Describe the impacts, variability and uncertainty regarding precipitation in your area associated with climate cycles such as ENSO, madden-julian oscillation MJO or seasonal monsoon. What are trends and future projections

The IPCC report give these three statements with high or very high confidence regarding climate change and climate variability.

"Many terrestrial, freshwater, and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to ongoing climate change."

"Based on many studies covering a wide range of crops, negative impacts of climate change on yields have been more common than positive impacts."

"Impacts from climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability."

Definitions of ENSO, MJO

ENSO:

El Niño and the Southern Oscillation, also known as ENSO is a periodic fluctuation in sea surface temperature (El Niño) and the air pressure of the overlying atmosphere (Southern Oscillation) across the equatorial Pacific Ocean.

El Niños occur irregularly approximately every two to seven years. El Nino effects Asia but the effect of El Nino on India is probabilistic in nature. El Nino in isolation may not have a definitive effect on India, but in combination with Indian ocean temperatures, it may impact, depending on air wind currents, El Nino causes short term climate changes in Parts of globe like delay in monsoons, deficit rainfall, massive drought conditions, flooding, Africa, Asia, Latin America are worst effected by El Niño

MJO:

The Madden-Julian Oscillation (MJO) is an oceanic-atmospheric phenomenon which affects weather activities across the globe. It brings major fluctuation in tropical weather on weekly to monthly timescales.

Impact of El Niño and La Nina on Indian Monsoon

- El Nino and La Nina are among the most powerful phenomenon on the Earth. These are known to alter climate across more than half the planet and dramatically impact weather patterns.
- Over Indian subcontinent, El Nino during winter results in development of warm conditions. During summer, it leads to dry conditions and deficient monsoon. It also

leads to drought in Australia. On the other hand, La Nina results in better than normal monsoon in India. At the same time, in Australia it has caused floods.

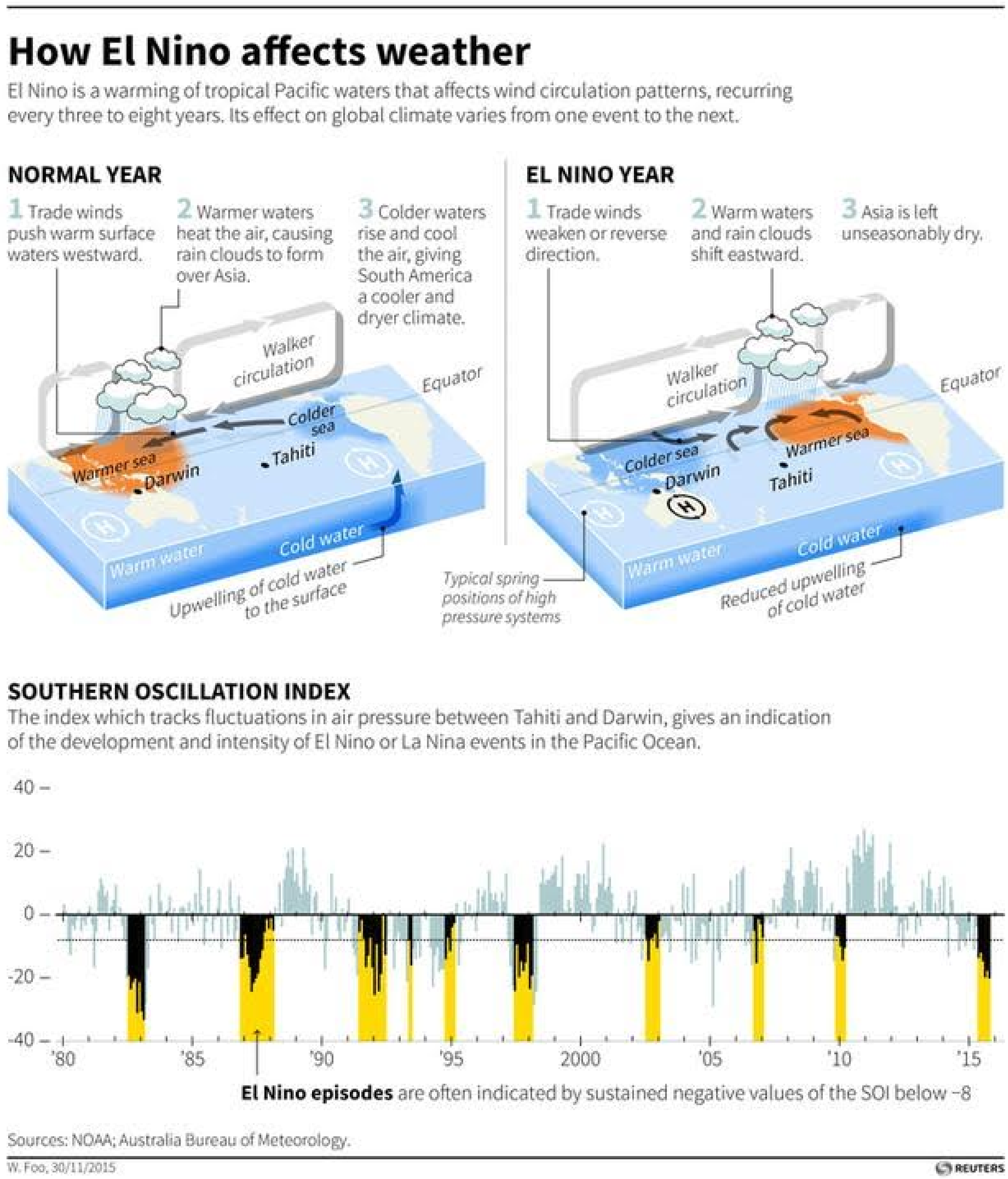
- In the recent past, India experienced deficient rainfall during El Nino years 2002 and 2009 whereas monsoon was normal during El Nino years 1994 and 1997. *This so far implies that in about 50 per cent of the years with El Nino during summer, India experienced droughts during monsoon*.
- This implies that *El Nino is not the only factor that affects monsoon in India*. There are other factors that affect India's rainfall pattern. These include North Atlantic SST, Equatorial SE Indian Ocean SST, East Asia Mean Sea Level Pressure, North Atlantic Mean Sea Level Pressure and North Central Pacific wind at 1.5 km above sea level.

