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Spatial and temporal variability of rainfall in Khordha district of Odisha

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Abstract
Seasonal variability of rainfall in different blocks of Khordha district is of utmost importance in this existing scenario of changing climate and temperature. The present study has been undertaken using rainfall data of the district for 25 years (1993-2017). Seasonal rainfall has been characterised under four seasons-Winter, Summer, South west monsoon and north east monsoon which contributes around 1.5%, 10.5%, 72.7% and 15.3% respectively to the mean annual rainfall of the district. Year wise variability of rainfall revealed that year 2013 has received the maximum annual rainfall (1873 mm) in 105 rainy days and year 1996 has received least annual rainfall (778 mm) in 80 numbers of rainy days. Trend line analysis of annual and seasonal rainfall and rainy days visualised a decreasing trend in number of rainy days whereas as slightly decreasing trend in annual rainfall and slightly increasing trend in seasonal rainfall. Extreme rainfall events of different blocks were different depending upon the highest amount of rainfall they received in the last 25 years. Markov Chain probability model determined the initial and conditional probabilities of dry and wet weeks at 20 mm threshold limit. Initial land preparations can be done in the standard meteorological weeks having more than 30% of initial probability of wet weeks (21-23 SMW) and sowing or transplanting can be done in the SMWs having more than 50% of initial probability of wet weeks (24-26 SMW). PET is also an important factor in assessing the drought condition and for better crop water management planning. PET calculated by modified Penman method is of more concern and it has been found out from the graph that the post monsoon period (October to December) and pre monsoon period (January to May) is having water deficit condition whereas monsoon period (June to September) is having water surplus condition. The surplus water needs to be stored for efficient utilisation in the future.

Keywords: Variability, Markov chain, SMW, PET, modified penman, surplus

Introduction
Odisha is an agriculture dominant state where about 70% of the citizens depend on agriculture for their livelihood. Therefore crop failure and yield loss creates havoc among the farmers. Hence, the crops can be saved by analysing the rainfall variability and deciding the probability of dry and wet spells using Markov chain probability model before sowing of the crops. Initial field preparation, planning of crop sowing/planting and carrying out all agricultural operations in an area requires the details of distribution of rainfall, onset and withdrawal of rainy season and periods of dry and wet spells. Markov chain probability model helps to study the chances of occurrences of dry and wet spells (Pandharinath, 1991). It can be used for analyzing rainfall data to obtain specific information needed for crop planning and for carrying out agricultural operations. Water surplus conditions also prevail during monsoon period and so the surplus water can be used in future during water stress condition in *rabi* season.

Rainfall is one of the substantial weather indicators of climate change. Spatial and temporal variability of rainfall not only provides the trend of the weather condition of an area but also helps the farmer to know when to perform the agricultural operations in the field. It is of utmost importance while preparing the agro met advisory services (AAS) keeping in view the trend of rainfall in a particular area. Rising temperature across the globe results in change in precipitation and atmospheric moisture through a more active hydrological cycle, leading to increase in water holding capacity throughout the atmosphere at a rate of about 7% per °C (Hossain *et al*., 2014) [2]. Rising temperatures in combination with rainfall anomalies due to climate change strongly influence soil moisture. Therefore, the study has been undertaken for analysing the spatial and temporal variability of rainfall patterns in Khordha district of Odisha.

Materials and methods

The study has been conducted for Khordha district of Odisha for rainfall characterisation and probability analysis which lies between $19^0$55' to $20^0$25'N Latitude and $84^0$55' to $86^0$5'E Longitude. Khordha has normal rainfall of 1408 mm with maximum and minimum temperature of 42.2 and 11.1 degree Celsius respectively. The district comprises of 10 blocks namely Balianta, Balipatna, Banapur, Begunia. Bhubaneswar, Bolagarh, Chilika, Jatani, Khordha & Tangi. All the weather data including maximum temperature (T_{max}), minimum temperature (T_{min}), morning and evening relative humidity (RH_1, RH_2), bright sunshine hours (BSH), wind speed (WS) and evaporation (E) has been collected from the Department of Agricultural Meteorology, OUAT, BBSR for the period 1993-2017 (25 years). Block wise rainfall data of Khordha has been obtained from SRC site of Govt. of Odisha for the same period.

