**Analysis of Rainfall Patterns and Variability for Resilient Crop Planning in Drought-Prone Bolangir District of Odisha, India**

**ABSTRACT**

Crop planning in a drought-prone district is essential to maximize water efficiency, improve crop selection, optimize the use of available resources etc., which reduces the risk of crop failure and ensures better yield. In India, approximately 80% of the annual rainfall comes from the southwest monsoon. The spatial and temporal variations in monsoonal and annual precipitation are well recognized, and this year-to-year fluctuation in monsoon rainfall significantly affects agricultural production. Proper crop planning ensures the most effective utilization of the limited resources available in drought-prone regions. In this regard, a study has been done to analyse the spatial-temporal rainfall distribution and its variability in Bolangir which is a drought-prone district of Odisha. The study area was Bolangir district which is situated in the western region of the state of Odisha, India, bounded by Subarnapur and Boudh districts in the east, Nuapada in the west, Kalahandi in the south and Bargarh in the north. In order to study rainfall characteristics, rainfall data for 33 years (1991 to 2023) was collected from the Special Relief Commissioner (SRC), Odisha for the purpose of rainfall analysis in the study area. The daily rainfall data at the block level were subjected to a non-parametric Modified Mann-Kendall Test using ‘mmky’ package in ‘R studio’ software to detect trends in annual and seasonal rainfall. The present study revealed that the average annual rainfall in Balangir district was 1245.5 mm, consisting of one block with high rainfall, six blocks under very low rainfall and the rest under moderate to low rainfall category. The 90% dependable rainfall is above 1000 mm in Balangir and Gudvella which assures the water requirement of medium duration rainfed rice for these blocks and probability at 75% is more than 1300 mm in Gudvella block which is considered as suitable for most crops. Blocks namely Bangomunda and Patnagarh showed a significant increasing trend whereas Belpada and Loisingha showed a significant decreasing trend for both rainfall and rainy days. The insights gained from this analysis can help farmers and agricultural planners select suitable crop varieties, determine optimal planting and harvesting schedules, and implement water-efficient irrigation strategies. As further advancements in technology and data analysis are made, the potential to improve decision-making in crop planning will only increase, offering more robust solutions to mitigate the impacts of climate variability and encourage drought-resilient agricultural systems.

***Keywords:*** *Rainfall, Climate change, SW monsoon, Trend, Drought*

1. **INTRODUCTION**

One of the primary factors influencing agricultural productivity is rainfall, which directly affects crop yields, soil moisture, and overall ecosystem health. The significance of rainfall as a determinant of agricultural productivity is well-established. Studies have consistently shown that agricultural output is profoundly influenced by variations in rainfall patterns. Previous research delved into the spatial and temporal dimensions of rainfall, emphasizing the need for precision in evaluating its impact on different crops and regions (Wang et al., 2024). The varying rainfall patterns require insistent and appropriate interest because they affect the entire environmental and human life cycle in any geographical region ([Dore, 2005](https://www.frontiersin.org/journals/climate/articles/10.3389/fclim.2025.1492260/full#ref7)).

As a result, understanding rainfall patterns, trends, and variability is critical for sustainable agricultural planning and crop management. Among climatic factors, precipitation is one of the most unstable, showing marked spatial and temporal differences over daily, decadal, and longer periods (Aravena & Luckman, 2009). Variability in rainfall patterns such as changes in intensity, and frequency, can have profound effects on crop growth, yield, and overall food security. In addition to non-uniform rainfall reception across the country, the agricultural sector experiences non-periodic (temporal change) pour affecting crop yield and soil health ([Attri and Tyagi, 2010](https://www.sciencedirect.com/science/article/pii/S2666592123000811" \l "bib3)). In Karnataka, an analysis ([Sanjeevaiah et al., 2021](https://www.sciencedirect.com/science/article/pii/S2666592123000811" \l "bib42)) done in the southern region of the state, proclaims that there is a temporal variability in rainfall spells, diversely affecting the agricultural stability in the state. In the context of climate change, rainfall patterns have become more unpredictable, making the ability to analyze and adapt to rainfall variability an essential strategy for resilient agricultural planning (Lobell *et al*., 2011). Rigorous scientific and political debate is ongoing concerning farmers' capability to adapt to changing climatic conditions and possibilities to mitigate climate change without threatening their livelihoods (Autio et al., 2021). Rainfall variability analysis is particularly important for regions where traditional farming practices are heavily dependent on predictable weather patterns. With changing climatic conditions, farmers are increasingly faced with uncertainty, making it crucial to develop adaptive strategies. Research suggests that only a few plant species are tolerant of rainfall variability or drought. Moreover, climate variability has many effects evident in the occurrence of fluctuations in climate, prolonged variations and crop diseases (Tchuenga Seutchueng et al., 2022). By integrating the knowledge of rainfall variability into crop planning, farmers can improve resilience to climate-induced stresses, reduce the risk of crop failure, and enhance productivity. Accessibility to information on agro-climatic onset (effective rainy season) is highly required for the planning of various agricultural activities like pre-sowing land preparation and sowing/ planting.