Impact of MJO on Indian Monsoon:

- The Indian Ocean Dipole (IOD), El Nino and MJO are all oceanic and atmospheric phenomena, which affect weather on a large scale. IOD only pertains to the Indian Ocean, but the other two affect weather on a global scale, up to the mid-latitudes.
- IOD and El Nino remains over their respective positions, while MJO is a traversing phenomenon. The journey of MJO goes through eight phases. When it is over the Indian Ocean during the Monsoon season, it brings good rainfall over the Indian subcontinent. On the other hand, when it witnesses a longer cycle and stays over the Pacific Ocean, MJO brings bad news for the Indian Monsoon.
- Basically, it is linked with enhanced and suppressed rainfall activity in the tropics and is very important for the Indian monsoonal rainfall. It has also been established that if the periodicity of MJO is nearly 30 days then it brings good rainfall during the Monsoon season. If it is above 40 days then MJO doesn't give good showers and could even lead to a dry Monsoon. Shorter the cycle of MJO, better the Indian Monsoon. Simply because, it then visits the Indian Ocean more often during the four month-long period.
- Presence of MJO over the Pacific Ocean along with an El Nino is detrimental for Monsoon rains.

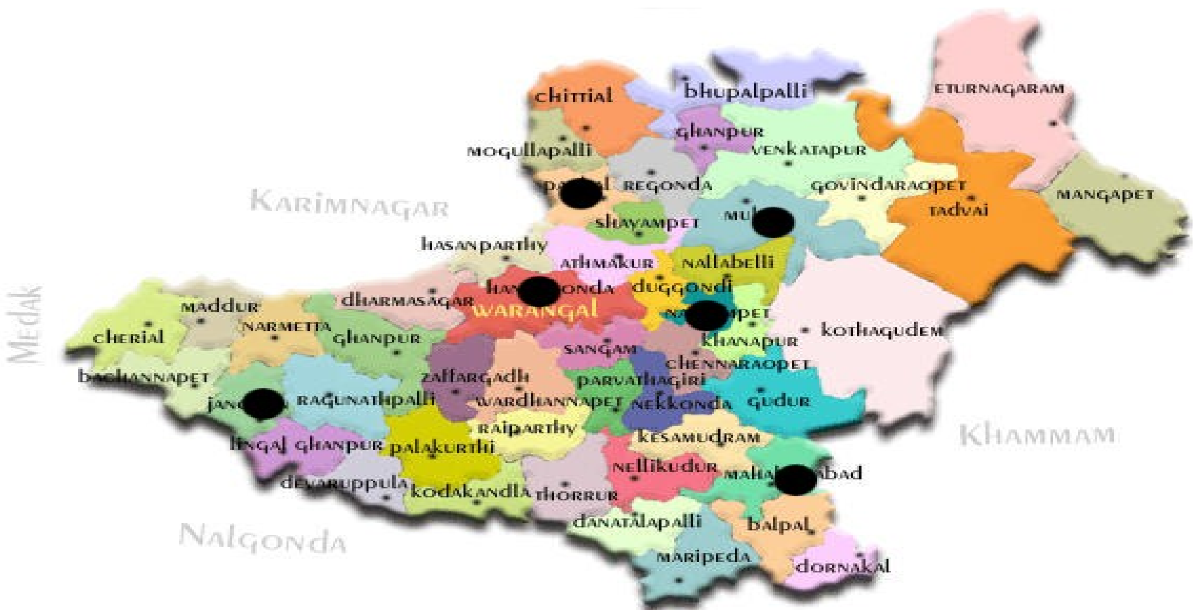
Impacts of uncertainty in precipitation:

- El Nino – a warming of sea-surface temperatures in the Pacific – affects wind patterns and can trigger both floods and drought in different parts of the world, leading to reduced harvests.
- Impacts of strong El Nino weathering patterns



- **Case study of a Warangal**

Warangal is located within 18.0° N, 79.58° E, and its elevation varies from 206m to302m above MSL. It is 140kms away from Hyderabad city. The district falls under Godavari Basin and Krishna Basin. The catchment area of Telangana in Krishna is 68.50% and in Godavari around 79%. The district is surrounded by Karimnagar, Nalgonda and Khammam districts and north part is bounded by Chhattisgarh and Orissa states. The district receives maximum rainfall during south west monsoon season i.e., from June to September. Six raingauge stations were selected to findout variability of rainfall in past, monthly rainfall data of 54 years i.e., from 1961-2014. The six raingauge stations selected were the ones with the longest records of data, viz., Jangaon, Hanamkonda, Mahabubabad, Narsampet, Parkal, and Mulugu, covering the entire district.



The average annual rainfall of Warangal district is about 990mm. The normal rainfall is higher than the average district rainfall in Mahabubabad, Mulugu, and Narsampet and Parkal mandals. Average numbers of rainy days are 45.6 in a year. South-West monsoon contributes the rainfall to this district although it spreads uneven in both temporally and regionally. During the period from June to September, mostly around 810mm of rainfall is recorded in the district. The rainfall of 94mm is recorded during months of October and November. The remaining rainfall of 87mm occurs during the other months.

It is noticed that about 80 per cent of the annual rainfall occurs during South-West monsoon period and 10 per cent during the North-East monsoon period. The relative humidity is highest in the months of August and September and is lowest in the month of May.

Data:

54 years (1961-62 to 2014-15) of monthly rainfall data season wise for all mandals of Warangal district

