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Application of Random Effect Model for Estimation of Rainfall Interval in Agro-Climatic Zones of Rajasthan

S.K. Kulshrestha[1] and Alok Chouhan[2]
[1]Department of Economics; [2]Department of Geography
Vardhman Mahaveer Open University, Kota, Rajasthan
Email: skulshrestha@vmou.ac.in; achauhan@vmou.ac.in

ABSTRACT

Rainfall plays a vital role in the state's economy because Rajasthan is a water-deficient state. The state of Rajasthan is classified into ten agro-climatic zones. These zones describe the upper and lower limit of the rainfall, a classification given by Indian Agricultural Research Institute (ICAR). This paper presents a new technique Random Effect Model (REM), to estimate these limits. The literature related to estimating rainfall interval using the statistical technique has not observed the heterogeneity among the units. The units may differ in size, magnitude, kind, impact etc. but the REM technique is beneficial for estimating the mean of heterogeneous groups like agro-climate zones. This paper attempts to use this technique to estimate rainfall confidence intervals among the state's ten agro-climate zones. This technique to estimate the rainfall interval of agro-climate has been used for the first time. The comparison between estimation of rainfall upper and lower limits obtained by these methods' has also been discussed. This paper deals with estimates variability of the rain across all districts, including ten agro-climate zones. The result shows that the REM is a statistically effective method to estimate rainfall intervals. The study shows no statistical difference in average rainfall between humid southern, eastern plain, flood-prone eastern plain, sub-humid southern plains, and the humid southern plain. The minimum level of rain in different agro-climate zones calculated by the ICAR is overestimated because the REM has not proved it. The maximum level of rainfall is almost similar in both estimations.

Keywords: Agro-climate zone, Annual rainfall, Confidence interval, Random effect model.

INTRODUCTION

The Indian Council of Agricultural Research (ICAR) has delineated India into 126 agro-climate zones. Rajasthan has been divided into ten agro-climates zones based on rainfall, temperature, topography, soil, cropping pattern and irrigation availability (Fig.1). Rainfall variability depends on climate types and periods, which must be forecast because it has socio-economic implications. Rajasthan is a state that remarkably differs from other states of India because of its climate, which varies from arid to sub-humid. The Aravalli range diagonally divides Rajasthan into two parts. There is more variability in rainfall across the agro-climatic zones. The southwest monsoon often begins in the last week of June in the eastern parts and sustains till mid of September.

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Many researchers have used different methods for constructing confidence intervals (CI) of rainfall for the expected mean of several distributions. For example, Fairweather (1972) used a linear combination of Student's *t* to make CI for the predicted mean of rainfall by using several normal distributions.

Jordan and Krishnamoorthy (1996) also solved the problem of CI by using Student's *t* and independent *F* test to find out standard under unknown and unequal variances. The estimated CI of Fairweather (1972) and Jordan and Krishnamoorthy (1996) was compared by Krishnamoorthy and Mathew (2003) with its Generalised CI (GCI). GCI for the expected mean of several normal populations was developed by Lin and Lee (2005). Tye *et al.* (2011) used a highly computational GIS environment with real-time Average Recurrence Interval (ARIs) are computed based on gauge-corrected radar-estimated rainfall maps. Lin and Wang (2013) tested their hypothesis using interval estimation for several log-normal means. A new method for the variance estimates recovery (MOVER) approach for the common mean of log-normal distributions was developed by Krishnamoorthy and Oral (2015).

In this paper, considering the heterogeneity among the group panel data has been used to estimate the rainfall interval. A new technique called REM was used for this estimation because Rajasthan state's ten agro-climate zones are different from their size, and these zones have some districts which are also heterogeneous in size. Therefore, to consider the heterogeneity among zones REM technique has been used in this paper. We develop our argument through simulations, evaluation and testing using REM and find how this model cope with some inferences regarding the confidence interval of rainfall which is also classed as rainfall interval.

