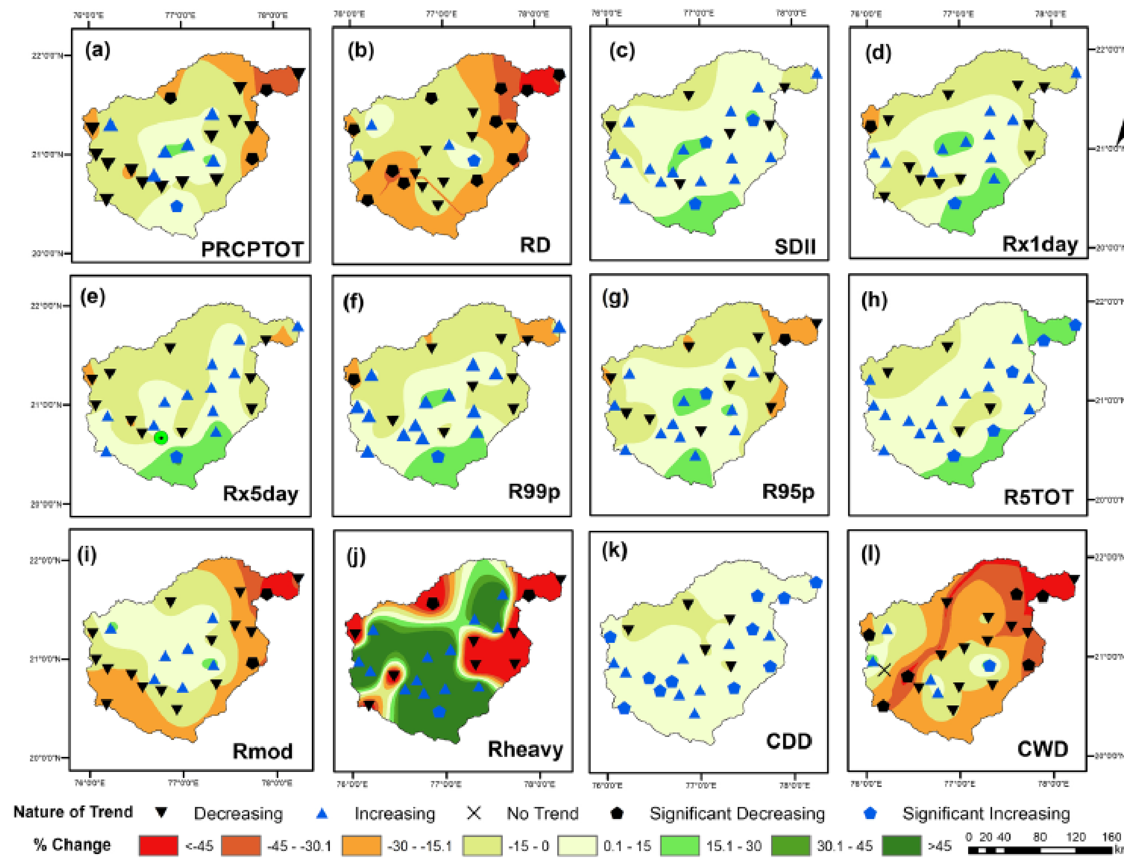
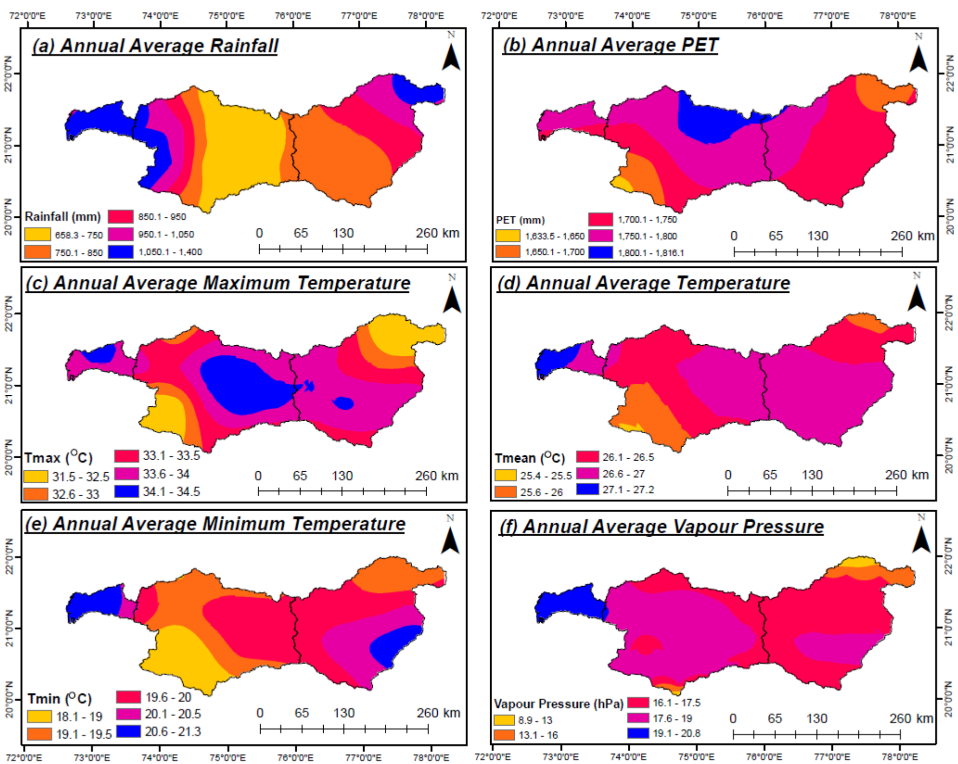


