Stream Flow Trends and its Association to El Nino Southern Oscillation (ENSO) in the Tons River Basin

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Outline

- Purpose
- Methods
- Study area
- Results
- Conclusions

PURPOSE

- Test for significant changes over time in historical stream flow data
- Quantify the magnitude of changes
- Quantification of El Niño Southern Oscillation (ENSO) impact on Stream flow

Method

Autocorrelation test-to test the serial correlation in data

Mann–Kendall test (Mann (1945) & Kendall (1975) and
Modified Mann–Kendall test- to identify significant trends

Theil–Sen (Theil, 1950 and Sen, 1968)-to magnitude of slope

1) TECHNIQUES for TREND detection

Non-parametric tests

Time series: $x_1, x_2, \ldots, x_n$

H_0: no trend vs H_1: trend

AUTOCORRELATION Test

$$r_k = \frac{\sum_{t=1}^{n-k}(x_t - \bar{x}_t)(x_{t+k} - \bar{x}_{t+k})}{\left[\sum_{t=1}^{n-k}(x_t - \bar{x}_t)^2 \times \sum_{t=1}^{n-k}(x_{t+k} - \bar{x}_{t+k})^2\right]^{1/2}}$$

Student t-test with n-2 DF (Cunderlik & Burn,2004):

$$t = |r_1|\sqrt{\frac{n-2}{1-r_1^2}}$$

Data is significant correlated At 5% SL $t > t_{\alpha/2}$

Thei and Sen's Slope estimator Test

$$\beta = \text{Median}\left(\frac{x_j - x_i}{j-1}\right)$$ for all i < j

A positive value of β indicates an upward (increasing) trend

A negative value of β indicates an downward (decreasing) trend

1) TECHNIQUES for TREND detection

Non-parametric tests

Time series: $x_1, x_2, \ldots, x_n$

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MANN-KENDALL Test

If $n \geq 8$ and H_0 holds, the statistic

$S \sim N(E(S), Var(S))$

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i)$$

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} 1 \ldots\ldots if\ (x_j - x_i) > 0 \\ 0 \ldots\ldots if\ (x_j - x_i) = 0 \\ -1 \ldots\ldots if\ (x_j - x_i) < 0 \end{cases}$$

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{n_t} t_i (t_i - 1)(2t_i + 5) \right]$$

The test statistic $Z_{MK} \sim N(0,1)$

$$Z_{MK} = \frac{S+m}{\sqrt{V(S)}}$$

Trend is significant if: $|Z_{MK}| > Z_{1-\alpha/2}$

MODIFIED MANN-KENDALL Test

Variance correction factor

$$\frac{n}{n_S^*} = 1 + \frac{2}{n(n-1)(n-2)} \times \sum_{k=1}^{n-1} (n-k)(n-k-1)(n-k-2) r_k$$

To account only for significance autocorrelation number of lag can be 3 (Rao et al., 2003)