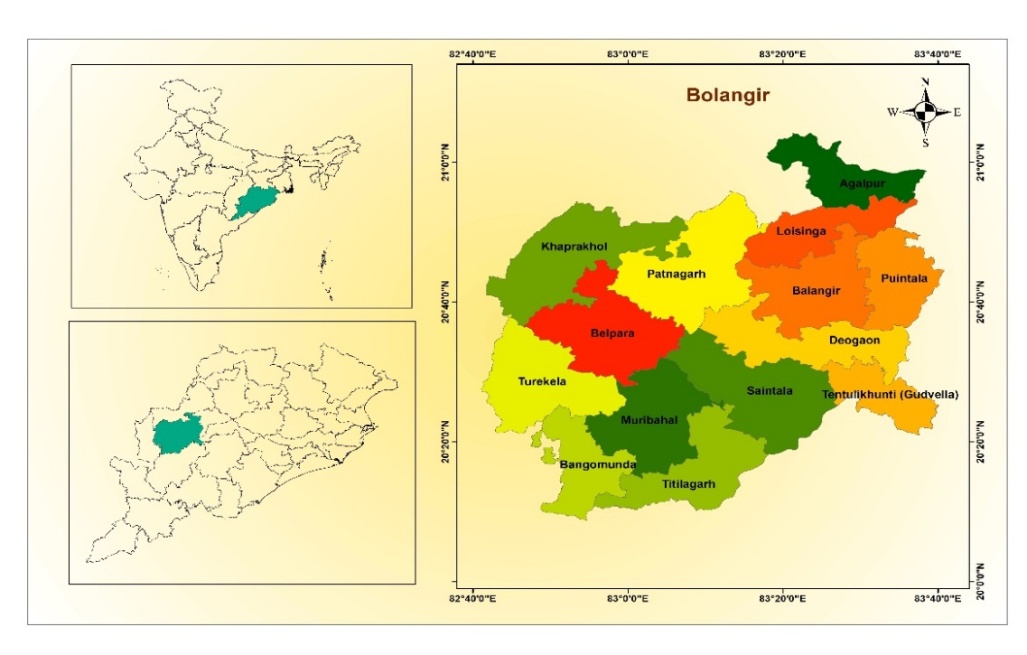
Precipitation is the main dynamic force; its pattern variability and seasonality can impact available water resources in a particular area (te Wierik et al., 2021). Variability in rainfall distribution and the amount stimulates changes in the spatial-temporal distribution of soil moisture, runoff, and groundwater and could change the frequencies of floods and droughts. Changes in rainfall patterns, variability, and seasonal distribution affect water availability (surface and groundwater) ([Sharma et al., 2013](https://www.frontiersin.org/journals/climate/articles/10.3389/fclim.2025.1492260/full#ref25); [Singh and Kumar, 2014](https://www.frontiersin.org/journals/climate/articles/10.3389/fclim.2025.1492260/full#ref28)), the frequency of disasters, cropping patterns, agricultural productivity and vegetation cover ([Singh and Mal, 2012](https://www.frontiersin.org/journals/climate/articles/10.3389/fclim.2025.1492260/full#ref29)). So, proper crop planning ensures the most effective utilization of the limited resources available in drought-prone regions. Resilient crop planning hinges on the ability to anticipate and mitigate the impacts of drought, ensuring food security and reducing vulnerability in affected regions. Additionally, integrating rainfall variability analysis with advanced decision-support tools can help in the identification of optimal sowing dates and crop types that are most likely to succeed under varying climatic.