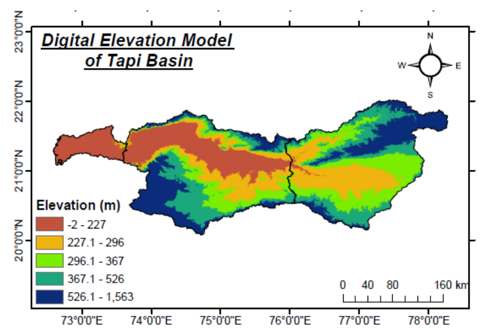
Fig. 3 a–e Distribution of average rainfall over Upper Tapi Basin (1944–2013)

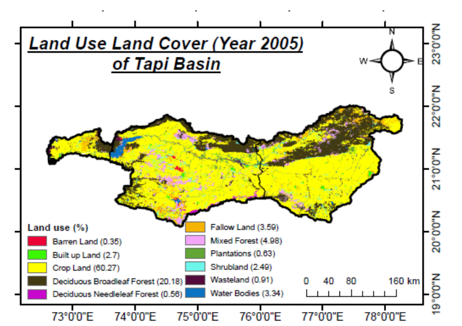


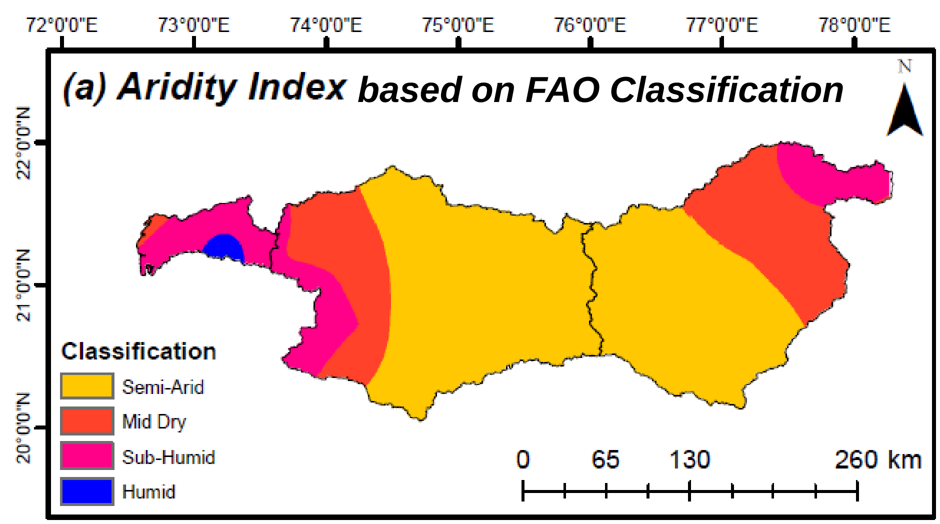
1) Sharma, P. J., Loliyana, V. D., Resmi, S. R., Timbadiya, P. V., & Patel, P. L. (2017). "Spatiotemporal trends in extreme rainfall and temperature indices over Upper Tapi Basin, India." Theoretical and Applied Climatology, 134(3-4), 1329-1354.

Aridity, Rainfall, PET, Mean Temperature spatial variation across Tapi River Basin







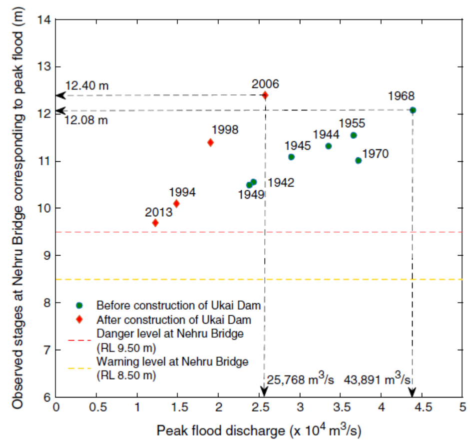


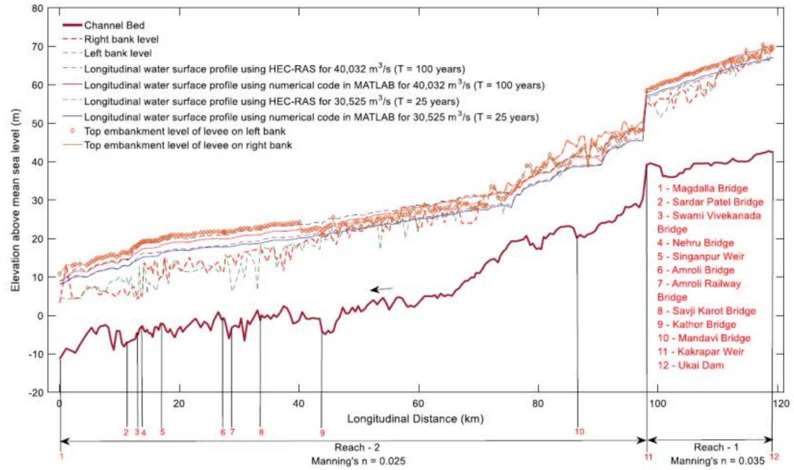
Flood Frequency Analysis and Flood Modelling using Matlab, HEC-RAS 1D, HEC-RAS 2D for Surat City, India