Fig. 1: Agro-Climate Zones in Rajasthan state.
source: www.krishi.rajasthan.gov.in

The ICAR Research Review Committee-1980 classified the state into nine agro-climatic zones based on rainfall, soil type, availability of irrigation water, existing cropping pattern and administrative units. In 1996, one more agro-climatic zone was defined by the re-organisation of the Arid Western Plain. Climatic conditions and topography play a crucial role in the agricultural sector. Farmers' cropping pattern depends on many agro-climate conditions such as rainfall, temperature, humidity, wind velocity and sunshine. Table-1 shows Agro-Climate Zones Classification and Rainfall Interval of Rajasthan.

Table-1: Agro-Climate Zone classification and rainfall interval.

Zone	**Districts**	**Rainfall Interval (mm)**
IA-Arid Western	Barmer, Jodhpur	200-370
IB-Irrigated North Western Plain	Sriganganagar, Hanumangarh	100-350
IC-Hyper Arid Partial Irrigated Zone	Bikaner, Jaisalmer, Churu	100-350
IIA-Internal Drainage dry Zone	Nagaur, Sikar, Jhunjhunu	300-500
IIB-Transitional Plain of Luni Basin	Jalore, Pali, Sirohi	300-500
IIIA-Semi-Arid Eastern Plain	Jaipur, Ajmer, Dausa, Tonk	500-700
IIIB-Flood Prone Eastern Plain	Alwar, Dholpur, Bharatpur, Swai Madhopur, Karoli	500-700
IVA-Sub Humid Southern Plain	Bhilwara, Rajsamand, Chittorgarh	500-900
IVB-Humid Southern	Dungarpur, Udaipur, Banswara, Pratapgarh	500-1100
V-Humid Southern Eastern Plain	Kota, Jhalawar, Bundi, Baran	650-1000

Source: Directorate of Agriculture, Government of Rajasthan.

OBJECTIVES

The two-fold objectives are as follows:

1. To calculate the rainfall interval in different agro-climate zones based on newly developed method.
2. To compare it with the ICAR interval of rainfall.

MATERIALS AND METHODS

This paper is based on the secondary data on rainfall from 1980 to 2010 collected from the Directorate of Economics and Statistics, Jaipur for 27 districts of Rajasthan. The ICAR presented a similar analysis in 2011 using data from 1980 to 2010; therefore, the same time frame has also been considered in the present study to compare results. Few administrative changes were taken in terms of the internal adjustment of district boundaries within the state. Some districts have been carved out during and after the present study. Nevertheless, required and feasible adjustments have made the data consistent.

A random effects or variance components model is used where the model parameters are random variables in statistics. It assumes that the data being analysed are drawn from a heterogeneous group. In econometrics, random effects models are used in panel analysis of panel data when one assumes no fixed effects (it allows for individual effects). A random-effects model is a particular case of a mixed model. The random part of the model includes two terms a random effect to the intercept and a random to the within slope that allows heterogeneity in the within-effect of X_{it} across individuals (Bell *et al.,* 2019). Each of these is usually assumed to be Normally distributed. Wooldridge (2010) elaborated REM assist in controlling for unobserved heterogeneity when the heterogeneity is constant over time and not correlated with independent variables. This constant can be removed from longitudinal data through differencing since taking the first difference will remove any time-invariant model components. Yair and Yahav (1981) proved the effectiveness of the fixed effect and random effect model over ANOVA.

The random Effect Model (REM) is used here with the agro-climate zone dummies to estimate the coefficients of the rainfall. There are nine dummies and one benchmark dummy variable to calculate the impact of rains in ten agro climates zones. The total observations used in this paper are 810, which are 27 districts, 30 years. Each dummy variable shows the presence of the district of its agro-climate zone, which represents the district's presence in its agro-climatic zone. We have used the REM technique for estimating rainfall intervals. It is a better statistically estimating method and can be used for better estimation.

Model framework

$$Y_{it} = \alpha + D_{1t} + D_{2t} + D_{3t} + D_{4t} + D_{5t} + D_{6t} + D_{7t} + D_{8t} + D_{9t} + U_{it} \qquad \text{(Eq. 1)}$$

Eq.1 i stands for each agro-climate zone and t for each year. Other coefficients are as below mentioned.

