Future climate and LULC dynamics on sustainability of Krishna River basin, India

T. Shashidhar and Ch.Tirupathi

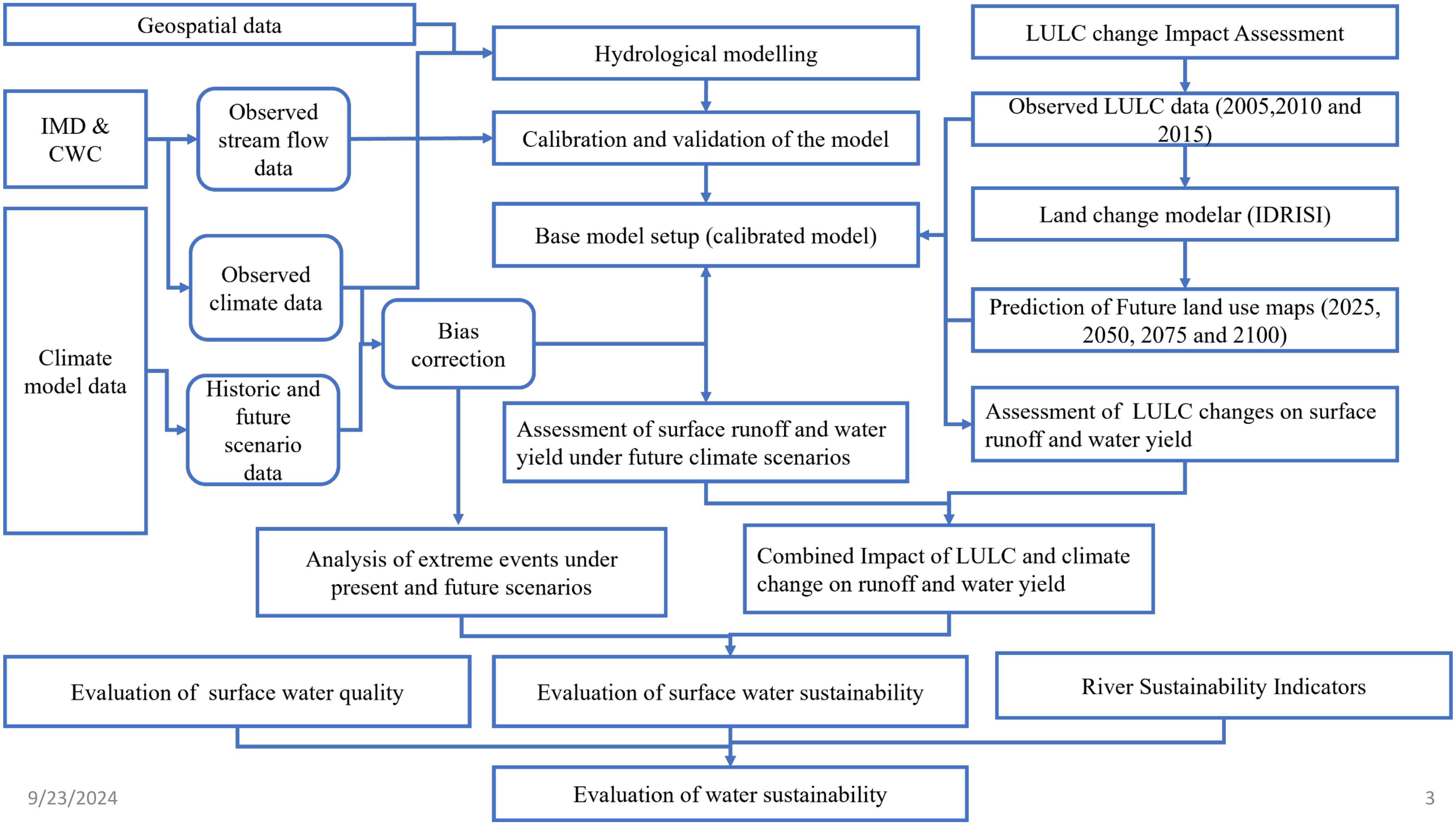
भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

SASI AUTONOMOUS INSTITUTE OF TECHNOLOGY & ENGINEERING TADEPALLIGUDEM WEST GODAVARI DIST.,A.P

Objective

To assess the combined influence of both climate and LULC changes on the availability of water resources and its influence on the sustainability of Krishna River Basin (258,948 km^2), India

Detailed Framework



Study Area

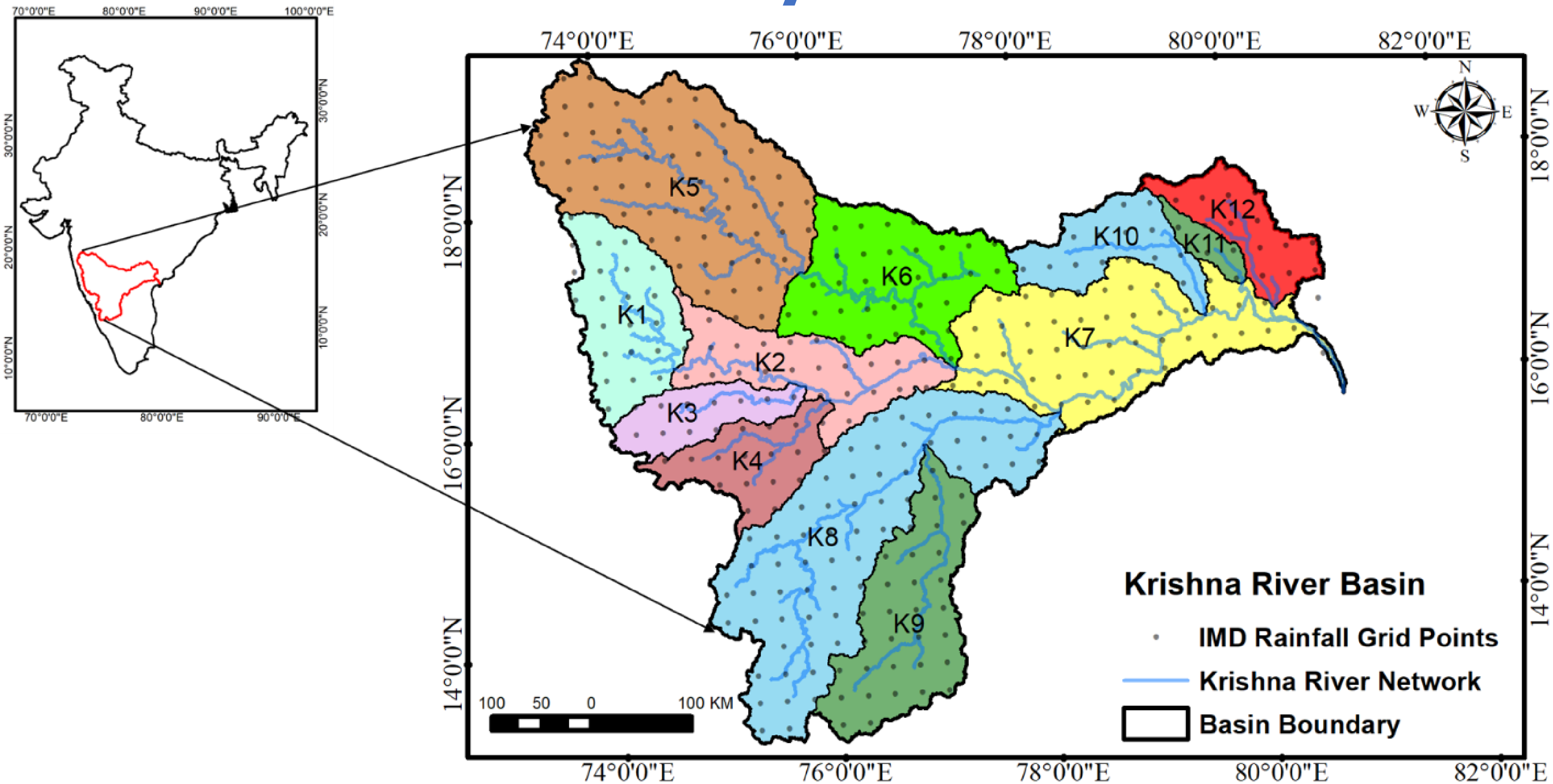


Fig. Study Region (Krishna river basin) along with gauge stations

It lies in the coordinates of 13°5′58″ - 19°24′35″N, 73°20′28″- 81°0′43″E

Krishna basin Description

- Total geographic area of 2,58,948km^2 and flows over a length of 1400km
- The annual average rainfall of the basin is about 770 mm.
- The majority of the basin consists of Archaean and crystalline rocks (80%) and basalts (20%) (Deccan Traps).
- It was dominated by black and laterite soils
- The Krishna basin is subjected to frequent droughts while 80% of the agriculture in this basin is rain-fed

Geospatial data

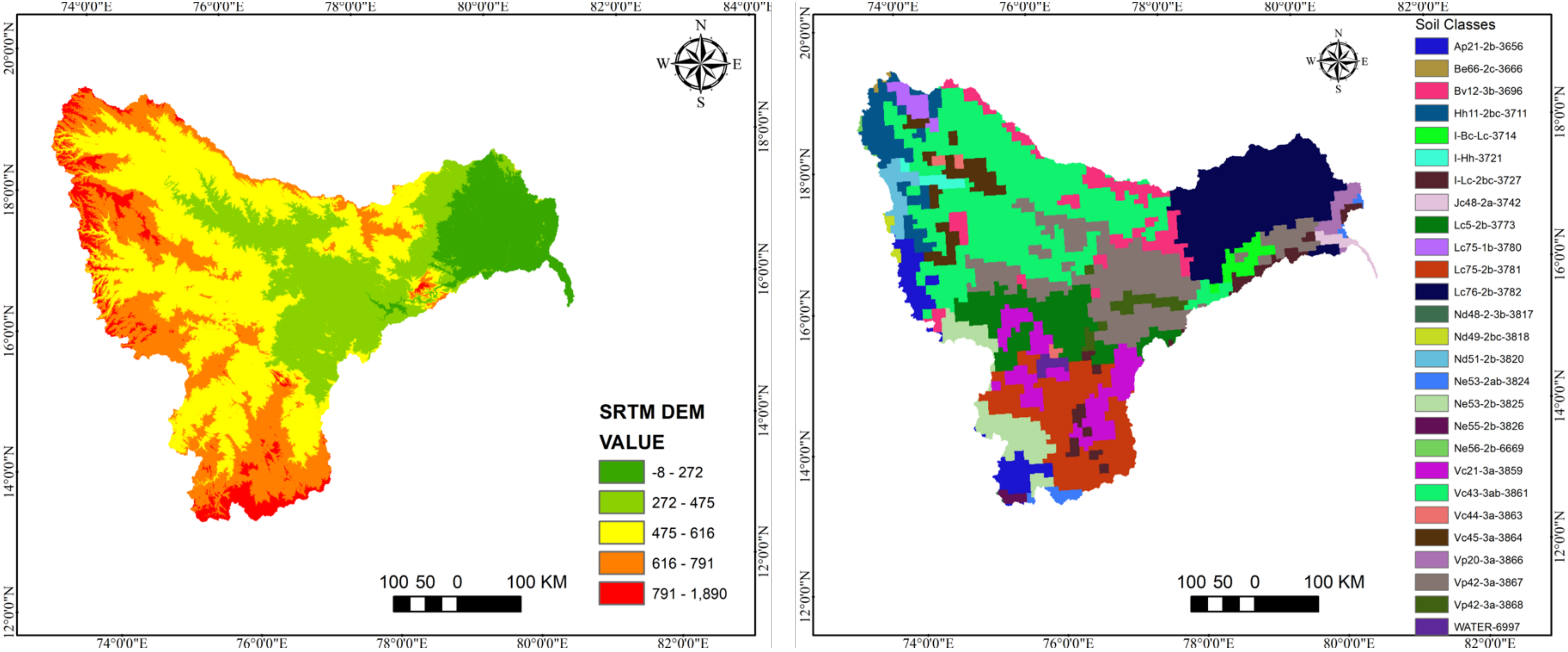


Fig. a) SRTM DEM and b) Soil maps of Krishna river basin.

