Analysis of Non-Stationarity in Hydro-Meteorological Data of Dhadhar River Basin

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***Abstract*—Hydrological estimates like water availability and design flood are required for the design of water resources project like dams, weirs, barrages, bridges, hydro-power, thermal power and nuclear power projects and water supply projects. The estimation of hydrological parameters requires the analysis of spatial data of toposheets, river network etc. and analysis of time oriented data of rainfall, temperature, discharge data etc. The procedure for design flood estimation and water availability estimation are based on the assumption of stationarity i.e. past data is representative of future. In the present study the hydro-meteorological data of Dhadhar river basin have been analysed in detail for the presence of any non-stationarity like changes in mean, presence of short and long term dependence and presence of trend etc. For this purpose observed data of rainfall and temperature at various stations over Dhadhar basin have been analysed and results presented.**

Keywords- Non-stationarity, trend, Dhadhar river basin, Mann Kendell test, rainfall and discharge data

I. INTRODUCTION

Hydrological estimates like water availability and design flood are required for the design of water resources project like dams, weirs, barrages, bridges, hydro-power, thermal power and nuclear power projects and water supply projects. The estimation of hydrological parameters require the analysis of spatial data of toposheets, river cross sections, longitudinal profiles etc. and time oriented data of rainfall, temperature, discharge data etc.

The procedure for design flood estimation and water availability estimation are based on the assumption of stationarity i.e. past data is representative of future. In the present study, the hydro-meteorological data of Dhadhar river basin have been analysed in detail for the presence of any non-stationarity like changes in mean, presence of short and long term dependence and presence of trend etc. For this purpose observed data of rainfall and discharge at various stations in Dhadhar basin have been analysed. The broad objective of the study is to investigate the presence of non-stationarity in the rainfall and discharge data of Dhadhar basin.

II. BRIEF REVIEW

Lye, et. al (1993) studied the “Long-term dependence in annual peak flows of Canadian rivers”. In this paper, 90 Canadian rivers were analyzed for both short and long term dependence and results show that although short-term dependence is partially absent for most of the peak flow series, significant long-term dependence is present for a large number of peak flow series tested.

Ceschia., (1994) in his study “Trend Analysis of Mean Monthly Maximum and Minimum Surface Temperatures of the 1951-1990 Period in Friuli-Venezia Giulia” analyzed the behavior of seasonal and yearly average of the monthly means of maximum and minimum daily surface temperature, covering the period 1951-90, in some stations of the Italian Hydrographic Service spread over the region of Friuli-Venezia Giulia by the Spearman’s test with the aim of determining a possible trend.

Jain et. al (2012) studies pertained to trends in rainfall rainy days and temperature over India whose statistical parameters were assessed by the Mann-Kendall test. Spatial units for trend analysis vary from station data to sub-division to sub-basin or river basins.

Mandal, et. al (2012) mainly concerned with the changing trend of rainfall of a river basin of Orissa near the coastal region which faced adverse effects of flood almost every year. It was an effort to analyze one of the most important climatic variable i.e. precipitation, for analyzing the rainfall trend in the area. Daily rainfall data of 40 years from 1971 to 2010 had been processed in the study to find out the monthly variability of rainfall for which Mann-Kendall (MK) Test. Monthly precipitation trend had been identified to achieve the objective which was shown with 40 years of data. There was a rising trend of precipitation in some months and a decreasing trend in some other months obtained by these statistical tests suggesting overall insignificant changes in the area.

III. STUDY AREA AND DATA AVAILABILITY

Dhadhar river basin lies in the state of Gujarat. This section first gives details of Gujarat state, which is followed by the description of Dhadhar basin.

Gujarat, located in western part of India, has 6% of land, and 5% population of the country. However, Gujarat is blessed with only 2.38% of country's surface water resources. Pattern of surface water available within three different regions of the state is quite skewed from water abundance to totally water scarce regions. The state has only 3 major perennial rivers and all of them are located in its southern region. For all these perennial rivers, Gujarat is a terminal state. An average rainfall of 35 cm to 200 cm with high coefficient of variance underlines state's dependence on dependable irrigation for agriculture. As a result of over extraction, groundwater tables are falling steadily. Droughts have been acute and frequent in recent years. The drought of

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the year 2000 was very severe in the state where a total of about 9,500 villages in 17 out of 25 districts, besides four metropolis and 79 towns were affected and a population of 25 million had been hit. Water in almost all the reservoirs of Saurashtra, Kachchha and North Gujarat had dried up in the summer months creating severe problem of drinking water supply for human and for cattle consumption. All this underscores the pressing need for harnessing and importing fresh water in drought prone regions to provide a permanent solution.

IV. DHADHAR RIVER BASIN

Dhadhar River is one of the west flowing rivers of Gujarat State and its catchment has been selected for the present study. The catchment area of Dhadhar river is is 3788.84 km^2 and lies between east longitude 72^{o}30' and 73°45' and north latitude 21°45' and 22°45'. There is only one major dam namely 'Dev dam' in the Dhadhar basin. The basin receives most of the rainfall from the south west monsoon from June to September. The total population dependent on Dhadhar basin is about 11.23 lakh.

