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Short communication

Evaluation of LARS-WG model for generating climate data over lower Gangetic West Bengal

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Climate is one of the single most important factors affecting ecosystems and water resources (Mazumder and Molders, 2009). Both climate change and climate variability can lead to severe impacts on rainfed farming system through reducing its yields and profitability. It is desirable to have an idea about the change of some highly sensitive climatic variables like air temperature, rainfall and radiation on crop growth and development in addition to get future water resources planning and management in the region (Chen *et al.,* 2013). The projection of future air temperature is important as it influences crop evapotranspiration (ET), yield and quality. Assessment of long term past and future climate change works over many places, sometimes faced different types of obstacles due to limited data availability and data quality which contains lots of missing values. It is to be mentioned that locations having some missing values in the long-term meteorological data, LARS-WG can play a crucial role to generate continuous data which can be used to replace missing values, then this new data series without any missing values can be used to estimate long-term climate change information location-wise. Weather generators (WGs) are statistical models that generate numerous possible weather variables including precipitation, temperatures, solar radiation, and wind velocity at a daily time step and, ideally, with the same statistical characteristics as those of observed data (Trzaska and Schnarr, 2014). LARS-WG is a stochastic weather generator specially designed for climate change impact studies (Semenov and Burrow, 1997). In India WGs have been used by Bal *et al.* (2010) and Reddy *et al.* (2014) over Punjab and Telengana, respectively for climate change studies. Haris *et al.* (2010) used LARS-WG for validating the model over Bihar regions for climate change assessment. Kumar *et al.* (2013) suggested that the model is able to downscale the point data to quiet a good extent which can be used successfully for climate assessment studies. Sarkar and Chicholikar (2015) studied the performance of LARS-WG over Gujarat and concluded that the model performed excellent in generating rainfall and temperature parameters with high accuracy level.

Although LARS WG has been used in some parts of India, there is still no literature on how this weather generator performed on different districts over West Bengal. Therefore, the following study was conducted to investigate the performance of LARS-WG over some smaller locations of West Bengal states using some conventional statistical indices. Three districts of new alluvial agro climatic zones of West Bengal (NAZ) namely Murshidabad (24.22°N, 88.24°E), Nadia (23.47°N, 88.55°E), and Burdwan (23.45°N, 87.61°E) were selected for the study. The three districts were chosen primarily due to the fact that the regions are very economically rich in terms of crop productivity and crop diversification. Hence assessing the climatic parameters over these three districts will help us for simulating future crop productivity using crop simulation models by using the generated weather parameters through LARS-WG.

IMD high resolution (0.25°×0.25°) gridded rainfall data has been taken as reference observational data. This IMD product has been prepared using daily rainfall records from 6955 number of rain gauge stations over Indian landmass covering a period of 110 years (1901–2010). After applying the standard quality control tests such as tests for typing and coding errors, missing data, duplicate station check, extreme value check etc. The data were interpolated at fixed spatial grid points of 0.25°×0.25° resolution by inverse distance weighted interpolation (IDW) scheme. Similarly, a high resolution daily gridded temperature data set (1º×1º) for the Indian region was developed India Meteorological Department (IMD). For the present work, daily temperatures (maximum, minimum and mean) from the IMD gridded data (1º×1º) for the period 1981-2010 was considered as reference data sources for assessing the performance of LARS-WG.

At first, daily IMD gridded rainfall and temperature data were interpolated using bi-linear interpolation (Akhter *et al.,* 2016) over three district locations of South Bengal to generate observed time series during 1981-2010. For calibration of the stochastic weather generator (LARS-WG) 1981-90 period was considered as base period. Observed rainfall and temperature data during base period have been used to calibrate LARS-WG and generate synthetic daily time series during 1981-2010. The conventional metrics like percentage bias, RMSE, RSR and NRMSE have been used to judge the skill of the weather generator as per suggestions of Qunying *et al.* (2009).

