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Predicting Karnataka's Average Annual Precipitation Through Arma Time-Series Modelling and Exceedance Probability Estimation

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ABSTRACT:
*The state of Karnataka receives significant amount of precipitation, strongly influenced by its varied topography and distinct climatic zones. The seasonal concentration of precipitation, with over 70% occurring during the southwest monsoon that is from June to September and there is also impact by the extreme events such as El Nino induced deficits and cyclonic surpluses on annual totals. The state comprises **four major agro-climatic regions with 31 districts**:*
*a) **Coastal Karnataka**, receiving the highest average annual rainfall, often surpassing **3,500 mm**, driven by orographic lifting, which is a weather process where a moving air mass is forced to rise over a geographical obstacle, such as mountain range of Western Ghats;*
*b) **Malnad (Hilly region)**, averaging around **2,000 mm**, benefiting from southwest monsoon intensity;*
*c) **North Interior Karnataka** and **South Interior Karnataka**, both semi-arid/dry zones with average annual rainfall near **700 mm**, largely dependent on monsoon progression and local convection (it is the method of heat transfer in fluids by the movement of the matter).*
In order to create strong rainfall forecasts and calculate exceedance probabilities in Karnataka, this study uses verified time-series data to examine yearly average rainfall patterns from 1989 to 2023 using an Auto Regressive Moving Average (ARMA) model.
*These findings deliver **evidence-based guidance** for:*
- ***Policy formulation** on drought mitigation and flood control;*
- ***Agricultural planning**, including crop diversification and water-efficient practices;*
- ***Sustainable reservoir management** and groundwater sustainability initiatives.*

*By integrating **time-series analytics** with **probability-based modelling**, this research paper establishes a **scientific foundation** for interpreting historical rainfall behavior and enhances **predictive capacity** for future climate variability in the state of Karnataka.*
Keywords: *Orographic Lifting, Convection, Exceedance Probabilities, Precipitation, Auto Regressive Moving Average Model (ARMA), Return Period, Root Mean Squared Error (RMSE), Dicky-Fuller Test (DFT), Standard Error (SE).*

INTRODUCTION:

The rainfall is the primary natural source for the agricultural productivity, use for human population and for the biosphere, hence the forecast model of the rainfall data provides a sigh of relief during the problems like drought and the flood in the state of Karnataka.
This paper uses 35 years of rainfall data from 1989 to 2023 and is obtained from the officially from the Directorate of Economics and Statistics, Government of Karnataka to trace the variations in the all agroclimatic zones of the Karnataka. The use of ARMA-statistical model one can predict the data for the future years.

- **Farmers** to optimize crop selection, sowing schedules, and irrigation strategies;
- **Water authorities** to refine reservoir operations and groundwater recharge plans;
- **Disaster management agencies** to strengthen early warning systems and contingency measures.

The data analysis provides the action oriented clever model for the developing climate-proof statistical model for the state of Karnataka.

LITERATURE REVIEW:

The rainfall data is in raw form and the analysis of this from time to time has not been taken for the use of the public both by the Government agencies and the research institutes in the state of Karnataka. The most of the

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source of raw data is being obtained from the Government of Karnataka's Directorate of Economics and Statistics, Karnataka State Natural Disaster Monitoring Centre and missing values are substantiated by the data from the Indian Meteorological Department, Pune.
The Data validation has been done to identify and fill the missing values, standardizing the unit of measurement, and uniformity. Three analytical approaches were employed to examine the rainfall data:

1. **Computation of exceedance probabilities**
2. **Stationarity testing using the Dickey-Fuller test**
3. **Forecasting via ARMA time-series modelling**

DATA COLLECTION: Secondary data were sourced from the Karnataka at a Glance report, an annual publication by the Directorate of Economics and Statistics, Government of Karnataka. An additional annual rainfall figures were obtained from the yearly reports of the Karnataka State Natural Disaster Monitoring Centre (KSNDMC), under the Revenue Department, Government of Karnataka.

