MAUSAM, **77**, 1 (January 2026), 29-44

MAUSAM

DOI: https://doi.org/10.54302/3a37t639
Homepage: https://mausamjournal.imd.gov.in/index.php/MAUSAM

UDC No. 551.583:551.557.3 (540.47)

Climate change with special reference to rainfall variability: A case study of Jambhira basin, Odisha, India

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(*Received 10 October 2024, Accepted 15 April 2025*)

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सार– वर्षा प्रवृत्ति विश्लेषण का अध्ययन जलवायु परिवर्तन को समझने के लिए अत्यंत महत्वपूर्ण है| जल उपयोग पर जलवायु परिवर्तन के प्रभाव को समझने के लिए बेसिन में जलवायु परिवर्तन का अध्ययन आवश्यक है। किसी नदी बेसिन में जलवायु परिवर्तन का आकलन जल उपयोग और सतत विकास पर इसके प्रभावों को समझने के लिए आवश्यक है। वर्तमान अध्ययन में जांभिरा बेसिन की वार्षिक तथा मानसूनकालीन वर्षा के प्रवृत्ति का 33 वर्षों (1988-2020) की अवधि के लिए विश्लेषण किया गया है। प्रवृत्तियों तथा उनकी सांख्यिकीय महत्ता का आकलन करने हेतु रैखिक प्रतिगमन विश्लेषण एवं MK परीक्षण जैसे विभिन्न सांख्यिकीय तरीकों का प्रयोग किया गया। वर्षा की परिवर्तनशीलता का अध्ययन परिवर्तन गुणांक (C.V.) के माध्यम से किया गया, साथ ही वर्षा तीव्रता, अत्यधिक एवं अधिशेष वर्षा घटनाएँ, आर्द्र एवं शुष्क अवधियाँ, मानसून आगमन एवं वापसी का भी विश्लेषण किया गया। परिणाम दर्शाते हैं कि अधिशेष वर्षा, अत्यधिक वर्षा घटनाओं, वर्षा दिवसों, आर्द्र अवधियों तथा शुष्क अवधियों में घटती प्रवृत्ति पाई गई है, जबकि वर्षा तीव्रता में वृद्धि की प्रवृत्ति देखी गई है। मानसून का आगमन सामान्य पाया गया, किंतु इसकी वापसी अपेक्षाकृत शीघ्र होती है। यह अध्ययन बेसिन के सतत विकास हेतु प्रभावी जल संरक्षण उपायों की योजना बनाने में सहायक सिद्ध होता है।

ABSTRACT. The Study of rainfall trend analysis is critical for the study of climate change. The study of the climate change in the basin is crucial to understand the impact of climate change on water uses. The present study has been attempted to analyze the trend of annual and monsoon season rainfall data of the Jambhira basin from 1988-2020 (33 years) employing different trend analysis methods i.e. linear regression analysis and MK test for trend significance, rainfall variability using C.V, rainfall intensity, extreme and excess rainfall, wet and dry spell, monsoon onset and withdrawal. Excess rainfall, extreme rainfall, rainy days, wet spell and dry spell shows decreasing trend, but rainfall intensity shows increasing trend. Monsoon arrival is normal but withdrawal is earlier. This results of the study helps various water conservation measures for sustainable development of the basin.

Key words Rainfall trend, Coefficient of variability, MK test, Extreme rainfall, Wet and dry spell.

1. Introduction

Climate change is of significant concern nowadays and affects all possible aspects of human survival. Climate change has a significant impact on rainfall, which has a high degree of variability. Rainfall plays a significant role in the natural environment by taking part in the 'hydrological cycle', and as an important ecological factor, it helps in the survival of human beings (Kipkorir, 2001). Furthermore, rainfall can also regulate economic development, as it is one of the key determinants of agricultural productivity. Any changes in rainfall frequency, intensity and other aspects of rainfall result in serious problems, such as drought and flooding, in turn have adverse impacts on the agricultural sector (specifically rain-fed crops). Moreover, the amount of rainfall determines several policy-making processes related to disasters such as floods, droughts and he poor/marginalized /underprivileged sections are at greater risk of climate change, which will intensify the rainfall variability, leading to fluctuating volume and discharge of the river (Lenderink *et al.*,2007). As a result, there is a greater threat of floods and conditions that resemble drought (Vrochidou,2013). Not only this, but intensified rainfall variability will also hinder the construction and design process of mega-structures like dams, high-altitude bridges, *etc*.(Kwon *et al.*,2009). The amount of rainfall has an impact on the availability of water for industrial, planning processes for the hydrology of any region. If rainfall occurs in excess, it causes widespread destruction in the form of floods and results in huge losses of life and property (Perwaiz and Yadav, 2020) On the other hand, low rainfall causes drought-like conditions, which causes water scarcity. In both cases mentioned above, crops suffer badly because too much water during floods hampers the seed germination process and water logging conditions damage the standing crops, during droughts, the lack of soil moisture does not favor the sowing process, and the water demands of crops are adversely affected. The consequences of crop failure can be severe to most severe (famine), and this fluctuation in rainfall is known as rainfall variability. Different researchers and policymakers have assessed the social, economic, and ecological impact of rainfall variability, depending on the location of that region (Chhibber and Lajaaj, 2008). This highlights the urgent need to conduct a research study at different temporal and spatial scales (McCarthy, 2001). This raises the urgent need for a research study at different temporal and spatial scales (McCarthy, 2001). Precise daily estimates of monsoonal rainfall are crucial for numerous water-related fields, including drought and flood prediction, as well as agricultural crop and water management. The significance of the fitted model was evaluated after a variety of spatially changing precipitation variables crucial for the sustainable management of water resources were fitted with temporal trends: Monsoon beginning date, extreme events, inter-annual variations, and annual and seasonal totals (Duncan, *et al*., 2013). Between 1951 and 2015, the annual and summer monsoon mean rainfall for all of India showed a declining tendency, particularly across regions in the Indo-Gangetic Plains and the Western Ghats. Over the course of the twenty-first century, climate models predict an increase in the mean annual and summer monsoon rainfall as well as an increase in the frequency of heavy rain events over the majority of India. Throughout the twenty-first century, it is anticipated that the inter annual variability of summer monsoon rainfall would rise (Krishnan *et al*., 2020). An analysis of Uttar Pradesh's rainfall data from 1981 to 2012 shows a marked decline in the total amount of rainfall each year. Additionally, it was observed that the frequency of below-normal annual rainfall was higher after the 1990s than it was prior to. After 1996, the yearly rainfall dropped dramatically from 1040.5 mm to 988 mm, or 5% (Kumar, *et al*., 2018). In Mediterranean agricultural regions, rainfall is the primary factor influencing crop growth, and its temporal and spatial patterns dictate yield potential. Crop development will be negatively impacted by rainfall reductions in hazards capes with higher historical rainfall reliabilities (Lyle, G., 2023).

As per the Intergovernmental Panel on Climate Change (IPCC) report, in developing societies, domestic, and other commercial use. Twisa and Buchroithner (1999) conducted a study in the Wami river basin and analyzed the impact of seasonal and annual rainfall variations on the rural water supply in the region. Buytaert *et al.* (2006) studied rainfall variability on temporal and spatial scales in the mountainous region of the South Ecuadorian Andes. Nouaceur *et al.* (2017) employed the Romanian plain to study rainfall variability, aiming to emphasize the connection between the prevailing climate change and precipitation patterns Ogallo (1979) examined the rainfall trends and periodicities at 69 stations in Africa and found no significant changes in the trends. Guhathakurta and Rajeevan (2007) carried out a comprehensive study on the spatial distribution of rainfall across the 36 meteorological substations in India. It is clear that rainfall variability is a world wide phenomenon and is directly linked to climate change. (Chaudhary *et al*., 2017). The findings show that both winter and summer precipitation are trending upward throughout all divisions; in particular, winter precipitation in southeast-central and southern Hunan and summer precipitation in southwest-central Hunan show a statistically significant tendency (Hu, *et al.,* 2019). The average yearly cycles of surface air temperature and precipitation for all of India show a general rise in both. The west coast and northeast of India show the greatest rise in rainfall, according to spatial patterns of change. In comparison to the current situation, PRECIS projects a 20% increase in summer monsoon rainfall across all of India in the future. All states except Punjab, Rajasthan and Tamil Nadu, which show slight decrease in precipitation in the future scenarios (Pant, *et al*., 2006).

In general, we can summarize that the unprecedented increase in atmospheric greenhouse gases (GHGs) is responsible for the global rise in temperature, which, as feedback to atmospheric dynamics and convection, has also led to changes in the characteristics of rainfall globally (Alexander 2016). It is often claimed that our climate is changing, and the rainfall is decreasing in certain places and increasing in other places. In the recent period 1951-2015, as well as 1986-2015, the annual rainfall series in India has shown a decreasing trend.

