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Impact of Rainfall Trend on Irrigated Agriculture of Narayanapura Command in a Semi-Arid Region of South India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Water demands have been exacerbated by the uncertainty in rainfall occurrences and distribution due to various factors in a changing climate and growing population. The irrigation sector has the highest water demand, accounting for 85 percent of total water use in Karnataka. Rainfall plays a critical part in meeting irrigation needs. To effectively allocate and manage water resources for command area management, examining rainfall patterns, distribution of rainfall trends, both regional and temporal variations is necessary. Hence, the primary focus of this research is to investigate the impact of rainfall trends on agricultural water requirements for a typical study area in semi-arid region.

To assess the rainfall trend, time-series statistical trend tests called Mann–Kendall (MK) test and the Innovative Trend Analysis (ITA) approach are used to examine the spatio-temporal distributions of long-term rainfall patterns for the Narayanapura command region. The results are then geo-processed to examine the spatial distribution of trends using the isohyetal concept. The findings illustrate the spatial distribution of rainfall trend for the command in a semi-arid region on a monthly, monsoon, and annual basis.

Spatio-temporal analyses from both methodologies indicates the trend in rainfall pattern is decreasing annually and in monsoon months, with a rising trend for pre-monsoon showers. The trend variation pattern also reveals periodic oscillation alignment in the direction of south-west monsoon movement. According to MK test results, monsoon rainfall is anticipated to decrease by

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12 percent by 2047, and by 21 percent from ITA results. Further, impact analysis indicates that, for every unit millimeter of rainfall deficit, there would be a 62 Ha-m increase in irrigation water demand.

Keywords: *Climate change impact on effective rainfall; crop water requirements; gross irrigation requirements; MK test; ITA method; rainfall trend.*

1. INTRODUCTION

In India, 38% of the country's geographical area falls under semi-arid regions and 16% of the area is arid [1]. In these semi-arid regions, the major source of rainfall is from south-west monsoons. Precipitation plays a significant role in irrigation management, particularly in the arid and semi-arid regions. Globally, 70 percent of all freshwater withdrawals is used for agriculture [2]. In India, the estimated average water potential is 1,869 BCM (including from snowfall contributions) and 85% of it is used for agriculture purposes [3]. The total irrigation potential of India is 139.86 MHa from all sources out of which 48.8% is under irrigation and 51.2 percent is rainfed [4]. The productivity per unit of irrigated land is double than that of rainfed agriculture. Rainfall is the major source of water for agriculture, both directly on planted fields as incident effective rainfall and indirectly through surface and groundwater irrigation sources.

Irrigation supplies are decided based on dependable rainfall patterns. Long-term rainfall records are used to calculate effective rainfall based on the likelihood of occurrence, and irrigation water conveyance and distribution systems are then designed to supply the crop's water shortfall. Because rainfall varies from year to year under climate change scenarios, long-term rainfall data must be updated to reflect current changes in rainfall behavior, and extreme rainfall conditions must be forecasted and factored into irrigation structure designs. Such approaches in agriculture play a critical role in increasing resilience to climate change. In recent years, several studies have been conducted to determine possible climate trends and changes around the globe, analyzing changes in temperature and rainfall [5]. The major impact of climate change is the change in rainfall patterns. Changes in rainfall due to global warming will have an impact on water demand especially in agriculture, which requires a review of hydrologic design and management practices [6].

Various statistical tests are used to determine trends in hydrological and hydrometeorological time series; these are classified as parametric and nonparametric tests [7]. The parametric test has great potential but requires independent data and is normally distributed, which is rarely true with the details of a hydrological time series. In non-parametric tests, data should be independent and outliers are more tolerable to these tests [8]. The Mann-Kendall (MK) trend test [9-10] is one of the most widely used non-parametric tests to find significant trends in the time series. The MK trend test is not affected by the actual distribution of data and is not very sensitive to outliers [11]. However, the MK trend technique utilizes certain mandatory assumptions [12] and has limitations in detecting non-monotonic trends [13]. In such cases, Innovative Trend Analysis (ITA) method is found to be more suitable in detecting sensitive data trends [12,14].

Innovative Trend Analysis is a method of working based on timeline from a data series assigned in the cartesian coordinate system to perform trend analysis. The ITA method overcomes any issues if present in MK and Spearman's rho (SR) tests for a given set of data [15]. ITA analyzes time series data based on sub-samples from the same time series without assumptions [16]. Potential trends in monthly and seasonal rainfall patterns are investigated by ITA, which allows for the detection of a low, medium, and high-value series [17]. In certain cases, the trend of rainfall variability is analyzed using ITA by comparing its output with the MK and Sen's slope test [14,18-19]. Further, season-wise geographical distribution of trend patterns can be assessed and visualized using GIS tools for proper management to climate variations [14,20-21].

Under the influence of climate change, regional strategies are essential in planning sustainable water resource management. Climate change has a direct impact on crop output and irrigation water supply due to changing rainfall patterns over time and space. Trend tests are used to study the rainfall patterns under changing climate and crop water requirements are computed for the forecasted conditions in order to examine the impact of rainfall availability on irrigation water demand [22-26]. However, spatial variability of rainfall trend over time from MK Test and ITA method needs to be explored to assess the impact of long-term variations in effective rainfall at command area level. Hence, this research is carried out with main emphasis on assessing the impact of changing rainfall patterns on irrigation water demand. To achieve the major focus of the research, this study was performed with the following specific objective stages: (i) to analyze the temporal trend of monsoon and annual rainfall time series data using the MK and ITA method; (ii) to compare the results of the MK method with the ITA; and (iii) to assess the impact of rainfall pattern on irrigation water demands.

2. STUDY AREA AND DATA

The focus of this study is on the command area of Narayanapura Left Bank Canal (NLBC). The command under NLBC extends from Longitude 76° 28' 58.3" E to 76° 35' 40" E and Latitude 16° 30' 49.6" N to 16° 33' 11.3" N (refer Fig. 1). The study area lies in the north Karnataka region of India characterized by semi-arid climate. The data collected for this study consists of daily rainfall data from raingauges in and around the study area (refer Table 1) and cropping pattern from project sources. The evapotranspiration and crop co-efficients values are from India Meteorological Department (IMD) for agroclimatic zone 2 (refer Table 2).

Long-term daily rainfall data of seven rain gauge stations in and around the command area is collected for a period of 58 years from 1960-2017. The daily data is transformed to monthly rainfall data since the analysis is carried out on monthly basis. The monsoon and annual rainfall provide an insight to the rainfall characteristics of the semi-arid study region. The locations of raingauges and attributes are as given in Table 1. The cultivable command area (CCA) is 47,223 hectares. The principal crops grown in this command are paddy, cotton, pulses and sorghum. The cropping pattern is primarily paddy occupying 46.8% of CCA followed by cotton with 28.5%, pulses by 14.1% and sorghum by 10.6%.