$$V^*(S) = V(S) \times \frac{n}{n_S^*}$$

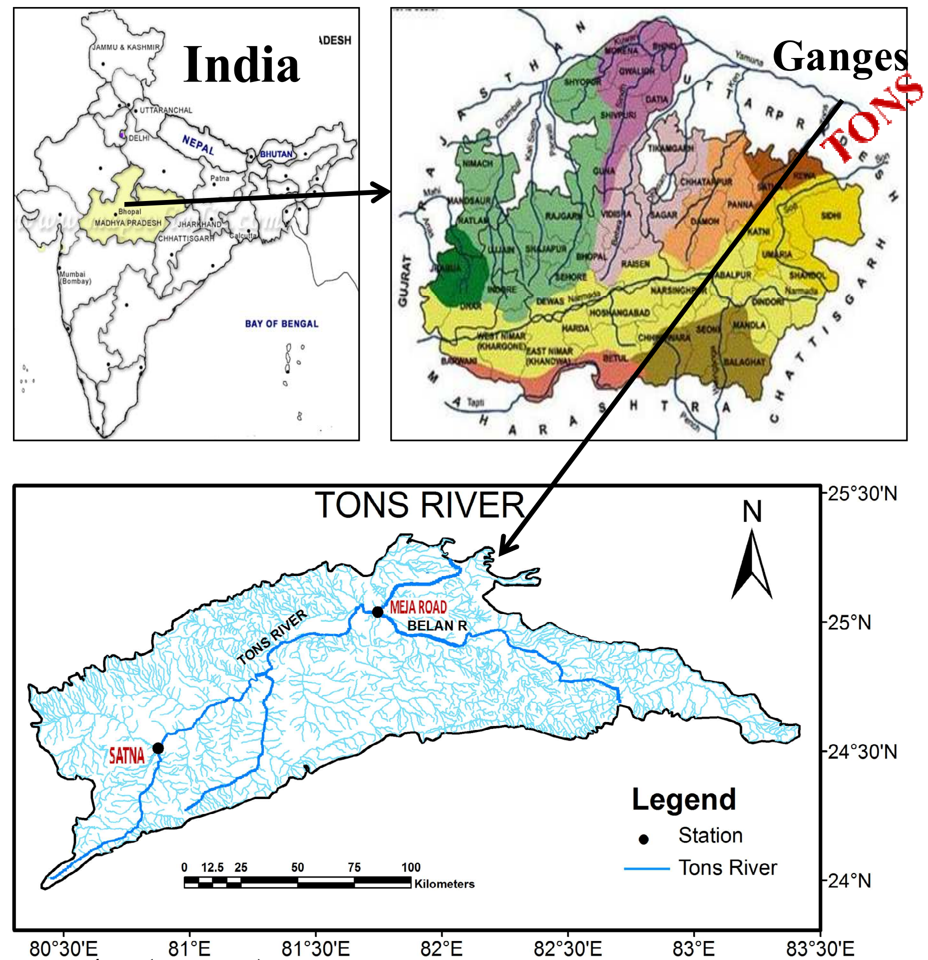
Tons River Basin

Latitude: 80^{0} 21'E to 83^{0} 25'E

Longitude: 23^{0} 57'N to 25^{0} 20'N

Total Area: 18159 sq.km

Temperature: daily maximum temperature goes upto 46°C (May-June), daily minimum temperature goes upto 5°C (January)



Wind speed: 0.43 m/s(November) to 1.29 m/s (June)

Mean relative humidity: 29 %(April)-81% (August)

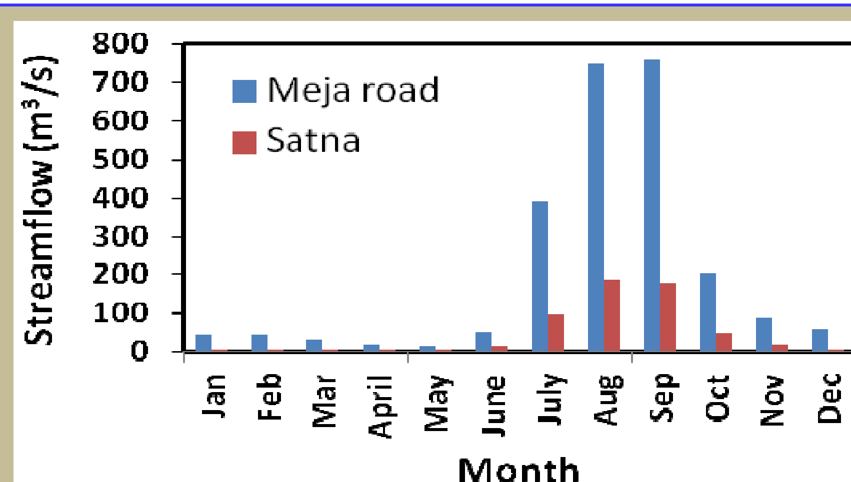
Annual rainfall : 1037 -1160 mm/year

DATA

Mean monthly flow (m^3/s)