Bolangir is a tribe-dominated district known for its high incidence of mass and chronic poverty. Manifestations of poverty in this area are persistent crop failures, starvation, malnutrition and migration. Severe droughts and floods also often visit this region in quick succession. In Bolangir district, agriculture is vulnerable to agricultural risks mainly because of low rainfall and erratic rainfall patterns. The normal annual rainfall in the district is 1289.8 mm, which is lower than the average state rainfall of 1451.2 mm. Only 20.6 per cent of the gross cropped area was irrigated during 2013–2014, which was lower than the state average (38.9%) (Swain & Hembram, 2020). By examining historical rainfall data, this research aims to uncover the patterns and trends in rainfall distribution in the draught-prone area of Odisha, Bolangir. These insights can help farmers and agricultural planners make data-driven decisions regarding the selection of crops, planting and harvesting schedules, irrigation needs, and the adoption of drought-resistant or rain-fed varieties.

**2. MATERIAL AND METHODS**

**2.1 Study Area**

Bolangir district is situated in the western region of the state of Odisha, India bounded by Subarnapur and Boudh district in the east, Nuapada in the west, Kalahandi in the south and Bargarh in the north. The district lies between 20°09’ and 21°05’ North latitudes and 82°41’ and 83°42’ East longitudes (Fig.1), falling in Survey of India toposheet nos. 64O, 64P & 64L. The district is located under the Western Central Table Land Agro Climatic zone covering an area of 6,575 square kilometers characterized by a hot and sub-humid climate, comprised of 14 blocks *viz*. Agalpur, Balangir, Bangomunda, Belpada, Deogaon, Gudvella, Khaprakhol, Loisingha, Muribahal, Patnagarh, Puintala, Saintala, Titilagarh and Turekela under Sub-divisions *viz*. Balangir, Patnagarh and Titilagarh. Bolangir has 91.9% of rural families below the poverty line and is one of the poorest districts in the country. Over the years, excessive tree falling and local climate change have had a significant negative impact on the district’s average rainfall. The district receives the second-lowest rainwater and stands at the 5th lowest position in terms of groundwater level in the state (Sahoo & Rath, 2023).



**Fig. 1. Location map of study area**

* 1. **Rainfall and rainy days analysis**

To study rainfall characteristics, rainfall data for 33 years (1991 to 2023) was collected from the Special Relief Commissioner (SRC), Odisha for the purpose of rainfall analysis in the study area. The analysis was conducted for each block of Bolangir districts. Annual and seasonal (Monsoon: June- Sept, Post monsoon: Oct-Dec, Winter: Jan-Feb and Summer: March-May) rainfall as well as the probability of rainfall was computed using the software known as ‘Weather cock’. A day is considered a rainy day (RD) if the rainfall is equal to or exceeds 2.5 mm, as defined by the India Meteorological Department for the Indian region. For rainfall and rainy-day variability analysis, the Coefficient of Variation (CV) was estimated using the formula below.

* 1. **Probability of Dependable Rainfall**

The incomplete gamma probability distribution was used to calculate the probability of rainfall at 90% and 75%, providing insight into the reliability of rainfall across different locations. The probability of rainfall was computed using the software known as ‘Weather cock’.

* 1. **Trend analysis**

The daily rainfall data at the block level were subjected to a non-parametric Modified Mann-Kendall Test using ‘mmky’ package in ‘R studio’ software to detect trends in annual and seasonal rainfall. The Modified Mann-Kendall (MMK) test (a non-parametric method) and Spearman's rho test (a parametric method) were utilized to identify trends. Sen’s slope method was used to determine the magnitude of the trends. The modified Mann-Kendall test (Yue and Wang, 2004) was used as it addresses the issue of serial correlation, which exists in time series data, by variance correction approach.

**2.5 Agro-climatic onset of cropping season**

An effective rainy season onset date is one that includes both empirical threshold rainfall and criteria for a false start (initial wet spell followed by a long dry spell of a week or more) as proposed by Sivakumar (1988). In this study, the agro-climatic (rainy season) onset of cropping season at block level was determined by defining the onset date as the first wet day of the three-day wet spell receiving at least 20mm of rainfall without a 10-day dry spell in the next 20 days (search period) starting from 1st June.

1. **RESULTS AND DISCUSSION**

**3.1 Rainfall and Rainy Days**

**3.1.1 Annual average rainfall & Rainy days**

The results presented in Table 1. revealed that the average annual rainfall in Bolangir was 1245.5 ± 364 mm and CV 29%. Out of fourteen blocks, Gudvella receives the maximum rainfall and comes under high rainfall (1600-1800 mm) category; Balangir and Puintala receive moderate rainfall (1400 to 1600 mm); Agalpur, Titilagarh, Deogaon, Patnagarh, and Saintala receive low rainfall (1200 to 1400 mm); Khaprakhol, Muribahal, Belpada, Loisingha, Turekela and Bangomunda come under very low rainfall (< 1200 mm) category. The annual average rainy days of the district range from 50 to 62 with SD 9 and CV 15%. Balangir & Titilagarh have the maximum number of rainy days (62) whereas Bangomunda has minimum rainy days of 50.