The objective of the current study is to analyze the trend of annual and monsoon season rainfall, decadal, rainy days, rainfall intensity, extreme rainfall, excess rainfall, wet spell, dry spell, monsoon arrival, and

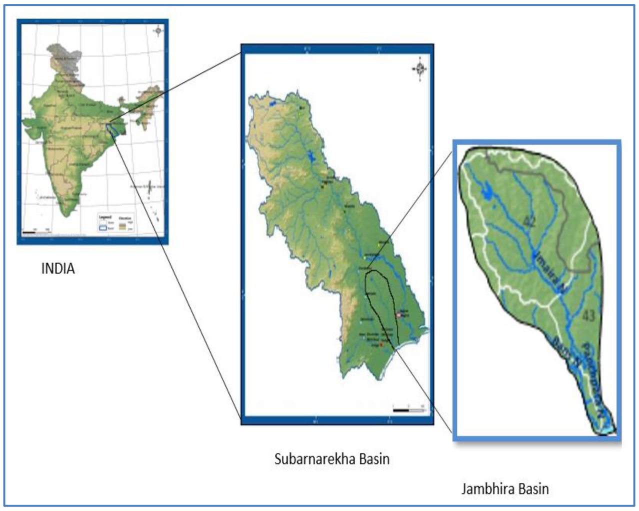

Fig. 1. Location map of the Jambhira Basin

withdrawal for 33 years (1988-2020) of the Jambhira basin. The trend analysis of rainfall was done using linear regression and the Mann-Kendall test.

2. Data and methodology

2.1. *Study area*

The Jambhira basin is a small river basin on the north coast of Odisha, located between latitudes 21º 30′ N to 22º 7′ 48″ N and longitudes between 86º 45′ E to 87º 8′ 24″ E. It is situated between the Subarnarekha basin in the north and the Budhabalanga basin in the south in the Balasore district. The Jambhira river rises from the west of Lakshman Nath village in the Balasore district and flows southeastward for a distance of 87.4 kilometers before draining into the Bay of Bengal. The basin has a length of 57 km^2 and is elongated. The basin covers two Community Development Blocks, Basta and Baliapal, in the Balasore district. The upper part of the basin covers the Basta block, and the lower part covers the Baliapal block. 610 per square km is the population density of the basin, which is economically developed.

The general slope of the basin is from north-west to south-east. The hilly and densely forested area makes up over 24% of the basin's area. The majority of the plain region of the basin is located within the 100-300 m. elevation zone. Tertiary and Alluvium plains are the geological formations found in the basin. The South West monsoon, which begins in June and lasts until October, typically has an impact on the basin. The basin experiences a prolonged dry spell after a period of heavy rainfall during the monsoon season. The basin receives 1400 mm of rain on an average each year. The climate is tropical with hot summers and moderate winters. The average monthly temperature ranges from 9.0 °C in December to 40.5 °C in May 47.2 °C is the highest recorded temperature, while 2.8 °C is the lowest. The range of the average annual maximum and minimum temperatures is 32.4 °C to 18.0 °C. Annual average maximum and minimum temperatures vary from 32.4 °C to 18.0 °C.

The Jambhira basin has extensive agricultural land that covers an area of 20.55 sq. km. because of the alluvial soil deposited by the rivers. The basin's other primary land use/cover categories are rural area (5.28 sq.km), river and stream (0.66 sq.km), waterbody (0.03sq.km) and fallow land (2.91sq.km). The basin is located in the agroclimatic region of the Lower Genetic Plain (Fig.1).

2.2. *Objectives of the study*

The objectives of the present research study are as follows:

(*i*) To carry out the trend analysis of rainfall (both annual and monsoonal) for the period 1988-2020.

(*ii*) To examine the variations in monthly and annual precipitation from 1988-2020

(*iii*) To analyze the frequency of rainy days, rainfall intensity, dry spell, wet spell, arrival and withdrawal of monsoon for 1988-2020.

2.3. *Data*

The daily rainfall data collected for the period of 33 years (1988-2020) from the office of the Special Relief Commissioner (SRC), Department of Revenue and Disaster Management, Government of Odisha., The Jambhira basin is delineated from the River Basin Atlas under the India Water Resource Information System (WRIS) of the Central Water Commission (CWC), Government of India. The WMO (1989) defined normal rainfall as the average of 30 years' of rainfall data.

2.4. *Methodology*

The current study calculated annual and monsoonal mean rainfall, rainfall trend, rainfall intensity, coefficient of variation, extreme rainfall, excess rainfall, wet and dry spells, monsoon arrival and withdrawal using daily rainfall data. The mean, standard deviation (SD), inter annual variability, and coefficient of variation (CV)for annual (January to December) and the monsoon season (June to September) data were all statistically analyzed to ascertain the normal variation of rainfall. For the annual and monsoon seasons, the threshold values for coefficient of variation (CV) were Determined to be <25%, <50%,

TABLE 1

Different categories of rainfall events based on intensity as classified by IMD

Sl. No	Terminology	Rainfall range (in mm/day)
01	Very light rainfall(VLR)	Trace-2.4
02	Light rainfall (LR)	2.5-15.5
03	Moderate rainfall(MR**)**	15.6-64.4
04	Heavy rainfall(HR**)**	64.5-115.4
05	Very heavy rainfall (VHR)	115.5-204.4
06	Extreme heavy rainfall (HER)	≥ 204.5
07	Exceptionally heavy rainfall (Exc.HR)	When the amount is near the highest recorded rainfall at or near the station for the month or season. However, this term is used only when the actual rainfall amount exceeds 24cm

TABLE 2

Rainfall classification by IMD

Sl. No	Terminology	Rainfall
01	Near Normal rainfall	96-104% of the Long Period Average of rainfall
02	Below Normal rainfall	90-96 %of the Long Period Average of rainfall
03	Above Normal rainfall	104-110%of the Long Period Average of rainfall
04	Deficiency rainfall	Less than 90% of the Long Period Average of rainfall
05	Excess rainfall	More than 110% of the Long Period Average of rainfall

<100%, and<150% (Manorama *et al.,* 2007). Rainfall is regarded as extremely reliable if the coefficient of variation falls within the variability threshold limit, and vice versa. IMD divided rainfall occurrences into seven categories based on the intensity of the 24hour total rainfall: very light, light, moderate, heavy, extremely heavy, extreme heavy, and exceptionally heavy rainfall (Table 1 & 2). The annual and monsoon seasons' decadal rainfall variations are computed. Rainfall intensity, frequency, number of rainy days, dry days, and wet days are all computed. The number of days with "no rain" is known as "dry days." Wet days are the number of days receiving a given amount of rainfall (equal to or more than 1mm/day; (Pal and Tabbaa, 2011). To evaluate the trend of annual and monsoon season rainfall, total number of rainy days, and various rainfall events, a non-parametric Mann-Kendall test at a 95% significance level was used (Waghayeet *et al.,* 2018: Tiwari *et al*, 2019) Gross data mistakes and outliers have no effect on the MK test (Guhathakurta *et al.,* 2011).

3. Results and Discussion

In this study, the rainfall parameters of the Jambhira basin in Odisha have been analyzed at several temporal scales (annual and monsoon season).The results are discussed below.

3.1. *Annual rainfall*

Rainfall data spanning 33 years (1988-2020) has been used to assess the Jambhira basin's annual rainfall. Although the average annual rainfall is 1532.02 mm, there are significant temporal variations. In 2004, it was 997 mm, and in 2013, it was 2264 mm. With inter annual variations, the Rainfall shows an increasing tendency. Rainfall increased by 25% from 1988(1448mm) to 2020 (1811 mm). Table 5 displays the findings of the MK test for rainfall. The growing tendency is represented by the positive Z statistics values. Based on the results of Z (2.32) value, the trend is indicated at the 95% significance level. Rainfall was less than the mean in 17 years, approximately 52% of the years analyzed. Less than the mean rainfall varies from 8.21mm (0.53%) in 1990 to 525.21mm (34.28%) in 2004. Deficient rainfall of less than 90% in 13 years (40%). Annual rainfall exceeding the mean in 16 years, approximately 48% of the total number of years analyzed. Excess rainfall varies from 34.79 mm. (2.27%) in 1992 to 731.79 mm (47.76%) in 2013.Surplus rainfall of more than 10% of the mean rainfall observed in 11 years. Out of 17 years, 12 years had rainfall less than the mean and the total rainfall was 2370.25 mm. before 2004. Out of 16 years, 11 years had rainfall exceeding the mean rainfall of 2370.04. after 2004 (Table 3 & Figs. 2-4).

