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Rainfall And Drought Characteristics For Crop Planning In Cuttack District Of Odishastate, India

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Abstract
The increasing frequency of agricultural droughts and variability in rainfall patterns over the past three decades prompted this study, which analyzed 34 years of block-wise daily rainfall data (1988-2021) from Cuttack district, Odisha. The aim was to determine the long-term average and temporal variability of rainfall on weekly, monthly, seasonal, and annual scales, with a focus on identifying strategies to mitigate production risks in the region. The average annual rainfall in Cuttack was 1597.6 mm, with August receiving the highest amount of rainfall (476 mm), followed by July (407 mm) during the monsoon season. A trend analysis on rainfall over the past 34 years showed an increasing pattern of an average 6.03 mm and 3.6 mm per year in annual and kharif season rainfall, respectively. Agricultural droughts were frequently observed during the early (22-28 Standard Meteorological Week) and late (36-42 SMW) stages of kharif crops. The study also revealed that the station is prone to mild-moderate meteorological droughts of different intensities, including mild, moderate, and severe. To minimize production risks, short duration, low water-requiring, high-value crops such as maize, pulses, oilseeds, and some vegetables are recommended for this region.

Keywords: *Rainfall variability, Agricultural drought, Meteorological drought, Initial and conditional probabilities, incomplete gamma distribution, Crop planning.*

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I. Introduction

The weather has a direct impact on whether our food security is assured or threatened since rain is a natural blessing and drought is a calamity for all living things. Defining the ways to reduce risk towards sustainable production will undoubtedly benefit from characterising these weather occurrences. To highlight the consequences of rainfall variability in agricultural planning and management, rainfall records must be interpreted in connection to the local agricultural practises that are practised. Cuttack district located in the east coast plain and hill region (XI) of Odisha state, is a unique district that experiences tropical climate, with the summer being hot and the winter cold. The unpredictability of monsoonal rainfall significantly influences agricultural productivity. The planning ofrainfed agriculturein the region is therefore governed by the quantity and spatial variability of rainfall. A location's climatological information is crucial for reducing production risk. (Jena *et al*., 2022). Planning the most effective agricultural operations or activities in this situation requires the notion of assessing probabilities with regard to a certain amount of rainfall. To explore the likelihoods of rainfall occurring, the Markov chain model has been widely employed (Mandal, 2015; Manikandan et al., 2016; Pattanayak et al., 2018; Dabral et al., 2019;). Many times during a given crop growing period, decisions must be made depending on the likelihood of obtaining a specific quantity of rainfall during a specific week. The primary crop in the area is rice. The choice of crops, their management, and the overall agricultural planning of an area depend on an understanding of both the intensity and frequency of drought.

The primary objective of this study is to investigate the changes in rainfall patterns in Cuttack district, Odisha, over the past 34 years and their impact on agriculture, with a particular focus on drought management. Specifically, the study aims to analyze 34 years of daily rainfall data to understand how rainfall averages and patterns vary throughout the year, including weekly, monthly, seasonal, and annual trends. It will also identify any trends in total annual rainfall and during the kharif season (monsoon period). Additionally, the study will examine the frequency and intensity of agricultural droughts, especially during critical stages of the kharif cropping season. Based on these findings, recommendations will be provided for crop selection to mitigate the risks associated with fluctuating rainfall patterns and drought conditions in the region.

II. Material And Methods

The study site

Cuttack is the oldest district of Odisha State, and is located at a latitude of 20° 03″ to 20° 40″ N and a longitude of 84° 58" to 86° 20″ E and altitude is 36m above mean sea level (Figure 1). Cuttack city is flanked by river Mahanadi in the north and Kathajodi in south. The district comprises three subdivisions (Cuttack, Athagarh, Banki) and 14 development blocks (viz. Baranga, Cuttack Sadar, Mahanga, Kantapada, Niali, Nischintakoili, Salepur, Tangi-Choudwar, Banki, Damapada, Athagarh, Badamba, Narasinghpur, Tigiria).