Table 1. Historic floods and corresponding water levels in Surat city

Serial number	Date	Peak flood discharge (m^3/s)	Corresponding water level at Nehru Bridge (m)
1	August 7, 1942	24,355	10.56
2	August 18, 1944	33,527	11.32
3	August 24, 1945	28,996	11.09
4	September 18, 1949	23,842	10.49
5	September 17, 1959	36,642	11.55
6	August 6, 1968	43,891	12.08
7	September 7, 1970	37,208	11.02
8	August 31, 1978	25,145 (12,459)[a]	8.59[a]
9	August 12, 1979	24,296 (9,345)[a]	8.22[a]
10	September 8, 1994	25,117 (14,866)[a]	10.10[a]
11	September 16, 1998	29,817 (19,057)[a]	11.40[a]
12	August 7, 2006	34,122 (25,768)[a]	12.40[a]
13	September 23, 2013	20,673 (12,257)[a]	9.70[a]

[a]Refers to peak discharge released from Ukai Dam and corresponding water level observed at Nehru Bridge.





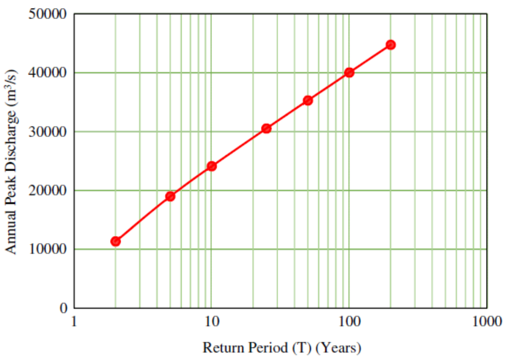
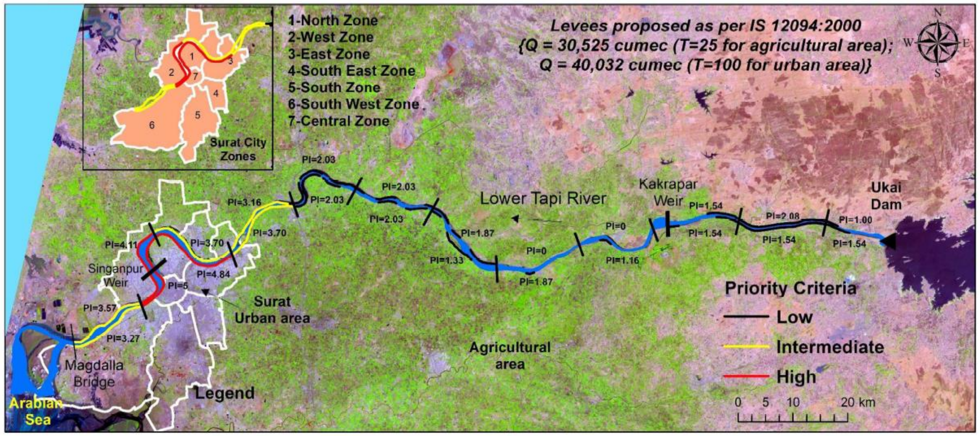


Fig. 4. Flood frequency analysis of annual peak discharge series of lower Tapi River observed at Kathor/Ukai from 1939 to 2013 using extreme value Type I distribution.



Vora, A., Sharma, P. J., Loliyana, V. D., Patel, P. L., & Timbadiya, P. V. (2018). "Assessment and prioritization of flood protection levees along Lower Tapi River, India." Natural Hazards Review (ASCE), 19(4), 05018009 1-11.

Climate Variability Statistics as per WMO Standards need to be analysed for 02 scenarios:
a) Historical
b) Future RCPs

Indicator	Indicator name	Indicator definitions	Units
PRCPTOT	Annual total rainfall	Annual total rainfall from days ≥ 2.5 mm	mm
RD	Rainy days	Number of days when rainfall ≥ 2.5 mm	days
SDII	Simple daily intensity index	The ratio of annual total rainfall to the number of rainy days	mm/day
Rx1day	Maximum 1-day rainfall amount	Annual maximum 1-day rainfall	mm
Rx5day	Maximum 5-day rainfall amount	Annual maximum consecutive 5-day rainfall	mm
R99p	Extremely wet days	Annual total rainfall from days > 99th percentile	mm
R95p	Very wet days	Annual total rainfall from days > 95th percentile	mm
R5TOT	Rainfall extreme proportion	Proportion of annual rainfall from top 5 events in a year	%
Rmod	Number of moderate rainfall days	Number of days when annual rainfall ≥ 7.5 and < 64.5 mm	days
Rheavy	Number of heavy rainfall days	Number of days when annual rainfall ≥ 64.5 and < 124.5 mm	days
CDD	Consecutive dry days	Maximum number of consecutive days when rainfall < 2.5 mm	days
CWD	Consecutive wet days	Maximum number of consecutive days when rainfall ≥ 2.5 mm	days
TXx	Hottest day	Monthly/seasonal/annual maximum value of daily maximum temperature	°C
TXn	Coldest day	Monthly/seasonal/annual minimum value of daily maximum temperature	°C
TNx	Warmest night	Monthly/seasonal/annual maximum value of daily minimum temperature	°C
TNn	Coldest night	Monthly/seasonal/annual minimum value of daily minimum temperature	°C
DTR	Diurnal temperature range	Monthly/seasonal/annual mean difference between daily maximum and minimum temperature	°C

Sharma, P. J., **Loliyana, V. D.**, **SR, Resmi.**, Timbadiya, P. V., & Patel, P. L. (2018). Spatiotemporal trends in extreme rainfall and temperature indices over Upper Tapi Basin, India. *Theoretical and Applied Climatology*, *134*(3), 1329-1354.