3.2. *Decadal rainfall*

The decadal rainfall shows an increasing trend at different rates. The trend is gradually shifting, with an increase in surplus rainfall and a decrease in deficit rainfall. The MK test of decadal rainfall shows an increasing trend. There has been an increase in the decadal rainfall trend from 1988 to 1997.Rainfall in the decade was 14,269 mm, which is 6.88% less than the decadal mean rainfall. In this decade rainfall recorded less in 7 years, 4 years of deficit rainfall, 3 years of surplus rainfall, and 1 year of excess rainfall. The basin experienced a decrease of 1607.07 mm. (14.98%) in rainfall over a span of 7 years, with amounts ranging from 8.21 mm. (0.54%) in 1990 to 519.81 mm. (33.92%) in 1996. In a span of 3 years, a total of 554.37mm (12.06%) of additional rainfall

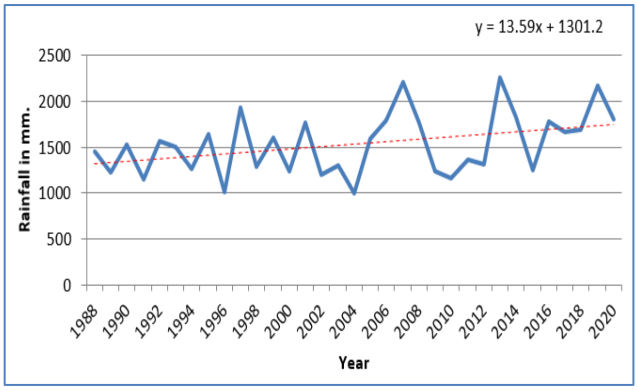

Fig. 2. Trend of annual rainfall in mm. in Jambhira basin (1988-2020)

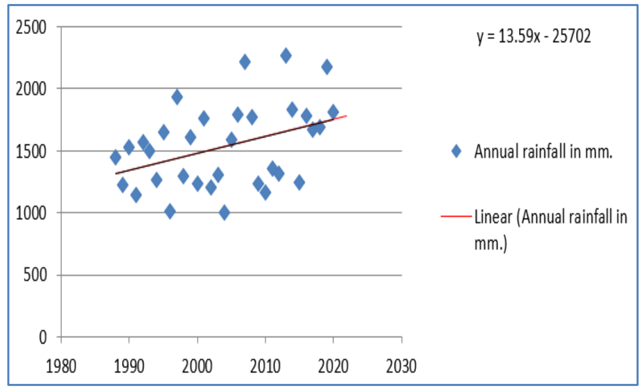

Fig. 3. Regression analysis of the annual rainfall in mm.in Jambhira Basin (1988-2020)

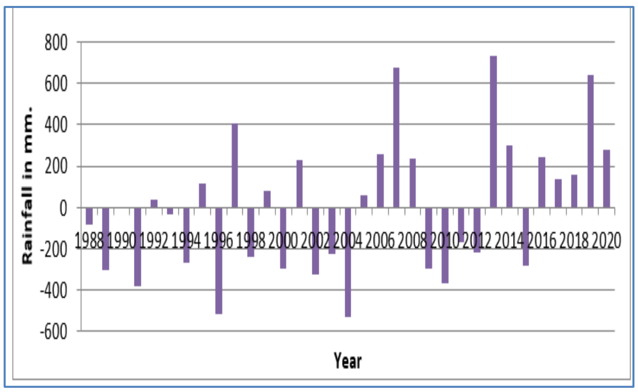

Fig. 4. Deviation of annual rainfall from mean rainfall in mm.in Jambhira basin (1988-2020)

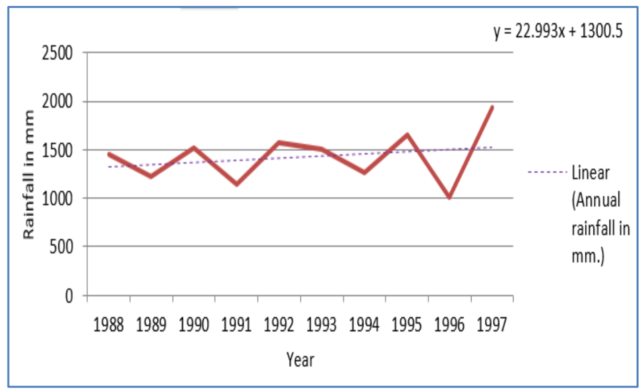

Fig.5. Trend of annual rainfall in the decad in mm.in Jambhira basin (1988-1997)

TABLE 3

Annual rainfall and deviation from mean in Jambhira basin (1988-2020)

Year	**Annual**	**Deviation from the mean**	**Percentage deviation**	**Year**	**Annual**	**Deviation from the mean**	**Percentage deviation**
	Rainfall in mm.	Rainfall in mm.	%		Rainfall in mm.	Rainfall in mm.	%
1988	1448	-84.21	-5.49	2004	997	-525.21	-34.28
1989	1227	-305,21	-19.92	2005	1591	59.09	3.86
1990	1524	-8.21	-0.54	2006	1789	256.79	16.76
1991	1145	-387.21	-25.27	2007	2211	678.79	44.30
1992	1567	34.79	2.27	2008	1769	237,79	15.52
1993	1500	-32.21	-2.10	2009	1236	-296.21	-19.33
1994	1262	-270.21	-17.63	2010	1159	-373.21	-17.83
1995	1648	115.79	7.55	2011	1360	-172.21	-11,24
1996	1012	-519.81	-33.92	2012	1313	-219.21	-14.31
1997	1936	403.79	26.35	2013	2264	731.79	47.76
1998	1293	-239.21	-15.61	2014	1833	300.79	19.63
1999	1608	75.79	4.95	2015	1248	-284.21	-18.55
2000	1236	-296.21	-4.95	2016	1777	244.89	15.98
2001	1764	231.79	15.13	2017	1666	133.79	8.73
2002	1206	-326.21	-15.13	2018	1687	154.79	10.10
2003	1304	-228.21	-14.89	2019	2171	638.79	41.69
				2020	1811	278.79	18.20

Source: Special Relief Commissioner, Odisha was recorded, with amounts varying from 0.79 mm (2.27%) in 1992 to 403.79 mm (26.35%) in 1997. The period from 1998 to 2007 experienced a total of 14,999 mm of precipitation, representing a decrease of 2.11% compared to the average rainfall for that decade. It experienced 5 years with less rainfall and a deficit in 4 years, as well as5 years with more rainfall, accompanied by excess rainfall in 3 years. It received 5 years less rainfall with a deficit in 4 years, and 5 years more rainfall, with excess rainfall in 3 years. The amount of less rainfall received was 1615.05mm (21.08%), ranging from 525.21mm (34.28%) in 2004 to 296.21 mm (4.95%) in 2000. Rainfall received more was 1302 mm (17%), which ranges from 59.09mm (3.86%) in 2005 to 678.79mm (44.30%) in 2007. During this decade, the deficit rainfall decreased and surplus rainfall increased. The decade 2008 - 2017 experienced 15625 mm of rainfall, representing 1.98% higher than the average decadal rainfall. It experienced 5 years with deficit rainfall and more rainfall in 5 years with excess rainfall in 4 years.

The deficit rainfall received was 1345.05 (17.56%), which varies from 172.21 mm (11.24%) in 2011 to 296.21 mm. (19.33%) in 2009. More rainfall received was 1649.05 mm (21.53%), which varies from 133.79 mm (8.73%) in 2017 to 731.79 mm (47.76%) in 2013. Between the years 2018 and 2020, the total rainfall recorded amounted to 5669 mm, a significant increase of 23.32% when compared to the average rainfall observed over a three-year period.

The region experienced successive periods of excessive rainfall, with recorded amounts escalating from 154.79 mm (10.10%) in 2018 to 638.79 mm (41.69%) in 2019. The Mann-Kendall test shows an increasing trend of decadal rainfall. The data indicates a discernible trend wherein the river basin, influenced by the prevailing climate change phenomenon, has undergone a statistically significant augmentation in rainfall levels within its catchment area over the preceding thirty-three-year period. Concurrently, this period has been characterized by a reduction in deficit occurrences and a concomitant rise in surplus conditions (Table. 3, Figs. 5, 6 & 7).