METHODOLOGY-1: Calculations of Exceedance Probabilities:
A pretty modest, graphic method to calculate the probability of amount of average annual rainfall is explained here. The following data represents annual rainfall pattern in millilitres for 35 years in Karnataka from 1989 to 2023.

Table-1: Annual Rainfall in Karnataka from 1989-2023 (in mm)

Year	Average Annual rainfall	Year	Average Annual rainfall	Year	Average Annual rainfall	Year	Average Annual rainfall	Year	Average Annual rainfall	Year	Average Annual rainfall
1989	1130	1995	1219	2001	1194	2007	1578	2013	1409	2019	1635
1990	1227	1996	1327	2002	1033	2008	1340	2014	1414	2020	1567
1991	1252	1997	1489	2003	1036	2009	1544	2015	1160	2021	1474
1992	1095	1998	1479	2004	1271	2010	1500	2016	996	2022	1603
1993	1046	1999	1430	2005	1584	2011	1375	2017	1063	2023	959
1994	1389	2000	1420	2006	1403	2012	1094	2018	1366		

The data is initially ranked for calculation of the exceedance probabilities by using the below formula for each of the ranked observations.

$$P = \frac{m - 0.375}{N + 0.25} * 100$$

Where, the notations indicate the following meaning;
P = probability in % of the observation of the rank m,
m = rank of the observation,
N = total number of observations used(35),
T = Return Period (= 100/P)
Hence, the below values of the probabilities of exceedance and the Return Periods are obtained.

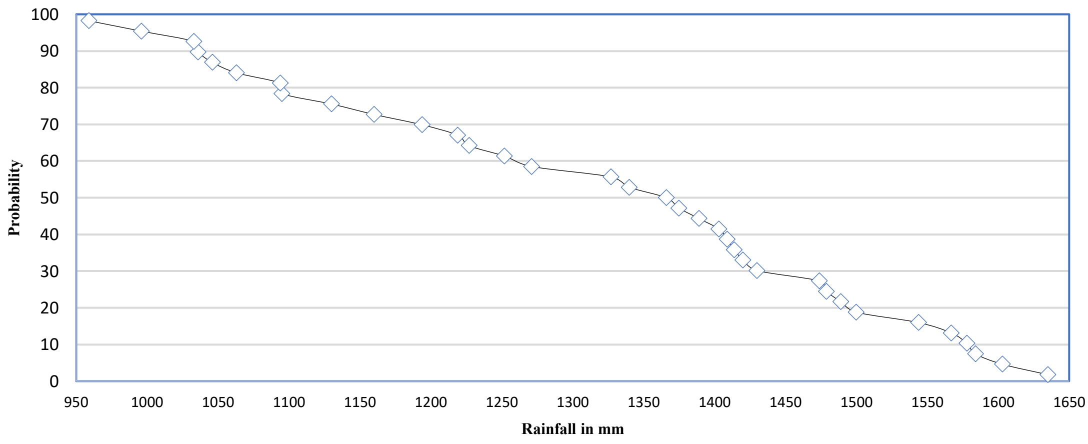
Table-2: Ranked Annual Rainfall in Karnataka from 1989-2023 (35 Years) (in mm)

Rank (m)	Year	Average Annual rainfall	P	T=100/P (years)	Rank (m)	Year	Average Annual rainfall	P	T=100/P (years)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	2019	1635	2	56	19	2008	1340	53	2
2	2022	1603	5	22	20	1996	1327	56	2
3	2005	1584	7	13	21	2004	1271	59	2
4	2007	1578	10	10	22	1991	1252	61	2
5	2020	1567	13	8	23	1990	1227	64	2
6	2009	1544	16	6	24	1995	1219	67	1