Monthly rainfall, monthly minimum and maximum temperature (1981-2010)

Monthly analysis of past rainfall data over the three districts of West Bengal shows that both Nadia and Murshidabad received highest amount of rainfall during June (442.9 mm and 286.2 mm, respectively) whereas Burdwan received higher amount of rainfall during the month of July (289.5 mm). The least amount of rainfall was recorded during the months November for Nadia and December for Murshidabad and Burdwan districts which were 7.8 and 11.8 mm, respectively. Daily median maxima of rainfall reflects that for Nadia it varied from as less as 0.7 mm during October to 44.5 mm during June for Nadia, 0.6 mm (November) to 56.5 mm (August) for Murshidabad and 1.0 mm in October to 55.1 mm during September for Burdwan. Measures of dispersion i.e Coefficient of variation (CV) of rainfall for Nadia, Murshidabad and Burdwan varied from 0.3-1.8, 0.4-1.9, and 0.3-2.2 respectively. Monthly analysis of past minimum temperature data over the three districts of West Bengal shows that month of January recorded the least minimum temperature over the period (13.0 °C, 11.4 °C and 12.2 °C for Nadia, Murshidabad and Burdwan, respectively) whereas the SD varied from 0.3-1.1, 0.4-1.0 and 0.3-1.1 respectively. The maximum temperature for Nadia, Murshidabad and Burdwan was recorded during the month of May, April and April-May respectively which were recorded as 35.5 °C, 36.6 °C and 36.5 °C respectively. The SD varied from 0.5-1.1, 0.4-1.4 and 0.5-1.4 for Nadia, Murshidabad and Burdwan, respectively.

District-wise model calibration and evaluation for rainfall and temperature

Nadia

The statistical comparison for Nadia district is summarized in which show that the Standard deviation (SD) of monthly rainfall is in close agreement with the generated data by LARS-WG. Model predicted result indicates that June (466.5 mm) received highest intra-annual rainfall which is in right agreement with observation (June, 442.9 mm). However, model prediction for the month (December, 11.5 mm) receiving lowest intra-annual rainfall was lagged by 1 month to that of observation (November, 8.5mm). The simulated SD and observed SD values varied between 14.2-118.5 and 13.6-191.9 respectively The RMSE, RSR and NRMSE between observed and simulated values were found to be 14.5, 0.802 and 8.3, (Fig. 1a) respectively which shows very high level of confidence among the observed and the simulated values.

The observed and generated monthly means of maximum and minimum temperatures are close to each other (Fig. 2a). The difference between observed and generated means of monthly minimum temperature varied from 0.02 to -0.01 °C. The temperature difference of -0.1 to 0.3 °C was observed in the case of monthly mean maximum temperatures of observed and generated series. The difference in both maximum and minimum temperature was within 2% indicating the good predictability of LARS-WG. Mehen *et al.* (2017) similarly showed similar result for LARS-WG in predicting temperature with very high accuracy. The model also captured observed intra-annual variation or seasonal cycle perfectly over this district. It is showing very less deviation between observed and generated means. The RMSE, RSR NRMSE for mean monthly minimum temperature were, 0.11, 0.024 and 2.4 respectively, and 0.11, 0.037 and 3.7, respectively for mean monthly Maximum temperature. It is of special mention that for eliminating the inherent biasness of the model the bias CF for minimum temperature was -0.031 °C and for maximum temperature was adjusted to be -0.024 °C.

Murshidabad

The statistical comparison for rainfall over Murshidabad district shows that the Standard deviation of monthly rainfall (SD) is in close agreement with the generated data by LARS-WG. Analysing the observed rainfall data it was observed that July (286.2 mm) received highest rainfall over the years similarly alike the model simulated values which also showed highest rainfall during the month of July (287.5 mm). Similarly, least rainfall was found during January (7.8 mm) and the model also predicted the least rainfall during the month January (7.2 mm) which was little underestimated. The simulated SD values varied between 10.2 -121.3 whereas the observed SD varied between 11.1 -155.1. The RMSE, RSR and NRMSE between observed and simulated values were found to be 15.7, 0.13 and 13.6, (Fig. 1b), respectively which shows very high level of confidence among the observed and the simulated values. The model bias correction factor (CF) which was incorporated for calibrating the model for better predictability of rainfall was adjusted to be -2.02.