**Table 1. Annual & Monsoon average rainfall & Rainy days**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Block** | **Annual RF** | | | **Annual RD** | | |
| Mean | SD | CV | Mean | SD | CV |
| Agalpur | 1396.4 | 546 | 39 | 55.2 | 10 | 19 |
| Balangir | 1496.9 | 401 | 27 | 61.9 | 8 | 14 |
| Bangomunda | 1021.7 | 306 | 30 | 50.3 | 9 | 18 |
| Belpada | 1049.9 | 382 | 36 | 51.7 | 9 | 18 |
| Deogaon | 1292.2 | 346 | 27 | 55.2 | 8 | 14 |
| Gudvella | 1665.7 | 488 | 29 | 61.1 | 9 | 14 |
| Khaprakhol | 1105.6 | 328 | 30 | 54.3 | 8 | 16 |
| Loisingha | 1037.0 | 300 | 29 | 51.7 | 7 | 13 |
| Muribahal | 1075.5 | 395 | 37 | 56.6 | 9 | 16 |
| Patnagarh | 1289.0 | 320 | 25 | 55.4 | 8 | 15 |
| Puintala | 1408.7 | 353 | 25 | 59.0 | 8 | 13 |
| Saintala | 1217.0 | 364 | 30 | 56.4 | 10 | 18 |
| Titilagarh | 1346.0 | 325 | 24 | 61.9 | 7 | 11 |
| Turekela | 1035.8 | 238 | 23 | 54.4 | 9 | 16 |
| **Dist Avg.** | **1245.5** | **364** | **29** | **56.1** | **9** | **15** |

**3.1.2 Seasonal average rainfall & Rainy days**

Monsoon average rainfall is 1109.2±354 mm with CV 32% and average rainy day is 46.8±8 with CV 16%. The rainfall ranges from 920.9 mm at Turekela (46 rainy days) to 1485.4 mm at Gudvella (50 rainy days). The district receives an average post- monsoon rainfall of 61.2± 56 mm with a very high variability of 92% during the period. The rainfall ranges from 40.7 mm at Bangomunda (3.2 rainy days) to 84.2 mm at Gudvella (4.8 rainy days). The winter average rainfall in the district is 16.7 mm with a range from 10.1 mm at Bangomunda to 32 mm at Balangir. Summer rainfall is 58.4± 53 mm and a very high variability of 93%. Like post-monsoon and winter, Bangomunda receives minimum rainfall (39 mm) and rainy days (2.9) during summer as shown in Tables 2 and 3.

**Table 2. Monsoon & Post Monsoon average rainfall & Rainy days**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Block** | **Monsoon RF** | | | **Monsoon RD** | | | **Post-Monsoon RF** | | | **Post-Monsoon RD** | | |
| Mean | SD | CV | Mean | SD | CV | Mean | SD | CV | Mean | SD | CV |
| Agalpur | 1264.7 | 511 | 40 | 46.8 | 9 | 20 | 58.2 | 53 | 91 | 3.5 | 3 | 79 |
| Balangir | 1300.5 | 396 | 30 | 49.9 | 7 | 14 | 77.0 | 64 | 83 | 4.6 | 3 | 68 |
| Bangomunda | 931.9 | 300 | 32 | 43.5 | 9 | 21 | 40.7 | 38 | 94 | 3.2 | 3 | 84 |
| Belpada | 933.0 | 368 | 39 | 43.8 | 7 | 17 | 48.6 | 46 | 94 | 3.2 | 3 | 84 |
| Deogaon | 1174.1 | 341 | 29 | 47.4 | 6 | 14 | 58.1 | 57 | 99 | 3.5 | 3 | 78 |
| Gudvella | 1485.4 | 497 | 33 | 50.4 | 9 | 17 | 84.2 | 83 | 99 | 4.8 | 3 | 65 |
| Khaprakhol | 974.2 | 301 | 31 | 45.4 | 7 | 16 | 57.1 | 49 | 86 | 3.7 | 3 | 75 |
| Loisingha | 934.5 | 296 | 32 | 44.2 | 7 | 15 | 47.3 | 44 | 92 | 3.2 | 2 | 70 |
| Muribahal | 953.7 | 373 | 39 | 47.0 | 8 | 17 | 53.2 | 56 | 105 | 3.9 | 3 | 83 |
| Patnagarh | 1136.7 | 304 | 27 | 46.2 | 6 | 14 | 69.6 | 69 | 100 | 3.5 | 3 | 83 |
| Puintala | 1255.4 | 361 | 29 | 48.9 | 7 | 14 | 66.9 | 60 | 89 | 4.3 | 3 | 70 |
| Saintala | 1085.7 | 343 | 32 | 46.6 | 9 | 19 | 66.9 | 67 | 101 | 4.0 | 3 | 72 |
| Titilagarh | 1177.9 | 333 | 28 | 49.9 | 7 | 14 | 74.3 | 58 | 78 | 4.5 | 3 | 64 |
| Turekela | 920.9 | 228 | 25 | 45.9 | 7 | 15 | 54.3 | 43 | 79 | 3.5 | 3 | 71 |
| **Dist Avg.** | **1109.2** | **354** | **32** | **46.8** | **8** | **16** | **61.2** | **56** | **92** | **3.8** | **3** | **75** |