Geospatial data

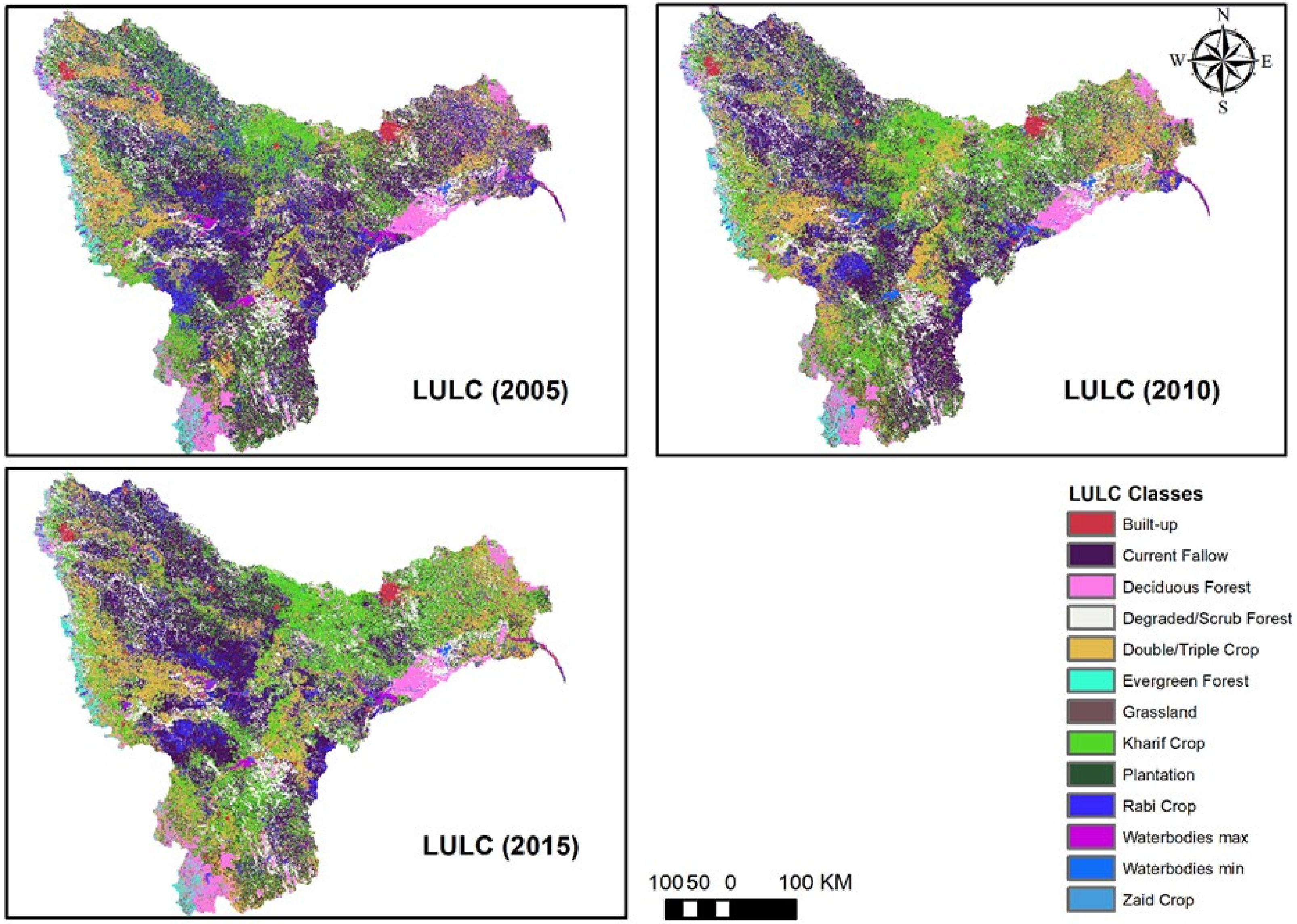


Fig. LULC maps of Krishna river basin (2005, 2010 and 2015) from NRSC, India.

Kharif Crop: July – October

Rabi: October – April

Zaid: April - June

Climate model data

Experiment Name	RCM	Driven CMIP5 AOGCM	Resolution
RCA4 (ICHEC-ESM)	RCA4	EC-EARTH	~0.44°×0.44°
RCA4 (IPSL-IPSL-CM5A-MR)	RCA4	IPSL-IPSL-CM5A-MR	~0.44°×0.44°
RCA4 (NCC-NorESM1-M)	RCA4	NCC-NorESM1-M	~0.44°×0.44°
RCA4 (MIROC-MIROC5)	RCA4	MIROC-MIROC5	~0.44°×0.44°
RCA4 (CNRM-CM5)	CCAM	CNRM-CERFACS-CNRM-CM5	~0.44°×0.44°
RegCM4(GFDL)	RegCM4	GFDL-ESM2M-LR	~0.44°×0.44°

Data sources

Data	Resolution	Source
Shuttle Radar Topography Mission Digital Elevation Model (SRTM-DEM)	90m	http://srtm.csi.cgiar.org/
LULC map (2005, 2010 and 2015)	60m	National Remote Sensing Centre (NRSC), Hyderabad, India
Soil map	1000m	http://www.waterbase.org/
Rainfall	0.25°×0.25°	Indian Meteorological Department (IMD), Pune, India
Minimum and Maximum temperature	0.5°×0.5°	Indian Meteorological Department (IMD), Pune, India
Streamflow	Daily	Central Water Commission (GOI), Hyderabad
Water storage structures (Dams, Reservoirs, and Tanks) data	Daily	India-WRIS (Water resources Information System) (http://www.india-wris.nrsc.gov.in/)

Hydrological modeling of Krishna river basin

- 48 major water storage structures (Almatti, Srisailam, Nagarjunasagar, etc.,)
- 143 sub-basins
- 1522 HRUs

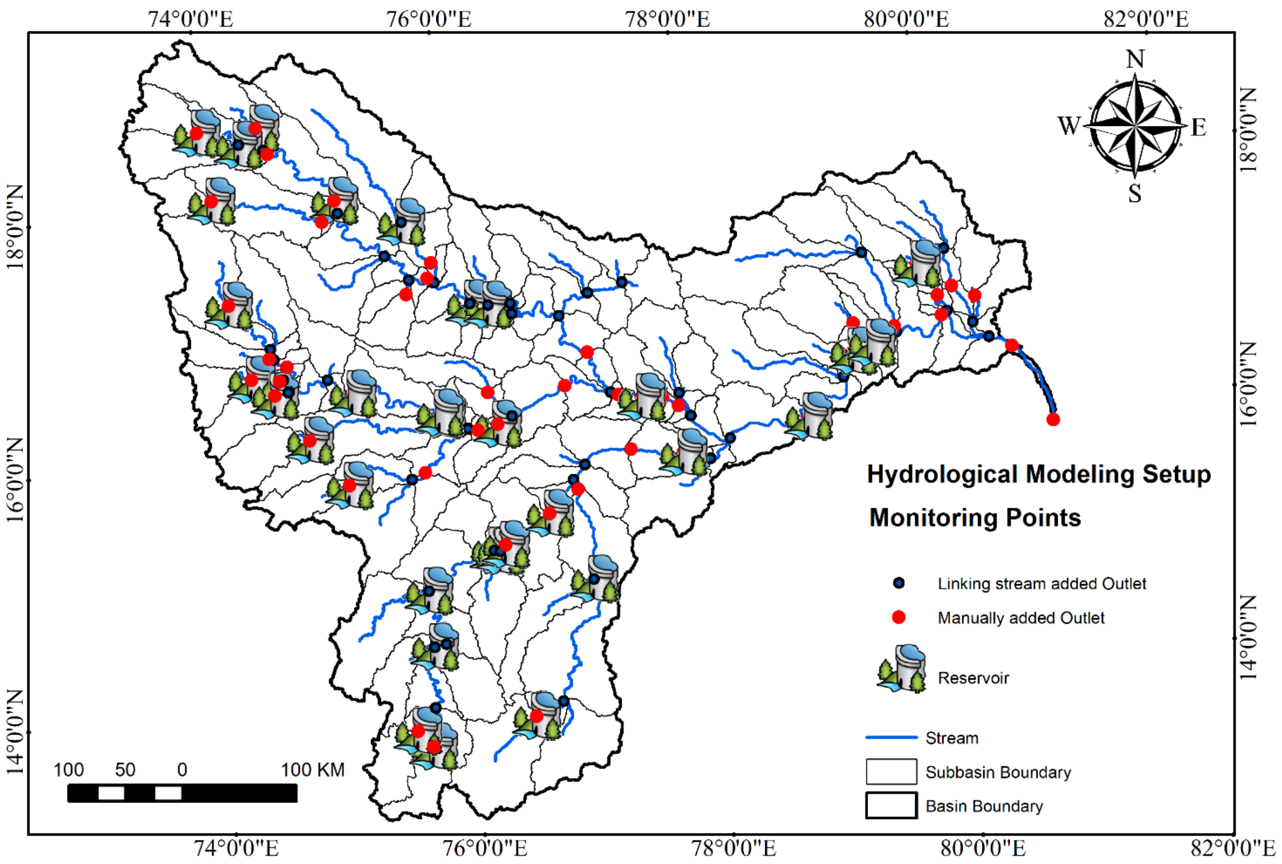


Fig. Hydrological modeling setup of the Krishna river basin.

Evaluation of the model performance

- SUFI-2 algorithm in SWAT -CUP.
- The model was calibrated and validated at Vijayawada gauge station from the available data

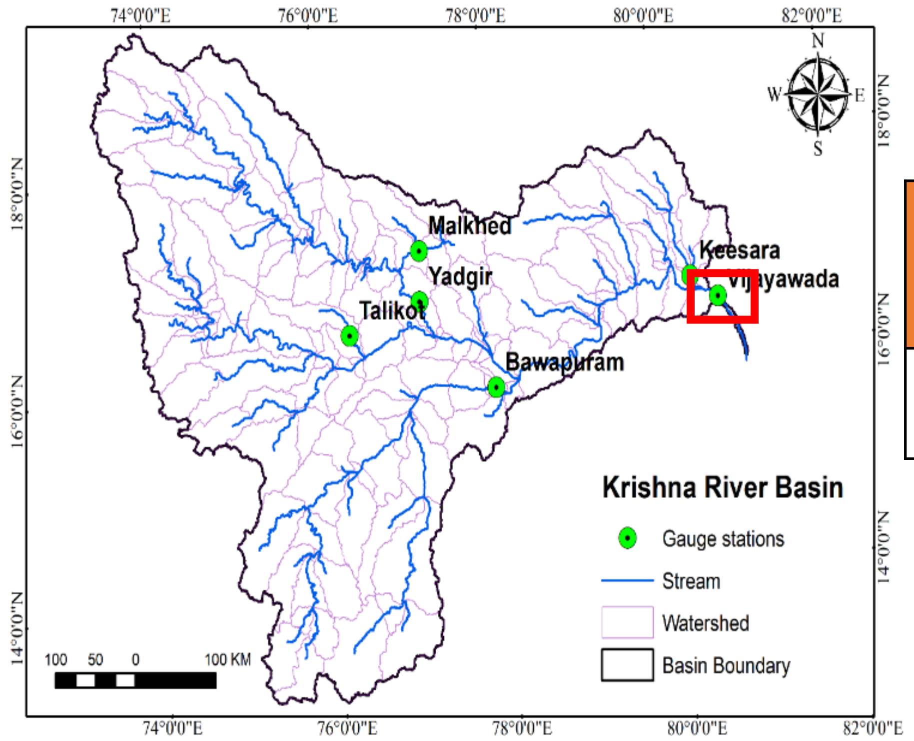


Fig. Location map of calibrated gauge station of Krishna river basin, India.