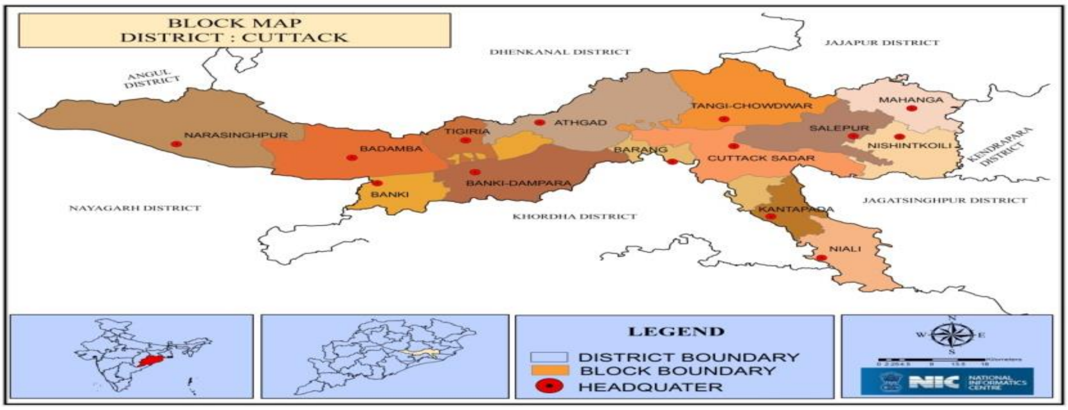

Fig.1. Study area showing blocks of Cuttack district.

The soils in the district fall under four orders - Alfisols, Inceptisols, Entisols, and Vertisols - as per the modern system of Soil classification, with the black soils of Tangi-Choudwar Block falling under Vertisols.

Data collection

Long-term daily rainfall data for **34** years (1988 - 2021) for all the blocks of the district were collected from the District Agricultural Office of Cuttack and also the SRC (Special Relief Commissioner) rainfall data of Cuttack district. Daily rainfall data were converted into a weekly, monthly, seasonal and annual basis. The detailed analysis of rainfall for four important parameters viz- agricultural drought, meteorological drought, initial and conditional probabilities and incomplete gamma probability was done by using a software (**WeathercockV** 1.0) at the Central Research Institute for Dryland Agriculture (CRIDA) Hyderabad, India. The criteria used under the software for individual parameters are as under.

Agricultural drought:

This situation can occur without being directly influenced by alterations in precipitation levels. Instead, it emerges due to inappropriate agricultural practices leading to soil degradation and erosion, which ultimately results in a deficiency of water accessible to crops. As stated by the National Commission on Agriculture (1976), this type of drought can be categorized into two: kharif season drought and rabi season drought. Kharif season drought is defined as experiencing a minimum of four consecutive weeks with less than half of the usual weekly rainfall of 5 mm or more. On the other hand, rabi season drought is characterized by enduring six consecutive weeks with less than half of the normal rainfall.

Meteorological drought:

Meteorological drought takes place when a region experiences an extended period of below-average rainfall. As outlined by the Indian Meteorological Department, there are three classifications of drought based on the deviation of rainfall from the normal levels:

a. Mild drought :< 25%
b. Moderate drought: 26-50%
c. Severe drought :> 50%

Initial and Conditional Probabilities:

The probabilities for four different conditions on a weekly basis have been derived using Markov chain analysis, as indicated in the following:

a. Initial Probability: The software employs specific formula to calculate the likelihood of receiving particular amounts of rainfall during a given week.

$P(D) = F(D)/n$ and $P(W)/n = F(W)/n$ (1)

Where,
P(D)- Probability of occurrence of a dry week in n years
F(D)- Frequency of occurrence of dry week in n years
P(W)- Probability of occurrence of wet week in n years
F(W) - Frequency of occurrence of wet week in n years

b. Conditional Probability: This represents the probability of the upcoming week being wet, given that the current week is also wet. It includes four different probabilities: P(W/W), P(D/W), P(D/D), and P(W/D). Where,
P(D/W) - probability of getting next week as dry provided the current week is wet
P(D/D) - probability of getting next week as dry provided the current week is dry
P(W/W) - probability of getting next week as wet provided the current week is wet

The first letter in the conditional probability indicates the next week and the second letter indicates the current week.