**Table 3. Winter & Summer average rainfall & Rainy days**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Block** | **Winter RF** | | | **Winter RD** | | | **Summer RF** | | | **Summer RD** | | |
| Mean | SD | CV | Mean | SD | CV | Mean | SD | CV | Mean | SD | CV |
| Agalpur | 18.3 | 29 | 160 | 1.1 | 2 | 144 | 55.2 | 62 | 112 | 3.7 | 3 | 72 |
| Balangir | 32.0 | 49 | 155 | 1.6 | 2 | 108 | 87.4 | 56 | 64 | 5.8 | 3 | 52 |
| Bangomunda | 10.1 | 22 | 218 | 0.8 | 1 | 173 | 39.0 | 52 | 133 | 2.9 | 3 | 100 |
| Belpada | 15.2 | 25 | 165 | 1.0 | 1 | 135 | 53.0 | 54 | 101 | 3.8 | 3 | 89 |
| Deogaon | 14.4 | 28 | 191 | 0.9 | 2 | 172 | 45.6 | 43 | 94 | 3.5 | 3 | 87 |
| Gudvella | 19.9 | 26 | 130 | 1.6 | 2 | 110 | 76.2 | 66 | 86 | 4.4 | 3 | 62 |
| Khaprakhol | 17.5 | 24 | 134 | 1.3 | 2 | 121 | 56.8 | 53 | 94 | 3.9 | 3 | 84 |
| Loisingha | 12.0 | 22 | 182 | 0.9 | 2 | 191 | 43.2 | 37 | 85 | 3.4 | 3 | 76 |
| Muribahal | 15.0 | 26 | 171 | 1.1 | 1 | 135 | 53.6 | 57 | 107 | 4.6 | 4 | 81 |
| Patnagarh | 17.4 | 22 | 128 | 1.2 | 1 | 121 | 65.3 | 59 | 91 | 4.5 | 4 | 82 |
| Puintala | 20.4 | 28 | 136 | 1.5 | 2 | 113 | 66.0 | 49 | 74 | 4.4 | 3 | 60 |
| Saintala | 12.0 | 17 | 143 | 1.2 | 1 | 121 | 52.5 | 42 | 81 | 4.6 | 3 | 67 |
| Titilagarh | 15.7 | 24 | 150 | 1.4 | 2 | 138 | 78.1 | 66 | 85 | 6.1 | 3 | 53 |
| Turekela | 14.5 | 25 | 170 | 1.0 | 2 | 150 | 46.2 | 42 | 92 | 3.9 | 3 | 83 |
| **Dist Avg.** | **16.7** | **26** | **160** | **1.2** | **2** | **138** | **58.4** | **53** | **93** | **4.2** | **3** | **75** |

* 1. **Probability of annual rainfall**

The results of the probability of annual rainfall in Fig. 2 indicated that 90% dependable rainfall is above 1000 mm in Balangir and Gudvella which assures the requirement of medium duration rainfed rice for these blocks. Deogaon, Patnagarh, Puintala and Titilagarh receive dependable rainfall between 850 to 1000 mm at 90% probability indicating rainfall deficit for moisture-sensitive crops. Rainfall probability at 75% is more than 1300 mm in Gudvella block which is considered as suitable for most crops.