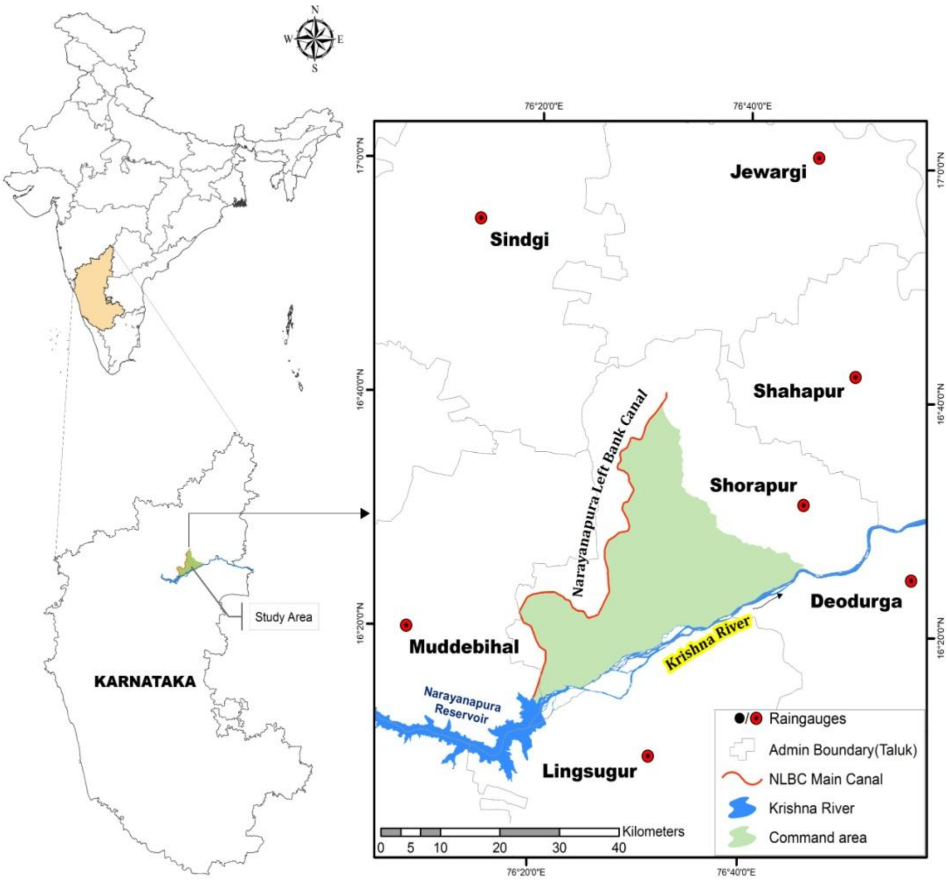


Fig. 1. Study area map with influencing rain gauges

Table 1, Raingauge locations for the study area

Sl. No.	Stations	Latitude	Longitude	Monsoon RF in mm		Annual RF in mm	
				Mean	SD	Mean	SD
1	Deodurga	16° 24 ' 53"	76° 56 ' 04"	514.92	171.90	732.51	242.42
2	Jewargi	17° 00 ' 51"	76° 46 ' 27"	563.06	221.40	779.46	280.27
3	Lingsugur	16° 09 ' 22"	76° 31 ' 21"	389.66	131.71	604.03	184.25
4	Muddebihal	16° 19 ' 57"	76° 08 ' 02"	378.11	133.88	594.51	173.88
5	Shahapur	16° 42 ' 10"	76° 50 ' 22"	594.62	240.73	841.05	281.82
6	Shorapur	16° 31 ' 07"	76° 45 ' 39"	503.16	217.68	716.54	291.35
7	Sindgi	16° 54 ' 58"	76° 14 ' 13"	452.40	146.57	637.39	188.74

3. METHODOLOGY

Statistical trend analysis for long-term Rainfall data along with spatiotemporal distribution mapping in the GIS platform is attempted in this study for the identified study area. This is further attributed to the impact of Irrigation water requirements in the command area.

In this study the sensitive trends in rainfall pattern are compared between two statistical methods. The trend analysis of the rainfall is carried out for monsoon season and crop base period months using two statistical methods i.e., the Mann-Kendall Trend Test and Innovative Trend Analysis method. The sensitive trends in rainfall patterns are compared using two statistical methods in this study. In many instances, the MK test limits itself to detect sensitive trends, in which case the ITA approach is a viable alternative [13,27]. The trends in rainfall pattern are assessed with appropriate confidence limits and used to compute the impact on irrigation water demand. The flowchart of the processes involved in this study is indicated in Fig. 2.

3.1 Mann-Kendall Test

The Mann-Kendall Trend Test is a non-parametric test popularly used for detecting increasing or decreasing trends in time series data. Assessment of the monotonic trends (i.e., increasing or decreasing) in the time series data is evaluated depend upon the normalized test statistics value called Z. The time series data is assessed for the trend at various significance levels by varying alpha (0.05 is the default).

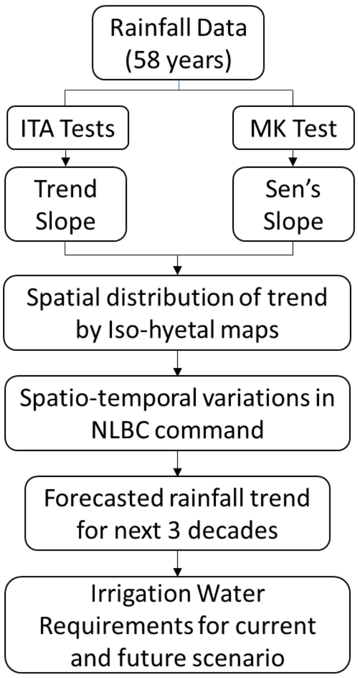


Fig. 2. Flowchart for computation of impact of rainfall trend on Irrigation water requirements

Table 2. Inputs for computing crop water requirements for the command area

Month Fortnight (1)	May I (2)	May II (3)	Jun I (4)	Jun II (5)	Jul I (6)	Jul II (7)	Aug I (8)	Aug II (9)	Sep I (10)	Sep II (11)	Oct I (12)	Oct II (13)	Nov I (14)	Nov II (15)
ETo	113.55	121.12	92.40	92.40	73.35	78.24	71.55	76.32	65.40	65.40	70.65	75.36	64.80	64.80
Khariff crops Kc														
Paddy				1.10	1.10	1.10	1.10	1.05	1.05	1.05	1.05	0.95	0.95	
Jowar				0.35	0.58	1.10	1.10	1.10	0.58	0.58				
Pulses				0.35	0.75	1.10	1.10	0.69	0.28					
Cotton		0.35	0.61	0.61	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	0.89	0.65

∗ As per IMD for Agro climatic zone-2

MK test compares the relative magnitudes of data rather than the data values themselves. In this test, each figure of data in a timeline is matched to all subsequent data figures. Initially, the MK statistics (S) value is to be considered zero, and if the value of data in subsequent periods is higher than the data value in the last period, S is increased by 1, and vice versa. The net outputs of all changes from zero give the final value of S.