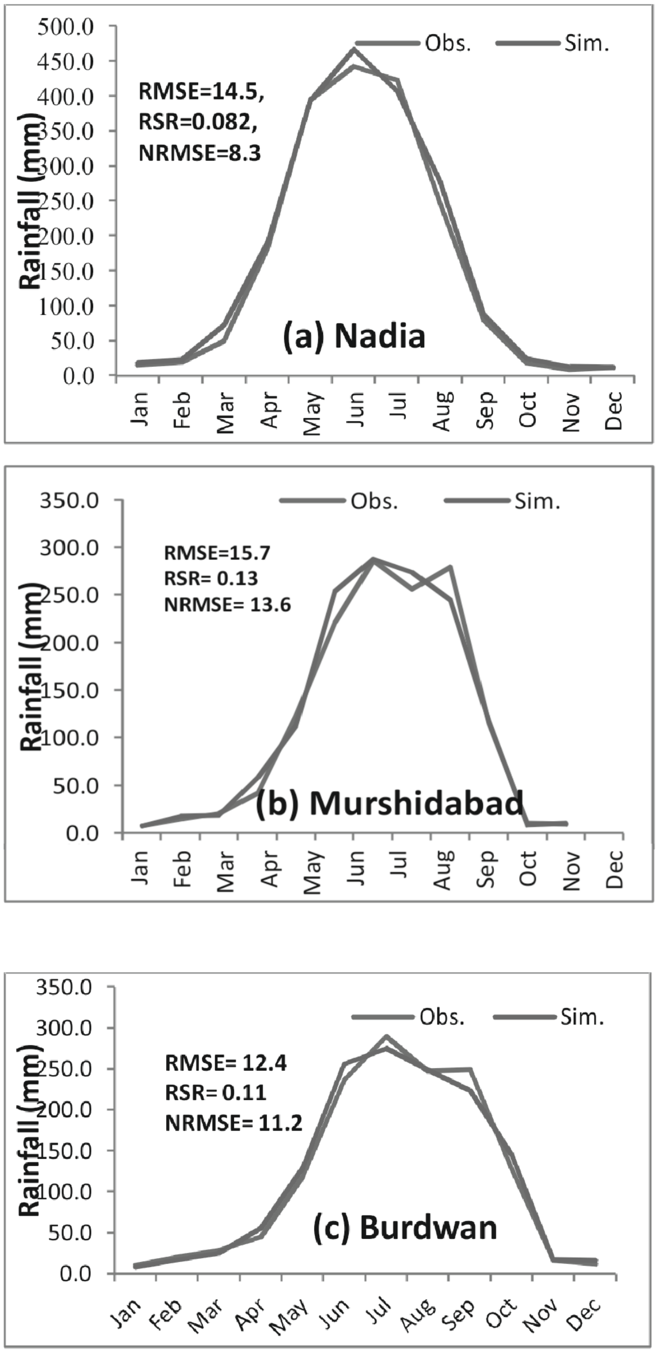

Fig. 1: Comparison of monthly observed and generated rainfall (mm) over (a) Nadia; (b), Murshidabad (c) Burdwan (1980-2010).