3.3. *Monsoon rainfall*

Monsoon season in the basin lasts four months, from June, July, August, and September. During monsoon season, the basin receives an average rainfall of 1095.52 mm over the past 33 years, accounting for 71% of the total annual rainfall. M K test of trend analysis for the monsoon season shows an increasing trend, less than the annual trend. Monsoon rainfall increases from June to August and decreases in September. Maximum rainfall is received in August. The annual rainfall pattern during the monsoon season displays a rising trend over time along with fluctuations from year to year. The highest amount of rainfall recorded was 1883 mm in 2007, which is approximately 70% greater than the average monsoon rainfall of the basin. Maximum rainfall received was 1883 mm. in 2007, which is about 70% more than the mean monsoon rainfall of the basin. The minimal amount of rainfall recorded was 659 mm. in 2003, representing approximately 39.85% lower than the average rainfall during the monsoon season. The lowest rainfall received was 659 mm. in 2003, which is about 39.85% less than the mean monsoon rainfall. Over the past 33 years, the basin experienced 18 years with reduced rainfall, including a deficit in rainfall for 15 of those years. Fifteen years recorded increased rainfall, accompanied by a decade of excess rainfall. Over the past 33 years, the basin has recorded a total of 3670.43 mm. less rainfall, representing an approximately 18.61% decrease over 18 years, alongside an increase in rainfall of 3670.2mm. which amounts to 22.33% moreover a span of 15 years. In the last 33 years, the basin received 3670.43 mm less rainfall, which is about 18.61% less in 18 years, and more rainfall of 3670.2 mm, which is 22.33% more in 15 years. MK test for the decadal rainfall shows a decreasing trend in 1988-1997, an increasing trend in (1998-2007), and no trend in 2008-2017. The decade (1988 - 1997) shows less rainfall of 684.24 mm (6.25%), (1998-2007) more rainfall of 142.76 mm (1.29%), (2008-2017) more rainfall of 643.8mm.(5.87%) and (2018-2020) less rainfall of 101.57mm(3.1%).There is a fluctuating tendency in the decades' maximum rainfall Rainfall in the decade (1988-1997), was maximum 1425 mm., (1998 - 2007) was 1883mm. and (2008-2017)) was 1593 mm. Rainfall in June is trending downward, according to the MK test based on the Z value.

The basin's mean monthly rainfall was 247.30 mm in June (22.57%), 269.575 mm in July (24.61%), 307.515 mm in August (28.07%), and 271.130 mm in September (24.75%). Rainfall continues to increase from June through August before decreasing in September. Rainfall in June is decreasing, according to the MK test based on the Z value. The amount of rainfall in June varies from 870 mm (351.80%) in 2008 to 78 mm (31.54%) in 2010. Eleven years received more rainfall and twenty two years received less rainfall. Rainfall shows an increasing trend in July on the basis of Z value of MK test Rainfall in July ranges from 627 mm (23.29%) in 2007 to 88 mm (32.64%) in 2002.Rainfall was higher in 15 years and lower in eighteen years. The MK test, based on the Z value, indicates a 90% significance level increase in rainfall throughout the month of August. Rainfall in August ranges from 62 mm. (20.16%) in 1998 to 619 mm. (201.29%) in 2007. Rainfall increased during 13 years and decreased during 20 years. Septembers' rainfall

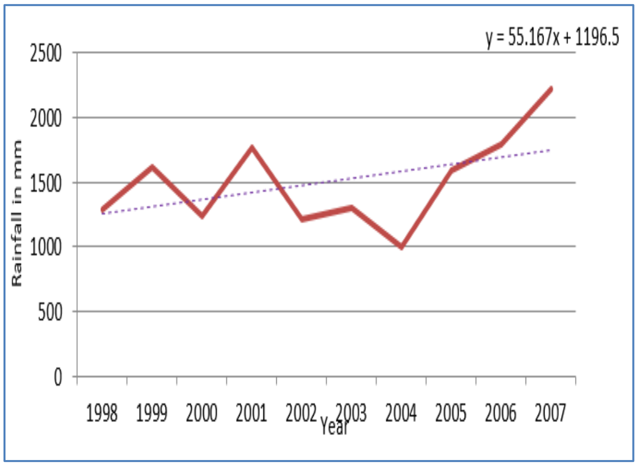

Fig. 6. Trend of annual rainfall in the decade in mm in Jambhira basin (1998-2007)

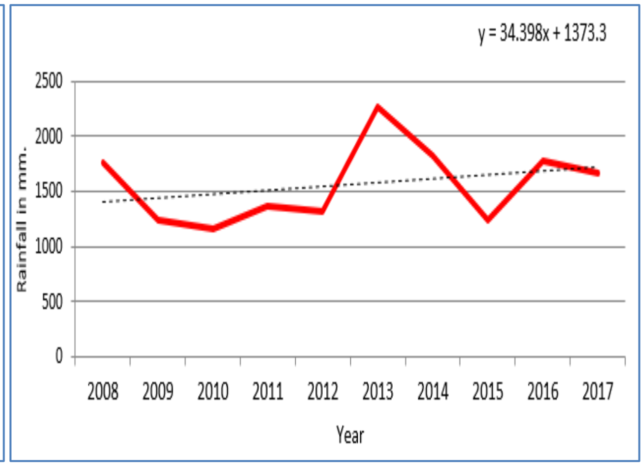

Fig.7. Trend of annual rainfall in the decade in mm in Jambhira basin (2008-2017)

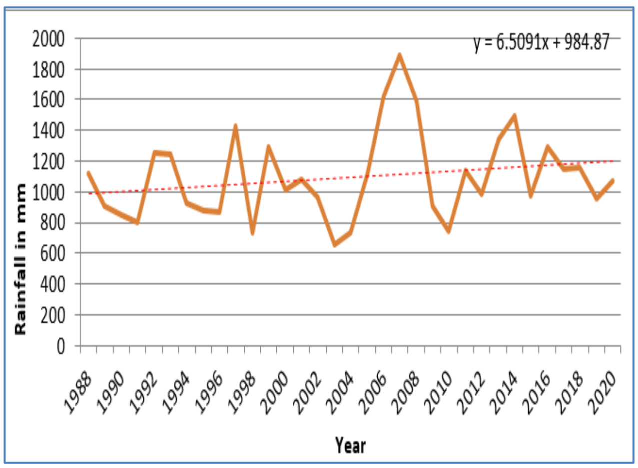

Fig. 8. Trend of Monsoon Rainfall in in mm. in Jambhira basin (1988-2020)

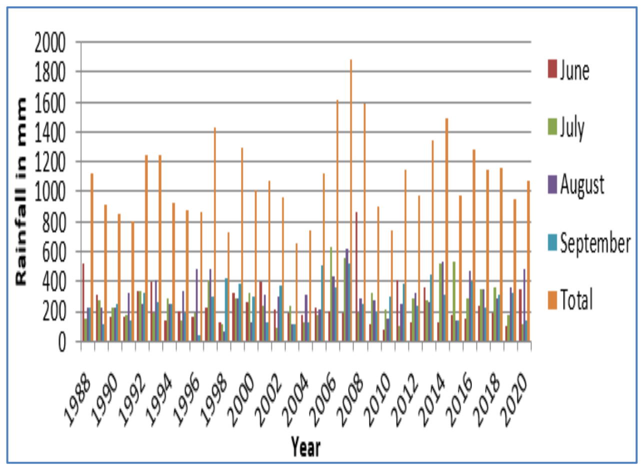

Fig. 9. Monsoon rainfall in the Jambhira basin (1988-2020)

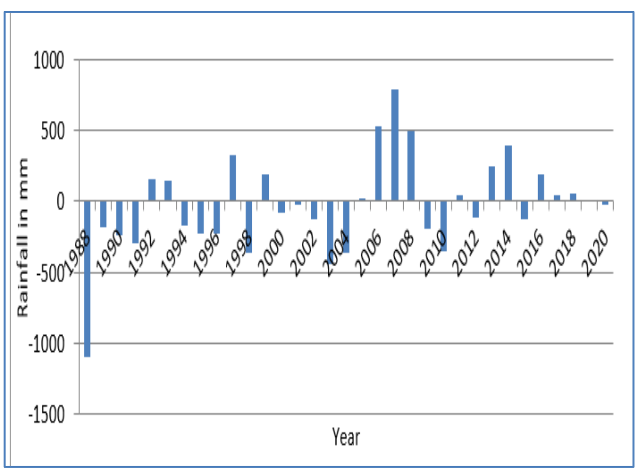

Fig.10. Deviation of Monsoon rainfall from mean rainfall in Jambhira Basin (1988-2020)

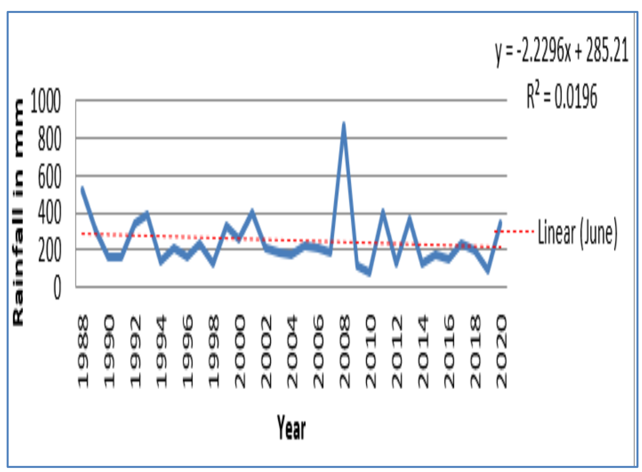

Fig. 11. Trend of monsson rainfall in the month of June in Jambhira basin (1988-2020)