α = Humid Southern Eastern Plain, which is the benchmark, the average rainfall
Y_{it} = Rainfall, U_{it} = Stochastic error term, D_1= IA dummy, D_2= IB dummy, D_3= IC dummy
D_4= IC dummy, D_5 = IIB dummy, D_6 = IIIA Plain dummy, D_7 = IIIB dummy, D_8 = IVA dummy
D_9 = IVB dummy, BenchMark = V-Humid Southern Eastern Plain

When all dummy variables are zero, then α = Humid Southern Eastern Plain estimated rainfall

Estimation of Mean of rainfall of each Agro-Climate Zone:

REM model Eq. 1 simulations reveal the model for estimating the mean of rainfall in different agro-climate zones in Rajasthan. The following models are used to calculate the mean of each agro-climate zone's help with REM.

(i) IA agro-climate zone estimated rainfall, other dummies =0,

$$Y_{it} = \alpha + D_{1t} + U_{it} \qquad \text{(Eq.2)}$$

(ii) IB agro-climate zone estimated rainfall, other dummies =0,

$$Y_{it} = \alpha + D_{2t} + U_{it} \qquad \text{(Eq.3)}$$

(iii) IC agro-climate zone estimated rainfall, other dummies =0

$$Y_{it} = \alpha + D_{3t} + U_{it} \qquad \text{(Eq.4)}$$

(iv) IIA agro-climate zone estimated rainfall, other dummies =0

$$Y_{it} = \alpha + D_{4t} + U_{it} \qquad \text{(Eq.5)}$$

(v) IIB agro-climate zone estimated rainfall, other dummies =0

$$Y_{it} = \alpha + D_{5t} + U_{it} \qquad \text{(Eq.6)}$$

(vi) IIIA agro-climate zone estimated rainfall, other dummies =0,

$$Y_{it} = \alpha + D_{6t} + U_{it} \qquad \text{(Eq.7)}$$

(vii) IIIB agro-climate zone estimated rainfall, other dummies =0,

$$Y_{it} = \alpha + D_{7t} + U_{it} \qquad \text{(Eq.8)}$$

(viii) IVA agro-climate zone estimated rainfall, other dummies =0

$$Y_{it} = \alpha + D_{8t} + U_{it} \quad \text{(Eq.9)}$$

(ix) IVB agro-climate zone estimated rainfall, other dummies

$$Y_{it} = \alpha + D_{9t} + U_{it} \quad \text{(Eq.10)}$$

The confidence interval displays a range of values that there is a specified probability that the value of a parameter lies within it. We want to generate a 95% confidence interval estimate for an unknown population mean. This paper deals with a 95% confidence interval for estimating the confidence interval of rainfall in different agro climate zones of the Rajasthan state. The formula given below is used for calculating a confidence interval:

95% confidence interval = Mean ± 1.96S.E. (Eq.11)

Breusch-Pagan Test Result (Breusch and Pagan, 1979):

Breusch–Pagan test is a chi-squared test used to test for heteroskedasticity in a linear regression model. Under the classical linear regression model, ordinary least squares are the best linear unbiased estimator (BLUE), *i.e.,* they are unbiased and efficient. It remains unbiased under heteroskedasticity, but efficiency is lost. Therefore, Breusch–Pagan test is needed to examine the presence of heteroskedasticity in REM.

Null hypothesis: Variance of the unit-specific error = 0
Asymptotic test statistic: Chi-square (1) = 141.966 with p-value = 9.89137e-033

Breusch-Pagan test shows no unit-specific error in the model, so there is no evidence of heteroskedasticity. The REM can be used in this analysis.

RESULTS AND DISCUSSIONS

Table-2 is based on the Generalised Least Square Method (GLS) using 810 observations across 27 districts (Fig.1) and 30 years (*t*) with nine dummy variables each for different agro-climate zones. The dependent variable is rainfall. Table-2 has explained the different coefficients of different agro climate zones, which the REM estimated. We now outline some simulations based on Eq. 2, Eq. 3, Eq. 4, Eq. 5, Eq. 6, Eq. 7, Eq. 8 and Eq. 9 that represent the estimated rainfall mean. We can conceive these equations and find the mean of rain in each agro-climate zone as mentioned in Table-3. The most general of the models that we consider in this paper is when all dummies are zero, and we find the V-Humid Southern Eastern Plain agro-climate zone rainfall coefficient, which is 759.848 mm. To calculate the other coefficients of nine agro-climate zones needs to put the dummy coefficient value with the V-Humid Southern Eastern Plain agro-climate zone rainfall coefficient because it is a benchmark in this model.