FAMS Intelligence

GIS based Dashboard for Informed Risk Advisory

Layer 1: Admin

Exposure
1. Current Status of Exposure
2. Current Status of Vulnerability
   - Projection 2015, 2020, 2025, 2030
   - Associated event projection

Layer 2: State

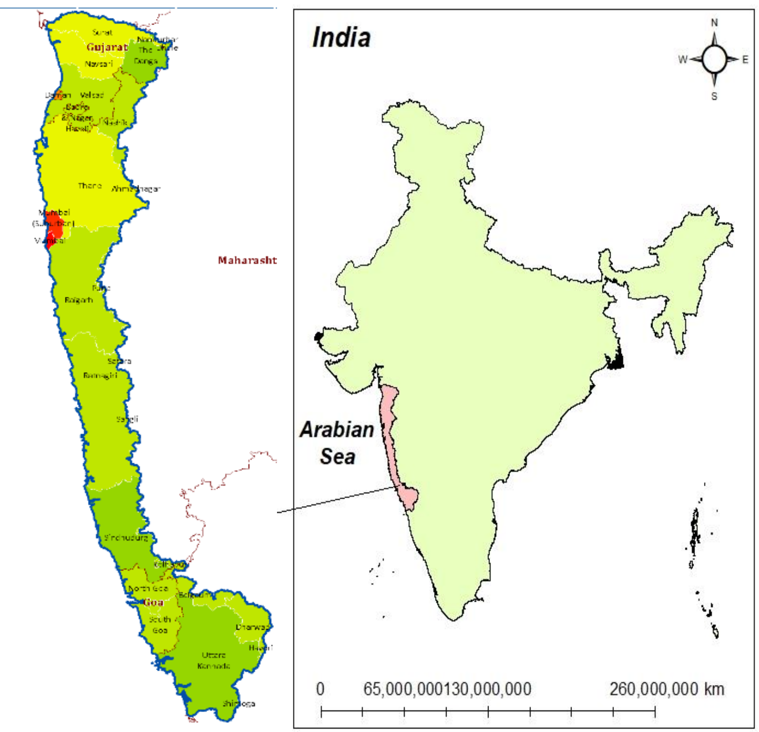
Exposure
1. Current Status of Exposure
2. Current Status of Vulnerability
   - Exposure wise Projection 2015, 2020, 2025, 2030
   - Associated event projection

Layer 3: Land use
Layer 4: Topography
Layer 5: Population Projection
1. 2011
2. 2021
3. 2031
4. 2041

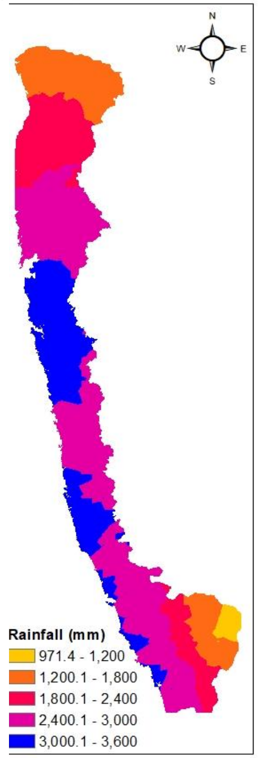
Layer 6: Assets (Climate Proofing of Infrastructure)
Layer 7: Potential impacts of
1.Hazard Indicators
2.Exposure Indicators
3.Vulnerability Indicators
4.Risk Indicators

Variability of Rainfall, Temperature and Potential Evapotranspiration at Annual Time Scale over Tapi to Tadri River Basin, India

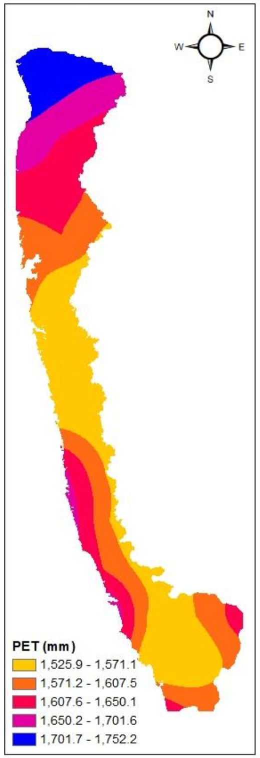
Tapi to Tadri River Basin, India



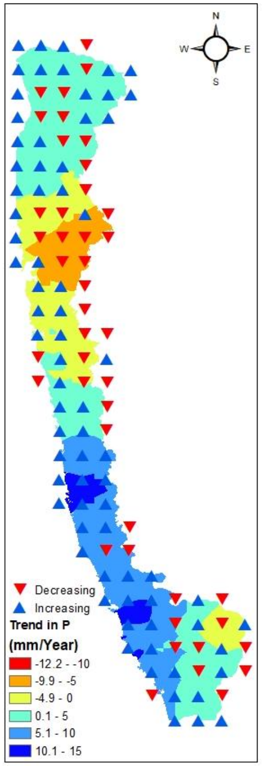
Average Annual Rainfall (1901-2016) for Tapi to Tadri Basin