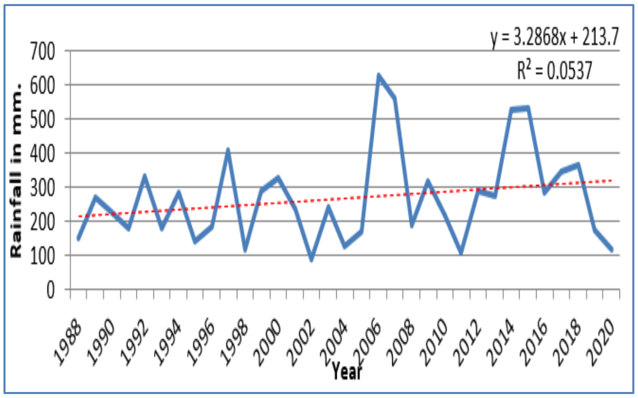

Fig. 12. Trend of monsoon rainfall in the month of July in Jambhira basin (1988-2020)

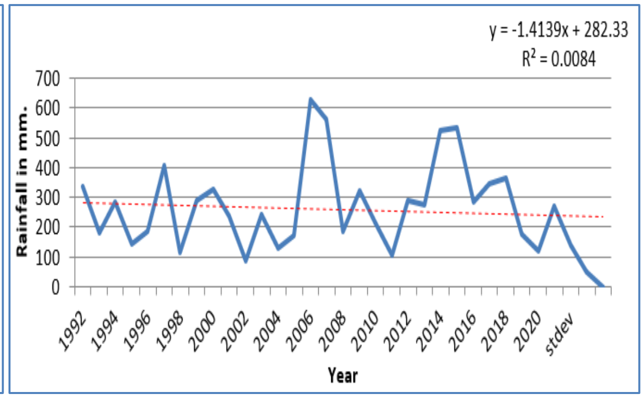

Fig. 13. Trend of monsoon rainfall in the month of August in jambhira basin(1988-2020)

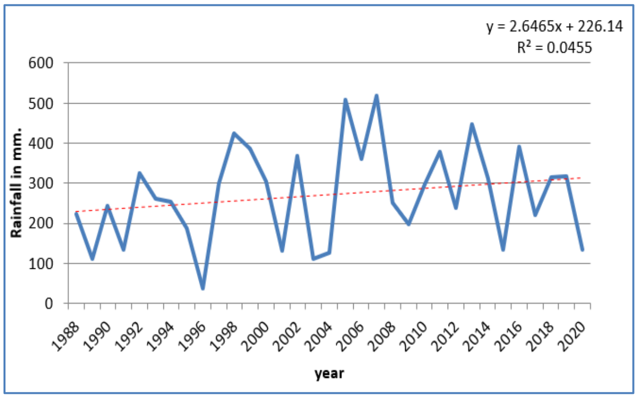

Fig.14. Trend of monsoon rainfall in the month of September in Jambhira basin (1988-2020)

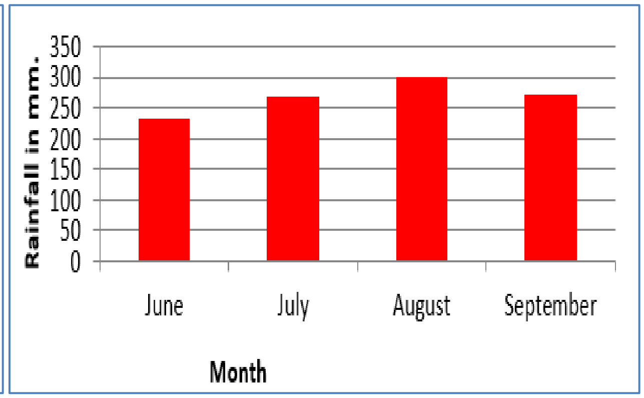

Fig.15. Mean monthly monsoon rainfall in Jambhira basin (1988-2020)

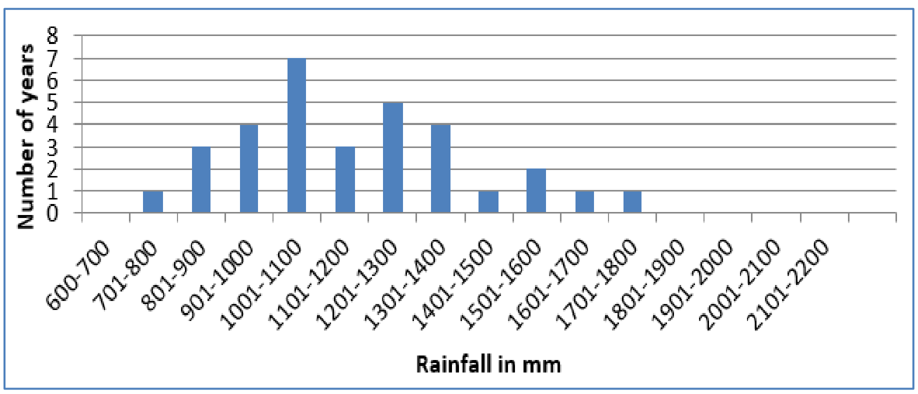

Fig. 16. Frequency of monsoon rainfall in Jambhira basin

trend is growing, according to MK test based on Z value. Between 1996 and 2007, the amount of rainfall in September ranges from 38 mm (14.02%) to 519 mm (191.42%).

Rainfall increased during 16 years and decreased during 17 years. The MK test indicates a declining trend for the first two decades and an increasing trend for the third decade for the decadal monsoon rainfall in June. The first decade exhibits no trend in July, whereas the second and third decade show an upward trend. Three decades exhibit an increasing trend in August, with the third decade's Z value of 1.71 indicating a trend at the 90% significance level. The first decade exhibits an increasing trend in September, the second decade shows no trend, and the third decade displays a decreasing trend. (Tables 4 and 5; Figs. 8 - 15).

TABLE4

Monsoon season rainfall, rainy days, rainfall intensity and extreme rainfall in Jambhira basin (1988-2020)

Year/ Month	June	July	August	September	Monsoon			
	Rainfall in mm.	rainfall in mm.	Rainfall in mm.	Rainfall in mm.	Rainfall in mm.	Rainy days	Rainfall intensity in mm.	Extreme rainfall in mm.
1988	515	152	230	224	1121	53	21.15	175
1989	308	269	222	111	910	57	15.96	120
1990	158	228	223	244	853	50	17.07	83
1991	163	181	328	133	805	45	17.88	97
1992	340	334	254	324	1252	54	23.18	104
1993	394	182	405	260	1241	56	22.16	185
1994	140	284	244	253	921	60	15.35	64
1995	204	144	33	188	873	53	16.47	52
1996	163	185	484	38	870	41	21.21	115
1997	229	407	489	300	1425	57	25	107
1998	127	117	62	425	731	46	15.89	52
1999	325	291	290	386	1292	43	30.04	132
2000	256	326	129	304	1015	47	21.59	78
2001	400	238	307	132	1077	62	17.37	82
2002	208	88	304	367	967	44	21.97	74
2003	188	242	117	112	659	42	15.69	62
2004	174	129	307	126	736	46	16	92
2005	221	172	216	508	1117	44	25.39	178
2006	205	627	428	360	1620	54	30	134
2007	183	562	619	519	1883	49	38.42	175
2008	870	187	286	250	1593	51	31.23	222
2009	118	320	270	198	906	46	19.69	60
2010	78	216	155	296	745	44	16.93	94
2011	406	107	250	379	1142	52	21.96	122
2012	123	290	329	237	979	44	22.25	72
2013	364	273	257	446	1340	56	23.92	117
2014	122	526	530	312	1490	48	31.04	150
2015	170	532	136	135	973	45	21.62	70
2016	145	283	469	391	1288	66	19.51	110
2017	234	344	344	221	1143	52	21.98	50
2018	192	366	283	315	1156	55	21.01	101
2019	96	176	365	318	955	42	22.73	91
2020	342	118	479	135	1074	47	22.85	127
Mean	247.303	269.575	307.515	271.130	1095.524	50	21.95	107.48
C.V%	62.19	50.87	41.53	44.26	25.96	12.62	24.41	40.17

TABLE 5

Mann-Kendall test 'Z' values for monsoon and annual rainfall (1988-2020)

Monsoon/Annual	D1	D2	D3	1988-2020
June	-1.33	-1.56	0.31	-1.20
July	0	0.31	0.16	1.06
August	0.78	0.55	1.71*	1.70*
September	1.30	0	-0.54	1.30
Monsoon	-0.46	0.47	0	1.28
Annual	0.62	0.62	1.40	2.32**

*Notes : *,** represent 90% and 95% significance levels, respectively*

TABLE 6

Annual and monsoon season rainfall variability (C.V%) in Jambhira basin 1988-2020

Decade	June	July	August	September	Monsoon	Annual
1988-1997	47.61	36.29	32.82	43.26	20.95	34.77
1998-2007	34.95	65.75	58.75	47.23	35.65	18.78
2008-2017	91.15	43.97	40.85	33.83	23.17	12.41
1988-2020	62.19	50.87	41.53	44.26	25.96	22.25

3.4. *Frequency of monsoon rainfall*

The frequency of monsoon rainfall over the last 33 years shows a maximum of 7 years with rainfall between 901 - 1000 mm. followed by 5 years with rainfall of 1001 to 1200 mm, 26 years of rainfall of 701 to 1300 mm. 79% of the years account for rainfall between 701-1300 mm. Five years have more than 1300 mm of rainfall, and one year has less than 700 mm. Rainfall in the area has never exceeded 1700 mm or fallen below 600 mm (Fig. 16).