Meja road: 1979-2008

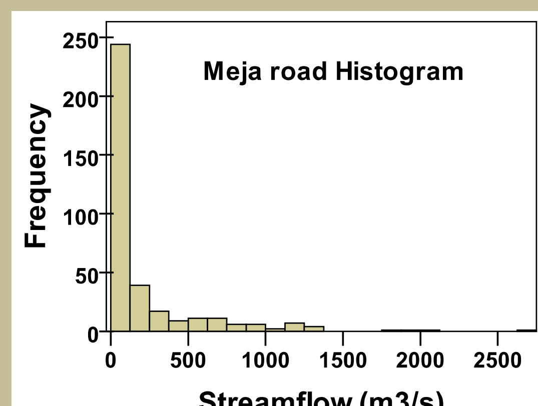
Satna:1977-2006

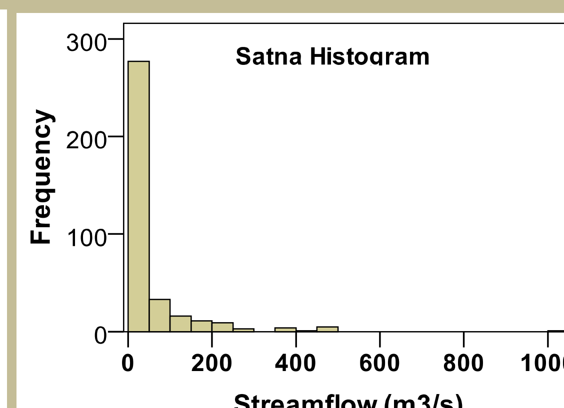


Variation in monthly mean stream flow

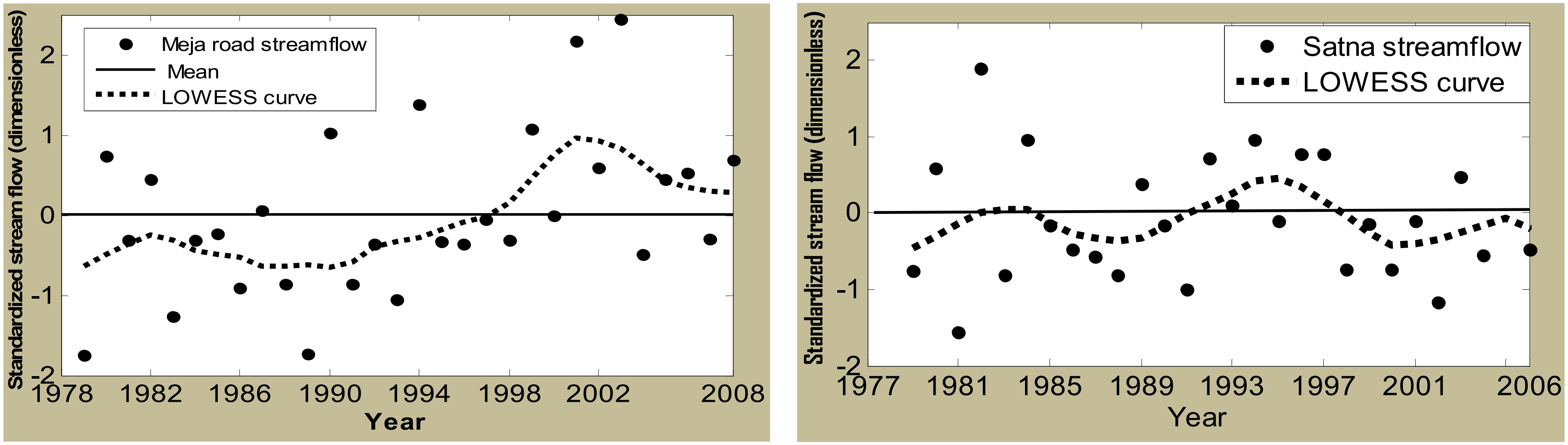
Normality test

Station name	Kolmogorov-Smirnov (K-S) test		
	Statistic	df	Sig.
Meja road	0.284	360	0.000
Satna	0.321	360	0.000