A. River characteristics

River Dhadhar originates from the Pavagadh Hills of Gujarat State and flows through Vadodara and Bharuch districts and meets to Gulf of Khambhat. The river Dhadhar after flowing 87km, receives Vishwamitri tributary from right bank at Pingalwada village 500m up stream of the Gauge and Discharge site. After flowing another 55 Km it falls in to the Gulf of Khambhat. The total length of the river from its source to outfall in the Gulf of Khambhat is about 142km. The important tributaries of the Dhadhar River are Vishwamitri, Jambuo River, Dev and Surya River.

The Vishwamitri River is a seasonal river and it originates in Pavagadh Hills of Gujarat state (India). The Vishwamitri flows west through the city of Vadodara and joins with the Dhadhar River and Khanpur River and empties into the Gulf of Khambhat, near Khanpur village. This river system includes the Sayaji Sarovar on the Vishwamitri River near Ajwa, and the Dev Dam on the Dhadhar Branch. Dev reservoir is located on Dev River at a distance of 26km. The length of Vishwamitiri River is 25km

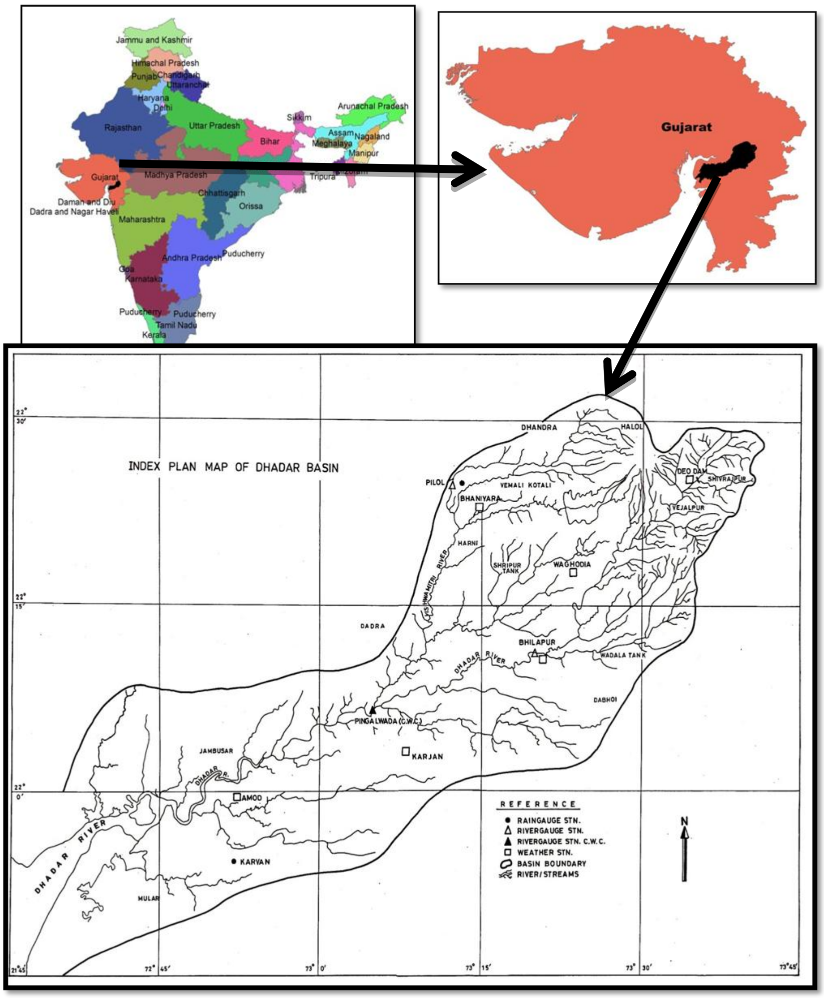

Fig. 1 Location and Index map of Dhadhar river basin

Dhadhar River is a rain-fed river which originates from Pavagadh Hills. The climate of the basin is characterized by a hot dry summer, a moderate winter and humid monsoon. June is the hottest month while January is the coldest month.

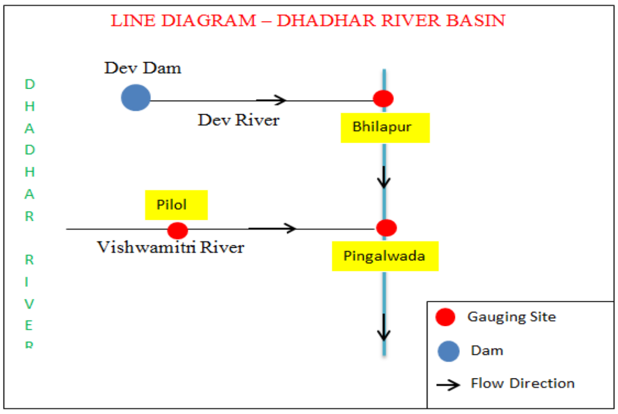

Fig. 2 Line Diagram of Dhadhar river basin

V. DATA AVAILABILITY

There are seven rain gauge stations and two gauge and discharge stations in Dhadhar river basin. The locations of the stations are shown in Fig. 1. The availability of data is given in **Table 1.**

VI. METHODOLOGY

This section presents the methodology for the investigation of non-stationarity in station data of rainfall and discharge, investigation of non-stationarity in spatially averaged gridded rainfall using Mann- Kendall test.