A. Temporal Variability of Rainfall and Rainy days

Daily rainfall data of Khordha district for 25 years (1993-2017) have been used to analyse the temporal variability. Year wise annual rainfall and rainy days along with Standard deviation and coefficient of variation have also been estimated. Trend lines have also been shown in the respective graphs.

B. Spatial Variability of Rainfall

Block wise daily rainfall data have been used for spatial variability of rainfall. Mean annual, seasonal and monthly rainfall variability have been worked out by analysing rainfall block wise using Weather cock. "Rainy Day.exe" module has been used to analyse the rainfall data.

Annual Rainfall and Rainy days

According to India Meteorological Department, a day with rainfall equal to or more than 2.5 mm is termed as a rainy day for Indian region. Mean annual rainfall and rainy days has been calculated for different blocks using "Rainy day.exe" module of Weather Cock model. Standard deviation (SD) and Co-efficient of variance (CV) are also being calculated by using statistical equation.

Seasonal Rainfall and Rainy days

The whole year in Odisha condition is categorised into four seasons – Winter which includes January, February and March; Summer consisting of April and May; South West monsoon consisting of June, July, August and September; North East monsoon which includes October, November and December. The seasonal rainfall and rainy days along with SD and CV have been calculated for the same using the above said model.

C. Extreme Rainfall Events

The extreme rainfall events of ten different blocks have been found out using the daily rainfall data of the blocks of last 25 years (1993-2017).

D. Probability Analysis of Rainfall

Markov chain probability model for dry and wet spell analyses

In this study, weekly rainfall values have been computed from daily data series and were used for estimation of initial and conditional probability analysis based on Markov chain probability model as described by Pandarinath, 1991. In this method, 20 mm or more rainfall in a week is considered as wet week otherwise dry as the previous researchers (Pandarinath, 1991; Dash and Senapati, 1992) [4, 1] also used 20 mm as the threshold value. Initial, and conditional probability analysis for 52 SMWs were made by using equations from 1-6.

Initial probability

$$P(D) = F(D)/N \quad \text{(Eq. 1)}$$

$$P(W) = F(W)/N \quad \text{(Eq. 2)}$$

Where, P (D) = probability of the week being dry, F (D) = frequency of dry weeks, P (W) = probability of the week being wet, F(W) = frequency of wet weeks, and N = total number of years of data being used.

Conditional probabilities

$$P(DD) = F(DD)/F(D) \quad \text{(Eq. 3)}$$

$$P(WW) = F(WW)/F(W) \quad \text{(Eq. 4)}$$

$$P(WD) = 1 - P(DD) \quad \text{(Eq. 5)}$$

$$P(DW) = 1 - P(WW) \quad \text{(Eq.6)}$$

Where, P(DD) = probability of a week being dry preceded by another dry week, F(DD) = frequency of dry week preceded by another dry week, P(WW) = probability of a week being wet preceded by another wet week, F(WW) = frequency of a wet week preceded by another wet week, P(WD) = probability of a wet week preceded by a dry week, and P(DW) = probability of a dry week preceded by a wet week.

E. Calculation of Potential Evapotranspiration

Weather parameters like maximum and minimum temperature (^{0}C), relative humidity (%), rainfall (mm), bright sunshine hours (hr), wind speed (m/s) and evaporation (mm/day) have been used to calculate the potential evapotranspiration (PET) using 'PET Calculator' designed by CRIDA, Hyderabad. The PET calculator calculates PET in seven different methods namely Modified Penman, Hargreaves, Turc, Blaney Criddle, Christiansen, PET Open Pan and Penman Monteith. The study is more concerned with Modified Penman method as it is the most trusted one and largely followed. Year wise mean monthly PET has been calculated to plot a graph with annual precipitation.