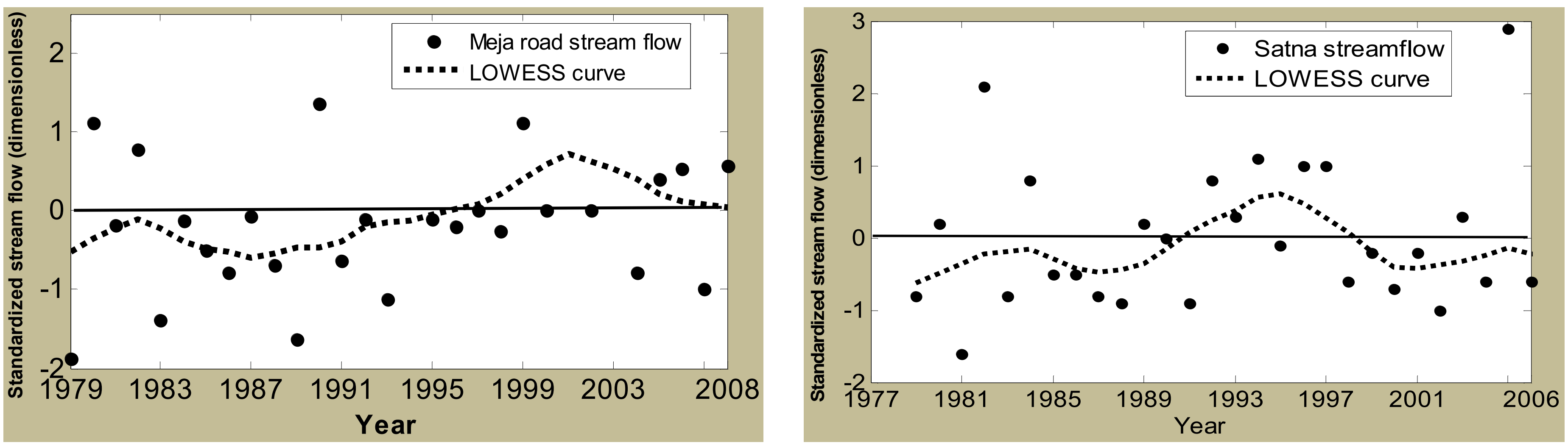




Histogram plot of monthly mean stream flow



Variation in annual stream flow



Variation in monsoon stream flow

Station name	Season	r_1	$t_{calculated}$	t_{table}	Serially Correlated
Meja road	Annual	-0.103	0.549	2.048	
	Winter	0.769	6.381	2.048	✓
	Pre-monsoon	0.324	1.814	2.048	
	Monsoon	-0.339	1.907	2.048	
	Post-monsoon	0.238	1.297	2.048	
Satna	Annual	-0.424	2.478	2.048	✓
	Winter	0.418	2.439	2.048	✓
	Pre-monsoon	0.268	1.472	2.048	
	Monsoon	-0.351	1.983	2.048	
	Post-monsoon	-0.145	0.774	2.048	

Table 1 Result Mann Kendall test statisc(Z)and Sen Slope estimator (β)

Station name	Meja Road		Satna	
Test statistic	Z	β	Z	β
Annual	**1.77**	57.28	0.29	2.94
Winter	**3.33**	15.93	**-2.78**	-1.49
Pre-monsoon	**3.29**	7.33	**-3.16**	-0.64
Monsoon	1.2	60.32	0.48	6.07
Post-monsoon	**2.57**	23.13	-0.05	-0.04

Station name	Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Meja Road	(Z)	**3.67**	**3.13**	**3.37**	**2.96**	**2.45**	1.13	0.37	0.65	0.50	1.39	**2.72**	**2.75**
	β	4.99	4.50	3.74	1.73	0.99	1.41	3.81	11.03	-1.64	11.33	7.60	5.92
Satna	Z	**-3.48**	**-2.48**	**-2.87**	**-3.07**	**-3.30**	-0.09	0.30	-0.30	0.27	0.05	-0.98	**-2.86**
	β	-0.41	-0.30	-0.24	-0.16	-0.19	-0.03	0.66	-1.18	1.58	0.07	-0.84	-0.59

Bold value indicate statistically significant at 1% SL.

Positive indicate increasing trend, Negative indicate decreasing trend

El Niño Southern Oscillation (ENSO)

El Niño is an ocean-atmosphere phenomenon where the cooler eastern pacific warms up once every 2–7 years.

The increase in eastern pacific Sea Surface Temperature (SST) is attributed to the weakening of the easterly trade winds that result in warm water from the western pacific moving to the east.

The ENSO phenomena consist of two oceanic phases—the warm El Nino phase and the cold La Nina phase—that are connected to the atmosphere through a sea-saw atmospheric pressure fluctuation in the South Pacific called the Southern Oscillation (SO).

Monthly Sea surface temperature (SST) anomaly from the Niño 3.4 region (120°W–170°W, 5°S–5°N), for the period January 1979 to December 2008, are obtained from the website of the National Weather Service, Climate Prediction Centre of National Oceanic and Atmospheric Administration (NOAA) (http://www.cpc.noaa.gov/data/indices/).

An average deviation of ±0.5 °C from historical mean of SST, for three consecutive months, indicates an ENSO event (NOAA, 2009).

A positive anomaly indicates El **Niño** and a negative anomaly indicates La **Niña**.

- For ENSO phase assignment, monthly values of ENSO are used and averaged over different season (Winter, Pre-monsoon, monsoon and post monsoon) to get ENSO information from 1979 to 2008.

- The entire period of 32 years (1977 to 2008) are classified as El Niño, La Niña or Neutral (Table 1).

Table 1 Number of years, by seasons, in each El Niño Southern Oscillation (ENSO) phase.