Incomplete Gamma Probability

Understanding and predicting rainfall patterns is crucial for effective crop planning, especially in rainfed regions.

a. Assured rainfall, which is calculated for each standard meteorology week, refers to the amount of rainfall at various probability levels (ranging from 10% to 90%). This computation is achieved by fitting the Incomplete Gamma Distribution model.

b. The software utilizes the gamma probability tool to generate tables of assured rainfall at different probability levels.

c. Analyzing the probability of rainfall offers significant advantages in predicting the minimum assured rainfall, particularly for effective crop planning in the rainfed regions.

The software implements the following formula (2),as suggested by Victor (2000) and Kar (2002):
The equation for the standard Gamma distribution is:

$$f(x) = \frac{x^{y-1}e^{-x}}{\tau(\gamma)} \text{where, } x \geq 0;\ \gamma > 0 \qquad (2)$$

$\gamma\ is\ the\ shape\ param, \tau\ is\ the\ Gamma\ function$ and f(x) is the probability function of the gamma distribution.

III. Result And Discussion

Block wise annual trend of rainfall of Cuttack district

The annual rainfall trend showed increasing trend in all of the blocks of Cuttack district. Sharp increasing trend was noticed in Banki&Damapada (34.82 mm/year) followed by Kantapada (25.25 mm/year), Mahanga (9.15 mm/year), Athagarh (8.68 mm/year). On the other hand trend of monsoonal rain is slightly decreasing only in five blocks (Barang, Cuttack Sadar, Niali, Narasinghpur and Tigiria). In the rest of the blocks, rainfall was increasing upto 26 mm/season (table 1)

Table 1: Rainfall trend in blocks of Cuttack district.

Block	Annual Rain (mm)	Annual rain equation	Monsoonal rain equation
Athagarh	1870	y = 8.687x + 1718	y = 6.384x + 1298
Banki	1808.5	y = 34.82x + 1199	y = 26.55x + 927.3
Damapada	1808.5	y = 34.82x + 1199	y = 26.55x + 927.3
Barang	1575.6	y = -3.924x + 1644	y = -5.292x + 1290
Badamba	1378.7	y = 7.291x + 1251	y = 2.789x + 1005
Cuttack-Sadar	1553.7	y = 3.325x + 1495	y = -1.891x + 1249
Kantapada	1789.3	y = 25.25x + 1347	y = 19.00x + 1031
Mahanga	1706.8	y = 9.15x + 1546	y = 6.436x + 1218
Niali	1662.3	y = -7.054x + 1785	y = -5.773x + 1332
Nischintakoili	1483.8	y = 4.057x + 1412	y = 1.109x + 1076
Narasinghpur	1410	y = -0.382x + 1416	y = -0.448x + 1077
Salepur	1436.4	y = 5.503x + 1340	y = 4.874x + 995.7
Tangi-Choudwar	1431.8	y = 8.185x + 1288	y = 5.617x + 990.2
Tigiria	1662	y = -10.34x + 1843	y = -8.938x + 1435