Results and discussion

1. Year wise annual rainfall and rainy days

Annual rainfall of Khordha district has been recorded highest (1873 mm) in 2013 and lowest (778 mm) in 1996 (Table 1). Whereas, most number of rainy days have been observed in the year 1998 (127 days) and least in 2009 (77 days). Variability of the district annual rainfall comes around 19% and rainy days around 13%. Trend line shows that number of rainy days is having a decreasing trend and annual rainfall slightly decreasing trend (Fig. 1).

Table 1: Year wise annual rainfall and rainy days of Khordha district

YEAR	RF (mm)	Rainy Days
1993	1378	101
1994	1463	106
1995	1859	108
1996	778	80
1997	1482	93
1998	1510	127
1999	1473	102
2000	1208	95
2001	1685	84
2002	1685	84
2003	1868	109
2004	1055	78
2005	1436	86
2006	1685	84
2007	1412	93
2008	1447	99
2009	1400	77
2010	1490	86
2011	1175	93
2012	1321	87
2013	1873	105
2014	1414	81
2015	1001	86
2016	1185	92
2017	1530	98
SD	269	12
CV %	19	13

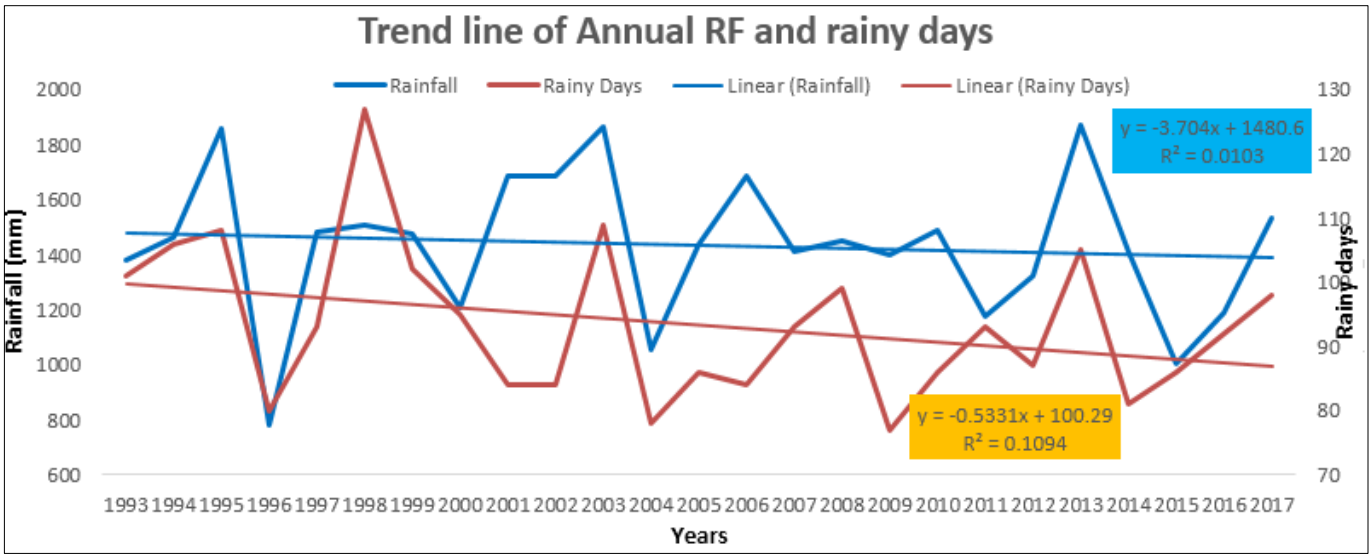

Fig 1: Trend line of annual rainfall and rainy days

2. Annual Rainfall and Rainy days

On an average the district receives annual rainfall of 1533 mm (1993-2017). Out of 10 revenue blocks most of them receives moderate rainfall (1300 to 1600 mm). Three revenue blocks with high rainfall (>1600) mm are Balianta, Bhubaneswar and Jatani and two blocks with low rainfall (<1300 mm) are Balipatna and Bolagarh (Table 2). The blocks receiving more than the district's average rainfall are Balianta, Bhubaneswar and Jatani. The Bhubaneswar block receives highest (1655 mm) rainfall while Balipatna the lowest (1111 mm).