The Mann-Kendall statistics (S) is given in the equation below:

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

Where,

n = Total number of observations;
x_i = Rank for i^{th} observations (i = 1, 2…n − 1);
x_j = Rank for j^{th} observations (j = i + 1, 2…n);

and sign function is computed as:

$$sign(x_j - x_i) = \begin{cases} 1\,; if\ (x_j - x_i) > 0 \\ 0\,; if\ (x_j - x_i) = 0 \\ -1\,; if\ (x_j - x_i) < 0 \end{cases} \quad (2)$$

The test statistic S is assumed for the series where sample size n > 10 is asymptotically normally distributed with mean E(S) and variance Var (S) as:
E(S) = 0, and

$$Var\ (S) = \frac{n\ (n-1)(2n+5)}{18} \quad (3)$$

If there is a possibility of a tie in the value of x, the variance is computed as:

$$Var(S) = \frac{n\ (n-1)(2n+5) - \sum_{i=1}^{P} t_i\ (t_i - 1)(2t_i + 5)}{18} \quad (4)$$

Where,

P = Number of tied groups indicates the summation over all tied groups;

and

t_i = Number of data values in the i^{th} tied group (i = 1,2,3...n).

After the calculation of Var (S) of time series data, the standardized Z_{MK} value is calculated using the equation:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}; if\ S > 0 \\ 0; if\ S = 0 \\ \frac{S-1}{\sqrt{Var(S)}}; S < 0 \end{cases} \quad (5)$$

The standardized MK test statistic (Z_{MK}) follows the standard normal distribution (Z) with mean zero (μ = 0) and variance one (σ^2 = 1). For the two-sided condition, the H_0 (null hypothesis) is that which represents no trend in the time series data and H_1 (alternative hypothesis) is that there is a trend in time series data. H_0 and H_1 are tested at a level of significance, α = 5% with Z=±1.96. If $\pm Z_{MK} > Z_\alpha = \pm 1.96$, then H_0 is rejected and H_1 is accepted. A negative value indicates a negative trend similarly, a positive value indicates a positive trend in time series data. If the significance level is raised, appropriate Z values are taken into account.

3.2 Innovative Trend Analysis Method

The concept of ITA was first proposed by Sen [11] which was later applied by many researchers [16-21]. The analysis is initially carried out by visual interpretation from drawing the graphs. In this method, time-series data is divided into two halves (first half and second half) from the first to the last time. Then these series of two halves are sorted in ascending order. The first half series (y_i: i=1, 2, 3, …n/2) is put on the horizontal axis (i.e., X-axis) and the last half series (y_j; j=n/2+1, n/2+2, … n) is put on the vertical axis (Y-axis) as shown in Fig. 3. The scale and range of both axes are kept equal to form a square graph diagram and this square is split into two equal triangles by drawing a 1:1 (45^0) line from the origin point of the graph.

A scatter plot of arranged time series data is plotted, the trend in the rainfall pattern is detected based on the position of the data clusters. If the points fall in the upper half of the triangle, then it indicates an increasing trend and if the points fall below the dividing line in the lower triangle, then the rainfall pattern has a decreasing trend. There is no trend in time series data if the points nearly fall on the 1:1 dividing line. The precise distribution of scatter points near or on the 1:1 line indicates weaker trends or no trends. Further [28] the ITA concept is extended to find the trend analysis at different significance levels (1%, 2%, and 10%) to a better understanding of trends in time series data.

The trend slope is computed using the following expression [28]:

$$s = \frac{2\,(\overline{y_2} - \overline{y_1})}{n} \quad (6)$$

Where,

s = Trend line slope;
$\overline{y_2}$ and $\overline{y_1}$ = Arithmetic averages of the second and first halves time-series data (y, sequence) respectively; and
n = Total number year for which data considered.

Fig. 4 is the graphical representation for understanding the concept of trend slope. After the calculation of the slope of the trend line, the standard deviation of sampling slope is calculated as:

$$\sigma_s = \frac{2\sqrt{2}}{n\sqrt{n}}\sigma\sqrt{1 - \rho_{\overline{y}1\overline{y}2}} \quad (7)$$

Where,

σ_S = Standard deviation of sampling slope;
σ = Standard deviation of whole data series; and
$\rho_{\overline{y}1\overline{y}2}$= Cross-correlation coefficient between the ascending sorted two halves arithmetic averages.

The confidence limits (upper and lower) of the trend slope at the significance level (α) are expressed using the following expression:

$$CL_{1-\alpha} = \pm Z \times \sigma_S \quad (8)$$

Where,

$CL_{1\text{-}\alpha}$ = Upper and Lower confidence limits at 'α' significance;
σ_S = Standard deviation of sampling slope.
Z = Z-score

For the two-sided condition, the H_0 (null hypothesis) is that which represents no trend in the time series data and H_1 (alternative hypothesis) is that there is a trend in time series data. H_0 and H_1 are tested at a level of significance, α = 5% with Z=±1.96. If ±S >±$CL_{1-\alpha}$, then H_0 is rejected and H_1 is accepted. A negative value indicates a negative trend similarly, a positive value indicates a positive trend in time series data [23].

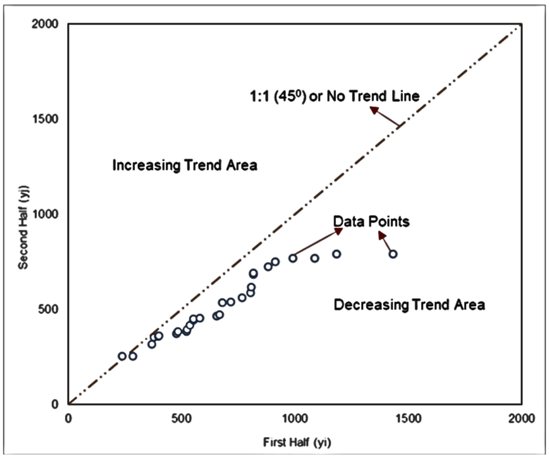


Fig. 3. Trend in time-series data by a visual interpretation by ITA method

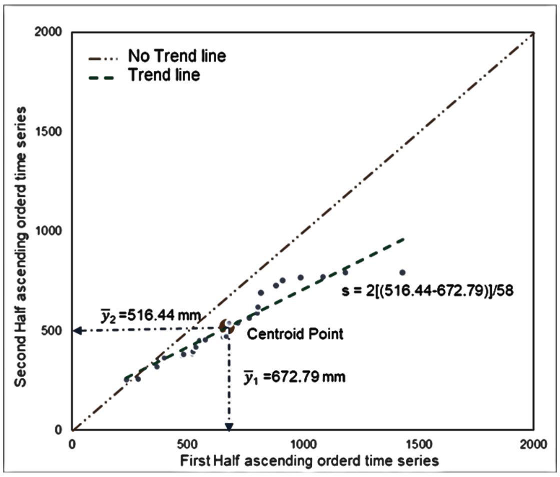


Fig. 4. Slope analysis by the ITA method

3.3 Crop Water Requirements

Crop water requirements is calculated for the crops in NLBC command and Gross irrigation requirements for the project command is computed using the following standard equations as per Food and Agriculture Organization [29-30].