3.5. *Variability of rainfall*

The annual rainfall variability of the Jambhira basin in the last 33 years is 22.25%. The rainfall variability's decadal trend indicates an upward trend. Rainfall variability was 34.77% from 1988 to 1997, 18.78% from 1998 to 2007 and 12.41% from 2008 to 2017.Monsoon season rainfall variability was 25.96% in the last 33 years, which is higher than the annual rainfall variability Monthly rainfall variability of the monsoon season from June to September is much higher than the rainfall variability of monsoon season. The highest rainfall variability occurs in June (62.19%), followed by July (50.87%), August (41.53%) and September (44.26%). There are different trends in the decadal monthly monsoon season rainfall variability. The variability of rainfall in June for the decade 1988 - 1997 was 47.61%, 1998-2007 was 34.95%, and 2008-2017 was 91.15%.

The variability of rainfall in July for the decade 1988–1997 was 36.29%, 1998–2007 was 66%, and 2008–2017 was 44%. The variability in August for the decade, 1988-1997 was 32.82%, 1998-2007 was 58.75% and 2008-2017 was 40.85%. The variability of rainfall in September for the decade 1988-1997 was 43.26%, 1998-2007 was 47.23% and 2008-2017 was 33.83%. It shows that there is higher rainfall variability in June and July. Rainfall in June is extremely important for growth of kharif crop (Table 6).

3.6. *Extreme rainfall*

The IPCC Special Report on Extremes (SREX; According to the 2012 assessment by the Intergovernmental Panel on Climate Change, there will undoubtedly be an increase in extreme precipitation occurrences worldwide in the future. Extreme precipitation occurrences over the Indian mainland have also increased in frequency since 1950 (Sillmann *et al.*, 2013, Goswami *et al.*, 2006, Rao *et al.*, 2014) detecting changes in the characteristics of extreme rain events is an important issue in view of their large impacts on human society (Ghosh *et al.*, 2016). It is challenging to link anthropogenic climate change to a particular monsoon extreme event. More severe weather is predicted as a result of a warming atmosphere. The frequency and intensity of extreme heavy rain events over central India have been found to have significantly increased since 1950, whereas the frequency of moderate rain events has decreased (Goswami *et al.*,2006; Dash *et al.*, 2009). The majority of research on climate change has been on variations in rainfall mean values. Nonetheless, it is becoming more widely acknowledged that evaluating the socioeconomic effects of climate change requires a thorough understanding of how these changes present themselves in the frequency of extreme weather and climatic events, especially at the regional and local levels. Daily rainfall data requires in order to analyse extremes. With the available data, some worldwide analysis of the extremes has been conducted; nevertheless, a comprehensive regional picture of these changes has not yet been completed. To create appropriate indices that accurately reflect the extremes, the World Meteorological Organization's joint commission for climatology on climatic variability and predictability on climate change detection, monitoring, and indices coordinated activities. The highest one-day precipitation index is taken into consideration in this regard. Over the past 33 years, the basin's extreme rainfall has been decreased. August had the most number of years with excessive rainfall, followed by June, September, and July. The highest amount of rainfall that occurred in a single day was 222 mm in June 2008, while the lowest was 50 mm in July 2017. The highest rainfall recorded in August during the 1988–1997 decade was 185 mm, while the lowest was 52 mm. Rainfall ranged from 178 mm in August to 52 mm in September between 1998 and 2007.Rainfall ranged from 222 mm in June to 50 mm in July from 2008 to 2017. Extreme rainfall lasts for a maximum of ten years in August, eight years in June and September, and six years

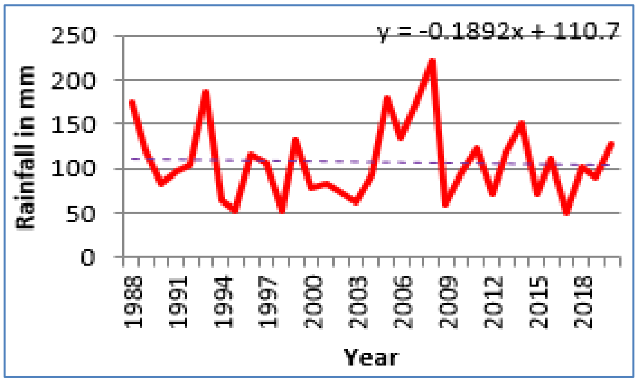

Fig. 17. Extreme monsoon rainfall in Jambhira basin (1988-2020)

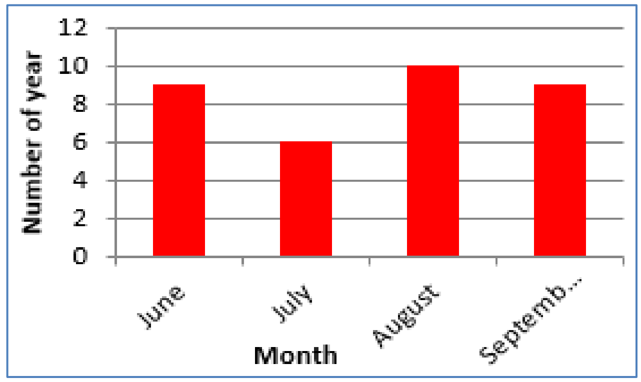

Fig. 18. Monthly number of years of Extreme rainfall in mm. in monsoon season in Jambhira basin (1988-2020)

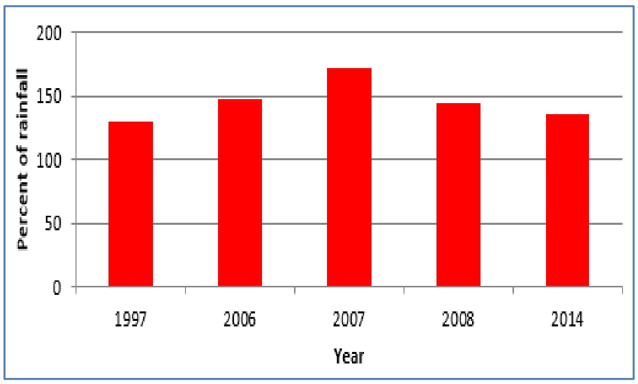

Fig. 19. Percentage of annual excess rainfall in Jambhirabasin (1988-2020)

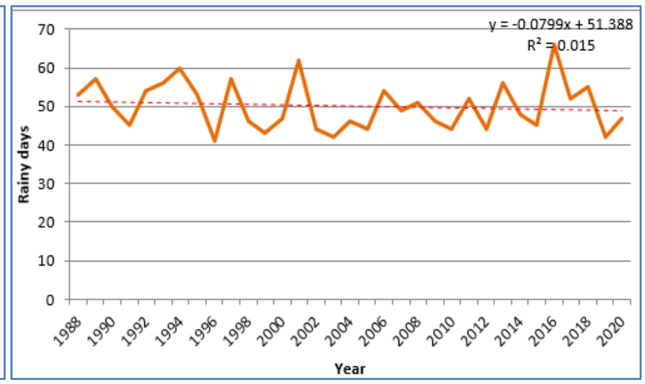

Fig.20. Trend of rainy days in monsoon season in Jambhira basin (1988-2020)

in July. Extreme rainfall has a coefficient of variation of 40.17%. (Figs. 17 and 18)

3.7. *Excessive rainfall*

Rainfall that is sufficiently above average is a major contributor to the occurrence of foods. Rainfall that is 125% or more of the average annual rainfall is deemed excessive for the purposes of this study. In 1997, 2007, 2013 & 2019, the basin had four years of excessive rainfall.