The block wise mean annual rainfall variability in the district is observed to be 22 % (Table 2). Blocks namely, Banapur, Begunia, Bhubaneswar, Bolagarh and Khordha have high variability (>25%) whereas five blocks, namely Balianta, Balipatna, Chilika, Jatani and Tangi have low variability (<24%). Variability is maximum in Bolagarh block (32%) and minimum in Balipatna and Jatani blocks (20% each).

The district records on an average 56-69 rainy days annually (Table 2). Tangi block has the highest rainy days (69 days) and Bolagarh has the lowest rainy days (56 days). The number of rainy days observed in Balianta and Khordha blocks is close to the district average. Bolagarh has the highest variability (21%) of rainy days, while Banapur has the lowest variability (12%) of rainy days. Average variability of rainy days of the district is observed to be 13 % (Table 2). Seven out of ten blocks has the variability of 12-15 % of annual rainy days.

Table 2: Block wise mean annual rainfall with standard deviation and CV (%)

Block	Mean Rainfall	SD	CV (%)	Mean Rainy Days	SD	CV (%)
Balianta	1608	365	23	64	9	15
Balipatna	1111	227	20	60	9	16
Banapur	1423	359	25	67	8	12
Begunia	1336	396	30	59	8	14
Bhubaneswar	1655	419	25	67	9	13
Bolagarh	1241	392	32	56	12	21
Chilika	1445	312	22	60	10	17
Jatani	1625	329	20	68	9	13
Khordha	1430	354	25	65	10	15
Tangi	1452	341	24	69	10	15
District Mean	1533	330	22	64	10	13

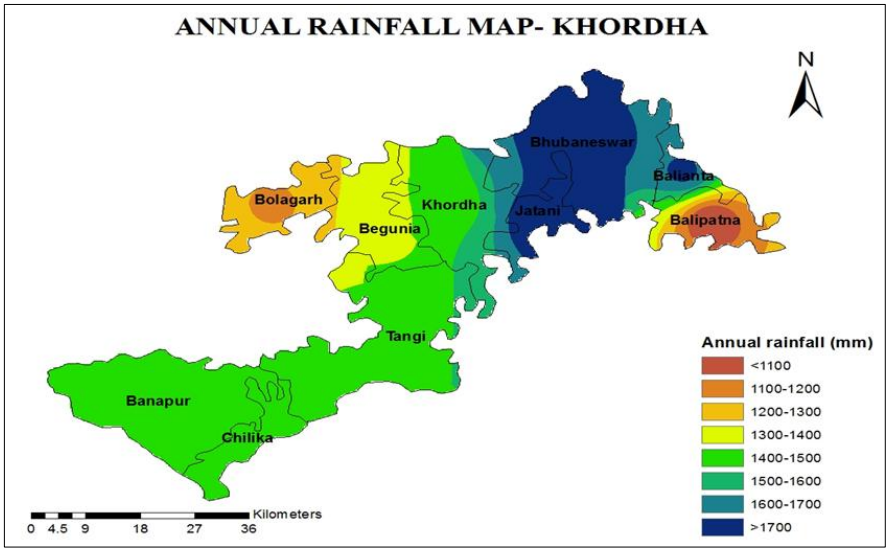

Fig 2: Mean Annual Rainfall of Khordha district

Pasupalak, 2015 reported that the variability of annual rainfall in Odisha was 21%. The variability of annual rainfall of Khordha district was calculated to be 22%. So, the present results confirmed the results of Pasupalak, 2015 for the Khordha district. Eight districts had high variability (>23%), while 10 districts had low variability (<20%). Variability was maximum (25%) in Sonepur district and minimum (16%) in Sundargarh district. In general the districts having high rainfall had less variability and more rainy days.

3. Seasonal Rainfall and Rainy days

Seasonal analysis of rainfall has been done for four seasons: Winter (December to February), summer (March to May), South West monsoon (June to September) and North East monsoon (October to November).