It is evident from Table-2 that the difference with Humid Southern Eastern Plain is statistically significant with the D_1, D_2, D_3, D_4, D_5, D_6 dummies variable, but it is statistically different with D7, D_8 and D_9 dummies variable. Therefore, it implies that the seven agro-climate zones of the state have significant differences in terms of rainfall with Humid Southern Eastern Plain. Still, on the other hand, three agro-climate zones' rainfall is similar to Humid Southern Eastern agro-climate zone rainfall.

Table-2: Estimation of the mean of ten Agro-Climate Zones calculated by using REM.

	Coefficient	Std. Error	t-ratio	p-value	Sig.
Const.	759.848	63.8066	11.9086	<0.00001	***
D_1	-440.268	100.887	-4.3640	0.00001	***
D_2	-478.07	127.613	-3.7462	0.00019	***
D_3	-482.03	90.2362	-5.3419	<0.00001	***
D_4	-341.328	90.2362	-3.7826	0.00017	***
D_5	-278.987	90.2362	-3.0917	0.00207	***
D_6	-195.994	90.2362	-2.1720	0.03018	**
D_7	-104.065	84.4082	-1.2329	0.21802	
D_8	-36.6828	100.887	-0.3636	0.71626	
D_9	32.2596	90.2362	0.3575	0.72082	

Note: *** represent 1% and ** represent 5% level of significance

Table-3 indicates a comparative picture of REM's rainfall interval and ICAR rainfall interval. Rainfall interval needs to be calculated using Eq. 11 in, which will be used to find out the confidence interval at a 95% confidence. The approach is to estimate the rainfall intervals of different agro-climate zones. It is mentioned as a new rainfall interval classification based on the confidence interval using the REM technique for all agro-climate zones of the state.

Table-3: Comparison of Rainfall (1980-2010)

Zone	Coefficients	S.E	New Rainfall interval Classification #	Rainfall Interval (ICAR) Classification
IA	319.58	100.887	122-517	200-370
IB	281.778	127.613	32-532	100-350
IC	277.818	90.2362	101-455	100-350
IIA	418.52	90.2362	242-595	300-500
IIB	480.861	90.2362	304-658	300-500
IIIA	563.854	90.2362	387-741	500-700
IIIB	655.783	84.4082	490-821	500-700
IVA	723.1652	100.887	525-921	500-900
IVB	727.5884	90.2362	615-969	500-1100
V	759.848	63.8066	635-885	650-1000

Authors' self-calculated through the confidence interval of the model

It can be inferred from Fig. 2 that the minimum level of rainfall calculated by the ICAR is overestimated except IB and IC agro-climate zones because the REM has not proved it. Fig 3 depicts the maximum level of rainfall interval of different agro-climate zones presented by ICAR and calculated by the REM (Authors' model). The top-level of rainfall is almost similar in both models. The upper limit of rainfall interval trends is also identical in both classifications. Semi-arid Eastern plain and Sub-humid southern plain the limit is almost the same.