7	2010	1500	19	5	25	2001	1194	70	1
8	1997	1489	22	5	26	2015	**1160**	73	1
9	1998	1479	24	4	27	1989	1130	76	1
10	2021	**1474**	27	4	28	1992	1095	78	1
11	1999	1430	30	3	29	2012	1094	81	1
12	2000	1420	33	3	30	2017	1063	84	1
13	2014	1414	36	3	31	1993	1046	87	1
14	2013	1409	39	3	32	2003	1036	90	1
15	2006	1403	41	2	33	2002	1033	93	1
16	1994	1389	44	2	34	2016	996	95	1
17	2011	1375	47	2	35	2023	959	98	1
18	2018	1366	50	2					

Further, plot the ranked average annual rainfall data (columns 3, 8 of Table-2) against the corresponding values of the probabilities (columns 4, 9 of Table-2).

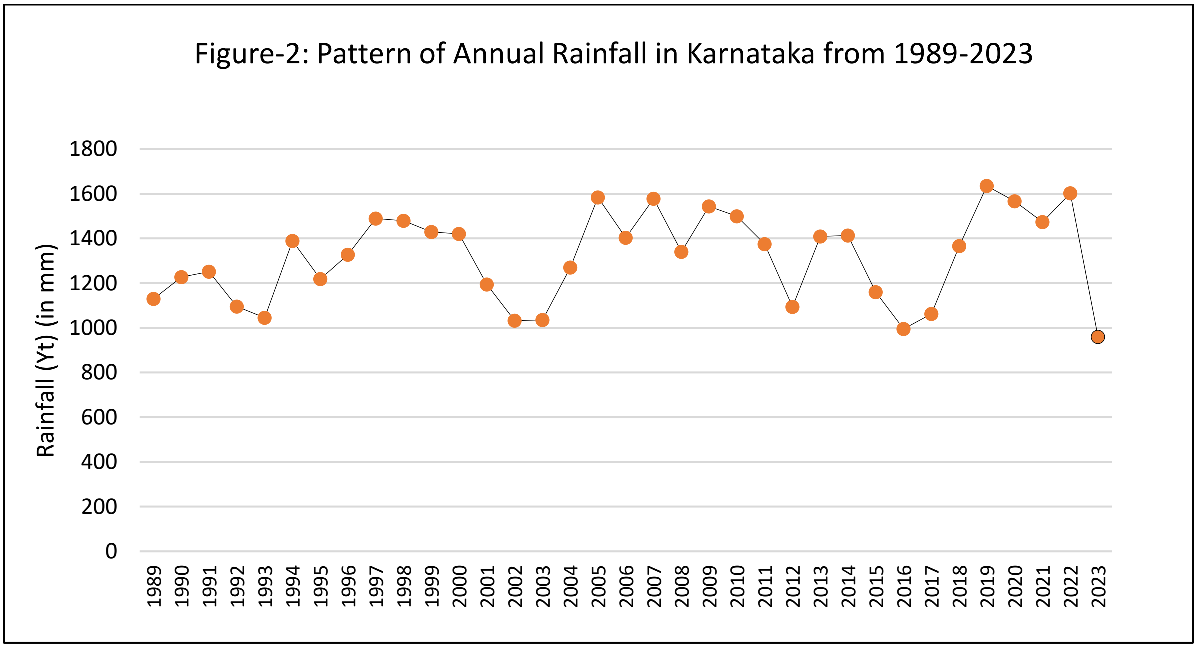
Figure-1 : Cummulative Distribution of Rainfall in Karnataka from 1989 to 2023



RESULTS-1: From the above graph it is likely to obtain the probability of incidence or exceedance of a rainfall of a precise scale. Contrariwise, it is also possible to obtain the amount of the precipitation matching to a given probability.