Winter

The average winter rainfall in the district comes around 23 mm contributing 1.5% to the annual rainfall. Six blocks receives more than 20 mm rainfall with Jatani as the highest (27 mm) and Balianta (15 mm) as the least (Table 3). The average rainfall variability is 116% with maximum variability of Chilika (181%) and minimum of Balianta (116%). The variability of rainy days is 99% and the number of rainy days varies within 1-2 days (Table 4).

Summer

All the regions receive summer rainfall more than the winter rainfall with average of 161 mm in Khordha district. Bhubaneswar receives highest amount of summer rainfall of 155 mm as compared to other blocks and Balipatna receives the least, i.e., 85 mm (Table 3). Average variability of summer rainfall is 81%. Mean rainy days of summer season varies from 4-7 days. The rainy days variability during summer has been observed as 29%. Bolagarh shows maximum (68%) variability and Balipatna the minimum (31%) (Table 4).

South West monsoon

Normal rainfall during SW monsoon is 1114±266 mm, which is nearly 72.6% of the normal annual rainfall (Table 3). Four blocks namely, Balianta, Bhubaneswar, Jatani and Khordha receives high amount of monsoon rainfall (>1100 mm). Bhubaneswar block receives the maximum (1241 mm) and Balipatna block receives minimum (845 mm) of monsoon rainfall. Average amount of monsoon rainfall has been received by 4 blocks, namely, Banapur, Begunia, Chilika and Tangi.

Variability of rainfall during SW monsoon comes around 24% in the district. Begunia, Bolagarh and Khordha blocks has high variability (>30%) of monsoon rainfall (Table 3). Begunia block has maximum (36%) variability while Tangi has the minimum (21%).

Average number of rainy days spread over the SW monsoon period in the district is 56 days. Most of the blocks have average rainy days of 47-52 days except Bolagarh and Chilika block (Table 4). Bolagarh has the minimum (44 days) number of rainy days. Balianta, Balipatna and Bolagarh blocks have the maximum (18%) variability of monsoon rainy days, while Banapur has the minimum (11%).

North East monsoon

Khordha district receives 235 mm mean of rainfall during the north east monsoon period which contributes 15.3% to the total rainfall of the district (Table 3). Four blocks namely Balipatna, Begunia, Bolagarh and Khordha has experienced less (<200 mm) north east monsoon rainfall, while four blocks have received more (>220 mm). Maximum rainfall has been observed in Balianta (249 mm) block and minimum in Balipatna (164 mm).

The variability of north east monsoon rainfall in the district is quite high (86%). Maximum variability is in Balianta block (111%) and minimum in Tangi (81%). Except three blocks, all the blocks have ≥90% variability of north east monsoon rainfall (Table 3).

Average number of rainy days is 7-9 days with the variability of 45% in the district (Table 4).

4. Year wise seasonal rainfall and rainy days

The seasonal rainfall and rainy days during South West monsoon (May to September) have been shown in Fig. 3 and both the parameters are showing a decreasing trend. Rainfall is having a very slow decreasing trend or almost no trend whereas rainy days are decreasing at a faster rate. It can be inferred that the number of rainy days are decreasing while the amount of rainfall remains to be nearly equal as compared to the previous years.

Table 3: Mean Seasonal Rainfall with Standard Deviation and CV (%)

Block	Winter			Summer			Southwest Monsoon			Northeast Monsoon		
	Mean	CV	% contribution to annual rainfall	Mean	CV	% contribution to annual rainfall	Mean	CV	% contribution to annual rainfall	Mean	CV	% contribution to annual rainfall
	mm	%	%	mm	%	mm	mm	%	mm	mm	%	Mm
Balianta	15	116	1	141	81	8.7	1203	25	74.8	249	111	15.5
Balipatna	18	135	1.5	85	101	7.7	844	28	76	164	91	14.8
Banapur	18	149	1.3	141	108	9.9	1022	28	71.8	242	88	17
Begunia	25	124	1.9	122	97	9.1	1016	36	76	173	106	13
Bhubaneswar	23	124	1.4	155	83	9.3	1241	29	75	236	99	14.3
Bolagarh	19	136	1.5	92	127	7.4	935	30	75.4	195	105	15.7
Chilika	22	181	1.5	143	109	9.9	1061	25	73.4	219	90	15.2
Jatani	27	123	1.7	147	89	9	1227	23	75.5	224	84	13.8
Khordha	21	147	1.5	111	115	7.7	1101	31	77	197	92	13.8
Tangi	20	138	1.4	139	93	9.6	1081	21	74.4	212	81	14.6
District Mean	23	116	1.5	161	81	10.5	1114	24	72.7	235	86	15.3