A. MANN–KENDALL TEST

The Mann–Kendall (M-K) test is a non-parametric test that can be used for detecting trends in a time series (Mann, 1945) where autocorrelation is non-significant. It has been found to be an excellent tool for trend detection to assess the significance of trends in hydro-meteorological time series data such as water quality, stream flow, temperature and precipitation (Santosh M. Pingale et. al 2011). The M-K test can be applied to a time series x_i ranked from i = 1, 2, 3 … n - 1 and x_j ranked from j = i + 1, 2, 3 … n such that:

$$\mathrm{Sgn}\,(x_j - x_i) = \begin{cases} 1 \text{ if } (x_j - x_i) > 0 \\ 0 \text{ if } (x_j - x_i) = 0 \\ -1 \text{ if } (x_j - x_i) < 0 \end{cases}$$

The Kendall test statistic S can be computed as:

$$S = \sum_{k=1}^{n-1} \mathrm{Sgn}\,(x_j - x_k)$$

where $\mathrm{sgn}(x_j – x_k)$ is the signum function. The test statistic S is assumed to be asymptotically normal, with E(S) = 0 for the sample size n ≥ 8 and variance as follows:

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

Table 1 Details of data availability

S. No.	Name of Station	Longitude (E)	Latitude (N)	Type of Data	Length	Type of station
1	Amod	72° 52' 22.8"	21° 59' 27.60"	Monthly	1955-2003	Rain gauge
2	Baniyara	73° 14' 49.20"	22° 22' 55.2"	Monthly	1997-2012	Rain gauge
3	Bhilapur	73° 20' 38.40"	22° 10' 51.60"	Monthly	1973-1998	Rain gauge
4	Karjan	73° 7' 55.2"	22° 3' 14.4"	Monthly	1955-2003	Rain gauge
5	Karvan	72˚ 52' 4.79"	21˚ 54' 18"	Monthly	1997-2012	Rain gauge
6	Pilol	73˚ 13' 4.8"	22˚ 24' 57.6"	Monthly	1997-2012	Rain gauge
7	Waghodia	73° 23' 20.40"	22° 17' 45.60"	Monthly	1955-2003	Rain gauge
8	Bhilapur	73˚ 20' 2.4"	22˚ 11' 5.99"	Monthly	1989-2010	G & D site
9	Pingalwada	73˚ 4' 47.99"	22˚ 6' 25.19"	Monthly	1997-2011	G & D site

where t_i denotes number of ties up to sample i .

The standardized M-K test statistic (Z_{mk}) can be estimated as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{if } S < 0 \end{cases}$$

The standardized MK test statistic (Z_{mk}) follows the standard normal distribution with a mean of zero and variance of one. The presence of a statistically significant trend is evaluated using the Z_{mk} value. A positive (negative) value of Z_{mk} indicates an increasing (decreasing) trend. If $\pm Z_{mk} \leq Z_{\alpha/2}$ (here $\alpha = 0.1$), then the null hypothesis for no trend is accepted in a two sided test for trend, and the null hypothesis for the no trend is rejected if $\pm Z_{mk} \geq Z_{\alpha/2}$.

VII. RESULTS AND DISCUSSION

The results of the trend analysis using Mann- Kendall test are summarized in **Table 2.**

It may be seen from this table that:

1. Rainfall data for Amod station showed a decreasing trend in annual and monsoon rainfall data sets.
2. For Baniyara and Pilol rain gauge stations, non-monsoon rainfall data were also seen to show a negative trend.
3. In discharge data, the non- monsoon flow series of Bhilapur site is showing decreasing trend.

There is need to further investigate the reasons of these trends and also study the implication of these trends on water availability.

Table 2 Mann-Kendall test results

S. No.	Station	Type	Annual (Z) MK	Monsoon (Z) MK	Remark	Non-Monsoon (Z) MK	Remark
1	Amod	Rain gauge	-3.04	-2.8	Decreasing Trend	-1.65	No Trend
2	Baniyara	Rain gauge	1.21	1.4	No Trend	-1.98	Decreasing Trend
3	Bhilapur	Rain gauge	0	-0.04	No Trend	0.34	No Trend
4	Karjan	Rain gauge	0.45	0.51	No Trend	-0.58	No Trend
5	Karvan	Rain gauge	0.68	0.68	No Trend	-1.4	No Trend
6	Pilol	Rain gauge	1.4	1.67	No Trend	-1.94	No Trend
7	Waghodia	Rain gauge	-1.54	-1.41	No Trend	-0.34	No Trend
8	Bhilapur	G &D	1.34	1.29	No Trend	2.5	Decreasing Trend
9	Pingalwada	G & D	-1.36	0	No Trend	-0.94	No Trend

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