ENSO Phase	Annual	Winter	Pre-monsoon	Monsoon	Post-monsoon
El Nino	7	9	7	6	10
La Nina	8	12	5	10	10
Neutral	17	11	20	16	12

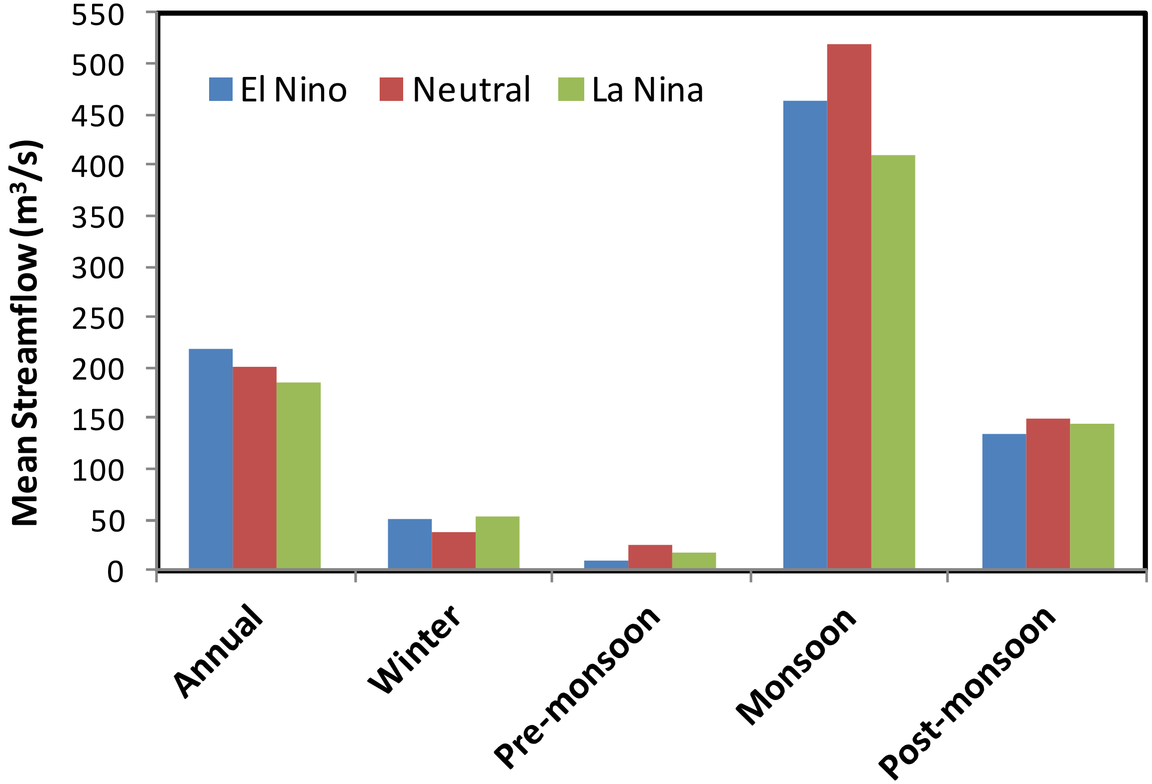
Relationship between ENSO and Stream Flow

To find the impact of ENSO on streamflow three method are used:

1. Cumulative frequency distributions (CDF)

2. Correlation Analysis

3. *Composite Analysis*



Mean streamflow for annual, winter, pre-monsoon, monsoon and post-monsoon during different El Nino Southern oscillation phases.

Cumulative distribution function (CDF)

- The **CDF** is a function that gives the probability that a random variable is less than or equal to the independent variable of the function.

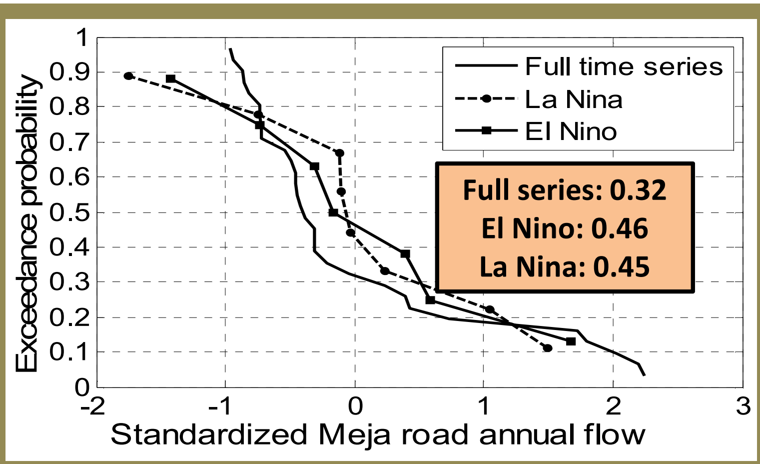
- To calculate the CDF, the stream flow is first standardized by deducting the mean value and dividing by the standard deviation.