Table: Objective functions and their corresponding values

Gauge station (Sub basin No)	Calibration				Validation			
	R^2	NSE	RSR	PBIAS	R^2	NSE	RSR	PBIAS
Vijayawada (59)	0.63	0.61	0.62	9.85	0.61	0.56	0.67	13.33

Prediction of Future Land Use/ Land Cover (LULC) change

- Cellular Automata (CA) Markov Chain model in Land Change Modeler (LCM) was used to predict future LULC Changes.
- 8 dominated transitions such as Kharif to Double/Triple crop, Kharif to current fallow land, Rabi to Kharif, Rabi to Double/Triple crop, Rabi to current fallow, current fallow to Kharif, current fallow to Double/Triple crop and wasteland to urban were considered and each transition modeled individually using Multi-Layer Perception (MLP) neural network

Note: Kharif Crop: July – October; Rabi: October – April; Zaid: April - June

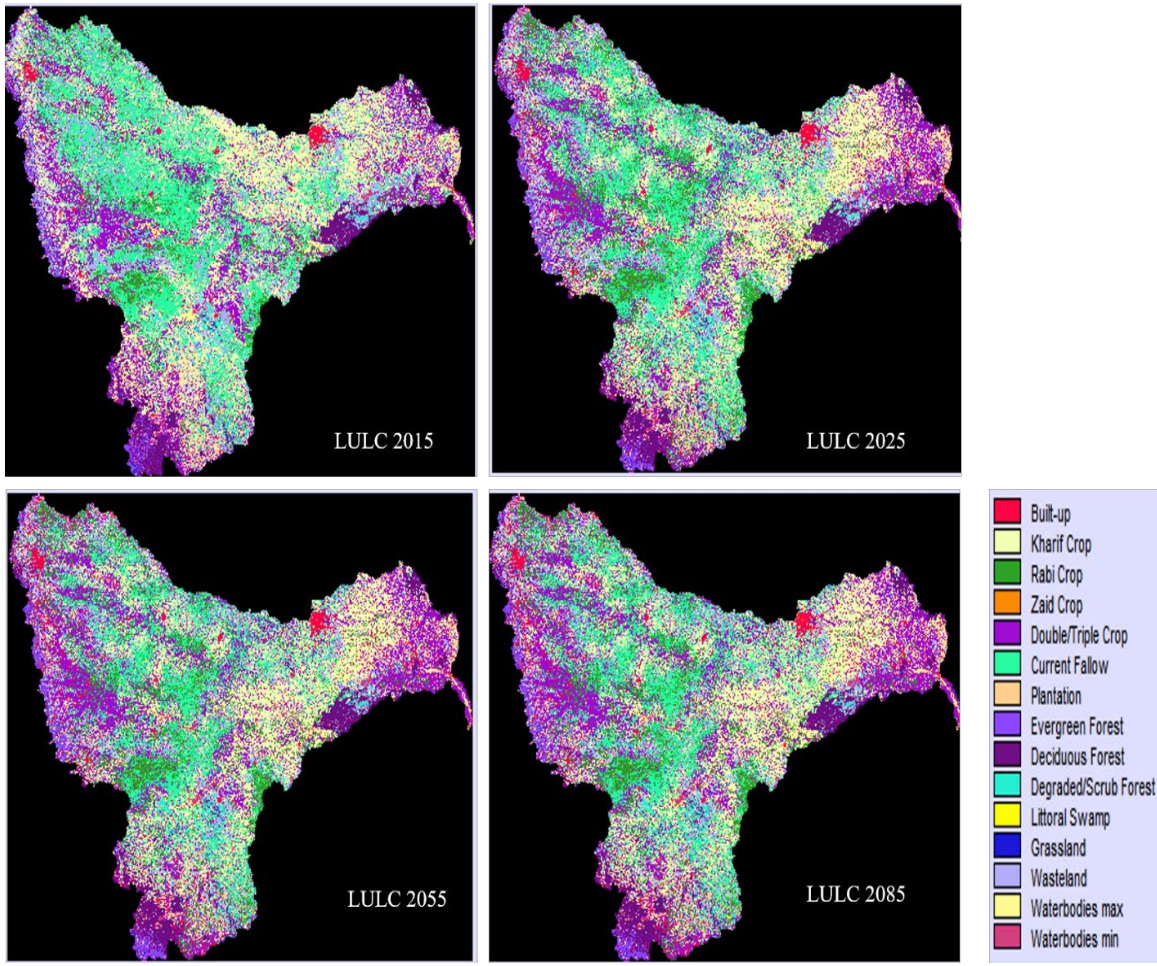


Fig. Comparison between the actual LULC map (2015) with the predicted LULC maps of 2025, 2055 and 2085.

(Chanapathi et al., 2020b)

Prediction of Future Land Use/ Land Cover (LULC) change

Six major driver variables such as

- Distance from roads,
- Distance from the rail network,
- Distance from drainage or river network,
- Distance from water bodies,
- Digital Elevation Model,
- Slope are considered to model the changes.

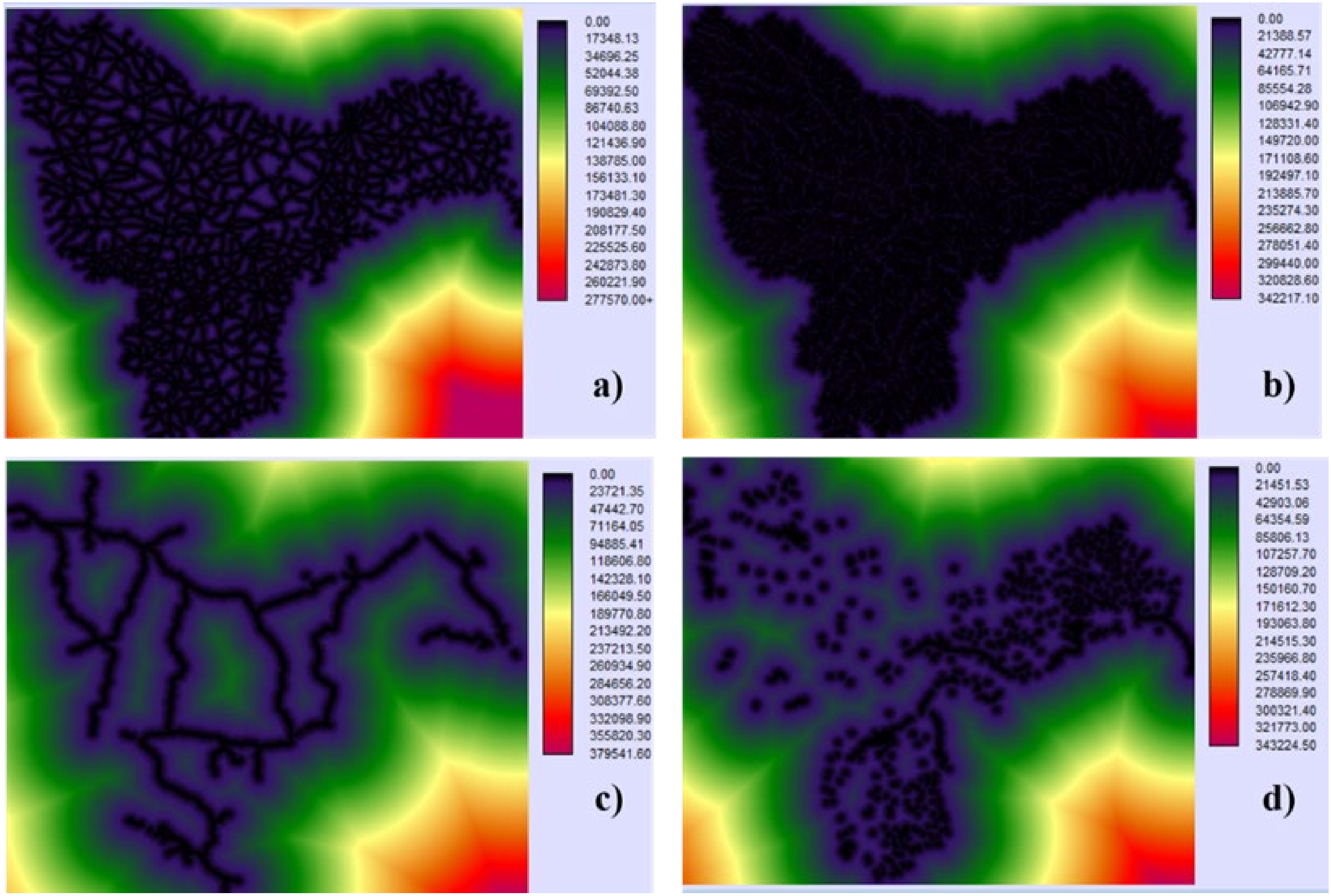


Fig. Driver variables a) distance from roads, b) distance from river network c) distance from the rail network, d) distance from water bodies.

Comparison between observed and simulated LULC

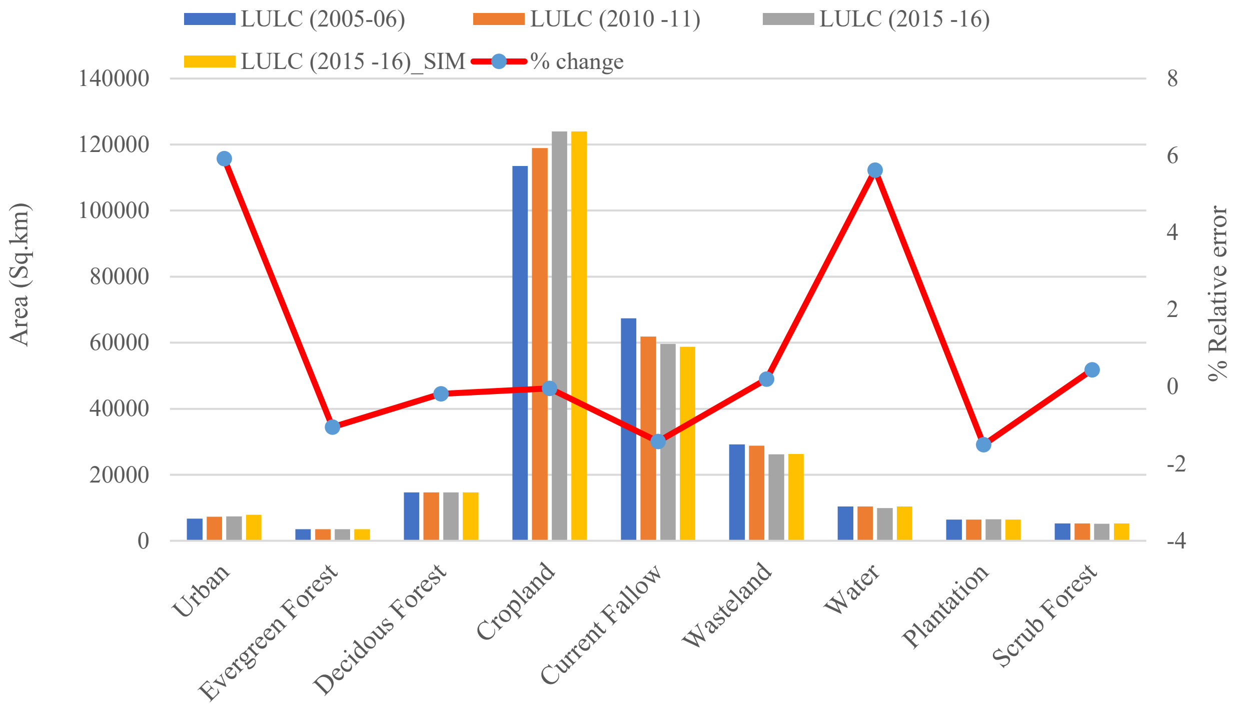


Fig. Comparison of Observed LULC data sets (2005, 10 and 15) with simulated LULC map of 2015.