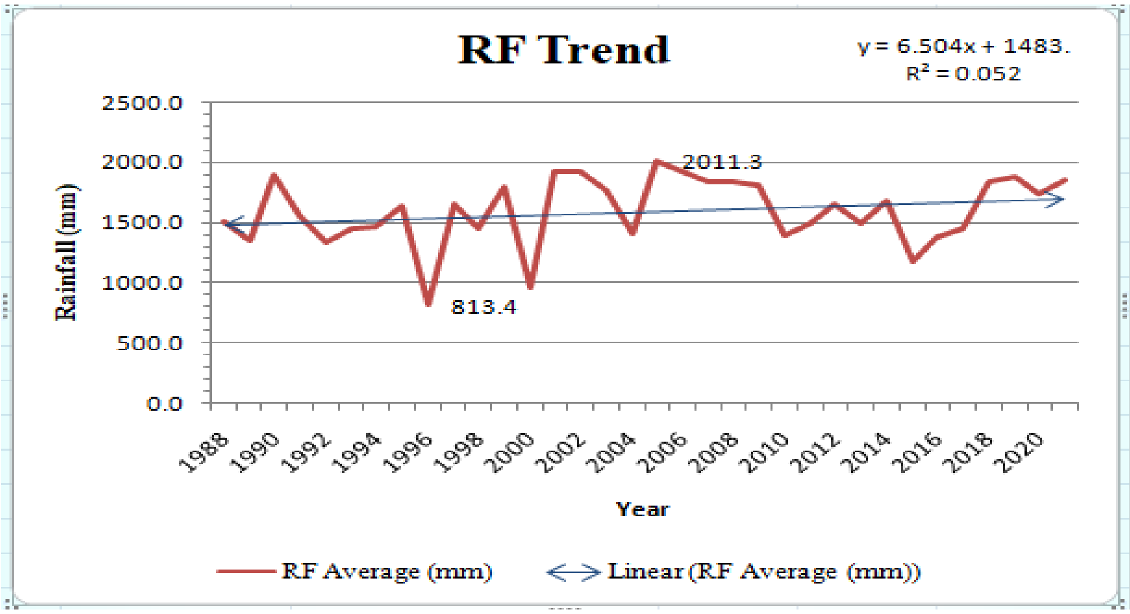

Fig. 2. Overal trend of rainfall about of 34 years.

The rainfall data over the years shows considerable fluctuations, with notable lows and highs. Around 1996, the average annual rainfall dropped to 813.4 mm, while in 2005 it peaked at 2011.3 mm. The linear trend analysis reveals a slope of 6.504, indicating a slight upward trend in average annual rainfall during the period. However, the R-squared value of 0.052 is quite low, suggesting that the linear model accounts for only about 5.2% of the variability in the rainfall data. This implies a weak linear relationship between the years and average rainfall. Examining the periods within the data, the early 1990s exhibit a general increasing trend in rainfall, followed by a noticeable drop in the early 2000s. The data then shows a peak around 2005, followed by fluctuating values until 2020.

Seasonal variability

Theresult of analysis of rainfall variability in Cuttack district's 14 blocks using standard deviation and coefficient of variation is given in table 2. Kharif season had lower variability (CV 45.3% to 60.6%) than rabi (CV 126.9% to 176.4%). Results showed that rainfall during kharif was more consistent and reliable than rabi (Table-2). The standard deviation values were higher during kharif, indicating a greater amount of rainfall during that season. Banki and Damapada blocks had the highest variation of CV percentage during rabi season (176.4%), while Badamba had the least variation during kharif season (45.3%). Rainfall cannot be relied upon in any season due to its coefficient of variation (CV) values being higher than the seasonal threshold level of 50%.Understanding rainfall variability is essential for effective water resource management and agricultural planning in the region.

Table 2. Block wise Seasonal rainfall variability of Cuttack district

Blocks	Season	Av. Rain (mm)	% of total rain	SD	CV %
Athagarh	Kharif	1410.4	75.4	174.6	49.7
	Rabi	209.7	14.9	124.0	140.0
Banki	Kharif	1392.0	77.0	199.6	57.1
	Rabi	212.3	11.7	141.8	176.4
Damapada	Kharif	1392.0	77.0	199.6	57.1
	Rabi	212.3	11.7	141.8	176.4
Barang	Kharif	1198.3	76.1	130.6	46.0
	Rabi	173.9	11.0	88.9	141.6
Badamba	Kharif	1054.7	76.5	118.5	45.3
	Rabi	152.6	11.1	87.9	154.7
Cuttack-Sadar	Kharif	1216.6	78.3	145.7	48.4
	Rabi	167.6	10.8	94.0	146.8
Kantapada	Kharif	1363.8	76.2	200.4	58.3
	Rabi	234.2	13.1	110.9	126.9
Mahanga	Kharif	1330.9	78.0	175.9	53.3
	Rabi	193.3	11.3	108.8	151.4
Niali	Kharif	1231.1	74.1	179.8	60.6
	Rabi	235.7	14.2	120.8	135.2
Nischintakoili	Kharif	1095.6	73.8	131.3	48.5