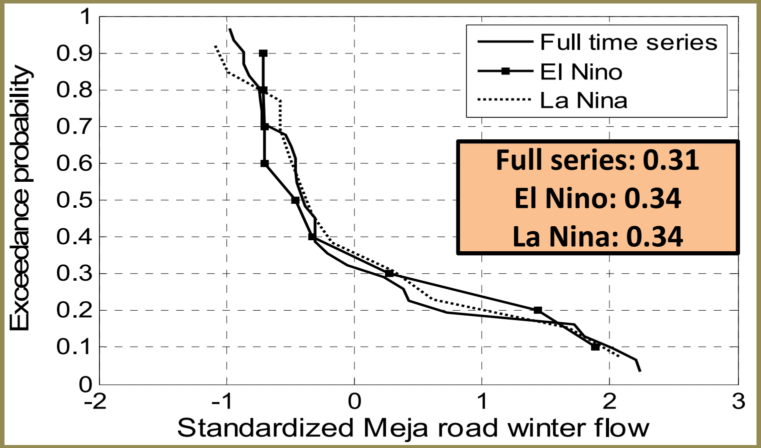
- Then the standardized data is arranged in descending order and rank m is assigned to it. For the first entry, m=1; for second entry m=2 and so on, till the last value for which m=n.

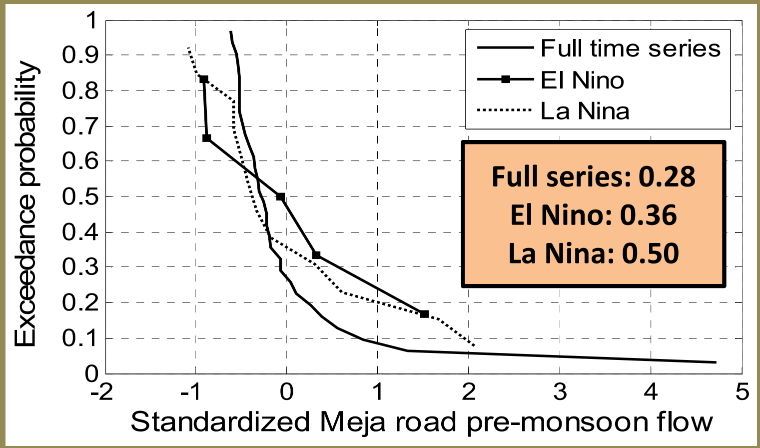
- Then, exceedance probability are obtained by the Weibull's formula F = m / (n + 1) where m is the m^{th} value in order of magnitude of the series and n is the number of data in the series.

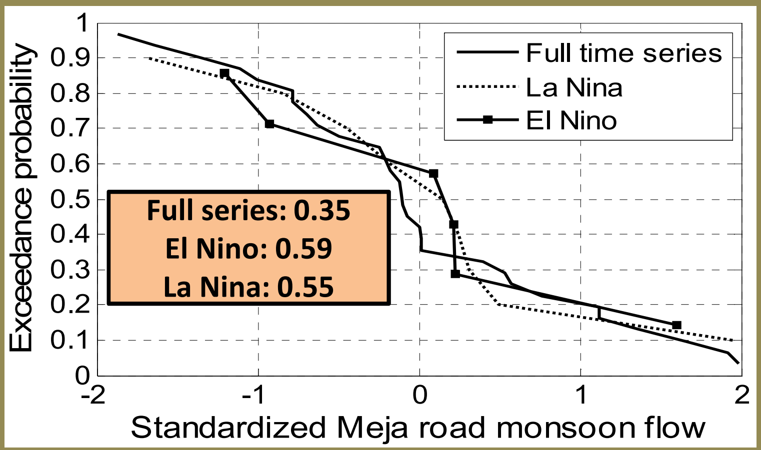
- Cumulative distribution function is plotted with cumulative probabilities on the vertical axis and data values on the horizontal axis.