$$ET_c = ET_o \times K_c \quad (9)$$

$$NIR = ET_c - P \quad (10)$$

$$GIR = \frac{NIR}{e} \quad (11)$$

$$e = \frac{e_c \times e_a}{100} \quad (12)$$

Where,

ET_c = Crop Evapotranspiration (mm),

ET_o = Reference Evapotranspiration (mm),
K_c = Crop Coefficient
NIR = Net Irrigation Requirement (mm)
P = Effective Rainfall (mm)
GIR = Gross Irrigation Requirement (mm)
e = Scheme irrigation efficiency (%)
e_c = conveyance efficiency (%)
e_a = field application efficiency (%)

4. ANALYSIS AND RESULTS

To carry out the trend analysis, 58 years (1960-2017) of daily rainfall data is considered for 7 rain gauges in and around the study command area. The average rainfall over 58 years indicates that the months January, February, March, April, November, and December has scanty rainfall (refer Fig. 5). Moreover, the kharif crop base period in the command is from May to November. Hence, the analysis and results are focused particularly on the months of monsoon with a buffer month of pre-monsoon showers and post-monsoon which has considerable rainfall. The annual average rainfall is 664.1 mm and the monsoon average rainfall is 450.5 mm. The temporal trend analysis of 7 rainfall stations for monsoon and annual rainfall is found using Mann Kendall and Innovative Trend Analysis methods at various significance levels.

4.1 MK Test Analysis

The MK Test trend for time series rainfall data is evaluated for the Pre-monsoon shower month of May; Monsoon months June, July, August, September, and onset post-monsoon month October, as well as overall monsoon period trends is indicated in Table 3. From the isohyetal plots, the average slope over the NLBC command is calculated using raster analysis. The average Sen's slope of NLBC command for different months is as shown in Fig. 6.

The average Sen's slope in the command for monsoon season is in decreasing trend at a rate of -1.86 mm/year and Annual rainfall is decreasing at a rate of -2.06 mm/year. The months January to April, November, and December have little or no rainfall and the trend is insignificant (refer Fig. 6). The pre-monsoon showers month of May has an increasing trend and the monsoon months June to September have a decreasing trend of rainfall pattern (refer Fig. 6). It's also worth noting that the Sen's slopes are inconsequential in the majority of trends with significance levels ranging from 5% to 20%. The analysis of monthly rainfall trend indicates that only few months provide rainfall trend with required confidence limit (5% to 20%) as indicated with corresponding superscript letters "$*^{A, B, C}$ *and* ^{D}" (refer Table 3). This shows that although MK Test provides the negative trend in rainfall series (months of June, July, August and September), the trend may be monotonic or non-monotonic. Hence, more resilient test is required to detect the sensitive trend in the rainfall pattern with a greater confidence level, which is carried out by the ITA method, in order to validate the trend of the MK test.

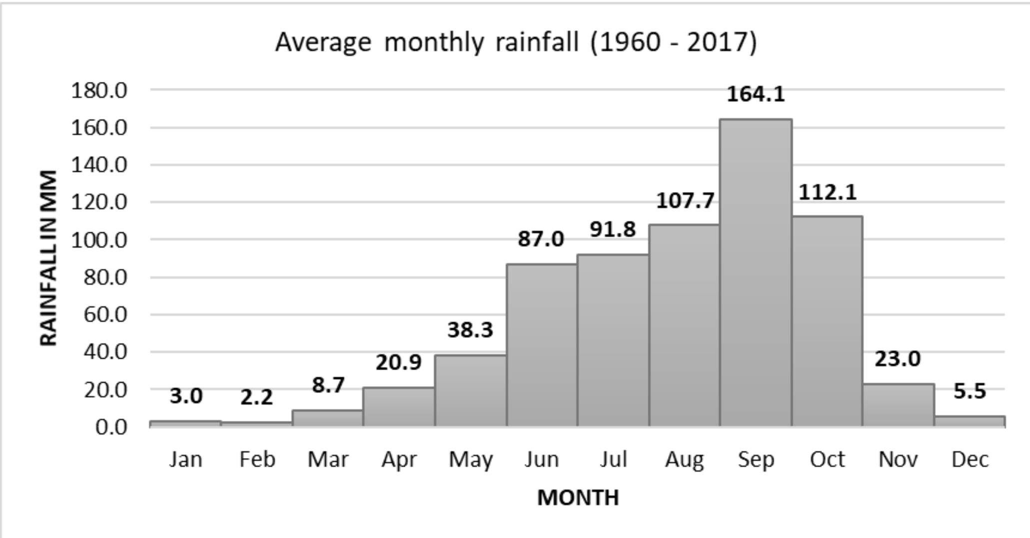


Fig. 5. Average monthly rainfall from 1960 to 2017 for NLBC command

Table 3. Sen-slope of rainfall pattern using MK-test for 58 years (1960-2017)

Sl.No.	Rain gauge	May	Jun	Jul	Aug	Sep	Oct	Nov	Monsoon
1	Deodurga	0.38^{A}	-0.12	-0.22	-0.16	-0.02	0.27	0.00	-0.85
2	Jewargi	0.26^{C}	-0.47	-0.84^{D}	-0.49	-0.36	0.05	0.00	-3.00^{B}
3	Lingsugur	0.06	0.12	-0.76^{A}	0.21	-0.89	0.00	0.00	-1.30
4	Muddebihal	-0.03	0.26	-0.47^{D}	-0.06	-0.15	-0.21	0.00	-0.58
5	Shahapur	0.11	-0.62	-0.81	-0.10	-0.95	0.21	0.00	-2.88^{B}
6	Shorapur	0.42^{A}	-0.73^{B}	-0.47	-0.69	-1.32^{C}	0.14	0.00	-3.08^{B}
7	Sindgi	0.00	-0.02	-0.25	0.92^{B}	-0.65	0.01	0.00	-0.06

^{*A} α = 5%; $Z_\alpha = \pm1.96$; ^{*B} α = 10%; $Z_\alpha = \pm1.645$; ^{*C} α = 15%: $Z_\alpha = \pm1.44$; ^{*D} α = 20%: $Z_\alpha = \pm1.282$

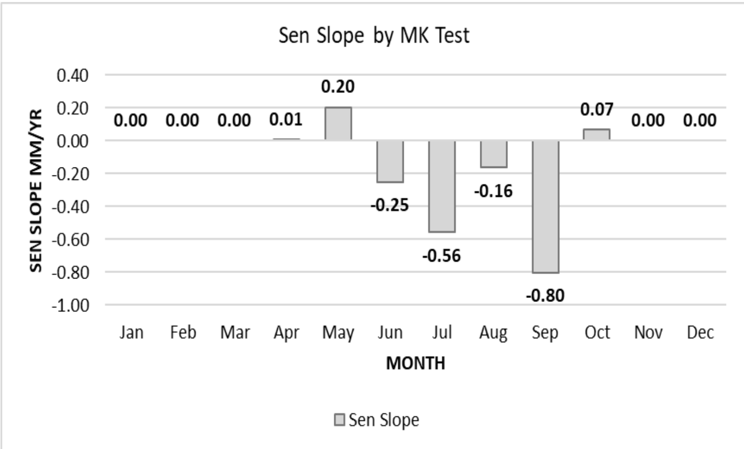


Fig. 6. Monthly average Sen's slope (trend) for NLBC command

4.1.1 Spatial distribution and pattern of rainfall trend by MK Test

The trend results from MK test of raingauges are mapped in the GIS platform using the isohyetal concept to know the distribution and behavior of rainfall trends over the command. Using the trend slope obtained from MK Test (refer Table 2), Inverse distance weighted (IDW) interpolation technique is used in ArcGIS environment to generate isohyetal rasters of trends (refer Fig. 7).