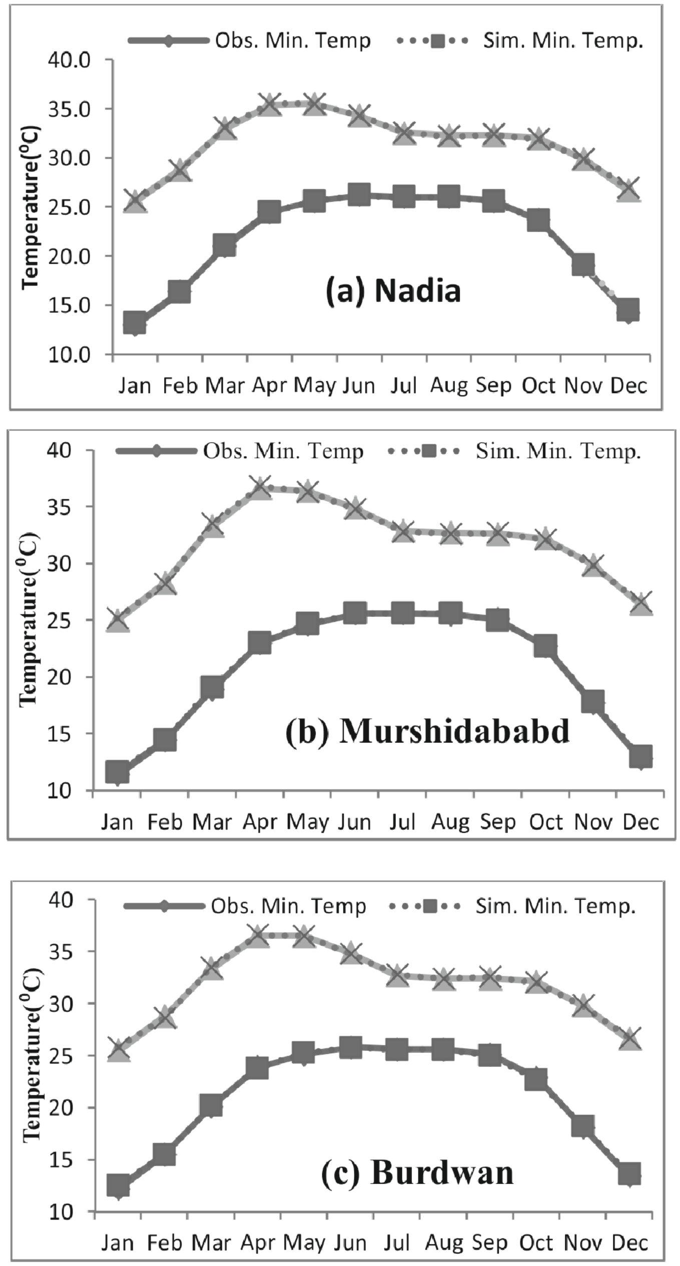

Fig. 2: Comparison of monthly observed minimum temperature, Maximum Temperature and generated minimum temperature and maximum temperature *(a)* Nadia (b*)*, Murshidabad (c) Burdwan (1981–2010).

The percentage difference (% bias) between observed and generated means of monthly minimum temperature varied from 0.2 to -0.01 °C. Both positive and negative differences were less than 2%. The temperature difference of -0.1 to 0.2 °C was observed in the case of monthly mean maximum temperatures of observed and generated series. The difference was within 2% indicating the best predictability of LARS-WG. The model behaviour is very good at Nadia in the case of temperature as the model has almost at par generated values, maintaining very less deviation between observed and generated means (Fig. 2b). The RMSE, RSR NRMSE for mean monthly minimum temperature were, 0.14, 0.028 and 2.8, respectively; and 0.14, 0.038 and 3.8, respectively for mean monthly Maximum temperature. For eliminating the inherent biasness of the model the Bias CF for minimum temperature was -0.017 °C and for maximum temperature was adjusted to be -0.030 °C.

Burdwan

The result show that the standard deviation of monthly rainfall (SD) is in close agreement with the generated data by LARSWG. The observed rainfall was found to be higher during the month of July (289.5 mm) and similar result was shown by the models which were found to be slightly lower than the observed values during the months of July (275.3 mm). However, least rainfall was found during January (10.5 mm) and the model also predicted the least rainfall during the month January (8.2 mm) which was little underestimated. The simulated SD and observed SD values varied between 10.7-87.6 and 15.9-126.6. The RMSE, RSR and NRMSE between observed and simulated values were found to be 12.4, 0.11 and 11.2 (Fig. 1c), respectively which shows very high level of confidence among the observed and the simulated values. The model bias correction factor (CF) which was incorporated for calibrating the model for better predictability of rainfall was adjusted to be -1.327.