For illustration, the exceedence is 1160 mm for the average annual rainnfall with the probaility of 73% (graph-1), i.e. on an average in 73% of time average annual rainfall of 1160 mm would be equalled or exceeded. For probability value of 27% of exceedance is 1474 mm. (refer Table-2 and graph-1).
The period of return that is T is calculated by T=100/P years.
From the above analysis, it can be seen that, the return period for the 73% and the 27%t exceedance probability trials are:
$T_{73\%}$=100/73=1.4 years.
It means on usual course the average annual rainfall of 1160mm or more is likely in 2 years out of 3 years;
$T_{33\%}$=100/27=3.7 years.
It means on an average the average annual rainfall of 1474mm or higher is expected in 1 year out of total 3 years.

METHODOLOGY-2: Ascertaining data for stationarity by Dicky-Fuller Test:
To assess the stationarity of annual rainfall data (1989–2023), an initial **visual inspection** of the time-series plot (Figure 2) is conducted, displaying precipitation in millimetres against the corresponding years. The graph reveals **no evident upward or downward trend**, with fluctuations appearing to oscillate around a relatively constant mean level (approximately 1,250 mm), and variance remaining fairly uniform over time—suggestive of stationarity.



However, visual assessment alone is insufficient due to potential subtle non-stationarities. Therefore, the statistical test for cheking the statioanrity of the data that is **Dickey-Fuller Test** is deployed to know whether there is stationarity in the data. This hypothesis test evaluates the null hypothesis (H_0): the data has a unique **root** (non-stationary) versus the alternative (H_1): the data is stationary.
At the significane level of 5% the test-statistic is calculated to be compared with critical value or table value. A value of p is less than the prescribed value that is 0.05, therefore the null hypothesis is rejected and the alternative hypothesis is accepted. Therefore it means that the data is stationary.
Let us consider a stochastic process, such that, $Y_t = B * Y_{t-1} + e_t$
Subtracting "Y_{t-1}" from both the sides, we obtain,
$Y_t - Y_{t-1} = (B - 1) * Y_{t-1} + e_t$
So, if, B — 1 = 0 or B = 1 (Unit root); the process is said to be stationary. That is, we test the following hypothesis,
H_0 : B-1 = 0 Vs. H_1 : B — 1 ≠ 0
Hence, we find that data is stationary nature.
So, when B — 1=0 that is null hypothesis is accepted that is data is stationary. To interpret test results, p-value with 5% level of significance, the value of $p=4.866 \times 10^{-31}$ which is less than 0.05. Hence, there exists a unit root that is the data is stationary.

RESULTS-2: The excel calculations of Regression analysis is given below:

	Coefficients	SE	value of t	value of p
Intercept	1325.350453	28.32877373	46.78460372	4.86619E-31
X Variable 1	0.531668994	0.134137049	3.963625248	0.00038788

METHODOLOGY-3: Fitting ARMA model for the rainfall data in Karnataka:
So as described in methdology-2, the data is stationary and is ready to be applied for the **ARMA Model** for calculation of forecasts. Here, we have used ARMA (1,1) model as below. The general equation of the Auto Regressive Moving Average model with p and q as parameters is the linear combination of past actual periods and the error terms and is given by;
$y_t = \phi_0 + \beta_1 y_{t-1} + \beta_2 y_{t-2} + \ldots + \beta_p y_{t-p} + \theta_1 e_{t-1} + \theta_2 e_{t-2} + - \ldots + \theta_q e_{t-q} + \epsilon$
As the data in Table-1 is Stationary and there exists a positive Auto Correlation and Partial Auto Correlation, hence best fit of the data is ARMA with (1,1) as parameters. Following steps are involved in calculation of forecasts are as below:
Centre each data by (Y_t- Y_{mean}) as in column 3 of Table-3.
Consider initial residual as zero.
Choose auto-regressive coefficient (β_1) and error coefficient (θ_1) as 0.5 each arbitrarily.
Calculate forecasts as the linear combination of centred data and residual of the previous period.

Calculate, RMSE = Sq. Root of (Sum of squared residuals ÷ No. of observations) (RMSE=196.38)
Now, find the minimum value of RMSE, for the optimum vales of (β_1) and (θ_1) by using *excel solver*. (They are RMSE=175.79, for the optimum vales of (β_1)=0.3 and (θ_1)=0.2)
Hence, the final forecast for these optimised RMSE, (β_1) and (θ_1) are obtained.