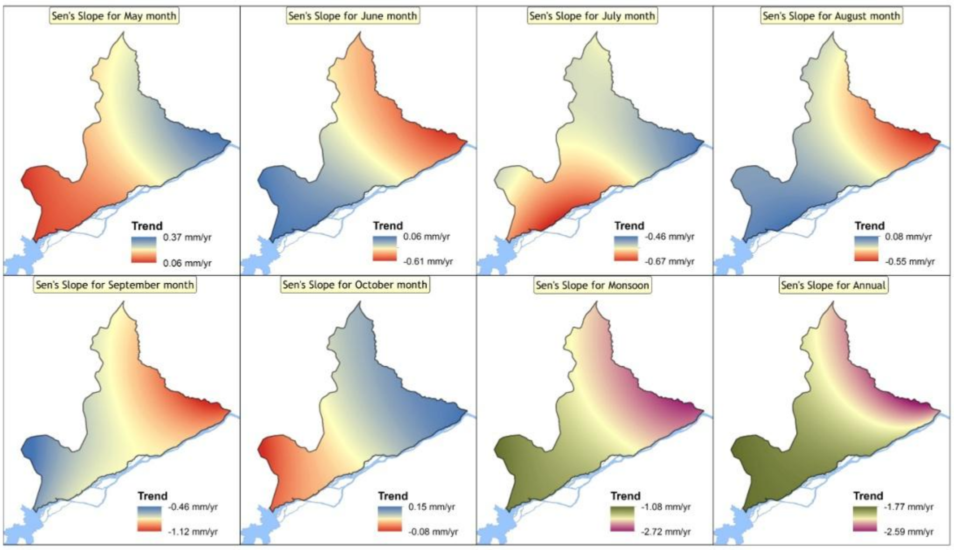


Fig. 7. Spatio – Temporal distribution of trend in rainfall pattern over NLBC command by MK test

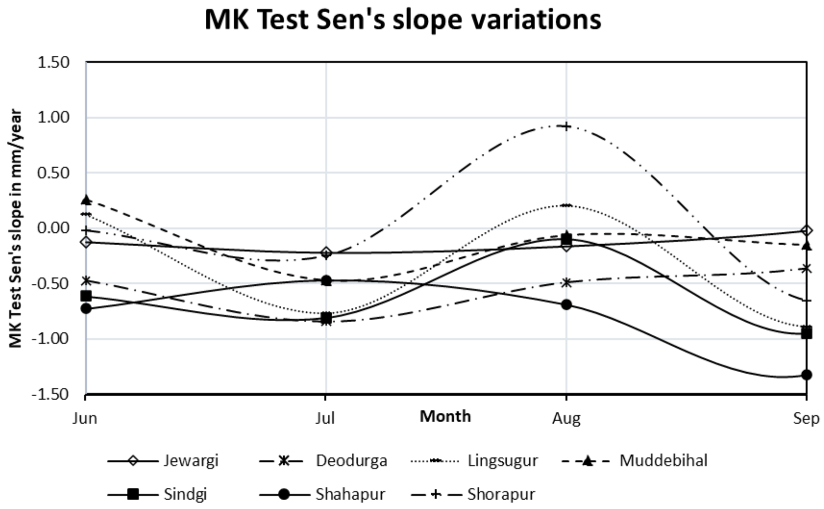


Fig. 8. Sen's Slope variations of raingauges for monsoon months

It can be observed from the analysis maps (refer Fig. 7 and Fig. 8), a low intensity increasing trend can be seen in the south-west corner in May. In June the same sector of the command has a high intensity declining trend. Further, the south-west sector experiences low-intensity trend in July and increases to a high-intensity trend in August and September. It is observed from the spatial distribution of Sen's slope that the intensity of trend alternatively varies monthly in the direction of south-west to north-east in to and fro pattern. In Fig. 7, the blue/green color scale indicates a low-intensity trend and red/purple color indicates a high-intensity trend. This behavior is occurring exactly in the same alignment as the general path of the south-western monsoon passing through this region. Hence, it is found that the intensity with which the rainfall pattern increases or decreases is occurring within the flow direction of the south-western monsoon.

4.2 Innovative Trend Analysis (ITA) Method

The primary task in ITA method is to assess the trend in rainfall pattern by plotting scatter graphs for the sorted time series data. The time-series data was divided into two halves first half from the year 1960 to 1989 and the second half for the years 1990 to 2017. This is sorted as per the ITA method and plotted on a scatter graph. The position of clusters is examined for the trend in rainfall pattern. The test is initially carried out with visual interpretation and further slope of the trend is found using applicable equations (refer eq. 6-8).

4.2.1 Visual interpretation of trend in Rainfall pattern for different rain gauges.

Trend analysis is carried out for all 7 Raingauges by the ITA method by visual interpretation from the rainfall pattern plots as shown in Fig; 9. A trendline is generated for each raingauge data plot to interpret the trend of rainfall pattern. The trendline of individual raingauges in the graph (refer Fig. 9) depict visual results of increasing or decreasing trend as per ITA methodology (refer Fig. 4).

It can be observed that the trendlines of rainfall in the month of May is located above the 'no trend line' and all subsequent months having trendlines located below the 'no trend line'. This demonstrates that the rainfall pattern for the time series data in the monsoon months up to November has a negative trend in most of the rain gauges. It is also noteworthy that the trend in rainfall pattern for the pre-monsoon month of May has a positive trend. Further, the inclination of the trendline provides an understanding of intensity of trend. This is determined from the value of slope calculation results (refer Table 4) and its spatial distributions from GIS techniques.

Table 4 shows that in most rain gauges, the rainfall trend is significant with a 95 percent confidence limit, and in a few cases, it is significant with a 90 percent confidence limit (Shahpur rain gauge in May). In May, June, and October, just a few rain gauges show no pattern. This demonstrates that the ITA approach is more effective in detecting subtle changes in rainfall patterns.