	Rabi	210.8	14.2	134.4	161.9
Narasinghpur	Kharif	1069.9	75.9	122.7	47.3
	Rabi	144.5	10.2	84.4	138.3
Salepur	Kharif	1081.1	75.3	131.8	50.7
	Rabi	184.3	12.8	111.7	154.5
Tangi-Choudwar	Kharif	1088.6	76.0	130.0	48.8
	Rabi	174.7	12.2	102.4	147.0
Tigiria	Kharif	1279.0	77.0	146.1	46.3
	Rabi	183.7	11.1	100.6	154.6

It may be concluded that the CV percentage inversely varied with the average rainfall of the respective blocks. i.e CV decreased in wet month and increased in dry month. When CV is more than 100 percent, we cannot depend upon the rainfall that may not be reliable.

Meteorological drought

Weather conditions in Cuttack were analysed over 34 years using IMD classifications of no drought, moderate drought, and severe drought. The overall scenario for meteorological drought was 85%, 12.5%, and 2.5% for no drought, moderate drought, and severe drought years, respectively, as shown in Table 3.

Table 3 Severity of meteorological drought in Cuttack district.

Blocks	Nodrought		Moderatedrought		Severedrought	
	No. ofyears	% of totalyears	No. ofyears	% of totalyears	No. ofyears	% of totalyears
Athagarh	27	79	6	18	1	3
Banki	26	76	8	24	0	0
Damapada	26	76	8	24	0	0
Barang	31	91	3	9	0	0
Badamba	30	88	3	9	1	3
Cuttack Sadar	29	85	4	12	1	3
Kantapada	26	76	6	18	2	6
Mahanga	29	85	4	12	1	3
Niali	29	85	3	9	2	6
Nischintakoili	30	88	2	6	2	6
Narasinghpur	31	91	3	9	0	0
Salepur	30	88	4	12	0	0
Tangi-Choudwar	28	82	5	15	1	3
Tigiria	31	91	3	9	0	0
DistrictAvg.	29	85	4.15	12.5	0.84	2.5

Among Cuttack's blocks, 76-91% of years had no drought. Three blocks faced more severe drought i.e 2 of 34 years. All blocks had 2-8 years of moderate drought, while Nischintakoili had only 2 years. Banki and Damapada had the maximum 8 drought years. Overall, moderate drought occurred more frequently. While moderate droughts can be managed through improvements in irrigation and crop management, during severe drought conditions, contingent crop planning and supplemental irrigation become indispensable for achieving successful crop production and providing forage for livestock.

Agricultural drought

All 14 blocks in Cuttack district experienced agricultural drought during the past 34 years. Narasinghpur, Salepur, BankiDamapada, and Kantapada had the most agricultural droughts, with 17, 16, 14, and 14 years respectively. Early and late agricultural droughts were more frequent than mid-season droughts across all blocks. Kantapada had the highest number of early droughts, while Salepur, Nischintakoili, and Narasinghpur had more mid-season droughts. Narasinghpur had more late-season droughts, and Barang had the least. Late-season droughts were more frequent than early and mid-season droughts, resulting in a significant reduction in grain yield. So the only option may be to sow rabi crops during this time.