Table: LULC distribution over Krishna river basin, India (km[2])

LULC Scenario	Observed/ Actual	Simulated/ Predicted	Future LULC Predicted		
	2015	2015	2025	2055	2085
Built up	7492	7857	9737	12901	13980
Evergreen Forest	3550	3513	3602	3631	3513
Deciduous Forest	14659	14633	14607	14579	14599
Crop land	124016	123956	140370	144305	143829
Current fallow	59622	58772	47487	41297	41642
Waste land	26206	26258	20552	19942	19192
Water	9871	10426	9871	9871	9871
Plantation	6540	6442	5666	5353	5367
Scrub Forest	5203	5226	5203	5203	5203
Grass land	93	95	93	93	93

- The urbanization effect is not significant in this basin as it (urban land) occupies only 2.6% of the total area of the basin (2005 LULC map) and is mainly dominated by agricultural land

Validation of LULC map

- The Kappa statistics such as $K_{standard}$ =0.8033, K_{no} =0.8871, and $K_{location}$ = 0.8817 were obtained in validation process indicates good agreement between projected and actual map, means the model predictions are reliable

- The LULC maps of 2005 and 2015 are used to model the transition potential maps along with transition potential matrix, to predict the future LULC maps of 2025, 2055, and 2085

- The expansion of cropland (+ 7.7%), built -up land (+2.5) and loss of current fallow land (-7%) and waste (barren) land (- 2.73%)

Analysis of rainfall and runoff under future scenarios (CNRM-CM5)

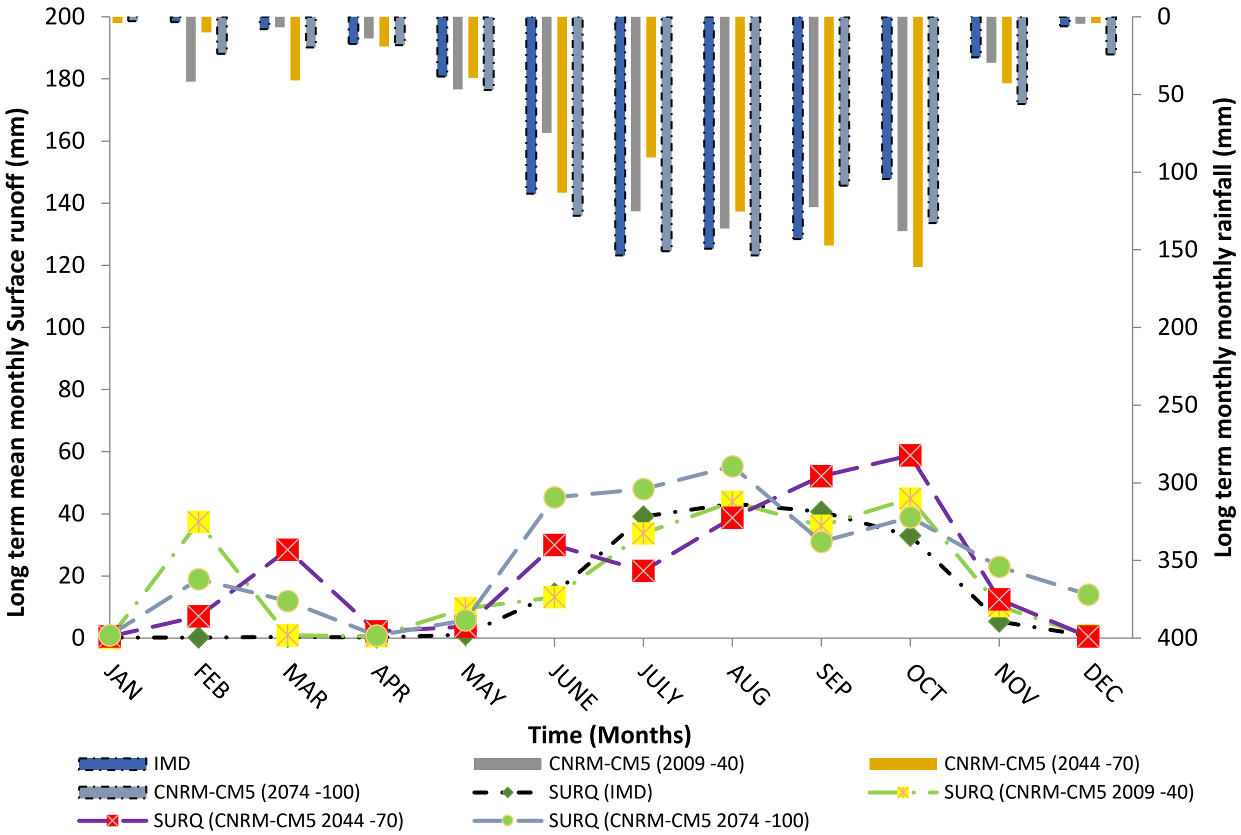


Fig. Rainfall and surface runoff variations due to impact of climate change for different future scenarios (RCP 4.5).

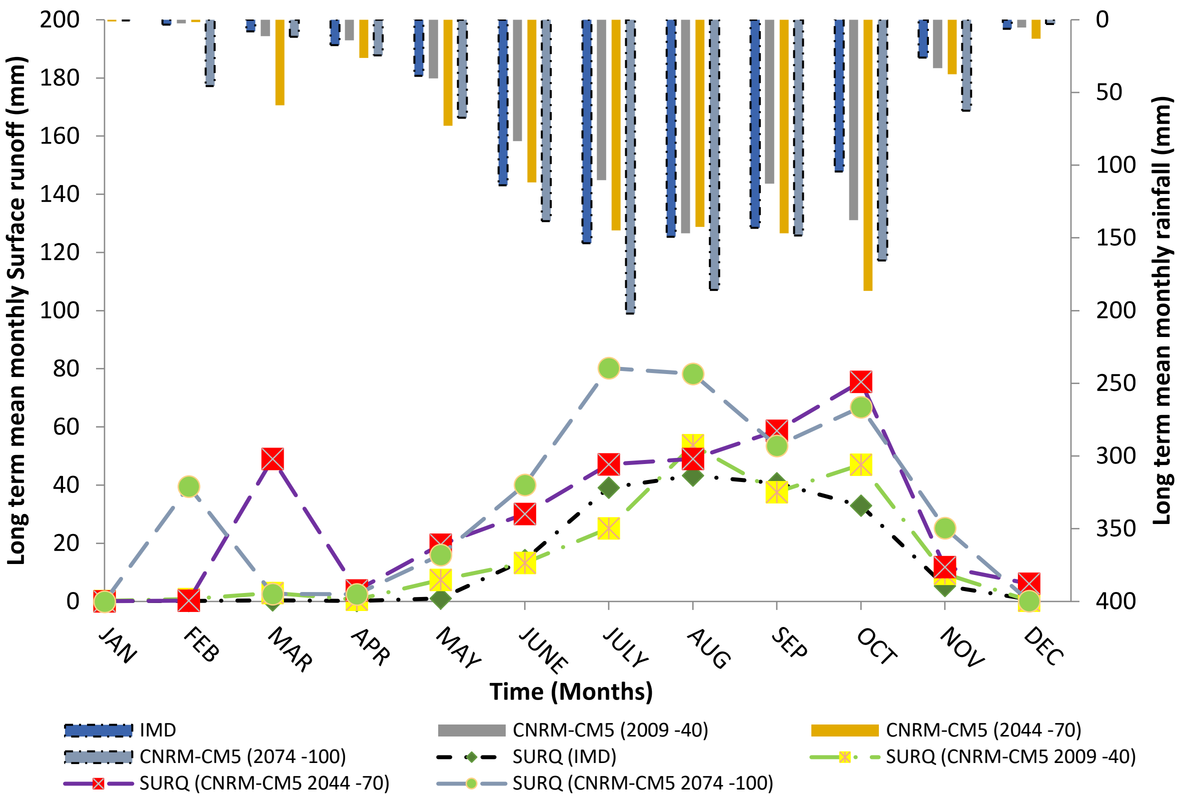
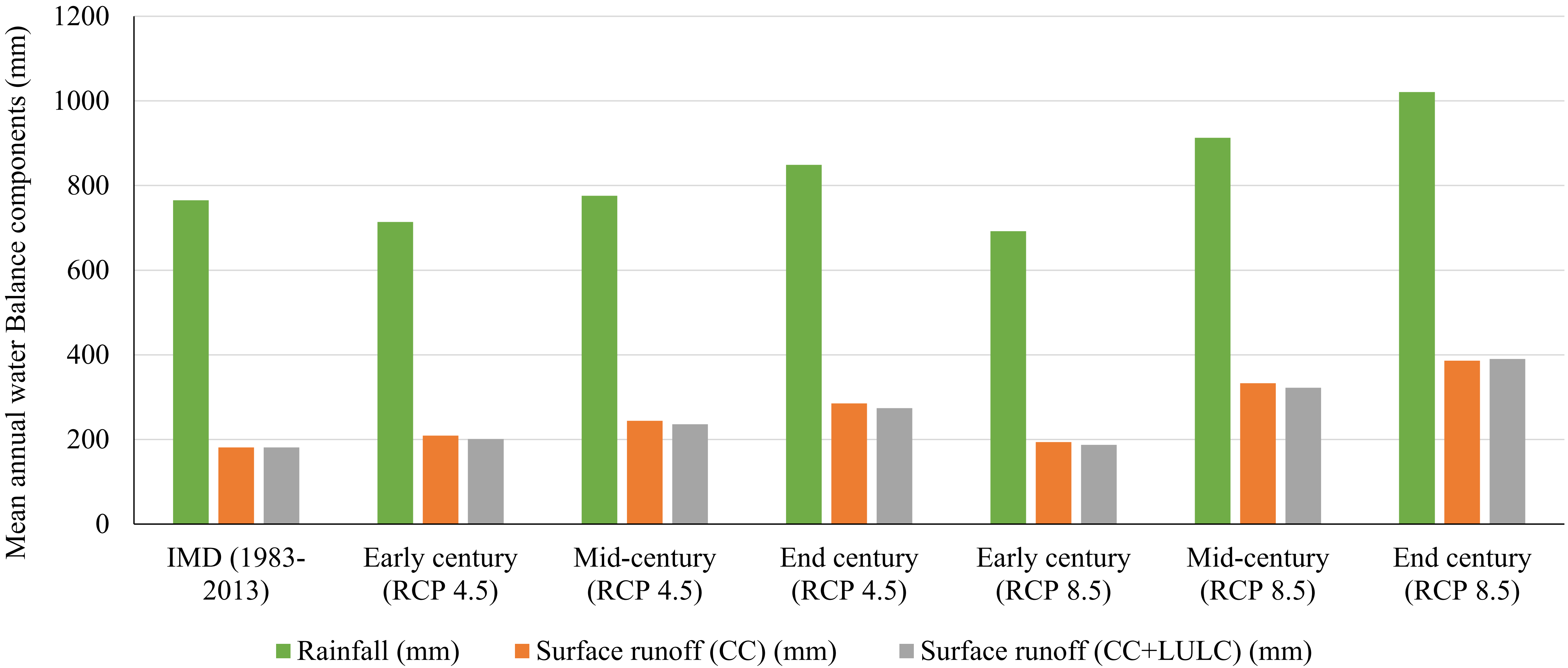


Fig. Rainfall and surface runoff variations due to impact of climate change for different future scenarios (RCP 8.5)