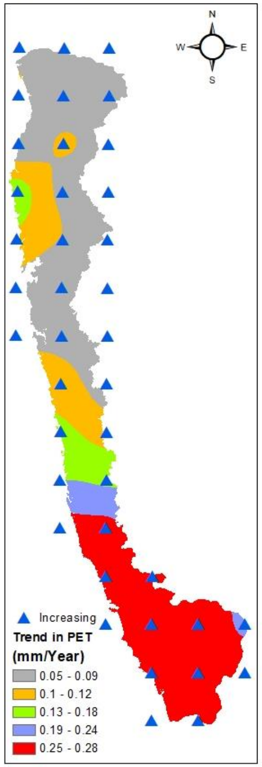
Average Annual PET (1901-2016) for Tapi to Tadri Basin



Trends in Average Annual Rainfall for Tapi to Tadri Basin



Trends in Average Annual PET for Tapi to Tadri Basin



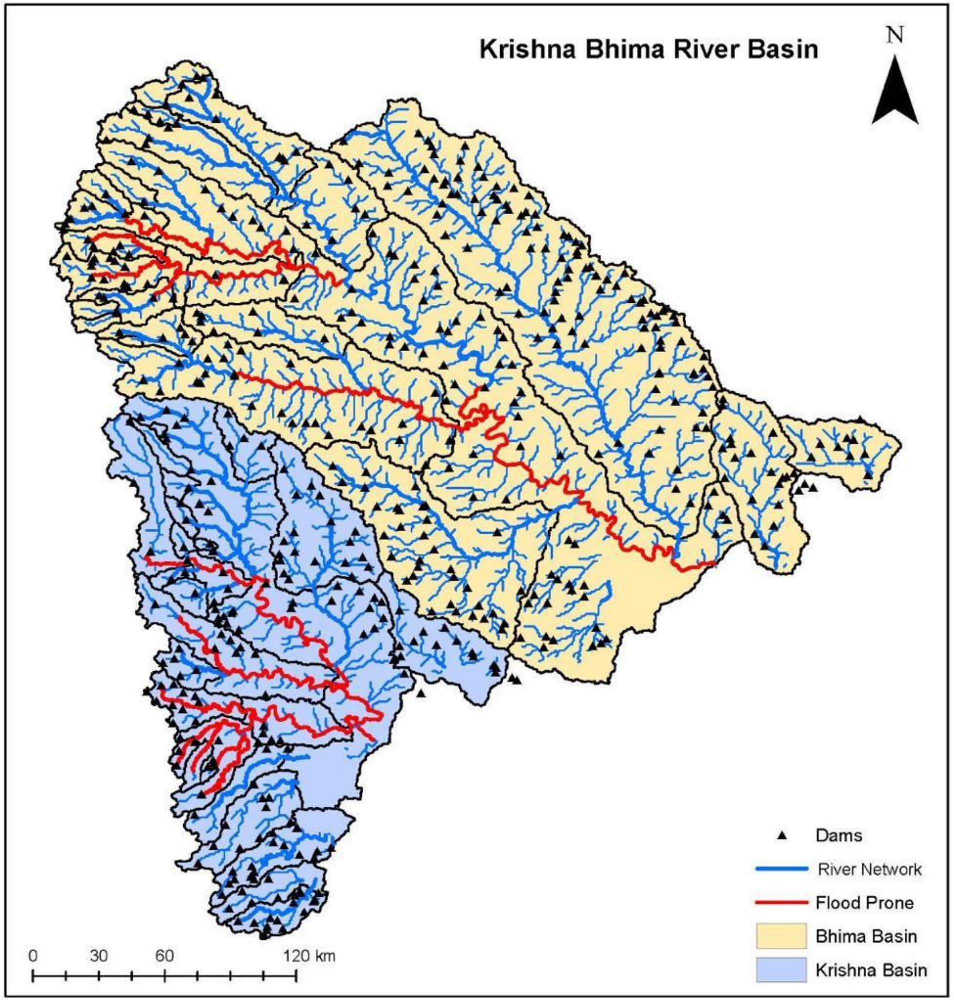
1) Mahyavanshi et al. (2021). "Variability of Rainfall, Temperature and Potential Evapotranspiration at Annual Time Scale over Tapi to Tadri River Basin, India", Book Chapter, In: Jha R., Singh V. P., Singh V., Roy L. B., Thendiyath R. (Eds.) Climate Change Impacts on Water Resources (pp. 349-364). Springer, Cham.