Table 4: Mean Seasonal Rainy days with Standard Deviation and CV (%)

Block	Winter			Summer			Southwest Monsoon			Northeast Monsoon		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
	days	%	%	days	%	%	days	%	%	days	%	%
Balianta	1	1	122	5	3	52	50	9	18	8	6	73
Balipatna	1	1	118	5	2	31	47	8	18	7	5	67
Banapur	2	2	124	7	3	45	50	6	11	9	6	67
Begunia	1	2	126	5	2	44	45	6	14	8	5	61
Bhubaneswar	1	2	113	6	2	40	51	8	15	9	5	60
Bolagarh	1	2	143	4	3	68	44	8	18	7	6	76
Chilika	1	2	147	5	3	54	45	7	16	8	5	63
Jatani	2	2	122	6	3	48	52	7	13	9	5	62
Khordha	1	2	123	5	3	52	50	7	13	8	6	66
Tangi	1	1	109	7	3	47	52	8	15	9	5	59
District Mean	2	2	99	81	8	29	56	8	14	11	5	45

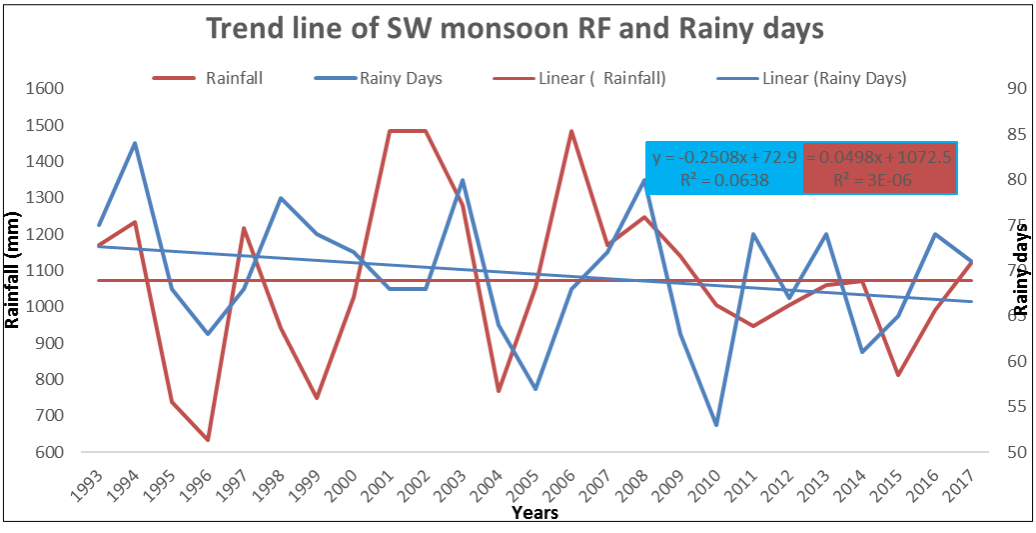

Fig 3: Trend line of rainfall and rainy days during SW monsoon

5. Extreme Rainfall Events

The day that has been recorded for receiving the highest amount of rainfall is known as the extreme event for that block. Table 5 reveals the extreme rainfall events for different blocks of the Khordha district.