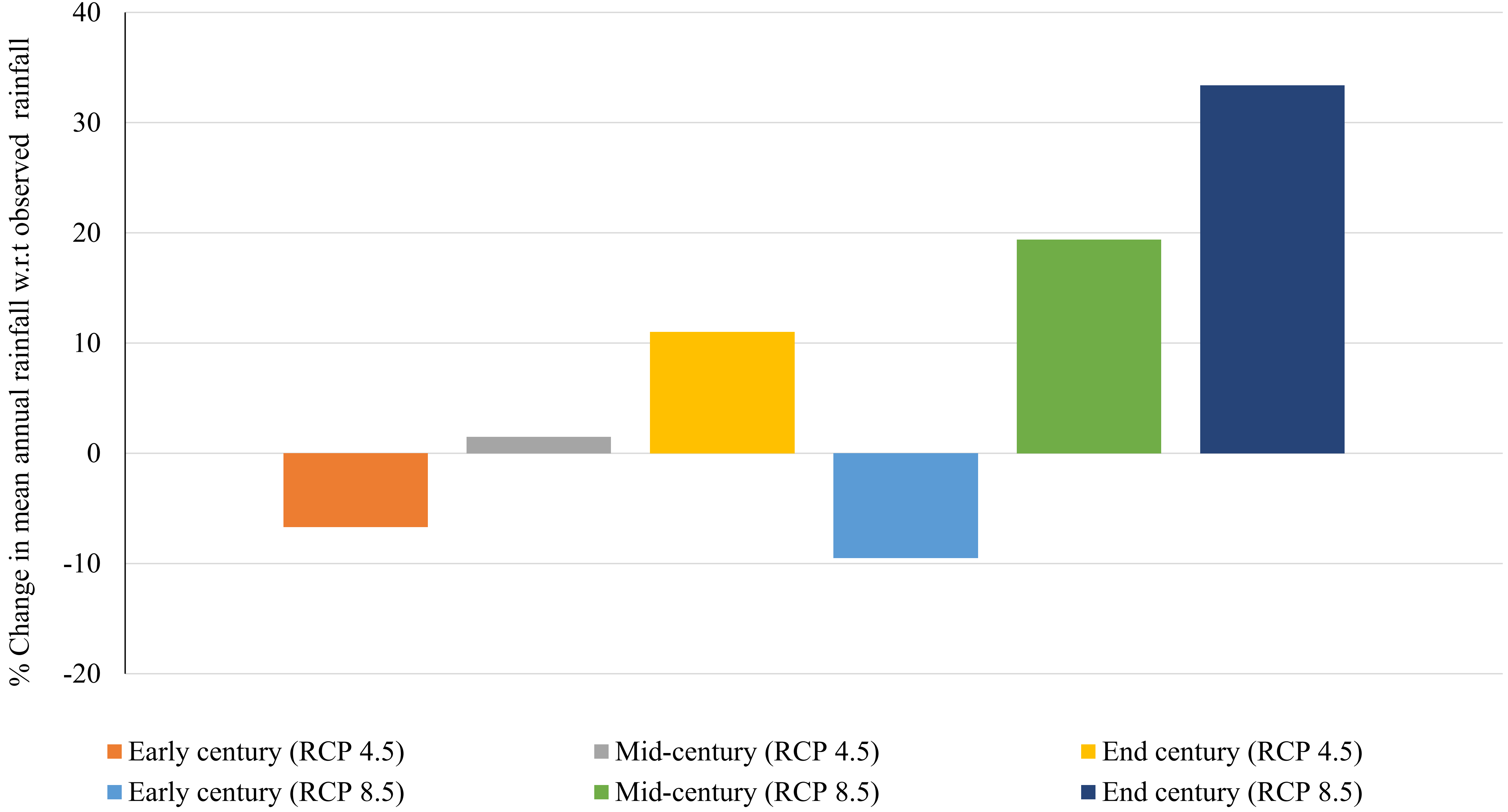
Note: IMD-Observed Rainfall data (1983-2013); SURQ (IMD)-Simulated Surface runoff using IMD Observed Rainfall (1983-2013)

Influence of climate and LULC changes on water balance components of the Krishna River Basin

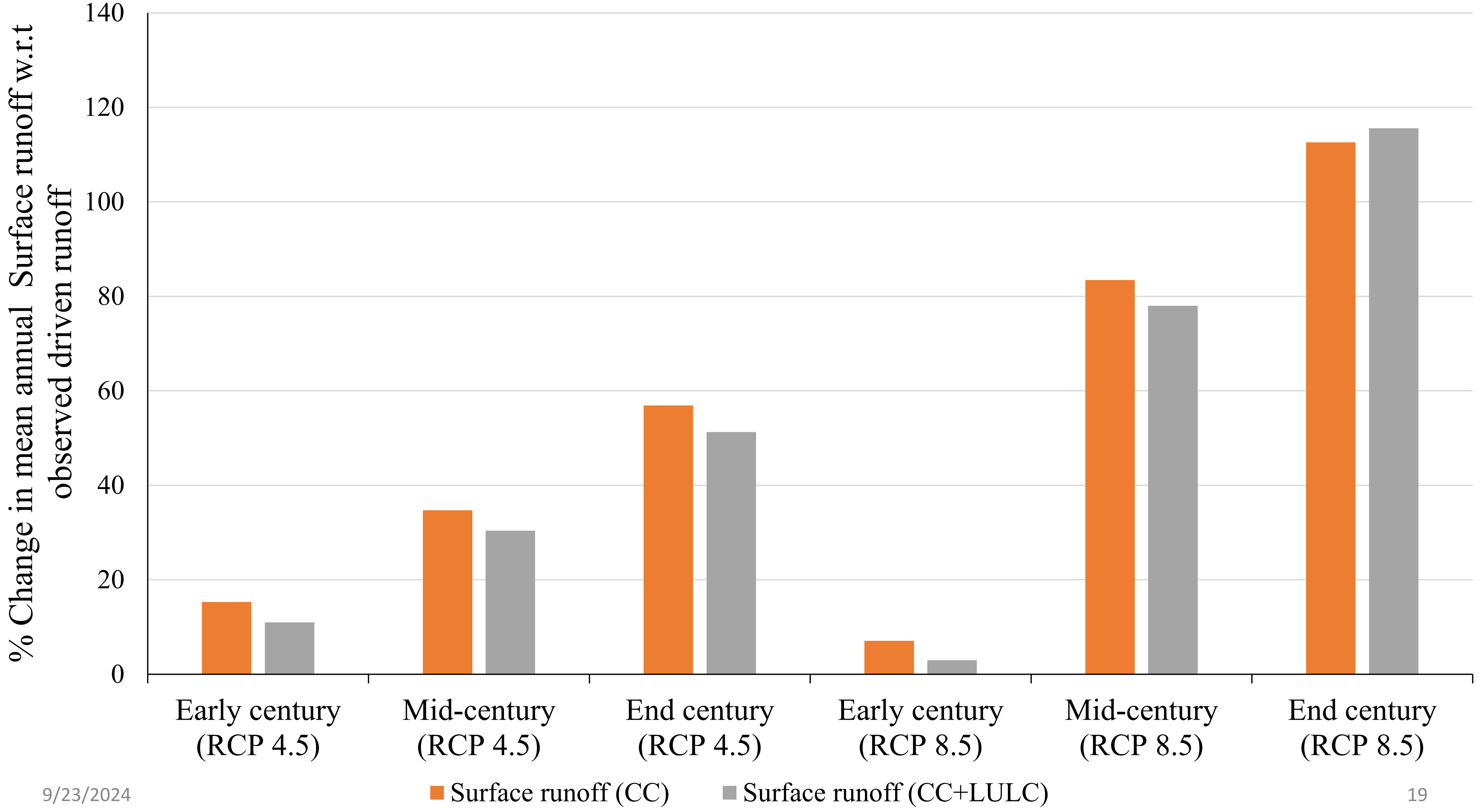


Note: IMD- Observed data; CC = Climate Change Scenario; LULC: Land Use/ Land Cover Change Scenario; Early century = 2014-2040; Mid-century = 2044-2070; End century = 2074-2100; values in ( ) indicates % deviation from long-term observed mean; -ve**:**deficit; +ve:excess. All the variables represent the mean annual values

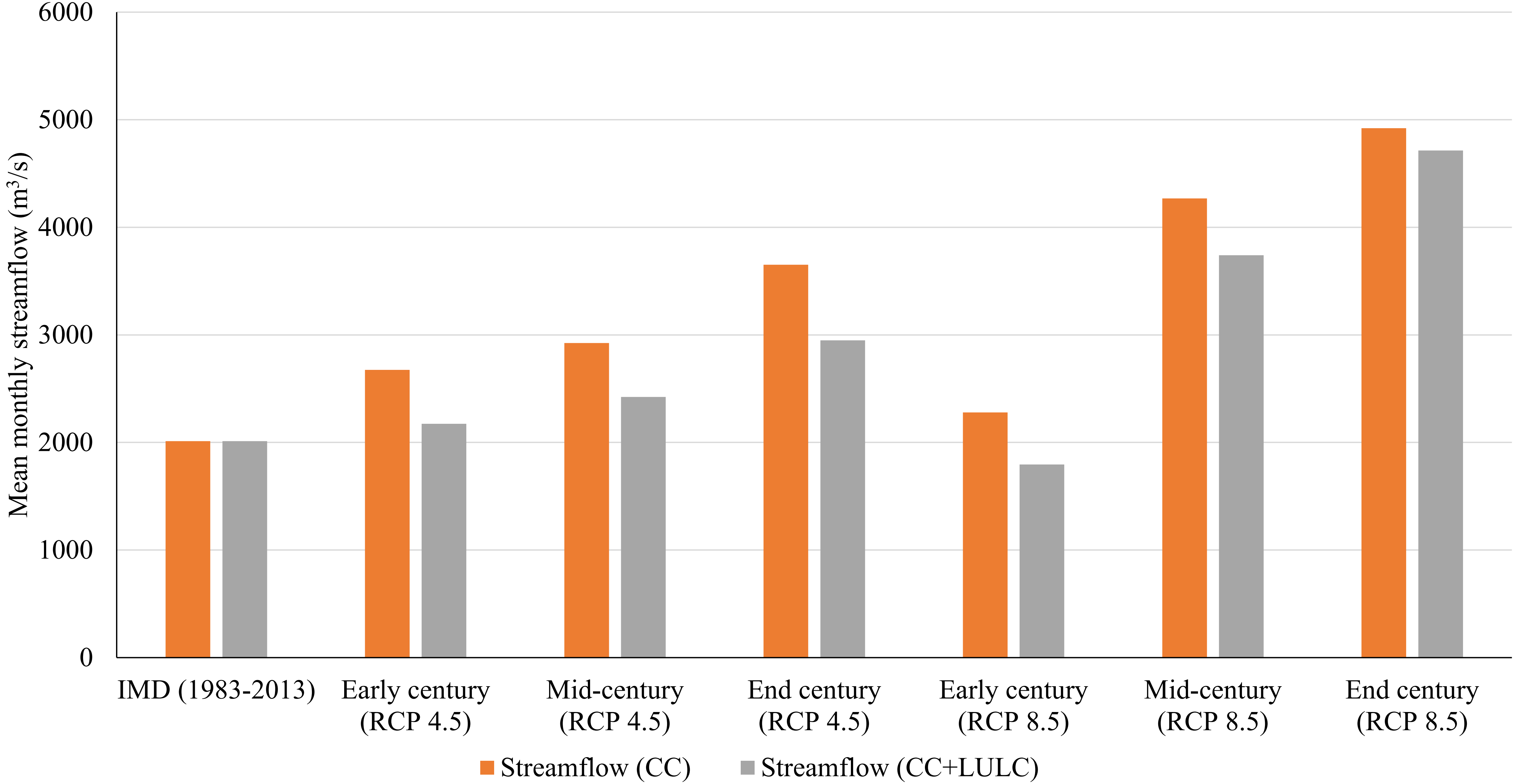
Variation of rainfall under future scenarios