The observed and generated monthly means of maximum and minimum temperatures are close to each other. The percentage difference between observed and generated means of monthly minimum temperature varied from 0.3 to -0.2 ^{o}C. Both positive and negative differences were less than 2%. The temperature difference of -0.2 to 0.3 ^{o}C was observed in the case of monthly mean maximum temperatures of observed and generated series. The difference was within 2% indicating the best predictability of LARS-WG. The model behaviour is very good at Burdwan in the case of temperature as the model has almost at par generated values, maintaining very less deviation between observed and generated means (Fig. 2c). The RMSE, RSR NRMSE for mean monthly minimum temperature were, 0.11, 0.021 and 2.2, respectively, and 0.13, 0.039 and 3.9, respectively for mean monthly Maximum temperature. It is of special mention that for eliminating the inherent biasness of the model the Bias CF for minimum temperature was -0.017 ^{o}C and for maximum temperature was adjusted to be -0.03 ^{o}C.

Present study revealed that the considered LARS-WG model has shown its satisfactory performance to reproduce the grossed climatic features of temperature and rainfall over three district locations of South Bengal. How the LARS-WG performed over three locations was justified through three different conventional statistical measures namely RMSE, RSR and NRMSE and the results obtained was encouraging as model produced results are very closed to IMD observed data as estimated by the lower values of different errors statistics. The performance varied from index to index and parameters to parameter. As for example, the agreement was even better for maximum and minimum air temperatures at all the three locations of the West Bengal region compared to rainfall while the values of NRMSE were slightly higher compared to RMSE and RSR.

REFERENCES

Abdul Haris, A., Khan, M. A., Chhabra, V., Biswas, S. and Pratap, A. (2010). Evaluation of LARS-WG for generating long term data for assessment of climate change impact in Bihar. *J. Agrometeorol.,* 12(2): 198–201.

Akhter, J., Das, L. and Deb, A. (2016). CMIP5 ensemble-based spatial rainfall projection over homogeneous zones of India. *Clim. Dyn.*, 49: 1885-1916.

Bal, S.K., Choudhury, B.U., Sood, A., Jalota, S.K. and Singh, H. (2008). Evaluation of climgen model to generate weather parameters in different climatic situations in Punjab. *J. Agrometeorol.* 10(1): 73-79.

Kumar, D., Arya, D.S., Murumkar, A.R. and Rahman, M.M. (2013). Impact of climate change on rainfall in northwestern Bangladesh using multi-GCM ensembles. *Int. J. Climatol.,* 34: 1395-1404.

Mazumder, D. and Molders, N. (2009). Theoretical assessment of uncertainty in regional averages due to network density and design. *J. Appl. Meteorol. Climatol.* 48: 1643–1666.

Mehan, S., Guo, T., Gitau, M.W. and Flanagan, D.C. (2017). Comparative study of different stochastic weather generators for long-term climate data simulation. *Climate*, *5*(2): 1-40.

Qunying, L., Bellotti, W., Williams, M. and Wang, E. (2009). Adaptation to climate change of wheat growing in South Australia: analysis of management and breeding strategies. *Agric. Ecosyst. Environ*., 129: 261–267.

Reddy, K.S., Kumar, M., NagarjunaKumar, R., Umesha, B., Vijayalakshmi and Venkateswarlu, B. (2012). Long term rainfall and temperature analysis through ClimGen model in Ranga Reddy district of Andhra Pradesh. *J. Agrometeorol.* 15 (Spec. Issue-I): 45– 50.

Sarkar, J. and Chicholikar, J.R. (2015). Climate Change Scenario in the Gujarat Region–Analyses based on LARS-WG (Long Ashton Research Station-Weather Generator) Model. *Asian J. Water Environ. Poll.*, 12(2): 31-41.