During these four years, the yearly rainfall exceeded 1915.26 mm. The frequency of excessive yearly rainfall decreased from nine years prior to 2007 to five years following that year. In the basin, the frequency of excessive rainfall is progressively rising. Of the 33 years, there have been roughly 12% of excessive rainfalls. It indicates that the basin is not vulnerable to flooding (Table.3 & Fig.19)

3.8. *Monsoon rainy days*

Rainy days are crucial for determining how much rainfall a region has received. The basin's number of rainy days is decreasing. Average rainy days in the four months of the monsoon season is 50 days. There were a minimum of 41 rainy days in 1996 and a maximum of 66 rainy days in 2016.The average number of rainy days in July and August is 14 days, followed by 12 days in September and 10 days in June. Over the past 33 years, the basin had a maximum of 17 rainy days in June 2001 and a minimum of 3 rainy days in 2010. July had a minimum of six rainy days in 2011 and a maximum of 22 rainy days in 2015.There were a maximum of 25 rainy days in August of 2016 and a minimum of 7 rainy days in August of 2005.September saw a maximum of 19 rainy days in 2013 and a minimum of 4 rainy days in 1996. The basin's decadal variation of rainy days from 1988 to 1997 indicates a slightly decreasing trend, with an average of 53 rainy days, a maximum of 60, and a minimum of 41. With an average of 48 wet days for the 1998–2007 decade, the maximum and minimum rainy day counts were 62 and 44, respectively. Rainy days have been on the rise from 2008 to 2017, with an average of 50 rainy days, a maximum of 66 rainy days, and a minimum of 44 rainy days. Monthly rainy day trends in June during the 1988–1997 decade show a higher rate of decrease with an average of 10 rainy days, with maximum and minimum being 15 and 7 days, respectively; the 1998–2007 decade shows a decreasing trend with an average of 10 rainy days, with maximum and minimum being 17 and 5 days, respectively; and the 2008–2017 decade shows a decreasing trend with an average of 9 rainy days, with maximum and minimum being 16 and 3 days, respectively. Rainy days in July show a decreasing trend in the decades 1988–1997 with an average of 14 rainy days, with maximum and minimum being 18 and 11 rainy days respectively; a higher increasing trend in the decade 1998–2007 with an average of 13 rainy days, with maximum and minimum being 18 and 7 rainy days; and a higher increasing trend in the decade 2008–2017 with an average of 15 rainy days, with maximum and minimum being 22 and 6 rainy days respectively. The trend of rainy days in August is increasing in the decade 1988–1997 with an average of 16 rainy days, with maximum and minimum being 21 and 11 rainy days, respectively; in the decade 1998–2007 with an average of 13 rainy days, with maximum and minimum being 20 and 7 rainy days, respectively; and in the decade 2008–2017 with an average of 14 rainy days, with maximum and minimum being 25 and 8 rainy days, respectively. Rainy days in September show a decreasing trend in the decade 1988-1997, with an average of 13 rainy days, with maximum and minimum being 17 and 4 rainy days, respectively; 1998-2007, with an average of 12 rainy days, with maximum and minimum being 16 and 9 rainy days; and 2008-2017, with an average of 13 rainy days, with maximum and minimum being 19 and 6 rainy days, respectively (Table 4 & Fig. 20).

3.9. *Monsoon rainfall intensity*

The intensity of the basin's annual monsoon rainfall intensity is on the rise, with an average of 22 mm, a maximum of 38 mm, and a minimum of 15 mm. The monsoon season's maximum monthly rainfall intensity is 25 mm in June, followed by 24 mm in September, 22 mm in August, and 20 mm in July. In June, there is a modest decrease in intensity trend, with a minimum of 13 mm and a maximum of 54 mm. The maximum and Minimum intensity in July are 48 mm and 10 mm, respectively, while the maximum and minimum in August are 41 mm and 8 mm, respectively. In September, there is no change in the trend, with the maximum and minimum intensity being 37 mm and 9 mm, respectively. The decadal annual monsoon rainfall intensity from 1988 to 1997 increased with an average intensity of 20 mm, with maximum and minimum intensities of 23 mm and 15 mm, respectively; from 1998 to 2007, it increased with an average intensity of 23 mm, with maximum and minimum being 38 mm and 16 mm; and from 2008 to 2017, it decreased with an average intensity of 23 mm, with maximum and minimum being 31 mm and 17 mm, respectively. Monthly decadal trend of monsoon rainfall intensity in June in 1988-1997 indicates a decreasing trend with an average of 25mm, maximum and minimum being 39mm. and 13 mm. The average intensity from 1998 to 2007 was 24 mm, with maximum and minimum being of 54 mm and 13 mm, respectively. The average intensity from 2008 to 2017 was 26 mm, with maximum and minimum being of 54 mm and 16 mm. With an average intensity of 17 mm, maximum and minimum being 21 mm and 11 mm, respectively. The period from July 1988 to 1997 exhibits an increasing trend, whereas the period from 1998 to 2007 exhibits an increasing trend with an average intensity of 21 mm, maximum and minimum being 42 mm and 7 mm. From 2008 to 2017, the intensity increased on average by 24 mm, reaching a maximum of 48 mm and a minimum of 13 mm. The average intensity for the August 1988–1997 decade was 21 mm, with the maximum and minimum being 37 mm and 12 mm, respectively. The average intensity during the 1998–2007 decade was 22 mm, with the maximum and minimum being 41 mm and 17 mm, respectively. There is an increasing trend from September 1988 to 1997 with an average intensity of 20 mm, with maximum and minimum values of 25 mm and 15 mm, respectively; from 1998 to 2007 with an average intensity of 27 mm, with maximum and minimum values of 47 mm and 12 mm, respectively; and from 2008 to 2017 with an increasing trend with an average intensity of 23 mm, with maximum and minimum values of 30 mm and 20 mm, respectively (Table 4 & Fig.21).

3.10. *Monsoon wet spell and dry spell*

The average number of monsoon wet spells in the basin is 12, with a maximum of 16 and a minimum of 9, indicating a declining trend. All four months' monthly wet spell trends indicate a downward trend. August saw four wet spells on average per month, followed by three in July, three in September, and two in June. June 4 and 0 had the highest and lowest wet spells, followed by July 7 and 1, August 6 and 1and September 5 and 0. The monsoon season's decadal wet spells indicate a declining tendency, with an average of 13, a maximum of 16, and a minimum of 11. In June 1988-1997, the decadal monsoon monthly wet spell trend increased with an average of two wet spells, with maximum and minimum being 4 and 1, while in 1998-2007, the trend decreased with an average of two wet spells, with maximum and minimum being 3 and 1, and in 2008-2017, the trend increased with an average of two wet spells, with maximum and minimum being 3 and 0. From 1988 to 1997, July exhibits a decreasing trend with an average of 4 wet spells, with maximum and minimum values of 5 and 2. From 1998 to 2007, there is an increasing trend with an average of 3 wet spells, with maximum and minimum values of 7 and 1,

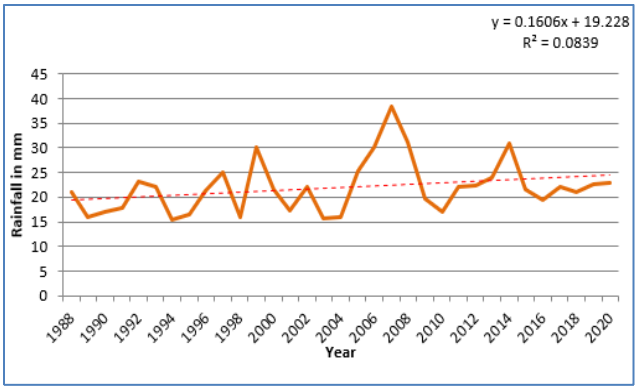

Fig. 21. Trend of rainfall intensity in Monsoon season in Jambhira basin(1988-2020)

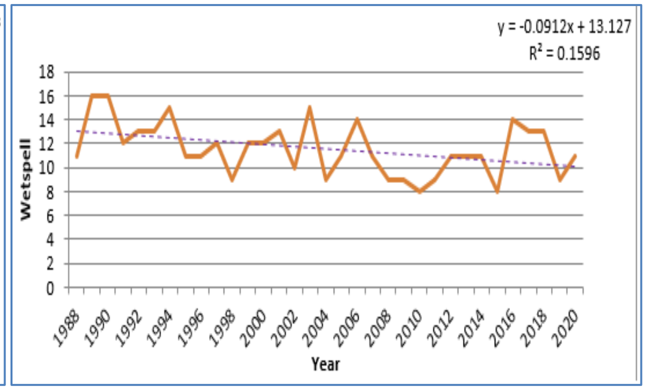

Fig.22. Trend of wetspell in Monsoon season in Jambhira Basin (1988-2020)