- Table showing basic statistics of six rain gauge stations

Jangaon				
	Annual	South West monsoon	North East monsoon	Non-monsoon
Mean (mm)	807.30	593.65	134.45	79.26
Maximum (mm)	1381.00	978.70	390.70	298.40
Minimum(mm)	468.50	275.50	0.00	0.00
Standard Deviation (mm)	206.91	170.04	97.36	57.60
Coefficient of Variation	0.26	0.29	0.72	0.73
Skewness Coefficient	0.63	0.53	0.74	1.41
Kurtosis	-0.02	-0.08	-0.12	2.88
Trimmed Mean (mm)	799.50	588.00	129.20	74.68
Hanamkonda				
Mean (mm)	940.42	743.71	125.35	71.36
Maximum (mm)	1472.50	1189.40	381.40	234.20
Minimum(mm)	494.20	344.40	0.00	0.00
Standard Deviation (mm)	234.50	213.47	91.98	56.83
Coefficient of Variation	0.25	0.29	0.73	0.80
Skewness Coefficient	0.32	0.24	0.66	0.76
Kurtosis	-0.64	-0.51	-0.14	0.05
Trimmed Mean (mm)	935.80	739.80	120.20	139.70
Mahabubabad				
Mean (mm)	1049.15	835.04	127.70	593.65
Maximum (mm)	1798.90	1438.00	331.00	978.70
Minimum(mm)	553.50	318.70	0.00	275.50
Standard Deviation (mm)	292.66	260.86	92.82	170.04
Coefficient of Variation	0.28	0.31	0.73	0.29
Skewness Coefficient	0.40	0.18	0.58	0.53

Kurtosis	-0.67	-0.67	-0.63	-0.08
Trimmed Mean (mm)	1039.90	831.50	123.60	77.80
Narsampet				
Mean (mm)	1098.46	901.68	117.32	79.46
Maximum (mm)	1685.40	1486.50	415.30	285.40
Minimum(mm)	525.80	391.50	0.00	0.00
Standard Deviation (mm)	276.47	267.08	87.29	61.64
Coefficient of Variation	0.25	0.30	0.74	0.78
Skewness Coefficient	0.09	0.18	1.31	0.95
Kurtosis	-0.52	-0.87	2.05	1.27
Trimmed Mean (mm)	1094.10	896.40	109.60	74.90
Parkal				
Mean (mm)	1048.80	867.82	116.10	64.89
Maximum (mm)	1701.20	1434.60	440.80	175.00
Minimum(mm)	591.40	457.00	0.00	0.00
Standard Deviation (mm)	272.03	253.29	93.43	43.17
Coefficient of Variation	0.26	0.29	0.80	0.67
Skewness Coefficient	0.56	0.43	1.39	0.64
Kurtosis	-0.31	-0.66	2.16	-0.13
Trimmed Mean (mm)	1036.70	859.80	107.70	62.70
Mulugu				
Mean (mm)	1166.67	977.29	114.60	74.78
Maximum (mm)	1828.20	1581.90	468.00	280.60
Minimum(mm)	621.70	489.50	0.00	0.00
Standard Deviation (mm)	278.44	261.07	92.22	59.22
Coefficient of Variation	0.24	0.27	0.80	0.79
Skewness Coefficient	0.32	0.31	1.53	1.14
Kurtosis	-0.34	-0.44	3.26	1.65
Trimmed Mean (mm)	1159.50	971.40	105.90	70.12

In addition to these basic statistics, Index of dispersion or variance to mean ratio (VMR) is calculated. The values of VMR are all greater than 1 which indicates that the data is over dispersed. VMR is a good measure of randomness of a given phenomenon. Trimmed mean, which is calculated by removing the outliers, is robust and highly efficient in finding location parameters. Since, required percentage of highest and lowest values of data are excluded, the trimmed mean has an advantage of being relatively resistant to outliers. Here, 5%trimmed mean is calculated. i.e., 5% of the lowest and 5% of the highest values are excluded and the mean is determined from the remaining observations. The mean located between 1st and 3rd quartiles of a distribution, i.e., 25% trimmed mean is also called as inter quartile mean.Mann Kendall's test and Sen's slope estimator methods are used to study the trends of rainfall.

Trends whose probability (p) is less than 0.05 is taken as significant, and whose value is greater than 0.05 is taken as insignificant trends.There is a significant trend of 0.81mm/year for Non monsoon period at Jangaon station. At 10% significance level, rainfall at Mahabubabad has a significant trend of -0.90mm/year and Parkal has an increasing trend of 0.60mm/year. At all remaining stations trends are insignificant and significance value is greater than 0.1. There is a decreasing trend in Annual, South West, and North East rainfall in Hanamkonda and increasing trend in Non monsoon period. Increasing trend is detected at Mahabubabad station in both Monsoon and Non monsoon seasons. Decrease in trend in North East monsoon was detected at Jangaon, Narsampet and Mulugu stations.