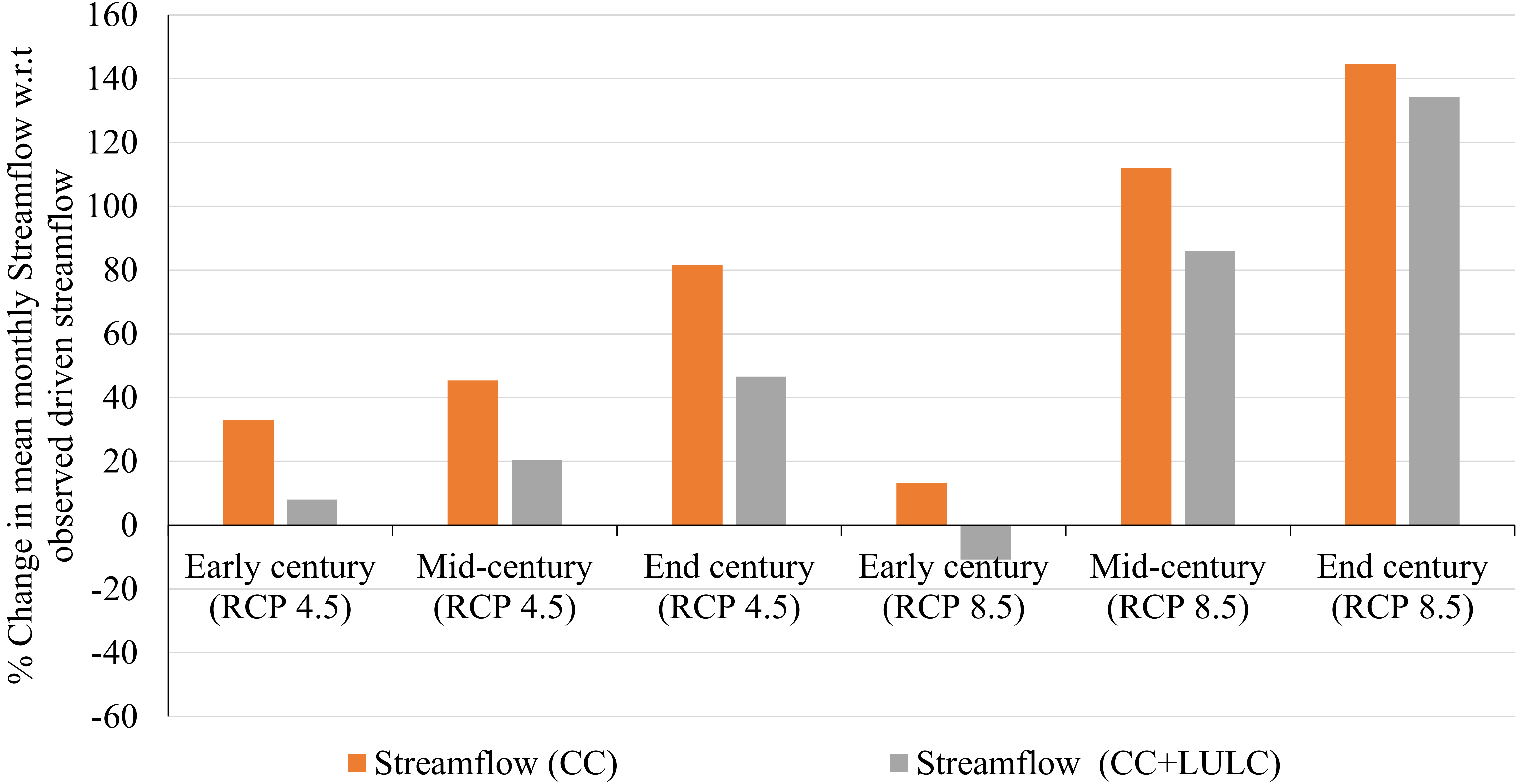
Variation of Surface Runoff under future scenarios



Influence of climate and LULC changes on streamflow of the Krishna River Basin



Variation of streamflow under future scenarios



- The streamflow may increase nearly 30 - 80% under RCP 4.5 Scenario.
- It may doubled in mid-century, while it may increase about 2.5 times under the RCP 8.5 scenario
- However, the LULC changes are offsetting the influence of climate change on streamflow by 17 to 19% and 4 - 12% under RCP 4.5 and 8.5 scenarios, respectively
- Surface runoff, water yield, and streamflow may increase by 10 - 50% under combined influence of both climate and LULC change scenario under RCP 4.5
- They may doubled under the RCP 8.5 scenario

Extreme event analysis under the climate Scenario

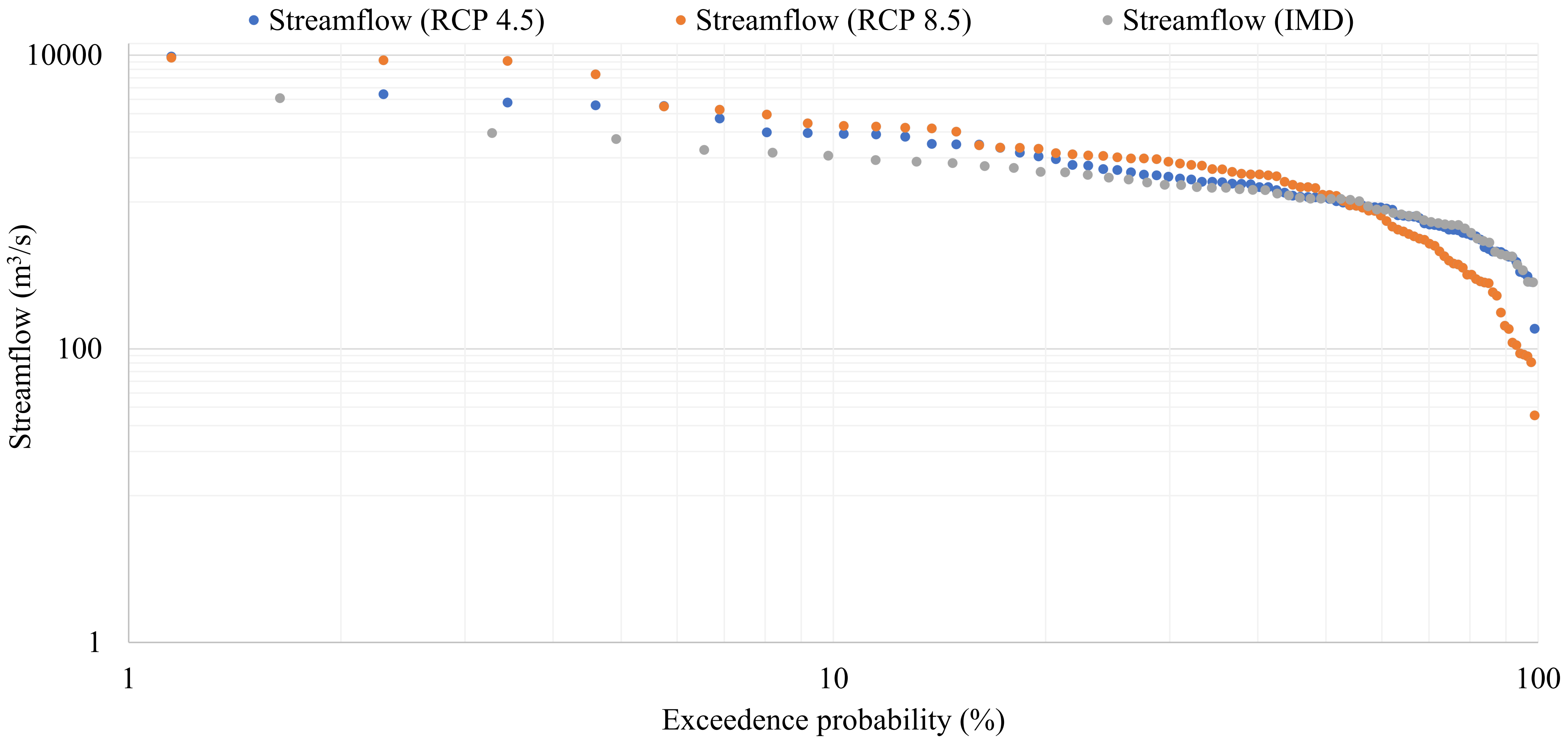


Fig. Flow duration curves of Krishna river basin (on log - log scale) under climate change scenarios.

Note: IMD- Observed scenario (1983-2013); RCP 4.5-2014-2100; RCP 8.5-2014-2100.

Extreme event analysis under the combined influence of climate and LULC changes

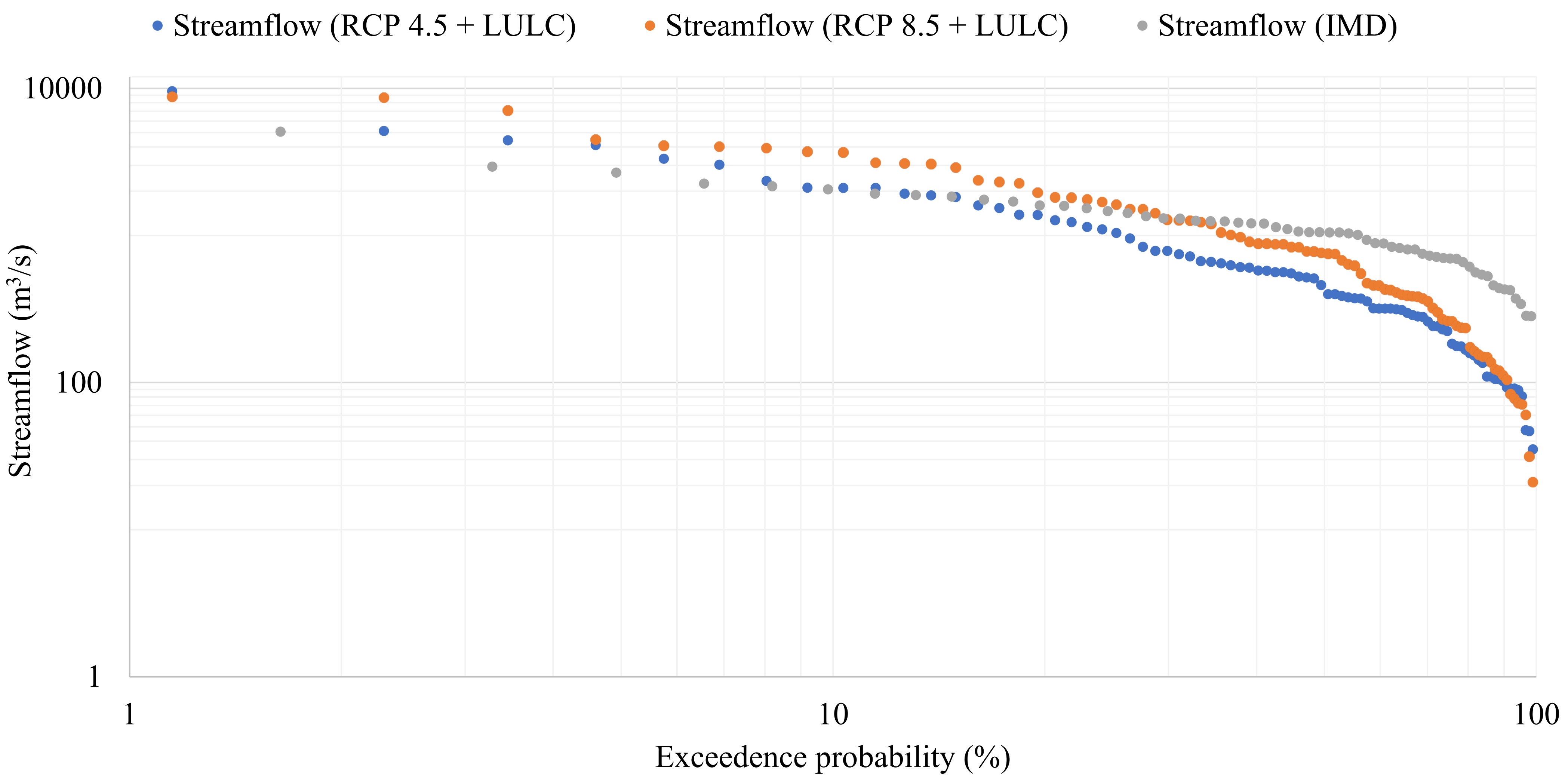


Fig. Flow duration curves of Krishna river basin (on log - log scale) under combined climate and LULC change scenarios.

Note: IMD- Observed scenario (1983-2013); RCP 4.5-2014-2100; RCP 8.5-2014-2100.

Extreme event analysis under the combined influence of climate and LULC changes

- High flows were projected to increase by 4 and 11%, while dry flows may increase by 29 and 17% under RCP 4.5 and 8.5 scenarios, respectively, with reference to historical.
- Under future scenarios there will be a rise in high flows and a reduction in low flows as compared to historical values and it may have serious consequences on the future water security and sustainability of the basin.

Table: Dependable flow values of the KRB under present and future scenarios.

Dependable flow	Observed (IMD)	RCP 4.5	RCP 4.5 + LULC	RCP 8.5	RCP 8.5 + LULC
10%	2095	2945	2238	3728	3178
20%	1867	2574	1899	3206	2713
30%	1640	2202	1570	2683	2247
40%	1412	1831	1241	2160	1781
50%	1184	1460	913	1638	1315
60%	956	1088	584	1115	850
65%	842	903	419	854	617
70%	729	717	255	592	384
75%	615	531	90	331	151

Table : Extreme events under future scenarios.

Flow conditions	Observed (1954 -2013) (IMD)	RCP 4.5	RCP 4.5 + LULC	RCP 8.5	RCP 8.5 + LULC
>=10% DF (High flows)	5 (8%)	16 (19%)	10 (12%)	19 (22%)	16 (19%)
10 - 40% DF (Moist conditions)	11 (18%)	12 (14%)	5 (6%)	18 (21%)	11 (13%)
40 -60% (Mid-range flows)	18 (30%)	18 (21%)	8 (9%)	9 (10%)	6 (7%)
< 60 (Dry conditions)	26 (44%)	40 (46%)	63 (73%)	40 (47%)	53 (61%)

Note: RCP +LULC indicates the combined influence of climate and LULC change; values in the ( ) indicates the percentage of events under each condition.