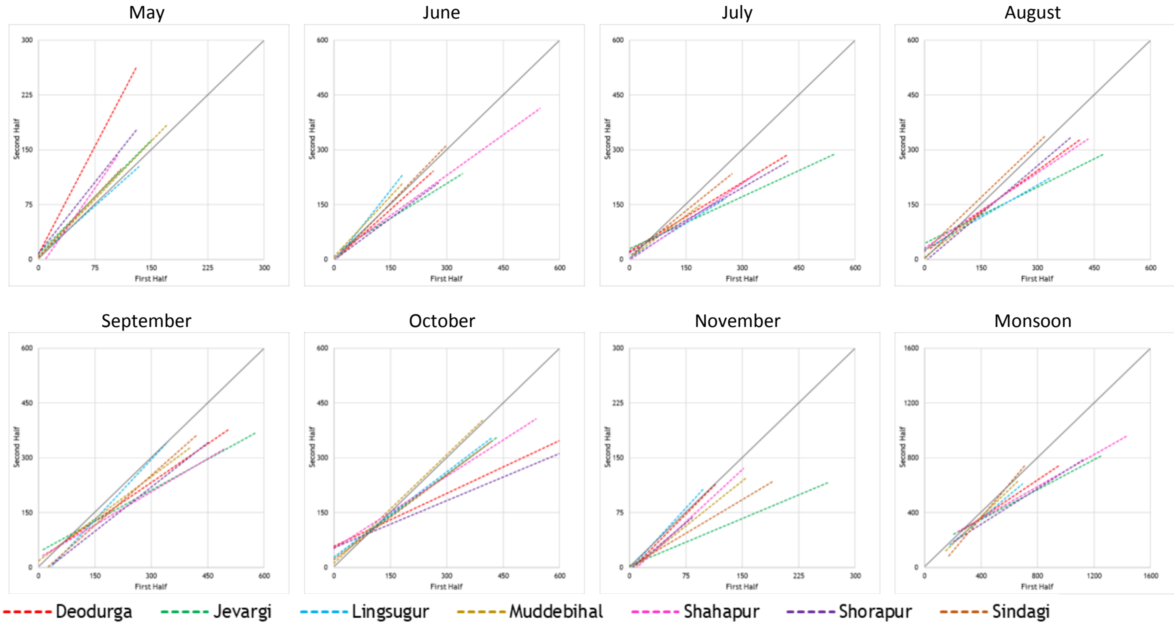
4.2.2 Slope by ITA method

The slope computed from the ITA method is indicated in Table 4. From the spatial distribution plots, the average slope of rainfall pattern by ITA method is calculated for NLBC command and results are tabulated in Fig; 10.

The average slope for NLBC by the ITA method shows a decreasing trend at a rate of 3.19 mm/year in the monsoon season and 3.32 mm/year for the annual rainfall pattern. The Pre-monsoon shower month of May has an increasing trend and the monsoon months June to September has a decreasing trend of rainfall. The post-monsoon months also shows a decreasing trend (refer Fig. 10).

4.2.3 Spatial distribution and pattern of Rainfall Trend by ITA method

To find the spatial variations in the pattern of trend the slope obtained from the ITA method, the results are plotted in GIS by the Isohyetal method (refer Fig. 11). From Fig. 10 and Fig. 11 it is observed that there is a decreasing trend of rainfall over the command in the South-west to northeast direction. However, as observed earlier in the case of MK test Sen's slope distribution pattern, the rain gauges in the ITA method also exhibit an alternative sinusoidal pattern in the intensity of the trend in the rainfall pattern (Fig. 12). The intensity of trend or the slope value varies between high and low alternatively during the monsoon months.



x-axis and y-axis are in mm of rainfall.
x-axis is first half of the data timeline 1960 – 1988
y-axis is second half of the data timeline 1989 – 2017

Fig. 9. ITA trendline graphs representation for monthly and monsoon rainfall

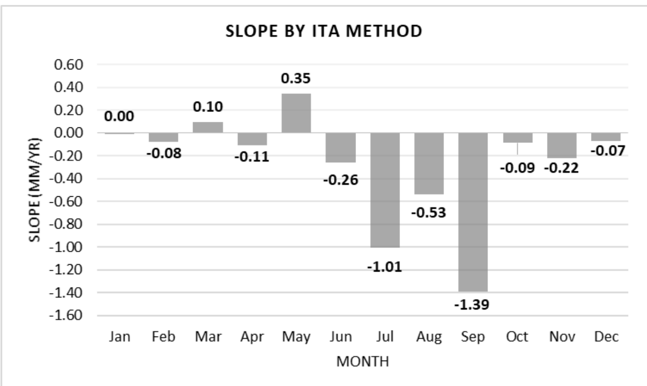


Fig. 10. Average Slope of Rainfall pattern for NLBC command from Isohyetal maps

Table 4. Slope results for 7 rain gauges for monthly and monsoon rainfall by ITA method

Station	May				June				July				August			
	Slope (s)	σ_s	Limits		Slope (s)	σ_s	Limits		Slope (s)	σ_s	Limits		Slope (s)	σ_s	Limits	
Deodurga	0.96	0.038	±	0.07	-0.35	0.073	±	0.14	-0.86	0.077	±	0.15	-0.61	0.099	±	0.19
Jevargi	0.30	0.037	±	0.07	-1.00	0.069	±	0.13	-1.69	0.202	±	0.40	-1.08	0.107	±	0.21
Lingsugur	0.04*C	0.035	±	0.07	0.48	0.074	±	0.15	-0.99	0.050	±	0.10	-0.41	0.069	±	0.13
Muddebihal	0.19	0.035	±	0.07	0.50	0.040	±	0.08	-0.43	0.052	±	0.10	-0.35	0.053	±	0.10
Shahapur	0.19*B	0.101	±	0.17	-0.90	0.094	±	0.18	-1.65	0.074	±	0.15	-0.62	0.064	±	0.13
Shorapur	0.54	0.036	±	0.07	-0.94	0.051	±	0.10	-1.16	0.067	±	0.13	-0.81	0.063	±	0.12
Sindagi	0.23	0.040	±	0.08	0.04*C	0.088	±	0.17	-0.24	0.098	±	0.19	0.71	0.112	±	0.22
Station	**September**				**October**				**November**				**Monsoon**			
	Slope (s)	**σ_s**	**Limits**		**Slope (s)**	**σ_s**	**Limits**		**Slope (s)**	**σ_s**	**Limits**		**Slope (s)**	**σ_s**	**Limits**	
Deodurga	-1.16	0.160	±	0.31	-0.16*C	0.276	±	0.54	-0.14*C	0.104	±	0.20	-2.97	0.199	±	0.39
Jevargi	-1.76	0.136	±	0.27	0.02*C	0.080	±	0.16	-0.07	0.048	±	0.09	-5.52	0.223	±	0.44
Lingsugur	-0.64	0.082	±	0.16	0.11*C	0.141	±	0.28	0.00*C	0.051	±	0.10	-1.56	0.155	±	0.30
Muddebihal	-0.71	0.062	±	0.12	0.36	0.056	±	0.11	-0.35	0.026	±	0.05	-1.00	0.140	±	0.28
Shahapur	-2.22	0.090	±	0.18	0.38	0.166	±	0.33	-0.37	0.112	±	0.22	-5.39	0.339	±	0.66
Shorapur	-2.10	0.157	±	0.31	-0.61	0.248	±	0.49	-0.26	0.082	±	0.16	-5.01	0.270	±	0.53
Sindagi	-1.28	0.064	±	0.13	0.00*C	0.131	±	0.26	-0.30	0.039	±	0.08	-0.78	0.120	±	0.24