Semenov, M.A. and Barrow, E.M. (1997). Use of a stochastic weather generator in the development of climate change scenarios. *Clim. Chang.,* 35: 397–414.

Trzaska, S. and Schnarr, E. (2014). A Review of Downscaling Methods for Climate Change Projections; United States Agency for International Development by Tetra Tech ARD: Pasadena, CA, USA.

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Short communication

Understanding and managing climatic variability in agriculture using agro-climatic characterisation

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Rainfall and temperature are two important weather elements that affect the phenological and morphological development of any living entity directly or indirectly. Favourable weather not only improves the growth and development of plants but also increases the pest and pathogen population associated with them. Alteration of these elements during different phenophases from their respective optimum affects the yield in terms of both quality and quantity. Therefore, present study aims to characterise agro-climatology of Sundergarh district which can be utilised while managing climatic variability and agricultural planning.

The present study was conducted with an aim to characterise the agro-climatology of Sundergarh district. North-western Plateau Agro-climatic zone of the Odisha (AEZ-7) extending from $21^0$35'N to $22^0$32' N latitudes and $83^0$32' E to $85^0$22' E longitude. The daily rainfall data over a period of 23 years (1995-2017) of 17 stations one in each administrative unit i.e., block and 33 years daily temperature data of the district were obtained from Department of Revenue and Disaster management, Special Relief Commissioner, Government of Odisha, India.

Statistical characteristics of rainfall was computed on weekly, monthly, seasonal and annual basis for all the seventeen blocks. To get an approximate value of the effective rainfall during different months, USDA Soil Conservation Service method was adopted which is widely used in India (AICRP on Water Management, 2009).

$P_e = P_t /125\ (125-0.2P_t)$ (when $P_t < 250$ mm) (Eq. 1)

$P_e = 125 + 0.1P_t$ (when $P_t > 250$ mm) (Eq. 2)

Where, P_e = monthly effective rainfall (mm) and P_t = total monthly rainfall (mm).

Block wise daily rainfall data were used to calculate the spatial and temporal rainfall variability. Standard deviation (SD) and coefficient of variation (CV) are the standard statistical measures to express variability in rainfall. The coefficient of variation (in percentage) is an indicative of dependability of rainfall. The threshold levels for CV is taken as <25 %, <50 %, <100 %, <150 % for annual, seasonal, monthly and weekly rainfall respectively during interpretation (Manorama *et al.,* 2007).

The rainfall trend analysis have been done on annual basis for different blocks using one of the most popular non-parametric test for monotonic trend detection in rainfall series called Mann-Kendall test. Probability distribution function, incomplete Gamma distribution has been used to compute the expected amount of rainfall at three different probability levels i.e. 50%, 75% and 90% by using block wise weekly rainfall data as input. The probability level of 60% is considered as dependable without risk; 50% is associated with 50% risk and 20% is very risk from the crop point of view (Kumar, 2009).

Markov chain probability model as described by Pandarinath (1991) has been used for estimation of initial, conditional and consecutive dry and wet spell analysis. In this method, a week receiving 20 mm or more rainfall is considered as wet week otherwise dry. We have also performed air temperature analysis for their normal and extremes; in case of extremes their frequency and the trend observed.

Rainfall analysis

The long term mean annual rainfall of the district is 1273 mm ± 325 mm with 26.1% coefficient of variation (Table 1). In the district the annual rainfall varied from 1077 mm in Rajgangpur to 1553 mm in Bonai. In genere the areas having high rainfall has low CV and Vice versa (Table 1). About 87 per cent of annual rainfall is received during June to September (monsoon season), 8 per cent in post monsoon and 5 per cent in pre monsoon sseason.

Based on the analysis it was reported that the mean monthly rainfall of July is 357 mm (Fig. 1), which is highest followed by August rainfall (345mm).