Table 4: Agricultural drought during Kharif season in all the blocks of Cuttack district

Block	Kharif						
	Total No. of Drought years	Early drought (22-28 SMW)		Mid drought (29-35 SMW)		Late drought (36-42)	
		No. of years	SMW	No. of years	SMW	No. of years	SMW
Athagarh	6	2	22-25	0	0	4	35-42
Banki	14	5	22-29	3	30-35	6	34-42
Damapada	14	5	22-29	3	30-35	6	34-42
Barang	7	6	22-30	0	0	1	36-40

Badamba	12	6	22-30	2	30-35	4	37-42
Cuttack-Sadar	11	4	22-29	3	30-37	4	34-42
Kantapada	14	7	22-31	3	30-38	4	34-42
Mahanga	11	4	22-31	2	32-38	5	35-42
Niali	10	5	22-30	1	30-40	4	35-42
Nischintakoili	11	2	22-32	4	29-37	5	35-42
Narasinghpur	17	5	22-26	4	29-38	8	36-42
Salepur	16	6	22-30	5	33-38	5	36-42
Tangi-Choudwar	13	4	22-30	3	29-38	6	33-42
Tigiria	10	3	22-27	3	30-39	4	38-42

SMW – Standard Meteorological Week

Incomplete Gamma distribution

Table 5 presents rainfall data for annual and weekly periods, indicating a Gamma distribution at five probability levels. The amount of assured rainfall is less at higher probability levels in all blocks of Cuttack district, and weekly patterns are similar. The table shows that the amount of assured rainfall at the 50% probability level is in line with normal values and annual rainfall data.

Table 5 Gamma distribution of assured annual rainfall at different probability levels.

Blocks	Annual Rain (mm)	Probability levels (%)				
		90	75	50	25	10
Athagarh	1870.0	1258.6	1509.4	1825.5	2183.1	2541.9
Banki	1808.5	1099.6	1379.9	1744.5	2168.4	2603.4
Damapada	1808.5	1099.6	1379.9	1744.5	2168.4	2603.4
Barang	1575.6	1170.5	1342.8	1553.5	1785.2	2012.3
Badamba	1377.8	998.2	1158.3	1355.5	1573.9	1789.4
Cuttack-Sadar	1553.7	1007.7	1228.8	1510.6	1832.7	2158.6
Kantapada	1789.3	1086.7	1364.4	1725.6	2145.9	2577.2
Mahanga	1706.8	1178.2	1397.0	1670.8	1978.3	2285.1
Niali	1685.6	1106.7	1342.1	1641.1	1981.6	2325.3
Nischintakoili	1483.8	1024.7	1214.9	1452.8	1719.9	1986.3
Narasinghpur	1410.0	1094.8	1231.2	1395.6	1574.0	1747.0
Salepur	1436.4	1001.3	1182.2	1407.7	1660.4	1911.8
Tangi-Choudwar	1431.8	987.5	1171.5	1401.7	1660.2	1918.2
Tigiria	1662.0	1185.7	1385.3	1632.4	1907.4	2179.6

Initial and Conditional probability

Table 6 shows the initial and conditional probabilities of receiving 10, 20, and 50 mm rainfall per week in a region with undulating topography, deep ground water, and varying soil texture. It is difficult to till the land for kharif crops without pre-monsoon showers, and at least 10 mm of rainfall per week is required to start land preparation, sowing, and other cultural practices. The probability of getting 10 mm or more rainfall exceeded 50% for 20 weeks during 21-40 SMW. Successful crop production requires 20 mm/week of rainfall in general and 50 mm/week for rice crops. The probability of receiving 20 and 50 mm rainfall per week is more than 50% for 17 (24-40 SMW) and 13 weeks (26-38 SMW), respectively, except in the 28th week, when the probability of getting 50 mm rain is only 47%.

After the onset of monsoon, the 24th standard week (11-17th June) can be considered for final land preparation and sowing of upland kharif crops. Maize can be sown in the 24th-25th standard week with low risk, as rainfall of 10 mm or more exceeds a 50% probability. It is favorable to sow rice crop earlier by broadcasting seeds around the 25th-26th week (18-31 June), and transplanting of rice should be completed by the middle of July.