Table 5: Extreme Rainfall Events

Blocks	Rainfall	Date
Balianta	372	31.10.1999
Balipatna	197	16.06.1993
Banapur	255	03.07.2001
Begunia	290	13.10.2013
Bhubaneswar	364	30.10.1999
Bolagarh	176	31.07.2014
Chilika	299	10.05.1995
Jatani	215	13.10.2013
Khordha	210	18.08.2012
Tangi	193	10.05.1995

6. Initial and Conditional Probability (Markov Chain Model)

The initial probability of occurrence of wet spell in Khordha district is <15 % during SMW 1- 17, 20-40 % during SMW 18-23, >70 % during SMW 24- 41, and then afterwards suddenly decreases to less than 40 % during SMW 42-52. On the contrary, the initial probability of occurrence of dry spell has been found to be very high (>70%) during SMW 1-23 and 41-52, whereas from 24-40 it is relatively less (Table 5).

The conditional probability of a wet spell followed by another wet spell, P(w/w) is very high (>70%) during SMW 25-40. However, the conditional probability of wet spell followed by a dry spell is least during this period and that of a dry week followed by wet week, P(w/d) is very high during 24-26, 28-40. There is 50% conditional probability during SMW 19 and 41 (Table 5). On the contrary, probability of getting two dry spells one after another is high in most of the weeks except during SMW 24-40 when probability is less than 50%.

As reported by Mandal *et al.,* 2015 probability of occurrence of dry spells in Daspalla region of Odisha were high from the 1–22 SMW and again in the 42 SMW to the end of the year. The probability of weeks (23–40 SMW) remaining wet varies between 62% and 100% for the region. Hence, this report completely supports the result for Khordha district.

Table 6: Initial and Conditional probability of Khordha district by Markov Chain Model

District	Initial Probability		Conditional Probability			
Week	P (W)	P (D)	P (W/W)	P (D/W)	P (D/D)	P (W/D)
1	0.04	0.96	0.00	0.00	0.96	0.04
2	0.08	0.92	0.00	1.00	0.92	0.08
3	0.12	0.88	0.00	1.00	0.87	0.13
4	0.00	1.00	0.00	1.00	1.00	0.00
5	0.04	0.96	0.00	0.00	0.96	0.04
6	0.00	1.00	0.00	1.00	1.00	0.00
7	0.08	0.92	0.00	0.00	0.92	0.08
8	0.08	0.92	0.00	1.00	0.91	0.09
9	0.08	0.92	0.00	1.00	0.91	0.09
10	0.08	0.92	0.50	0.50	0.96	0.04
11	0.12	0.88	0.00	1.00	0.87	0.13
12	0.04	0.96	0.00	1.00	0.95	0.05
13	0.08	0.92	0.00	1.00	0.92	0.08
14	0.20	0.80	0.50	0.50	0.83	0.17
15	0.12	0.88	0.20	0.80	0.90	0.10
16	0.16	0.84	0.00	1.00	0.82	0.18
17	0.16	0.84	0.00	1.00	0.81	0.19
18	0.20	0.80	0.25	0.75	0.81	0.19
19	0.44	0.56	0.00	1.00	0.45	0.55
20	0.36	0.64	0.36	0.64	0.64	0.36
21	0.40	0.60	0.44	0.56	0.63	0.38
22	0.12	0.88	0.30	0.70	1.00	0.00
23	0.36	0.64	0.67	0.33	0.68	0.32
24	0.76	0.24	0.67	0.33	0.19	0.81
25	0.80	0.20	0.84	0.16	0.33	0.67
26	0.88	0.12	0.90	0.10	0.20	0.80
27	0.88	0.12	0.95	0.05	0.67	0.33
28	0.72	0.28	0.68	0.32	0.00	1.00
29	0.76	0.24	0.78	0.22	0.29	0.71
30	0.88	0.12	0.89	0.11	0.17	0.83
31	0.92	0.08	0.91	0.09	0.00	1.00
32	0.92	0.08	0.91	0.09	0.00	1.00
33	0.88	0.12	0.87	0.13	0.00	1.00
34	0.88	0.12	0.91	0.09	0.33	0.67
35	0.92	0.08	0.91	0.09	0.00	1.00
36	0.80	0.20	0.78	0.22	0.00	1.00
37	0.88	0.12	0.95	0.05	0.40	0.60