Climate Variability and Flood Inundation Simulation of Krishna Basin, India

FAMS®

- Mapping of Hydraulic Structures
- Mapping of Hydro-Meteorological Stations (SRG, ARG, AWS, GD)
- Climate Variability Study
- Flood Prone River Identification

- Ongoing Studies for
  - Rainfall and Flood Frequency Analysis
  - Rainfall Runoff Modelling at sub-basin Scale
  - Hydrodynamic modelling and inundation study
  - Integrated Reservoir Operation Study
  - Fluvial Morphological Study and Implications with Flood



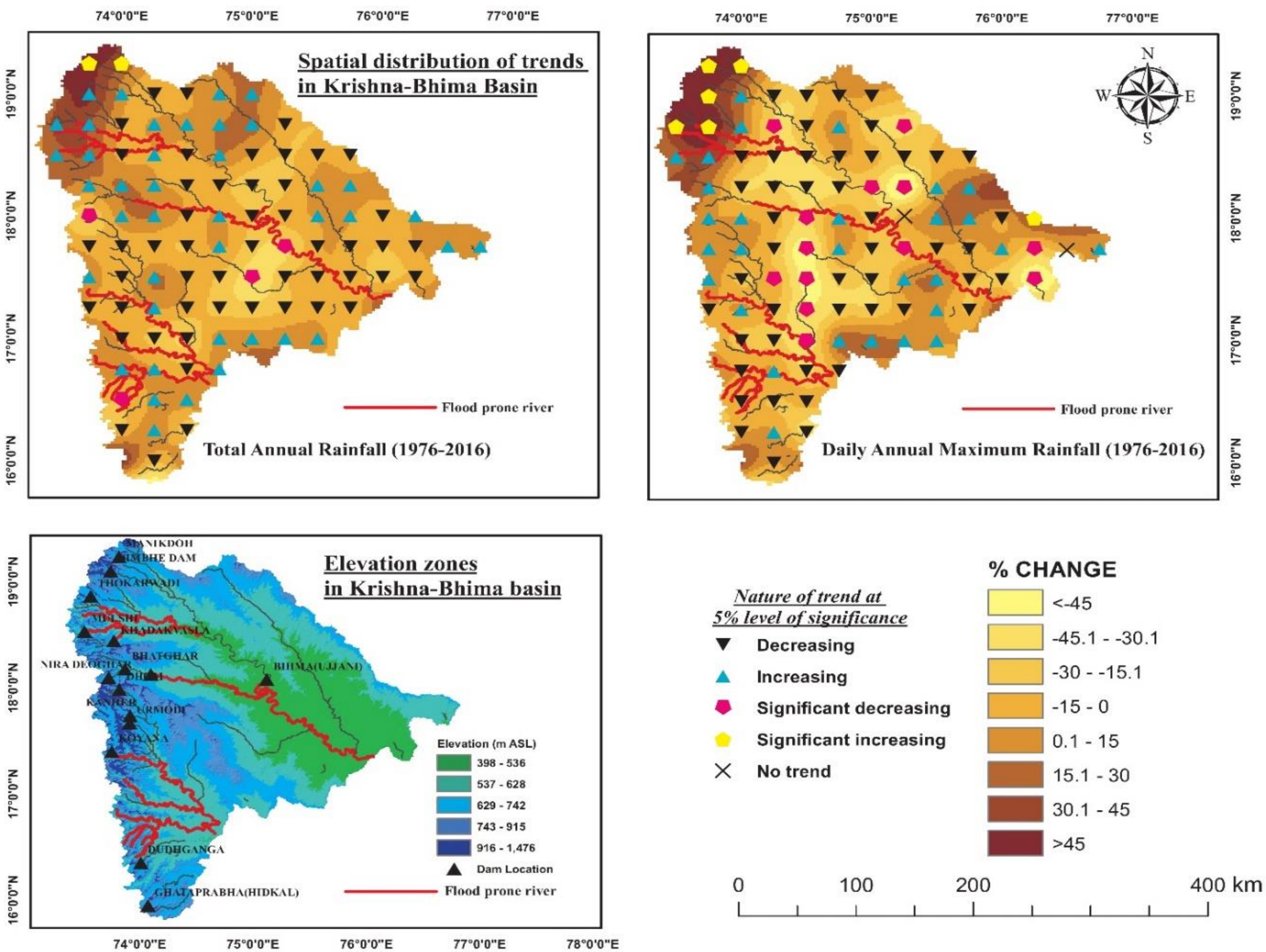
Indian Committee on Large Dams
Young Engineers Forum

INTERNATIONAL DAM SAFETY CONFERENCE

Dam Rehabilitation & Improvement Project

Central Water Commission

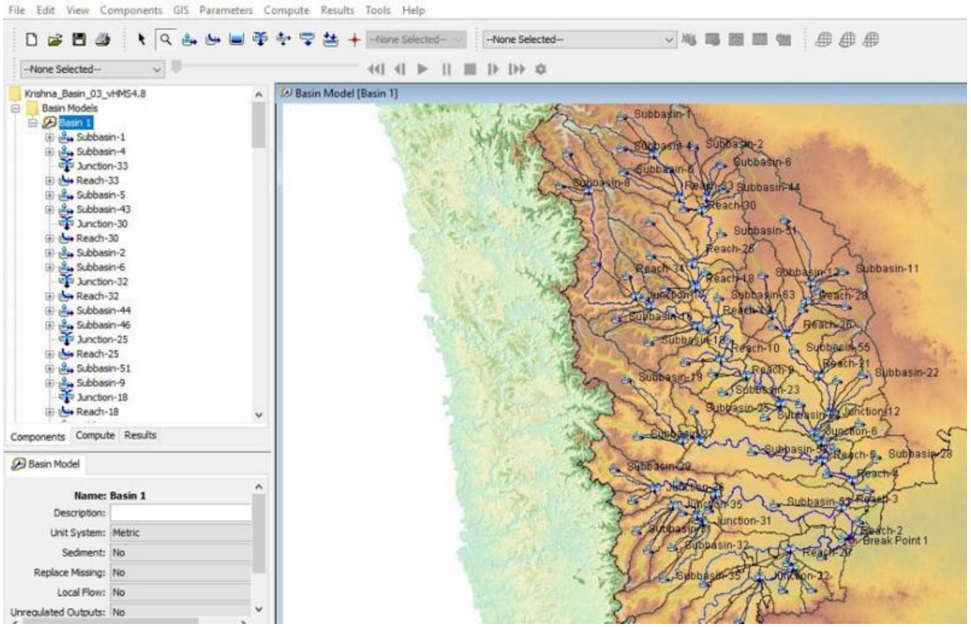
Climate Variability across Krishna Bhima Basin, India