Total annual effective rainfall (ER) is 758.4 mm which is about 60% of the total annual rainfall and it clearly indicates about 40% of rainwater is lost as surface runoff which necessitates the kind attention for reducing the losses and strategies for conservation.

***Probability analysis*: Expected rainfall at three different probability levels (50%, 75% and 90%) have been computed by fitting incomplete gamma distribution model (Table 2). Amount of rainfall expected at 75% and 90% probability level is considered as dependable and assured rainfall respectively. At 75% probability, four blocks namely Bonai, Hemgir,

Table 1: Statistical characteristics of annual rainfall block wise

S. No	Name of block	Rainfall (mm)	SD	CV (%)	No of rainy days
1	Balisankara	1242	264	20.8	58
2	Bargaon	1105	359	33.5	60
3	Bisra	1224	336	28.9	63
4	Bonai	1553	449	28.2	65
5	Gurundia	1343	287	21.8	60
6	Hemgir	1355	264	19.6	62
7	Koida	1323	321	25.0	70
8	Kuarmunda	1312	341	26.4	58
9	Kutra	1209	313	25.9	59
10	Lahunipara	1422	314	23.0	68
11	Lathikata	1425	317	23.7	65
12	Lephripara	1329	426	33.0	60
13	Nuagaon	1196	313	26.2	59
14	Rajgangpur	1077	348	33.6	55
15	Subdega	1151	283	24.9	58
16	Sundergarh	1280	262	19.4	65
17	Tangarpali	1118	331	29.4	59
	District average	**1273**	**325**	**26.1**	**61**

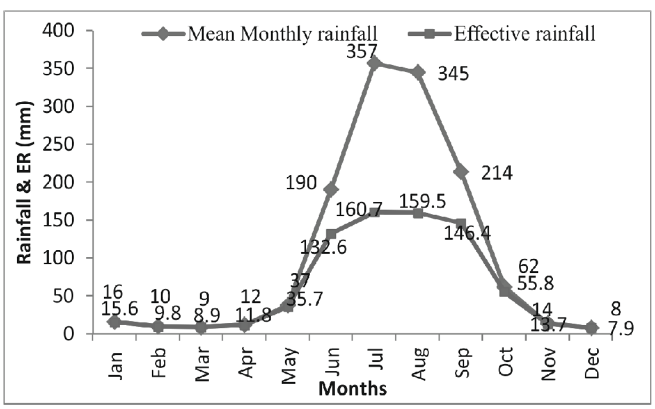

Fig. 1: Long-term average monthly rainfall and effective rainfall in Sundergarh

Lahunipara and Lathikata receive rainfall above 1150 mm. However, rainfall was below 900 mm for the blocks, namely Bargaon, Rajgangpur and Tangarpali and in remaining blocks they receive rainfall between 900-1150 mm.

Extreme temperature frequency

The mean annual temperature of the district is 24.8°C which has increased and is well above the 25.4°C from 2008 onwards. Number of days with $T_{max} \geq 40^{o}C$ was zero during 1990, 1993, 2000, 2006 and 2007 in the district (Table 2). Between 1985 – 1989, the district experienced significant number of temperature extremes (≥40°C) which afterwards reduced to less than 5 during 1990-99 except in the year 1996 when 12 days were recorded having temperature greater than 40°C. In subsequent years the number of temperature extremes increased remarkably and in the year 2012, 67 such days were recorded with 46.8°C being the highest temperature during that year.