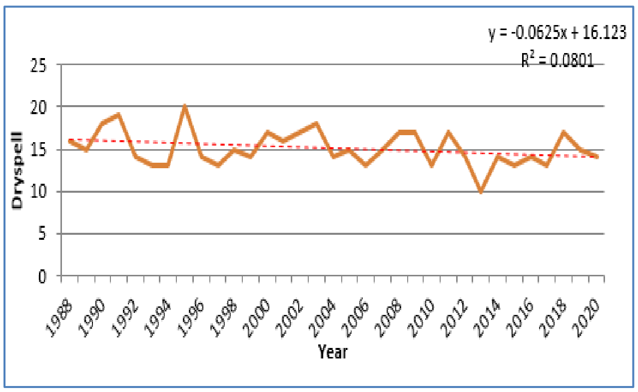

Fig. 23. Trend of Dry spell in the Monsoon season in Jambhira basin (1988-2020)

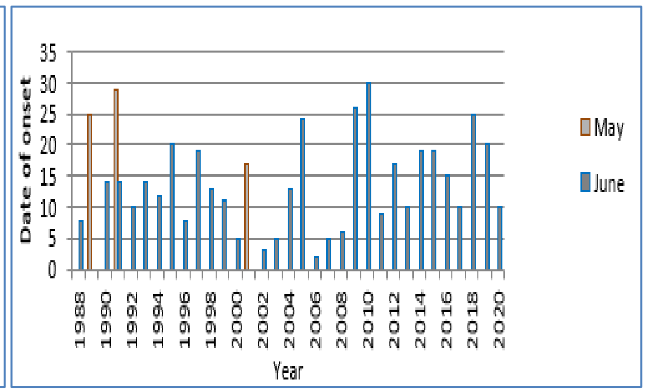

Fig. 24. Date of onset of monsoon in Jambhira basin (1988-2020)

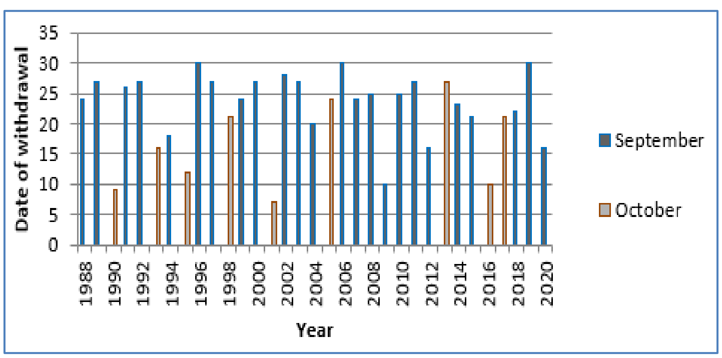

Fig. 25. Date of withdrwal of monsoon from Jambhira basin (1988-2020)

and from 2008 to 2017, there is an increasing trend with an average of 3 wet spells, with maximum and minimum values of 4 and 2. There was an increasing trend with an average of four wet spells from August 1988 to 1997, with maximum and minimum being 6 and 3. From 1998-2007 there was an increasing trend with an average of three wet spells, with a maximum and minimum of 5 and 2. From 2008-2017 there was an increasing trend with an average of four wet spells with a maximum and minimum of 4 and 1. Between September 1988 and 1997, the average number of wet spells decreased to 13, with maximum and minimum values of 16 and 11. From 1998 to 2007, the average number of wet spells increased to 12, with maximum and minimum values of 15 and 9. From 2008 to 2017, the average number of wet spells increased to 11, with maximum and minimum values of 14 and 8 (Table. 7 & Fig. 22).

3.11. *Dry spell*

The basin's monsoon dry spells are decreasing, with an average of fifteen dry spells, a maximum of twenty, and a minimum of ten. Wet spells are less than dry spells. The monsoon season's monthly dry spell displays four for every month. While the dry spell in August and September shows an increasing trend, the dry spell in June

TABLE 7

Wet spell and Dry spell in Jambhira basin (1988-2020)

Year	Wetspell	Dryspell	Year	Wetspell	Dryspell
1988	11	16	2004	9	14
1989	16	15	2005	11	15
1990	16	18	2006	14	13
1991	12	19	2007	11	15
1992	13	14	2008	9	17
1993	13	13	2009	9	17
1994	15	13	2010	8	13
1995	11	20	1011	9	17
1996	11	14	1012	11	14
1997	12	13	1013	11	10
1998	9	15	1014	11	14
1999	12	14	1015	8	13
2000	12	17	1016	14	14
2001	13	16	2017	13	13
2002	10	17	1018	13	17
2003	15	18	1019	9	15
			2020	11	14

and July shows a decreasing trend. July has a maximum dry spell of five and a minimum of one, while August and September have a maximum dry spell of six and a minimum of two. June has a maximum dry spell of seven and a minimum of zero. The monsoon season's decadal pattern of dry spells indicates a decreasing trend. The average dry spell from 1988 to 1997 was sixteen, with maximum and minimum values of twenty and thirteen, respectively; from 1998 to 2007, it was fifteen, with maximum and minimum values of eighteen and thirteen, respectively; and from 2008 to 2017, it was fourteen, with maximum and minimum values of seventeen and ten, respectively. The monsoon season's decadal monthly dry spell in June from 1988 to 1997 shows an increasing trend with an average of four dry spells, with maximum and minimum being seven and three respectively; from 1998 to 2007, there is a decreasing trend with an average of four dry spells, with maximum and minimum values of five and two, respectively; from 1997–2007, there is an increasing trend with an average of four dry spells, with maximum and minimum values of five and three, respectively; and from 2008–2017, there is a decreasing trend with an average of three dry spells, with maximum and minimum values of five and one, respectively. The decadal dry period in August has a decreasing trend The average for 1988–1997 is four dry spells, with maximum and minimum values of five and three, respectively; the average for 1998–2007 is four dry spells, with maximum and minimum values of six and two; and the average for 2008–2017 is four dry spells, with maximum and minimum values of six and four, respectively. September 1988–1997 exhibits a declining trend with an average of four dry spells, with maximum and minimum values of five and two, respectively; 1997–2007 exhibits an increasing trend with an average of four spells, with maximum and minimum values of six and two, respectively; and 2008–2017 exhibits a decreasing trend with an average dry spell of four, with maximum and minimum values of six and two, respectively (Table 7 & Fig. 23).

3.12. *Onset and withdrawal of monsoon*

The onset of the monsoon in the basin typically occurs during the first and second weeks of June. Over the past 33 years, data indicates that in 20 of those years, the monsoon set in during the first and second weeks of June, while in 7 years it arrived in the third week, and in 3 years it was recorded in the fourth week. Notably, only in the years 1989, 1991, and 2001 did the monsoon make an early arrival in the third and fourth weeks of May (Fig. 20).

The withdrawal of the monsoon from the basin typically occurs in the second week of October. Historical observations indicate that in only four years did the monsoon withdrew during the second week of October, while it withdrew in the third week on three years and in the fourth week two years. Overall, the monsoon withdrawal from the basin during the month of October in nine different years. Approximately twenty-four years, the monsoon withdrew earlier from the basin. Notably, the early withdrawal of the monsoon in September occurred in the fourth week for 18 years, in the third week for five years, and in the second week for one year. In most cases, the monsoon withdrew early in September (Fig. 24 & 25).

4. Conclusions

Rainfall has a significant impact on the studied area's agricultural development. Agriculture will suffer from any change in rainfall. The Jambhira basin's yearly rainfall analysis indicates an increasing trend. However, half of the years with limited rainfall showed increasing inter annual and inter decadal rainfall variability. The MK test indicates a pattern of increasing rainfall throughout the monsoon season and annually. In August, there is a noticeable increased trend in both yearly and monsoon rainfall. While the monsoon season exhibits substantial variability, annual rainfall variability is minimal. Rainfall variability decreases from June to September during the monsoon season. Rainfall throughout the monsoon season is increasing. There is a decreasing trend in excessive and extreme rainfall. While the number of rainy days is decreasing, the intensity of the rainfall is increasing trend. Both annually and decadally, there is a decreasing trend in the monsoon wet and dry spells. The first and second weeks of May mark the beginning of the onset of monsoon in the basin. The monsoon's early September retreat is clearly visible. For the sustainable growth of agriculture in the basin, appropriate planning is essential to overcome inter-annual and inter-decadal rainfall variability.

Data availability

Daily rainfall data is available online from the Special Relief Commissioner, Odisha. (www.srcodisha.nic.in)

Funding

No fund provided for the preparation of the research paper.

Acknowledgement

Authors are appreciative to Special Relief commissioner (SRC) for contributing daily rainfall data of the research area for rainfall and climate change analysis. The view expresses are of the authors without any conflict of interest.

Authors' contributions

Damodar Panda: The conception and design of the study and drafting the article.
Rashmi Rani Anand: Analysis and interpretation of data. (*email-rashmi.rani@sbs.du.ac.in*).
Maya Devi: Acquisition of data and revising it critically. (*email-mdevifpy@kiit.ac.in*).

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