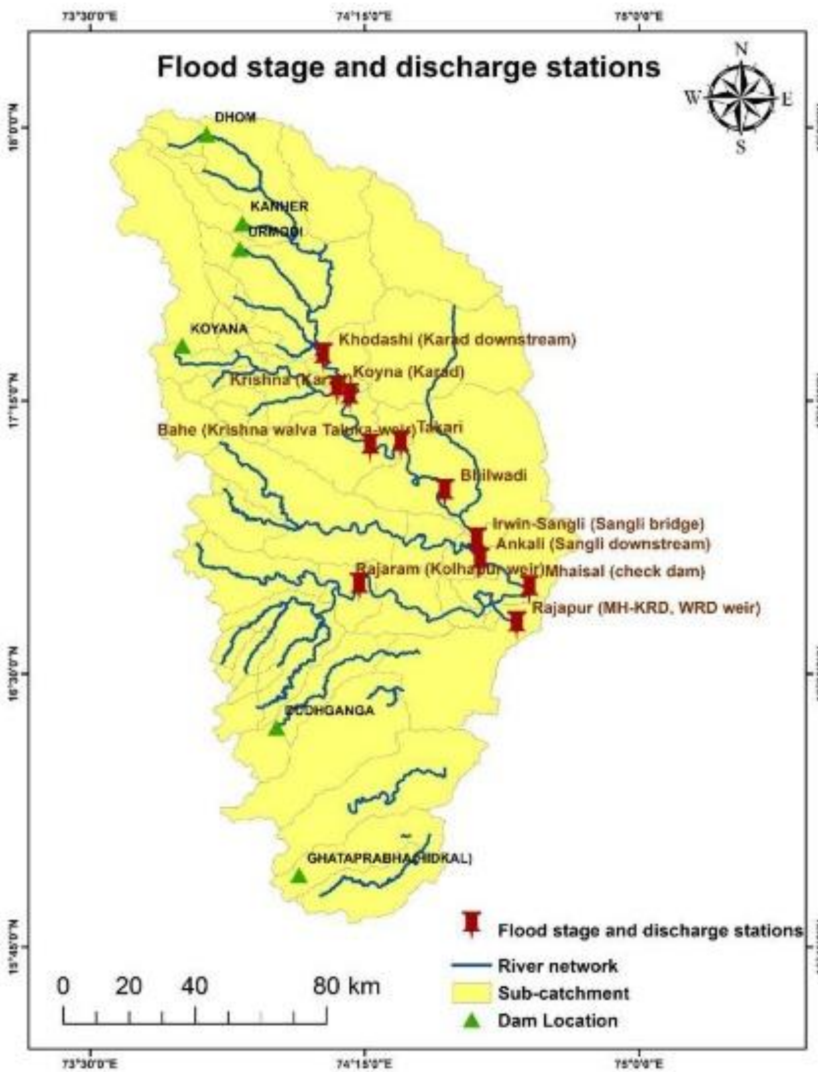


- **Trend analysis of Rainfall over Krishna Bhima Basin using last 44 Years (1976-2019) of India Meteorological Department (IMD) data.**