Results-3:Final forecast equation is $Y_{t+1} = Y_{mean}(1\text{-}\boldsymbol{\beta}_1) + \boldsymbol{\beta}_1\, y_t + \boldsymbol{\theta}_1\, e_{t\text{-}1}$

Table-3

Year	Annual Rainfall in mm (Yt)	Centred Data (Yt-Ymean)	Residue (initially it is 0) Centered data minus forecast	Initial Forecast ARMA	Residue or Error Square
1989	1130	-187.17	0	-	0.00
1990	1227	-90.17	-42.91	-47.26	1841.41
1991	1252	-65.17	-32.69	-32.48	1068.67
1992	1095	-222.17	-198.32	-23.85	39329.41
1993	1046	-271.17	-170.18	-100.99	28962.90
1994	1389	71.83	178.82	-106.99	31976.48
1995	1219	-98.17	-156.78	58.61	24581.25
1996	1327	9.83	70.10	-60.28	4914.69
1997	1489	171.83	153.48	18.35	23555.64
1998	1479	161.83	83.70	78.13	7006.11
1999	1430	112.83	53.02	59.81	2811.28
2000	1420	102.83	62.34	40.49	3886.08
2001	1194	-123.17	-163.25	40.07	26649.11
2002	1033	-284.17	-216.12	-68.05	46707.95
2003	1036	-281.17	-160.50	-120.67	25760.35
2004	1271	-46.17	61.15	-107.32	3739.63
2005	1584	266.83	264.64	2.18	70036.74
2006	1403	85.83	-41.45	127.28	1717.87
2007	1578	260.83	248.54	12.29	61771.66
2008	1340	22.83	-99.29	122.12	9857.85
2009	1544	226.83	243.54	-16.71	59310.92
2010	1500	182.83	70.43	112.40	4960.39
2011	1375	57.83	-4.28	62.11	18.29
2012	1094	-223.17	-236.80	13.63	56076.50
2013	1409	91.83	201.78	-109.95	40714.99
2014	1414	96.83	27.97	68.86	782.26
2015	1160	-157.17	-187.95	30.78	35325.56
2016	996	-321.17	-238.94	-82.23	57093.89
2017	1063	-254.17	-118.99	-135.18	14159.08
2018	1366	48.83	139.94	-91.11	19583.09
2019	1635	317.83	273.82	44.00	74979.52
2020	1567	249.83	107.60	142.23	11577.29
2021	1474	156.83	69.39	87.44	4815.42
2022	1603	285.83	230.52	55.31	53140.80
2023	959	-358.17	-482.52	124.35	232826.57

Thus, the forecasts for the years **2024:1118mm, 2025:1267mm, 2026:1304mm, 2027:1314mm, 2028: 1316mm, 2029:1317mm, 2030:1317mm** and so on.

CONCLUSION: The statistical examination confirms that Karnataka's annual rainfall time series spanning 1989–2023 exhibits **stationarity**, validated through the Dickey-Fuller Test, indicating no unit root and stable mean/variance over time. Further, based on ACF and PACF functions diagnostics, an ARMA(1,1) model was identified as optimal for capturing short-term dependencies and forecasting future precipitation. The basic model for the rainfall forecasts is identified. The study reveals that Karnataka's rainfall patterns exhibit periodic fluctuations with occasional extreme years.

The rainfall forecast shows retrieval from the 2023 and a steadiness at about 1317mm from 2030 in the future years. There exits huge potential for further analysing district and Taluka wise and predicting similar regional specific model in Karnataka. The above analysis is solid predication model for the selection of crop by the farmer and irrigation scheduling, and water resource personnel's activities in the state, hence enabling both the stake holders and the policy makers to take appropriate steps in this regard.

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