Summary and Conclusions

- Shift in the occurrence of the maximum amount of long-term mean monthly rainfall and maximum surface runoff and increase of rainfall in the months of October and November
- The expansion of cropland, built-up land, and loss of current fallow and waste (barren) lands are projected with LCM model
- The future LULC changes were offsetting the influence of climate change on streamflow by 17 to 19% under RCP 4.5 and 4 - 12% under 8.5 scenarios, respectively
- The Surface runoff, water yield, and streamflow may increase by 10 - 50% under RCP 4.5, while they may doubled under RCP 8.5 scenario
- The increase of high, low flows, and reduction of mid-range flows values were projected in future

References

- Chanapathi, T., Thatikonda, S., & Raghavan, S. (2018). Analysis of rainfall extremes and water yield of Krishna river basin under future climate scenarios. *J Hydrol Reg. Stud*, *19*, 287-306.
- Chanapathi, T., & Thatikonda, S. (2020). Investigating the impact of climate and land-use land cover changes on hydrological predictions over the Krishna river basin under present and future scenarios. *Sci. Total Environ*, *721*, 137736.
- Neitsch, S. L., Arnold, J. G., Kiniry, J. R., & Williams, J. R. (2011). Soil and water assessment tool theoretical documentation version 2009. Texas Water Resources Institute.
- Zhao, J., Huang, Q., Chang, J., Liu, D., Huang, S., & Shi, X. (2015). Analysis of temporal and spatial trends of hydro-climatic variables in the Wei River Basin. *Environ Res*, *139*, 55-64.

Thanks

Extreme rainfall events under multi – model projections

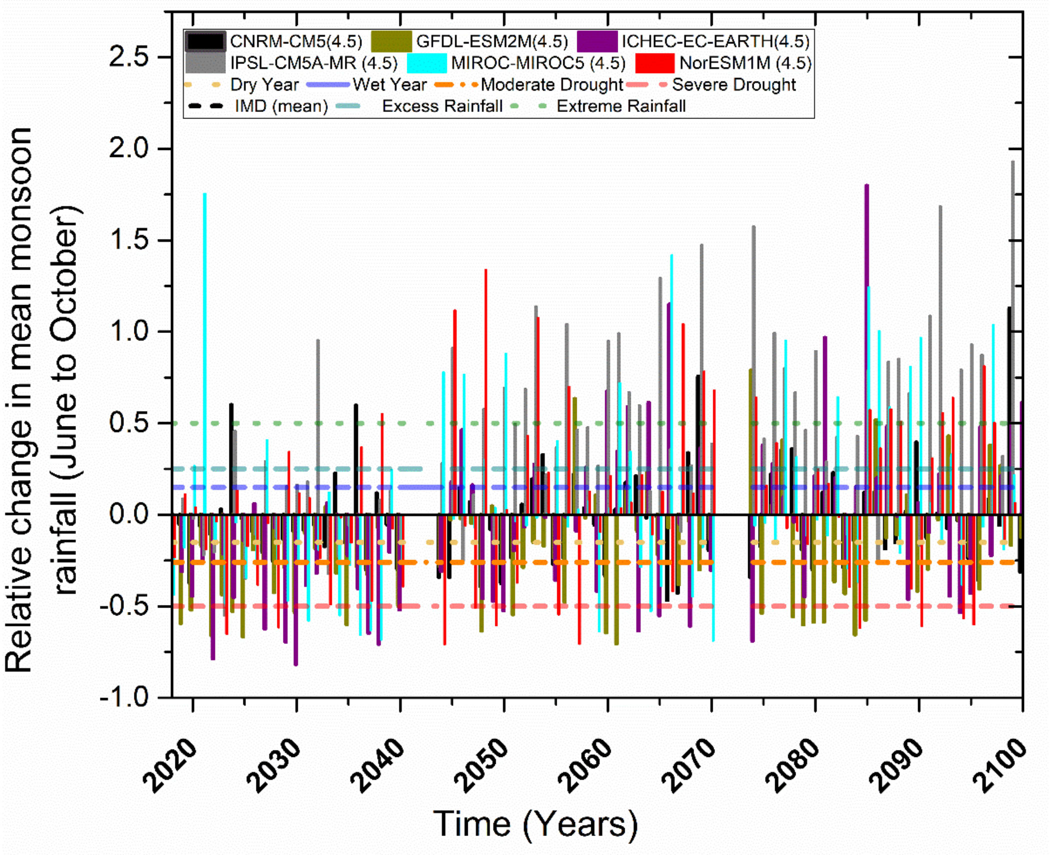


Fig. Relative change in mean projected rainfall of climate models with respective to historical mean under RCP 4.5 scenario.

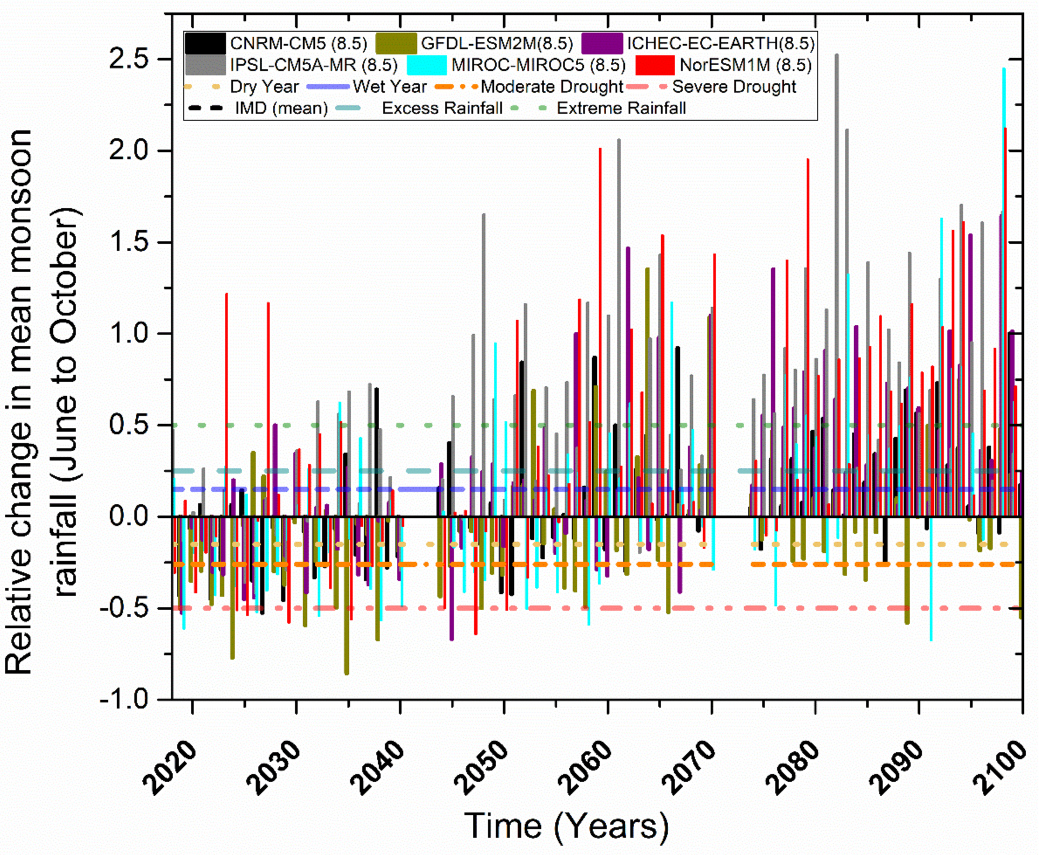


Fig. Relative change in mean projected rainfall of climate models with respective to historical mean under RCP 8.5 scenario.

(Chanapathi et al., 2018)

Classification of River basin sustainability indicators and their ranges

Model	Parameter	Type of Node	Range	Respective class
RSBN	1. Mean annual rainfall (mm)	Root	[200 1500]	>906 = High; 670 - 906 = Medium; 200 -670 =Low
	2. Number of Rainy days	Root	[50 150]	>111 = High; 83- 111 = Medium; 50 - 83=Low
	3. Temperature (°C)	Root	[20 42]	>33.36 = High; 32.26 - 33.36 = Medium; 20 – 32.26 =Low
	4. Land Use/ Land Cover (LULC) (% area)	Root	[0 100]	Built-up = 2.6; Cropland =44.2; Current fallow land =26.2; Wasteland =11.3; Other LULC = 15.7 (Prior probabilities)
	5. Rainfall Intensity	Child (1,2)	State	High; Medium; Low
	6. Evapotranspiration (mm)	Child (1,3,4,5)	[200 700]	>574 = High; 523 - 574 = Medium; 200 -523 =Low
	7. Runoff (mm)	Child (1,3-6)	[0 800]	>237 = High; 154 – 237 = Medium;< 154 =Low
	8. Streamflow (m^3/s)	Child (7)	[100 2300]	>960 = High; 740 – 960 = Medium; 100 - 740 =Low
	9. Slope (% rise)	Root	[0 100]	>17.74 = High; 2.92 – 17.74 = Medium; <2.92 =Low
	10. Erosion (Tones/km^2/year)	Child (4,5,7,9)	[0 300]	>50 = High; 10 – 50 = Medium; <10=Low
	11. Physiochemical Water quality	Root	[0 100]	>75 = Excellent; 55 – 75 = Good; <55=Poor
	12. Water quality	Child (4,8,10,11)	[0 100]	>75 = High; 55 – 75 = Medium; <55=Low
	13. Storage capacity (%)	Root	[0 100]	>70 = High; 30 – 70 = Medium; <30=Low
	14. Population growth rate (% per annum)	Root	[0 5]	>1.5 = High; 0.5 – 1.5 = Medium; <0.5=Low
	15. Consumption patterns (%)	Root	[0 100]	Rice = 39; Wheat =32; Maize =15; Other = 14 (Prior probabilities)
	16. Water demand (%)	Child (6,14,15)	[0 100]	>70 = High; 30 – 70 = Medium; <30=Low
	17. Reservoir releases (%)	Child (8,13,16)	[0 100]	>70 = High; 30 – 70 = Medium; <30=Low
	18. Water availability (%)	Child (8,13,17)	[0 100]	>70 = High; 30 – 70 = Medium; <30=Low
	19. Environmental flow (m^3/s)	Child (8,17)	[0 2000]	>1100 = High; 540 – 1100 = Medium; <540=Low
	20. Water stress	Child (16,18)	State	High; Medium; Low
	21. Extreme events	Root	[0 100]	Extreme rainfall = 2; Excess rainfall = 3; Wet year =7; Normal year =71; Dry year = 10; Moderate drought =7; Severe drought = 0 (Prior probabilities)
	River sustainability	Child (12,19,20, 21) Leaf	[0 100]	>85 = Very Highly Sustainable; 71 – 85 = Highly Sustainable; 56 – 70 = Medium Sustainable; 35 – 55 = Less Sustainable; <35 =Not Sustainable.

Note: The values in the brackets of type of node indicates the parent nodes to that corresponding child node.