Table 2: Expected annual rainfall (mm) at 90%, 75% and 50% probability levels

S.No	Block	Expected rainfall (mm) at		
		90%	75%	50%
1	Balisankara	923.3	1059.6	1226.3
2	Bargaon	699.3	877.8	1109.2
3	Bisra	790.1	956.7	1168.1
4	Bonai	1048.3	1261.8	1531.7
5	Gurundia	977	1122.6	1300.8
6	Hemgir	1027.4	1165.9	1333.9
7	Koida	892.6	1068.0	1288.9
8	Kuarmunda	914.9	1081.4	1289.2
9	Kutra	826.3	980.5	1173.6
10	Lahunipara	1030.7	1194.2	1395.6
11	Lathikata	996.3	1169.3	1384.2
12	Lephripara	762.2	968.1	1238.1
13	Nuagaon	747.3	920.2	1142.2
14	Rajgangpur	541.5	719.1	959.3
15	Subdega	773.3	921.1	1106.5
16	Sundergarh	978.6	1114.5	1279.8
17	Tangarpali	666.4	838.7	1063.2
	District	**858.6**	**1024.7**	**1234.7**

Despite of good amount of annual rainfall received by the district, cropping intensity is only 126.7%. This is because of the undulating hilly lands that creates heavy runoff i.e., around 45% during monsoon months which may cause flood and erosion of top fertile soil. But, if planned scientifically considering the local edaphic, topographic and relief features the same adversity can potentially be harvested to store the runoff and use it as life-saving irrigation for rainfed kharif as well rabi crops. In these areas artificial recharge techniques and rain water-harvesting methods; specifically In-farm Pond are required to be adopted based on site-specific conditions to take care of at least two crops without putting stress on any of them

Table 3: Temperature Extremes and their frequency (in days)

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Mean annual Temp (°C)	24.8	24.7	25.4	25	24.6	24.1	24.6	25.1	24.7	24.2	24.5
Highest temp (°C)	41.1	42.6	42.8	44.2	41.6	40.1	42.3	40.6	39.2	41.3	42.1
Lowest temp (°C)	9.1	6.3	6.8	9.5	6.7	8.7	7.3	5.5	9.6	7.6	5.6
No. of extremes (≥40°C)	10	12	23	11	10	0	2	2	0	3	5
No. of extremes (≤10°C)	13	13	18	2	18	7	12	20	5	11	17
Year	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Mean annual Temp (°C)	24.5	24.3	23.6	24.3	24.3	24	24.1	23.5	24.2	24.7	24.6
Highest temp (°C)	42.9	42.2	41.6	41.9	39.1	42.3	43.0	41.6	43.0	43.3	38.0
Lowest temp (°C)	8.3	7.6	6.8	7.4	8.3	7.2	7.2	7.8	6.4	8.4	9.7
No. of extremes (≥40°C)	12	3	3	5	0	5	5	4	9	19	0
No. of extremes (≤10°C)	13	17	18	25	11	15	10	18	17	21	2
Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Mean annual Temp (°C)	24.6	25.4	26.3	26.6	25.5	26.2	25.4	25.5	26	25.4	25.6
Highest temp (°C)	38.2	46.2	47.0	46.8	44.2	46.8	46.3	44.4	46.4	46	42.2
Lowest temp (°C)	9.3	6.8	9.4	7.0	5.3	5.9	4.4	5.6	5.9	5.5	5.8
No. of extremes (≥40°C)	0	40	51	56	28	67	43	42	41	58	46
No. of extremes (≤10°C)	3	16	2	23	28	19	33	37	26	22	28

REFERENCES

AICRP (2009). Annual Report of All India Coordinated Research Project on Water Management, 2008-09. Directorate of Water Management, ICAR, Bhubaneswar, India

Kumar, A. (2009). Assessment and management of Meteorological drought for crop planning in Tarai region of Uttarakhand. *Hydrol. J.*, 32 (1-2)

Manorama, K., Ravichandran, G., and Joseph, T. A. (2007). Rainfall analysis and crop planning for the Nilgiris. *J. Agrometeorol.*, 9: 209 215

Murari K.K., Ghosh S., Patwardhan A., Daly E., Salvi K. (2015). Intensification of future severe heat waves in India and their effect on heat stress and mortality. *Regional Environ. Change* 15(4): 569-579.

Pandarinath, N. (1991). Markov chain model probability of dry and wet weeks during monsoon periods over Andhra Pradesh. *Mausam*, 42(4): 393-400.

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