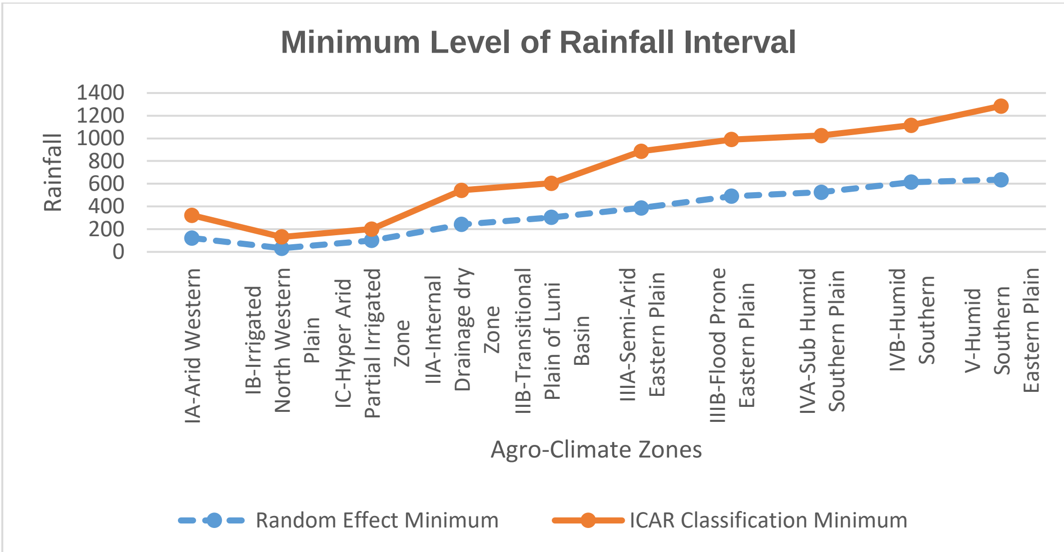

Fig. 2: Minimum level of rainfall in Agro Climate Zones.

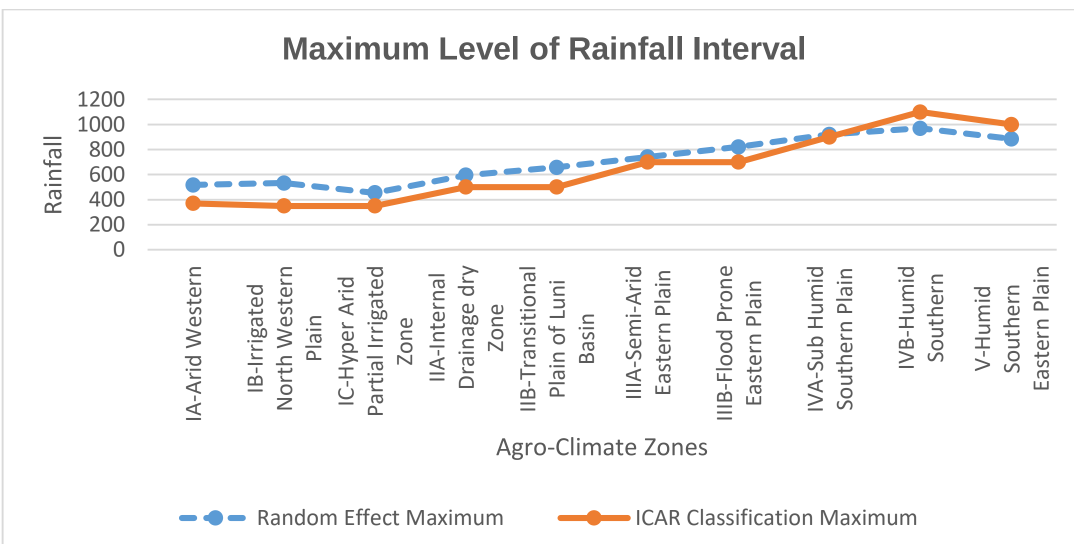

Fig. 3: Maximum Level of Rainfall in Agro Climate Zones.

CONCLUSIONS

The result shows that the REM is an effective method to estimate rainfall intervals. Average rainfall depends on many factors, but thirty years' data for all agro-climate zones have given us a vivid picture to calculate the average. Seven out of ten agro-climate zones are not statistically significantly different in average rainfall. Therefore, it is beneficial to estimate average rainfall and their interval by the model. The paper reveals no statistical difference in average rainfall between humid southern, eastern plain, flood-prone eastern plain, sub-humid southern plains, and the humid southern plain. The comparison founds that the variability of the arid western, irrigated northwestern and semi-arid eastern plains are higher as estimated by ICAR. The average rainfall in Sub Humid Southern Plain, humid southern and humid southern eastern plain agro climate zone has lower variability as estimated by ICAR. There is no significant difference in average rainfall between the internal drainage dry zone, the Luni basin's transitional plain, and the sub-humid southern plain. The REM discussed in the study is most suitable for Rajasthan state having significant diversities in climatic conditions. The estimation of heterogeneity can be described more logically and conveniently analysis of heterogeneity estimation using panel data.

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