38	0.92	0.08	0.95	0.05	0.33	0.67
39	0.60	0.40	0.57	0.43	0.00	1.00
40	0.72	0.28	0.67	0.33	0.20	0.80
41	0.52	0.48	0.50	0.50	0.43	0.57
42	0.36	0.64	0.46	0.54	0.75	0.25
43	0.16	0.84	0.22	0.78	0.88	0.13
44	0.20	0.80	0.50	0.50	0.86	0.14
45	0.12	0.88	0.20	0.80	0.90	0.10
46	0.16	0.84	0.00	1.00	0.82	0.18
47	0.04	0.96	0.00	1.00	0.95	0.05
48	0.00	1.00	0.00	1.00	1.00	0.00
49	0.08	0.92	0.00	0.00	0.92	0.08
50	0.04	0.96	0.00	1.00	0.96	0.04
51	0.00	1.00	0.00	1.00	1.00	0.00
52	0.00	1.00	0.00	0.00	1.00	0.00

7. Potential Evapotranspiration

Monthly average potential evapotranspiration (PET) has been calculated for the entire district taking all the weather parameters into account like maximum and minimum temperature, rainfall, relative humidity I and II, bright sunshine hour, wind speed and evaporation using PET Calculator for last 25 years (1993-2017). Monthly average rainfall of 25 years has also been calculated (Table 6). Fig. 4 reveals the fact that in the pre monsoon period of January to May and post monsoon months of October to December, PET is more than the precipitation and as a result there is water deficit condition for the plants. Whereas in the monsoon period of June to September PET is less than that of precipitation and water surplus condition prevails for the plants. This surplus water needs to be stored in harvesting structures for efficient utilisation during *rabi* season.

Table 7: Average monthly PET and Rainfall of Khordha district

Months	PET (Modified Penman)	Rainfall (mm)
January	100.53	8.71
February	115.35	12.07
March	157.84	14.86
April	176.20	27.49
May	188.96	85.23
June	140.77	171.76
July	124.97	310.27
August	121.36	341.03
September	117.10	250.10
October	119.34	175.16
November	105.16	30.73
December	96.41	5.15

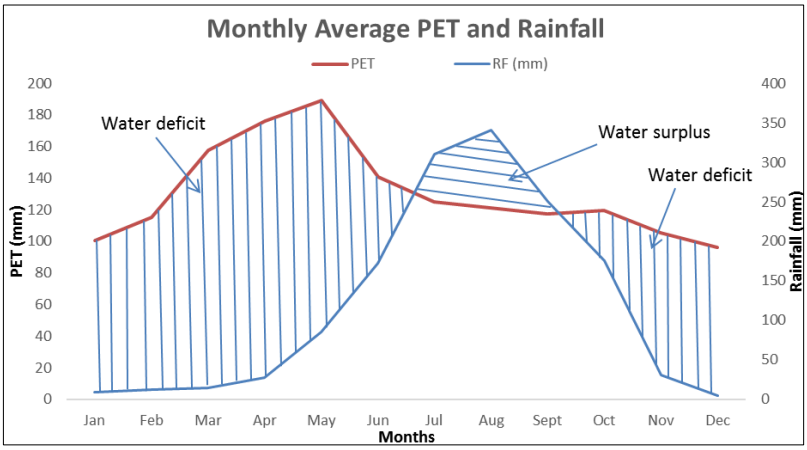

Fig 4: Monthly average PET and Rainfall of Khordha district

Conclusion

Existing spatial and temporal variability of rainfall in Khordha district reveals various trends and rainfall patterns. Year wise variability of annual rainfall and rainy days shows that the trend is slightly decreasing and decreasing respectively. The number of rainy days is decreasing gradually with slight increase in the monsoon rainfall. So, the crop planning should be done according to the number of rainy days available with the amount of rainfall during that period. Most of the times, moisture stress condition prevails during *rabi* season which can be overcome by harvesting the excess of water during water surplus condition and using efficiently during critical stages of the crops.

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