FAMS®

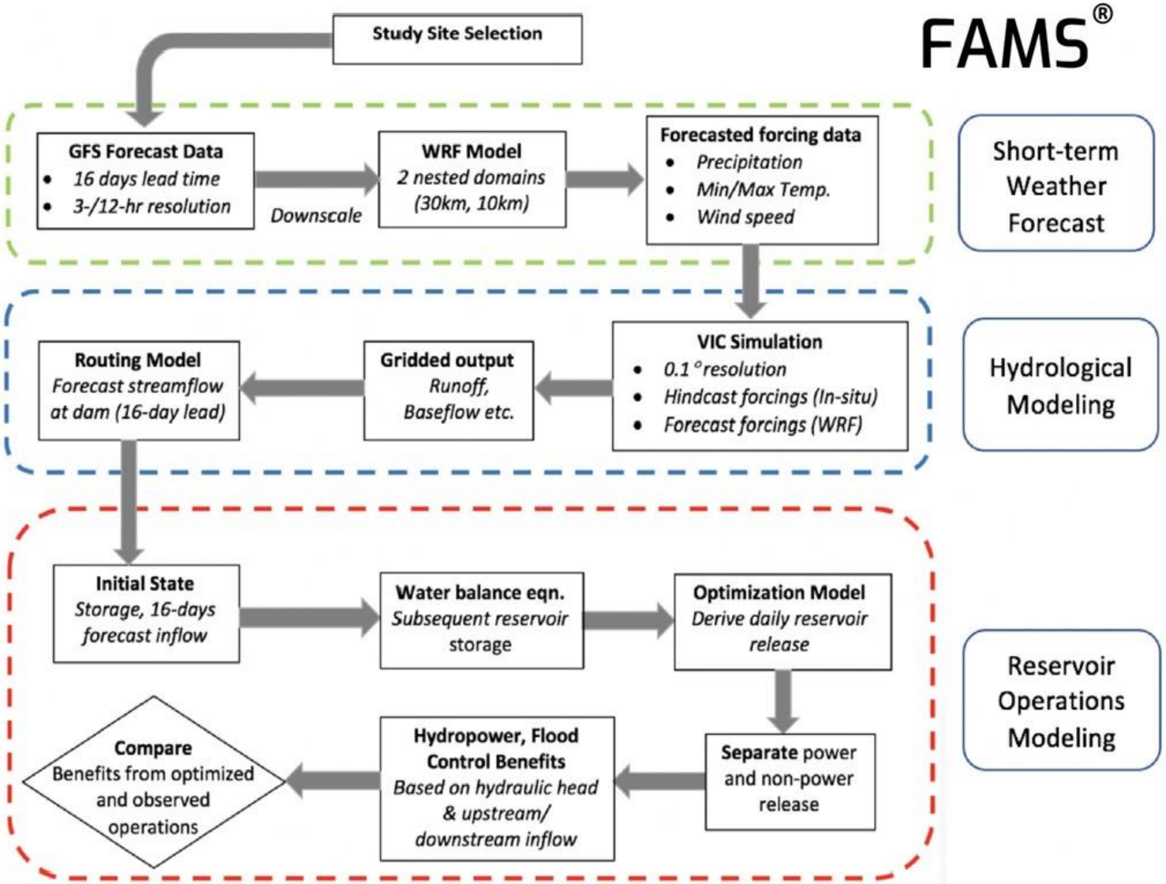
Hydrological and Hydraulic Models





- We believe sub-basin modelling will help to understand Physiography and Climate Change changes impact on Hydrological Cycle
- We are using HEC-RTS System
- Combination of HEC-HMS, HEC-ResSim, HEC-RAS
- Real Time and Forecast Data Integration
- Integrated with our Web Application

Operational Forecasting for Optimized and Observed Hydropower and Flood Operations



Indigeneous Atmospheric-Hydrological Forecasting System Methodology

Our R&D Initiative

Short term weather forecast

- WRF Model

Hydrological Modelling

- HEC-HMS 1D, 2D or
- VIC, SWAT or
- Neural ML Models

Reservoir Operation Modelling

- HEC-ResSim or
- ANN/GA/LP/DP Models

Hydraulic Modelling

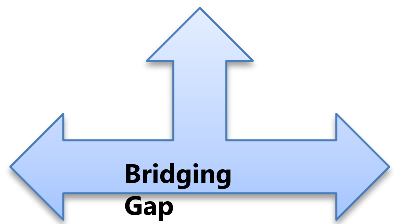
- HEC-RAS 1D, 2D or
- Neural ML Models

Bridging the Gap

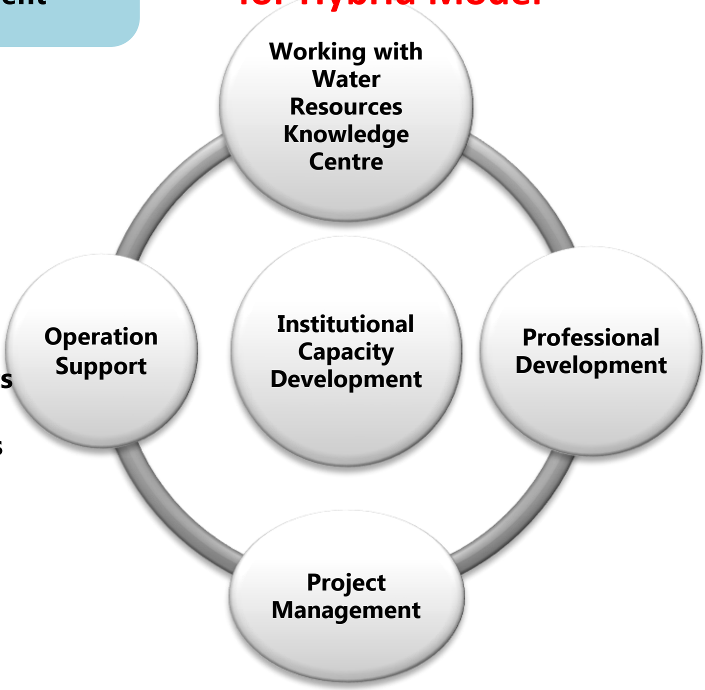
Weather Intelligence Flood Intelligence System Dynamics	Automated Data Analytics in Water, Irrigation, Weather & Smart Utility Sectors
IoT, Big Data, ML, AI Integration with Geo-Informatics	Institutional Capacity Development

FAMS

- Data Scanning
- Data Sorting & Validation
- Data Analysis
- Data Processing
- Data Visualization
- Data Presentation
- Data Integration for Hybrid Model



- Central Government Departments
- State Government Departments
- Institutions & Private Companies
- Non-profit organisations



Thanking you !!

We are ready to help you !!

Define Project → Data Collection → Data Analysis → Statistics → Modelling Simulation → Decision Making

Enabling Sustainability

Our Focus

FAMS®

Forecasting | Analytics | Modelling | Simulation

Enabling Sustainability

Dr. Viraj Loliyana
+91-7779090415
ceo@famsds.com