The probability of getting 50 mm rainfall exceeds 50% between 25-38 SMW, except in the 26th and 28th weeks, where it is only 47% and 48%, respectively. Regions with highly erratic and short rainfall may experience dry periods within the wet season, which can affect crop development if it coincides with a sensitive phonological stage. However, dry periods at the ripening stage of rice crop are sometimes beneficial. The peak vegetative growth stage and reproductive stage can be completed around the 38th standard week. As the probability of rainfall becomes considerably low from the 39th standard week, it is necessary to adjust sowing/transplanting so that the reproductive stage of the rice crop does not fall in this moisture stress period, which can have a detrimental effect on crop yield.

Table 6: Initial and conditional probability (%) of receiving weekly rainfall of 10, 20 and 50 mm in kharif season at Cuttack district

		Initial Probabilities (%)			Conditional Probabilities (%)	
		P (W)			P (W/W)	
SMW	**10 mm**	**20 mm**	**50 mm**	**10 mm**	**20 mm**	**50 mm**
20	50	38	15	62	60	30
21	57	43	24	58	47	22
22	47	34	12	57	41	17
23	57	44	23	64	57	28
24	72	63	42	69	63	49
25	83	78	50	86	84	50
26	88	78	50	90	79	47
27	91	85	58	92	85	59
28	81	73	47	80	73	48
29	93	86	62	93	88	60
30	95	86	60	95	86	53
31	91	85	60	92	87	59
32	94	89	67	93	88	63
33	95	90	68	95	91	70
34	90	83	59	89	85	61
35	89	79	60	90	82	64
36	90	80	59	89	78	57
37	86	77	51	88	82	53
38	84	76	50	87	81	55
39	70	58	34	69	57	38
40	67	57	33	70	59	28
41	59	46	30	61	52	35

IV. Conclusion

Crop Planning and Risk Mitigation for Rainfall Anomalies and Droughts

Analyze Rainfall Patterns

The study highlighted the need for a revised cropping pattern to minimize risks associated with rainfall anomalies and droughts in Cuttack district, Odisha. The analysis of 34 years of daily rainfall data showed significant variability in rainfall patterns, emphasizing the importance of adapting agricultural practices to these changes.

Investigate Agricultural Droughts

The findings underscored the frequency and intensity of agricultural droughts during critical stages of the kharif cropping season. By understanding these patterns, it becomes clear that strategic crop planning is essential to mitigate production risks.

Provide Crop Recommendations

Based on the rainfall and drought analysis, the study recommends cultivating short-duration rice varieties suitable for different land types to ensure resilience against rainfall variability. Varieties like Vandana, Jogesh, Kamesh, and Jaladidhan for uplands, Naveen, Sahbhagidhan, Lalat, and Kanchan for medium lands, and Pooja, Sarala, Swarna, and Mandakini for lowlands are suggested. Additionally, finishing rice transplantation by the first two weeks of July is crucial to leverage the probability of receiving adequate rainfall.

To conserve water and reduce input usage, adopting the System of Rice Intensification (SRI) is highly encouraged. For areas prone to variable rainfall, crops with lower water requirements, such as maize and pulses, are recommended. Maize varieties like Kiran, HQPM, VL-16, Pratap, and Kalinga Raj can be sown until the 25th week (18-24 June).

Strategies for Moderate and Late Drought Conditions

- Moderate Drought (up to 29th September): Direct seeding of short-duration rice (Jaladidhan, Jogesh, Sidhant), maize, and arhar is recommended. Intercropping combinations like Arhar + Cowpea (2:2), Arhar + Sesamum (2:4), Arhar + Radish (2:2), and Maize + Cowpea should be considered with assured irrigation.
- Late Drought (up to 21st October): Sesamum, Niger, Horse gram, rice bean, and winter crops like brinjal, okra, and radish are suggested. Intercropping options such as Arhar + Horsegram (2:3), Maize + Mustard, and Maize + Niger should be adopted with minimum tillage sowing. Fodder crops like mesta, roselle, rice bean, and cowpea are recommended for livestock areas.

These strategic recommendations aim to enhance the resilience of the agricultural system in Cuttack district against the challenges posed by changing rainfall patterns and frequent droughts.

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