Note: confidence limits
*α = 5%; $Z_\alpha = \pm1.96$ (by default for all figures above except *B and *C)*
**B α = 10%; $Z_\alpha = \pm1.645$*
**C no Trend*

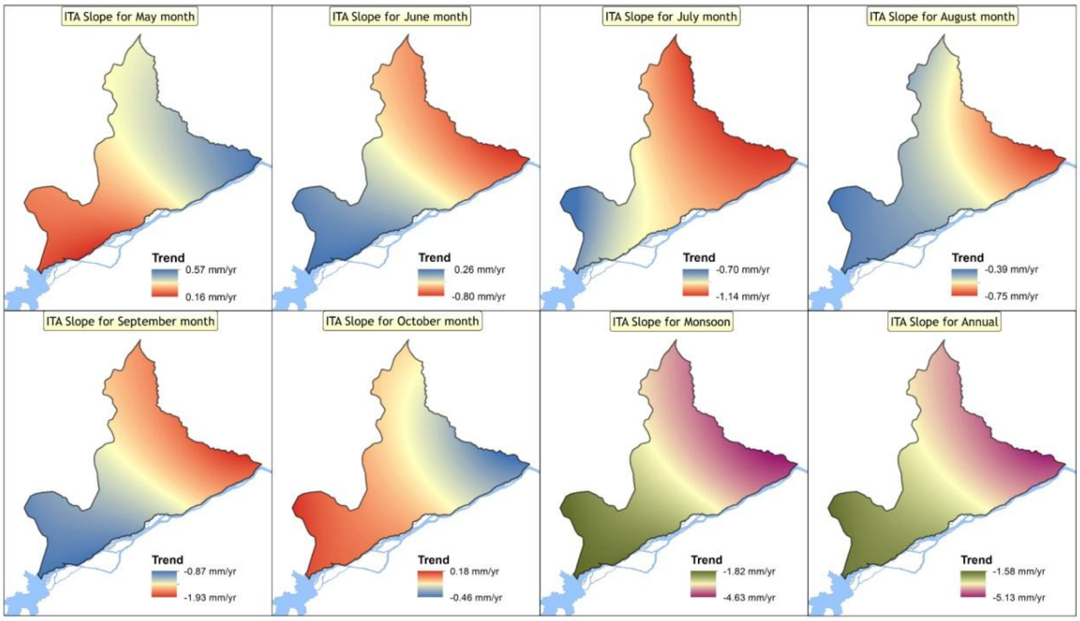


Fig. 11. Spatio – Temporal distribution of trend in rainfall Pattern over NLBC command by ITA method

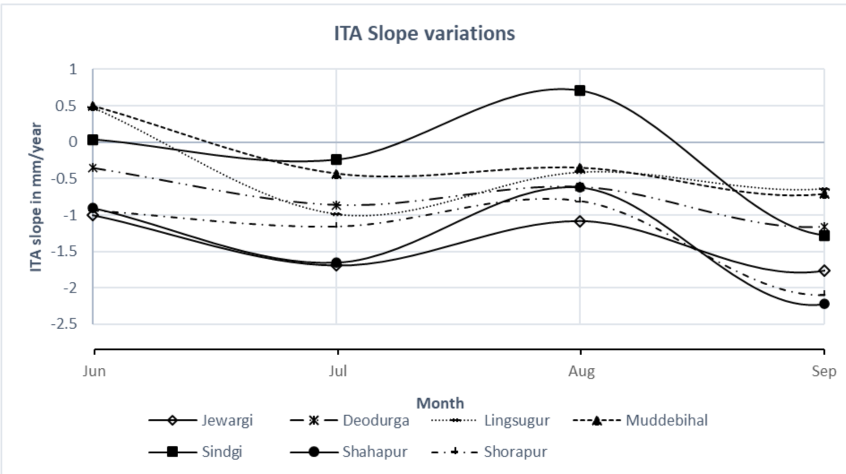


Fig. 12. Slope variations of raingauges for monsoon months by ITA method

4.3 Impact on Irrigation Requirements

The statistical trend analysis shows that the rainfall pattern has a negative trend in the monsoon months and positive trend in the pre-monsoon month of May. The trend is indicated in Fig. 6 and Fig. 10. The average rainfall over the NLBC command is computed using isohyets and effective rainfall is computed using USDA soil conservation service method (reference FAO) as indicated in Table 5. The MK and ITA trend are forecasted for 2047 (3 decades) and effective rainfall for the year 2047 is computed (refer Table 5).

Crop water requirements are computed using standard equations (refer eq. 9-11). Gross Irrigation requirement for the command is computed for existing irrigation system efficiency of 45% (refer eq.12). Conveyance efficiency (e_c) for existing canal-lined conditions is 75% [31] and application efficiency (e_a) of 60% for surface irrigation method [32]. Regionally published evapotranspiration data, crop co-efficient, and practicing crop seasons for Agro-climatic zone-2 is indicated in Table 6.

The crop water requirement is computed for current condition with average rainfall over the command and forecasted trending rainfall as per MK and ITA trends (refer Tables 6 & 7).

The analysis shows that the impact of rainfall trend on Irrigation demand. The consequences of rainfall pattern shifting to a lower average would result in increase in irrigation water requirements. The decreasing monsoon rainfall pattern would require an additional 2738.62 Ha-m of water to satisfy the agricultural needs (refer Table 6). This amounts to 4% increase in water allocation for the command in coming 3-decades. Further, the results show that an additional 4% of discharge has to be accommodated in the canal supplies in 3-decades to supply the additional demand. This is the result of 7% (45 mm) decrease in rainfall during the base period of crops as a common scenario in 3 decades. For unit millimeter of rainfall decrease, nearly 61 Ha-m excess water is expected to increase in gross irrigation requirements.