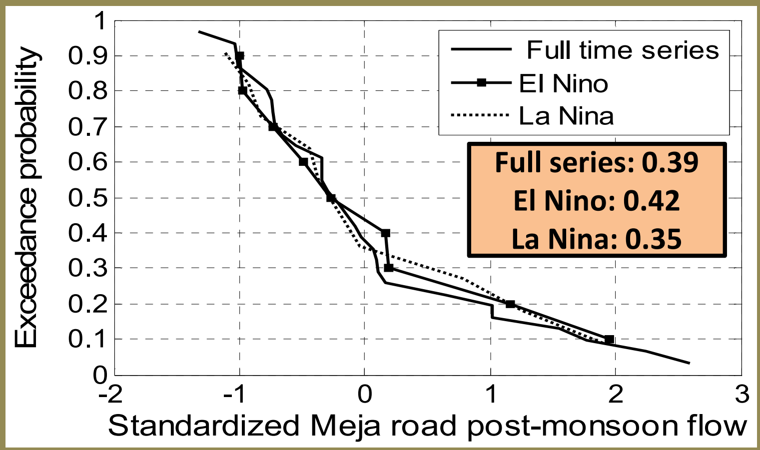
The cumulative frequency distributions of standardized river flow for full time series, El Nino and La Nino during all the season are shown in Figure below.











Correlation Analysis

The Pearson correlation coefficient (r) measures linear association. The null hypothesis—H^0, no correlation—was tested at a 95% level of significance for all the seasons using SAS.

Kendall's correlation (τ*A), which is a distribution-free rank correlation, was also calculated for the dataset. It does not require the variables to be normally distributed and is more efficient with high power (Kendall 1975).*

Table. Pearson's (r) and Kendall's (τ) correlation analyses results between ENSO and streamflow

Station name	Annual		Winter		Pre-monsoon		Monsoon		Post-monsoon	
	r	τ	r	τ	r	τ	r	τ	r	τ
Meja road	0.07	0.02	0.04	-0.04	-0.18*	-0.15*	0.14*	0.16*	0.04	0.02

* Indicates significant correlation

Negative correlation means lower streamflow during El Niño and higher streamflow during La Niña.

Positive correlation during monsoon, which means higher streamflow during El Niño and lower streamflow during La Niña.

Composite Analysis

Composite Analysis is a sampling technique based on the conditional probability of a certain event, such as El Niño or La Niña, occurring.

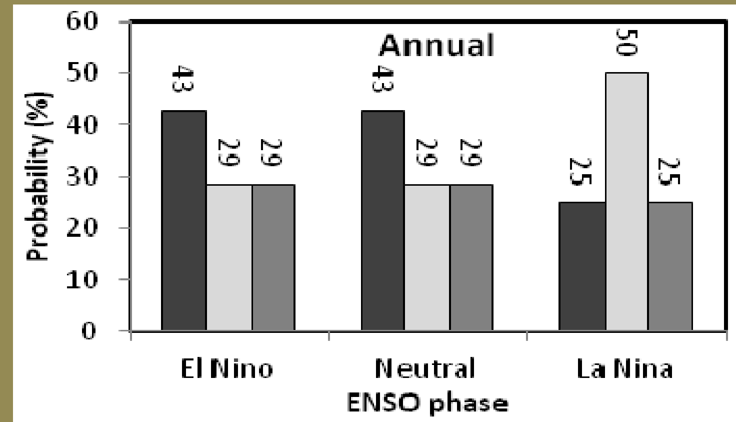
This analysis was performed on the dataset to find the conditional probability of El Niño, La Niña, and Neutral streamflow being above, below, or near normal, based on the historic data.

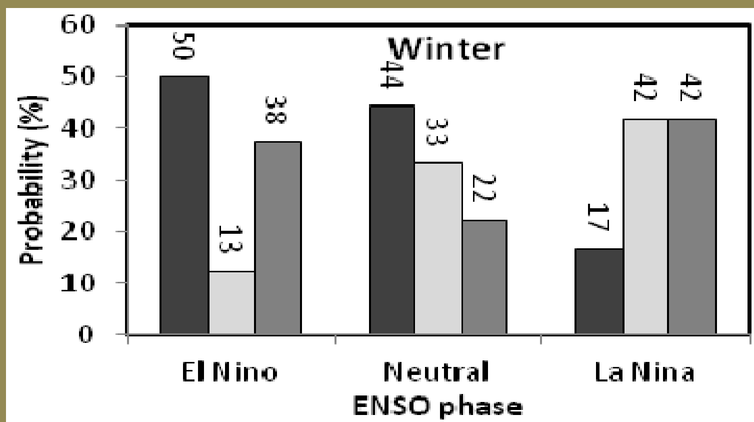
To obtain the cut points between, above, near, and below normal streamflow categories, Terciles vlaue is used.