	Jangaon		**Hanamkonda**		**Mahabubabad**		**Narsampet**		**Parkal**		**Mulugu**	
	Kendall's	Sen's	Kendall's	Sen's	Kendall's	Sen's	Kendall's	Sen's	Kendall's	Sen's	Kendall's	Sen's
Annual	1.17	2.00	-0.12	-0.32	1.66	4.18	0.33	1.02	-0.33	-0.88	1.06	3.15
South West	0.48	0.51	-0.28	-0.84	1.04	2.22	0.06	0.17	0.16	0.52	1.49	3.84
North East	-0.40	-0.29	-0.01	-0.02	0.11	0.10	-0.37	-0.31	-1.46	-1.09	-0.90	-0.57
Non monsoon	2.07	0.81	1.52	1.16	1.86	0.90	0.93	0.43	1.77	0.60	0.71	0.30

Percentage of Rainfall received:

Stations	Annual (mm)	S-W monsoon (mm)	% of rainfall received	N-E monsoon (mm)	% of rainfall received	Non monsoon (mm)	% of rainfall Received
Hanamkonda	940.42	743.71	79.08	125.35	13.33	71.36	7.59
Jangaon	807.30	593.65	73.54	134.45	16.65	79.26	9.82
Mahabubabad	1049.15	835.04	79.59	127.70	12.17	86.41	8.24
Narsampet	1098.46	901.68	82.09	117.32	10.68	79.46	7.23
Parkal	1048.80	867.82	82.74	116.10	11.07	64.89	6.19
Mulugu	1166.67	977.29	83.77	114.60	9.82	74.78	6.41

The preliminary analysis of the available data shows that rainfall varies from a low average value of 793.5mm at Jangaon in western part of the district to an average maximum value of 1166.7mm at Mulugu in the northern part of the district. Standard deviation varies from 43.17mm to 292.66mm respectively. Skewness coefficient varies between 0.09 and 1.53, indicating that annual rainfall during the period is asymmetric and lies to right of mean over all the stations. The value of kurtosisvaries from -0.87 to 3.26.The value at all stations are less than 3 except at Mulugu where it is 3.26.This indicates that, at Mulugu there are more outliers than the normal distribution, while at other stations outliers are less outliers than normal distribution.. Coefficient of variation is high in non monsoon period and is found to be varying from 24% to 80%. There is a decreasing trend in two stations in western part i.e., Parkal and Hanamkonda in annual rainfall.

From Sen's analysis it was observed that there is a maximum increase of rainfall trend at Jangaon by 2mm/year and maximum decrease of rainfall is -0.88mm/year. For South West monsoon, Mulugu has maximum increase in trend with 3.84mm/year and maximum decrease at Hanamkonda with -0.84mm/year. For North East, there is an increasing trend at Mahabubabad with 0.10mm/year and maximum decreasing trend occurred at Parkal with -1.09mm/year. For nonmonsoon season, there is anincreasing trend at every station. Slopes of Sen's and Mann Kendall's are similar and in same direction. There is a decreasing trend in annual rainfall at Hanamkonda and Parkal stations, and in South West monsoon of Hanamkonda station, in North East at all stations except Mahabubabad. These results can help in analysis of water availability and in effective utilisation. Only nonmonsoon in Jangaon is having significant trend of 0.81mm/year. Remaining all has insignificant trends. At all stations, major part of annual rainfall is received during South West monsoon period. For example, 82.75% of rainfall is received in South West monsoon, 1.54% in winter and 4.64% in Hot Weather. It shows that the rainfall is not evenly distributed. Therefore, large storage is to be created to meet demands of water. It was observed from Probability curves that, there is a flat variation of rainfall in nonmonsoonseason. This represents zero skewness, and sharp variation at South West and Annual rainfall, which shows positive skewness.