**Fig. 2. Probability of annual rainfall (Incomplete Gamma)**

* 1. **Trend Analysis**

A significant increase in annual average rainfall trend was observed at Bangomunda and Patnagarh whereas a significant decreasing trend was noticed at Belpada, Loisingha, Muribahal, Titilagarh and Turekela. Blocks like Agalpur, Balangir, Deogaon, Gudvella, Khaprakhol, Puintala and Saintala did not show any increasing or decreasing trend. Four blocks out of fourteen viz. Bangomunda, Khaprakhol, Patnagarh and Saintala showed a significant increase in annual rainy days trend whereas Belpada, Gudvella and Loisingha blocks showed a significant decrease in rainy days trend as displayed in Table 4.

Blocks namely Belpada, Loisingha and Turekela showed significant negative trends for both monsoon rainfall and rainy days. In the case of the monsoon trend, only Belpada showed a decreasing trend in rainfall trend and blocks namely Balangir, Bangomunda, Deogaon, Patnagarh, Puintala and Titilagarh showed a positive trend for both rainfall and rainy days. Khaprakhol and Muribahal showed an increasing trend in both winter rainfall and rainy days. Whereas in the case of summer trends, Bangomunda, Muribahal, Saintala and Turekela showed increasing trends for both rainfall and rainy days, whereas Patnagarh showed a decreasing trend for rainfall.

**Table 4. Annual and seasonal rainfall trend of Bolangir district**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Block** | **Winter** | | **Summer** | | **Monsoon** | | **Post-Monsoon** | | **Annual** | |
| **RF** | **RD** | **RF** | **RD** | **RF** | **RD** | **RF** | **RD** | **RF** | **RD** |
| Agalpur | **↑** |  |  | **↑** |  |  |  |  |  |  |
| Balangir |  |  | **↑** |  |  | **↓** | **↑** | **↑** |  |  |
| Bangomunda | **↑** |  | **↑** | **↑** | **↑** |  | **↑** | **↑** | **↑** | **↑** |
| Belpada |  |  |  |  | **↓** | **↓** | **↓** |  | **↓** | **↓** |
| Deogaon |  |  |  |  |  |  | **↑** | **↑** |  |  |
| Gudvella |  |  |  |  |  | **↓** |  |  |  | **↓** |
| Khaprakhol | **↑** | **↑** | **↑** |  |  |  |  |  |  | **↑** |
| Loisingha |  |  |  |  | **↓** | **↓** |  |  | **↓** | **↓** |
| Muribahal | **↑** | **↑** | **↑** | **↑** | **↓** |  |  | **↑** | **↓** |  |
| Patnagarh | **↑** |  | **↓** | **↑** | **↑** |  | **↑** | **↑** | **↑** | **↑** |
| Puintala |  |  | **↑** |  |  |  | **↑** | **↑** |  |  |
| Saintala |  |  | **↑** | **↑** |  | **↑** | **↑** |  |  | **↑** |
| Titilagarh |  |  |  |  |  | **↓** | **↑** | **↑** | **↓** |  |
| Turekela |  |  | **↑** | **↑** | **↓** | **↓** |  | **↑** | **↓** |  |

**(↑**= Significant increasing trend and **↓**= Significant decreasing trend)

**3.4** **Agro-climatic Onset of Monsoon**

The date for the agroclimatic onset of monsoon for all blocks of Balangir district was found between 10-25 June as shown in Fig 3. The onset for Titilagarh block was found between 10-15 June and for Agalpur, Balangir, Belpada, Deogaon, Gudvella, Muribahal, Patnagarh, Puintala, Saintala and Turekela blocks between 15-20 June. The onset for the rest of the blocks viz. Bangomunda, Khaprakhol and Loisingha were found between 20-25 June.

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**Fig. 3. Agro-climatic Onset of Monsoon (1991-2023)**

**4. SUMMARY AND CONCLUSION**

The findings of the study indicated that Balangir and Gudvella blocks are suitable for growing most crops, especially rice, green gram, horse gram, black gram, groundnut, sesame, mustard, sugarcane etc. and the major cropping system suggested is Rice-Pulses-Vegetable system. Based on the result of the agro-climatic onset of cropping season, it is recommended to start different agricultural activities like pre-sowing land preparation etc. from 10 to 25 June keeping in mind the monsoon onset of the respective year. With the ongoing challenges posed by climate change in drought-prone regions, adopting adaptive strategies based on detailed rainfall analysis becomes an essential tool for ensuring food security and enhancing agricultural productivity. As further advancements in technology and data analysis are made, the potential to improve decision-making in crop planning will only increase, offering more robust solutions to mitigate the impacts of climate variability and encourage drought-resilient agricultural systems.

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**2.**

**3.**

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