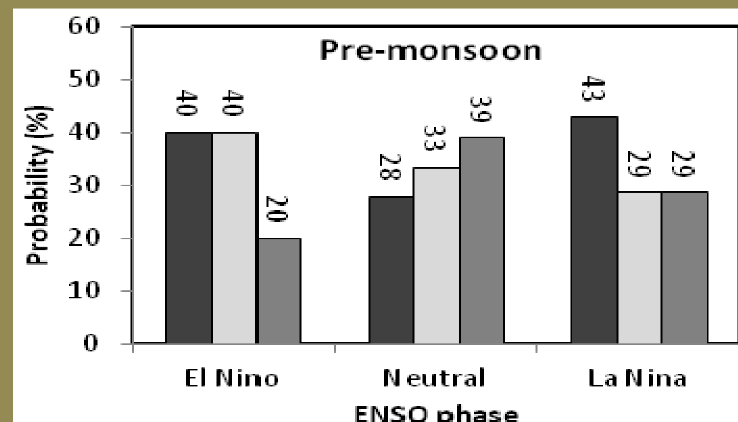
These tercile values were then compared with the streamflow values for each season to find whether the streamflow were above, near, or below normal.

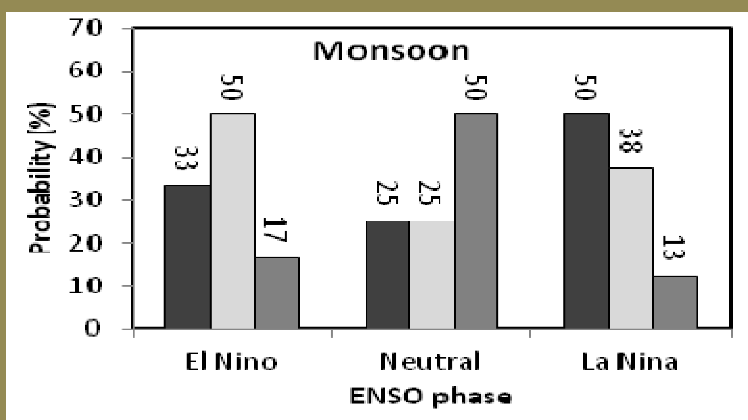
The number of each above, near, or below normal streamflow values were counted for each El Niño, Neutral, and La Niña event, and then the probability of occurrence was calculated.

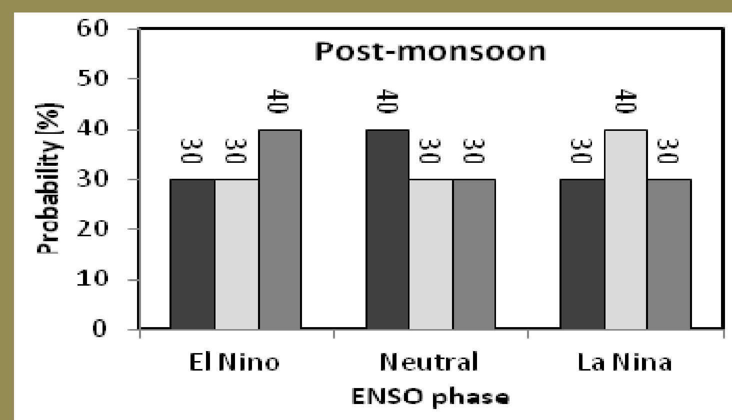
Figures. Conditional probabilities of streamflow during the three ENSO phases for all seasons as obtained by composite Analysis.











CONCLUSIONS

- ✓ At Meja road station, significant increasing trend in annual, winter, pre-monsoon and post monsoon.
- ✓ At Satna station, only winter and pre-monsoon seasons shows the significant decreasing trend.
- ✓ The annual discharge increase is 57 cumec/year at Meja road station and 2.9 cumec/year at Satna station.
- ✓ Around 70% months show the significant increase at Meja road station and significant decrease at Satna station.
- ✓ The increase in streamflow varied from 0.77 cumec/year (at May) to 7.99 cumec/year (in November) at Meja road station.
- ✓ The decrease in streamflow varied from 0.16 cumec/year (in April) to 0.59 cumec/year (in December) at Satna station

- ✓ El Nino streamflows were higher than neutral and La Nino during annual whereas in pre-monsoon, monsoon and post-monsoon season, neutral streamflow were higher than El Nina and La Nino.

- ✓ Significant negative correlation was found between ENSO and streamflow in pre-monsoon season and positive correlation in monsoon season.

- ✓ The probability of exceedance is high during El Nino and La Nina year than all the years during all the seasons which show the clear influence on ENSO event on the streamflow during all the seasons.

THANKS