(Chanapathi et al., 2020c)

Table: Weight and rating assigned to each component of the River Sustainability Bayesian Network (RSBN) model

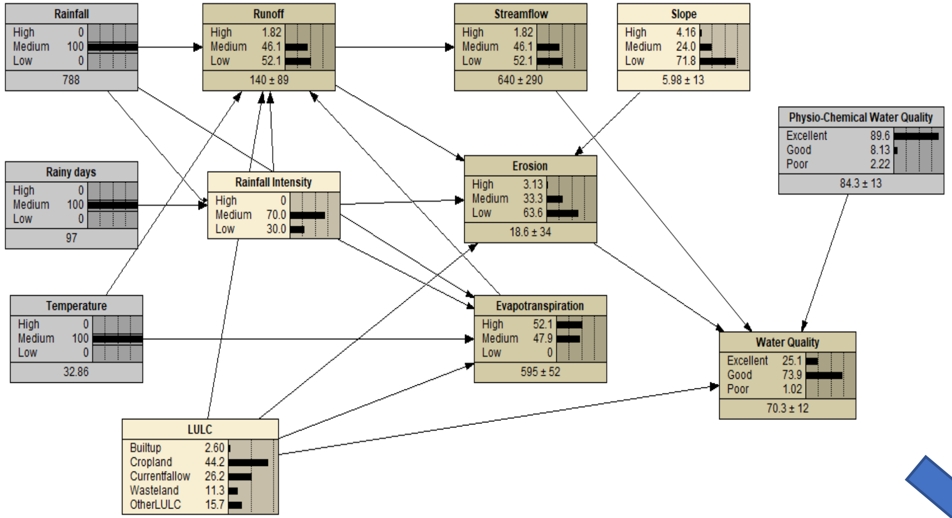
Component	Indicator Name	Weight	Rating (R) to be assigned to each indicator based on actual value and range
Evapotranspiration (mm)	Mean annual rainfall (mm)	5	10 = High; 7 = Medium; 3=Low
	Temperature (°C)	5	10 = High; 7 = Medium; 3 =Low
	Land Use/ Land Cover (LULC) (% area)	5	Built-up = 3; Cropland =10; Current fallow land =7; Wasteland =4; Other LULC = 5
	Rainfall Intensity	4	3 = High; 7 = Medium; 10=Low
Runoff (mm)	Mean annual rainfall (mm)	5	10 = High; 7 = Medium; 3=Low
	Temperature (°C)	3	3 = High; 7 = Medium; 10 =Low
	Land Use/ Land Cover (LULC) (% area)	4	Built-up = 10; Cropland =3; Current fallow land =8; Wasteland =7; Other LULC = 5
	Rainfall Intensity	5	10 = High; 7 = Medium; 3=Low
	Evapotranspiration (mm)	5	3 = High; 7 = Medium; 10 =Low
Erosion (Tones/km^2/year)	Runoff (mm)	4	10 = High; 7 = Medium; 3=Low
	Rainfall Intensity	5	10 = High; 7 = Medium; 3=Low
	Land Use/ Land Cover (LULC) (% area)	4	Built-up = 3; Cropland =4; Current fallow land =8; Wasteland =10; Other LULC = 5
	Slope (% rise)	5	10 = High; 7 = Medium; 3=Low
Water quality	Streamflow (m^3/s)	5	7 = High; 10 = Medium; 3=Low
	Physiochemical Water quality	5	10 = Excellent; 7 = Good; 3=Poor
	Erosion (Tones/km^2/year)	5	3 = High; 7 = Medium; 10 =Low
	Land Use/ Land Cover (LULC) (% area)	4	Built-up = 3; Cropland =5; Current fallow land =7; Wasteland =8; Other LULC (Forest) = 10
Reservoir releases (%)	Streamflow (m^3/s)	5	10 = High; 7 = Medium; 3=Low
	Storage capacity (%)	4	3 = High; 7 = Medium; 10=Low
	Water demand (%)	5	3 = High; 7 = Medium; 10=Low
Water availability (%)	Streamflow (m^3/s)	5	10 = High; 7 = Medium; 3=Low
	Storage capacity (%)	4	10 = High; 7 = Medium; 3=Low
	Reservoir releases (%)	3	3 = High; 7 = Medium; 10 =Low
Water demand (%)	Population growth rate (% per annum)	5	10 = High; 7 = Medium; 3=Low
	Evapotranspiration (mm)	4	10 = High; 7 = Medium; 3 =Low
	Consumption patterns (%)	3	Rice = 10; Wheat = 3; Maize = 7; Other = 5
River sustainability	Water quality	3	10 = Excellent; 7 = Good; 3=Poor
	Water stress	5	3 = High; 7 = Medium; 10 =Low
	Environmental flow (m^3/s)	4	10 = High; 7 = Medium; 3=Low
	Extreme events	5	Extreme rainfall = 1; Excess rainfall = 7; Wet year =10; Normal year = 5; Dry year = 3; Moderate drought =1; Severe drought = 0

(Chanapathi et al., 2020c)

Evaluation of river sustainability

Parameters: IMD (1954 -2013)

- Mean annual rainfall = 788mm (1954 -2013)
- Mean no of rainy days = 97 days (1954 -2013)
- Mean maximum temperature = 32.86 °C
- LULC (2005); Built-up land (2.6%); Crop land (44.2%); Current fallow land (26.2%); Waste land (11.3%); Other LULC (15.7%)
- Physio Chemical - water quality = Excellent = 89.2%; Good = 10.8%; Poor = 0.02%; (85.1+/-9.9)
- Slope: > 17.78 = 4.16%; 2.92 – 17.74%; 24%; <2.92 = 71.84%
- Storage capacity = 70% (mean annual flow / live storage capacity) = (78.1/54.8))
- Population growth rate = 24.67% / 19.6% in the duration of 9 years (2010 -2009). Annual growth rate 2.18%
- Consumption patterns (%): Rice = 39; Wheat =32; Maize =15; Other = 14 (Prior probabilities) from literature (Yee et al., 2009)
- Extreme events probabilities: Extreme rainfall = 2; Excess rainfall = 7; Wet year =3; Normal year =71; Dry year = 10; Moderate drought =7; Severe drought = 0



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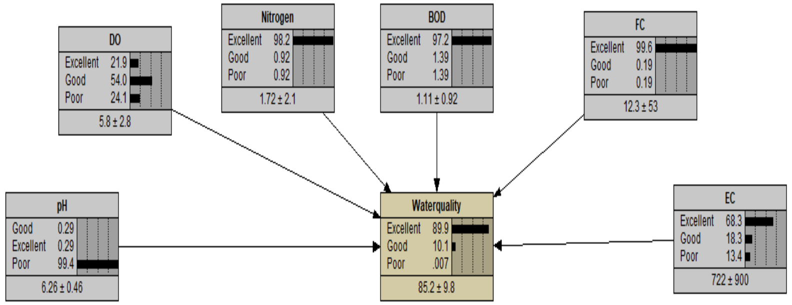
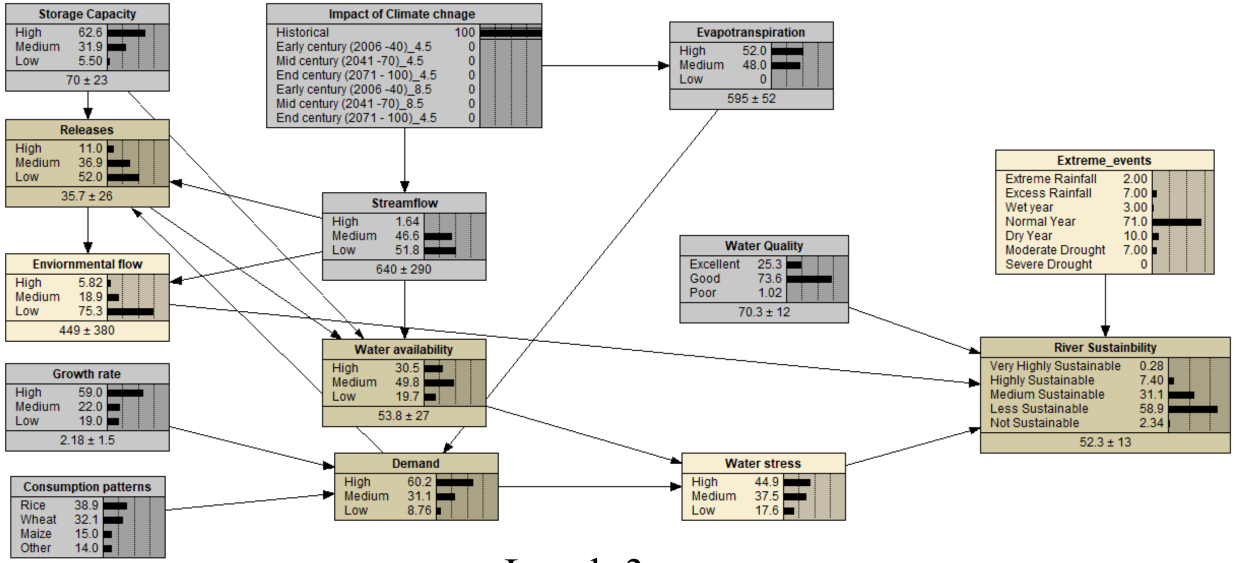


Level: 1



Level: 3

(Chanapathi et al., 2020c)

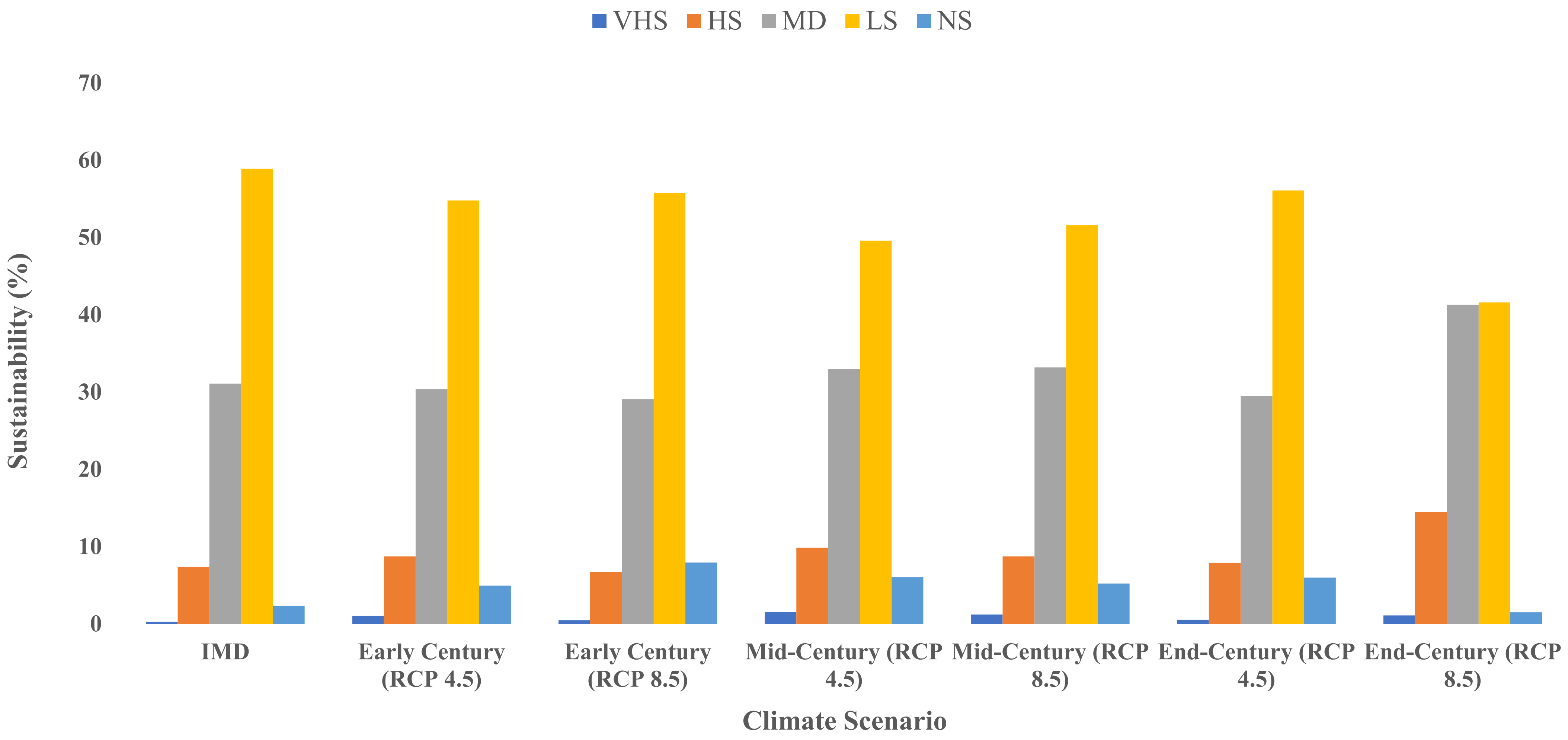


Fig. The variation in the sustainability of the KRB under present and future scenarios (CNRM-CM5)

(Chanapathi et al., 2020c)