The decreasing monsoon rainfall pattern would require an additional 5869.11 Ha-m (refer Table 7) of water to satisfy the agricultural needs. This amounts to 9% increase in water allocation for the command in coming 3-decades. Further, the results show that an additional 9% of discharge has to be accommodated in the canal supplies in 3-decades to supply the additional demand. This

Table 5. Effective rainfall for average condition and 3-decadal forecasted condition

Month	Average		MK Test		ITA Test	
	Average Rainfall (mm)	Effective Rainfall (mm)	Rainfall Trend (mm/yr)	Effective Rainfall for 2047 (mm)	Rainfall Trend (mm/yr)	ITA Effective Rainfall for 2047 (mm)
May	38.3	36	0.2	41.2	0.35	41.2
Jun	87	74.9	-0.25	69.4	-0.26	69.4
Jul	91.8	78.3	-0.56	66	-1.01	66
Aug	107.7	89.1	-0.16	86	-0.53	86
Sept	164.1	121	-0.8	108.7	-1.39	108.7
Oct	112.1	92	-0.25	93.3	-0.09	93.3
Nov	23	22.2	0.07	22.2	-0.22	22.2
Total	624	513.5	---	486.8	---	452.6

Table 6. Irrigation demand for the command area using rainfall trend from MK Trend test

Sl. No.	Crop	Cropped Area in Hectares	% Cropped Area	Days	Total water required			
					Average Rainfall Condition		3-decadal Change	
					in Ha-m	in cumecs	in Ha-m	in cumecs
1	**Paddy**	22,086.63	46.8%	153.00	44701.27	33.82	46024.17	34.82
2	**Cotton**	13,463.87	28.5%	199.00	15997.64	9.30	16874.39	9.81
3	**Sorgum**	4,994.67	10.6%	122.00	2925.80	2.78	3195.39	3.03
4	**Pulses**	6,677.84	14.1%	92.00	2945.51	3.71	3214.88	4.04
	Grand total	**47,223.00**	100.0%		**66570.21**	**49.60**	**69,308.83**	**51.71**

Table 7. Irrigation demand for the command area using rainfall trend from ITA test

Sl. No.	Crop	Cropped Area in Hectares	% Cropped Area	Days	Total water required			
					Average Rainfall Condition		3-decadal Change	
					in Ha-m	in cumecs	in Ha-m	in cumecs
1	**Paddy**	22,086.63	46.8%	153.00	44701.27	33.82	47728.48	36.11
2	**Cotton**	13,463.87	28.5%	199.00	15997.64	9.30	17954.62	10.44
3	**Sorgum**	4,994.67	10.6%	122.00	2925.80	2.78	3268.25	3.10
4	**Pulses**	6,677.84	14.1%	92.00	2945.51	3.71	3487.96	4.39
	Grand total	**47,223.00**	100.0%		**66570.21**	**49.60**	**72,439.32**	**54.04**

is the result of 15% (95 mm) decrease in rainfall during the base period of crops as a common scenario in 3 decades. For unit millimeter of rainfall decrease, nearly 62 Ha-m excess water is expected to increase in gross irrigation requirements.

5. DISCUSSIONS

The average rainfall in the command is 450.6 mm in the monsoon season and 664.3 mm annually. Nearly 68% of the average annual rainfall is received in the monsoon season. Such climate is typical to semi-arid zones of India with characteristics of low and erratic rainfall pattern. About 75% of the cropped area 131MHa out of 174 MHa lies in semi-arid regions of the country and highly dependent on rainfall for agricultural needs [33]. Statistical analysis was carried out to assess the possible irregularities in a typical command area of a semi-arid region. Two non-parametric statistical tests, Mann–Kendall test and the Innovative Trend Analysis method were carried out and the results were compared to assess the actual vagaries in rainfall pattern for the command area at a regional scale.

In this study, time series Mann-Kendall trend tests indicated that monsoon rainfall in the command is decreasing at a rate of 1.86 /year. Further tests result show that annual rainfall is decreasing at a rate of 2.06/year. Except for a few months, the MK trend tests do not detect most sensitive trends in the 5 percent, 10%, 15%, or 20% confidence limits. As a result, ITA tests were performed to discover the variations in rainfall patterns that were undetected by the MK test. The ITA results likewise reveal similar results to the MK test, but within 5-10 percent confidence limits. The slope of the rainfall pattern trend by the ITA method also indicates a decreasing trend in monsoon season at a rate of 3.19/year and annually by 3.32/year. On a wider scale, the behavior of decreasing trend in monsoon and annual rainfall for Southwest monsoon areas of India are widely accepted by researchers in their study [34-36] and also indicated in regional publications [37-38].

Monthly statistics from MK Trend test and ITA test show that there is an increasing trend in pre-monsoon showers (May). However, there is a declining trend in rainfall patterns for all the months in the monsoon and post-monsoon months. The increase in rainfall trend for the pre-monsoon season and month of May is also observed in regions of north Karnataka [39-40]. The declining trends in individual monsoon months are also shown in various research papers [34,36,38]. The reduction in the post-monsoon rainfall component has an additional impact on rain-fed agriculture and irrigation supplies. The deficiency of monsoon rain has a direct influence on irrigation supplies; if effective rainfall over command decreases, this must be compensated by supplying additional irrigation water for agriculture.

This study also shows that the variations in the magnitude of rainfall trend exhibit periodic seasonal fluctuations in south-west to north-east directions. A similar trend is also observed on a taluk level in the regional publication, where the taluks having a positive rainfall trend in pre-monsoon has a negative rainfall trend at the end of the monsoon [30]. Both statistical trend tests by MK test and the ITA method provides relatable results for the command area for detecting and assessing the local trend of rainfall pattern over long-term historical data. The behavior of sinusoidal patterns of rainfall trend also indicates the possible paradigm shift in the rainfall pattern not only during monsoon and annually, but also monthly which leads to possible changes in the regions having more rainfall in monsoon months to fall under the drought conditions in the direction of south-west monsoon movement. It can also be estimated that the intensities of rainfall will vary erratically to satisfy the oscillating behavior of the rainfall trend.

The impact of the decreasing rainfall trend on irrigation demand shows that there is a considerable increase in gross irrigation requirement and discharge in canal (refer Tables 6,7). This is validated by results from both MK and ITA tests. The results indicate that by MK trend test the rainfall decreases by 7% in 3 decades and accordingly there is 4% increase in water demand. The 3-decadal rainfall decreases by 15% by ITA results and 9% increase in water requirement by year 2047. However, by both the trend methodologies it is observed that for every unit millimeter decrease in rainfall there is 62 Ha-m of increase in Irrigation water demand.

6. CONCLUSIONS

The following conclusions are drawn from this research which would aid in planning water resources allocation for irrigated agriculture in command areas of semi-arid zones.

1. MK test and ITA test show complimenting results for rainfall trend. However, in case of sensitive trends ITA test results are more reliable in identifying the rainfall trend for long-term data.
2. Spatial analysis using Isohyetal methods for the trend results can indicate the spatial and temporal variations for different months and trend behavior. In this study, a substantial decreasing trend in monsoon month's rainfall can be observed. It is also found that the temporal variations in rainfall trends fluctuate periodically in the direction of the South-west monsoon path in an oscillating pattern.
3. The decreasing monsoon rainfall has considerable impact on irrigation demand in the command area. In a 3-decadal estimate of climate change trend of rainfall, a unit millimeter of rainfall loss is predicted to increase gross irrigation requirements by almost 62 Ha-m. Accordingly, the discharge in the canal has to accommodate additional 2 - 4.5 cumecs of water per 500 sqkm of command.
4. The impact differs depending on the command's cropping pattern and respective crop water requirements. The increase in water demand owing to shifting rainfall patterns is more or less the same for the most commonly grown crops in agroclimatic zone-2. This paper demonstrates the need of taking climate change into account when designing canals to accommodate variations in rainfall patterns over the canal system's lifecycle.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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