Orographic Effects on the Distribution of Rainfall in Mula River Basin

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Abstract: ***The present study examined the orographic effects on the distribution of rainfall over the Mula River catchment area located in north Ahmednagar district. The 30 locations rainfall data of the last 43 years (1980-2023) was used. The basin physiography shows that the elevation has sharply declined from the northwest towards the east while the Interpolation analysis by the inverse distance weighting (IDW) method highlights that the rainfall also sharply declined from northwest to east. The regression model result indicates that an increase of 100 m elevation causes an increase of 114.77 mm of rainfall means the distribution of rainfall is controlled by elevation over the Mula River basin.***

Keywords: Rainfall, Orographic effects, inverse distance weighting (IDW), regression model

1. Introduction

In India more than 80 percent of rainfall occurs from June to September, in general, the hills and mountain ranges block the rain-bearing monsoon winds causing heavy rainfall. The rainfall is the most crucial factor among all climatic parameters, it is quite difficult to predict in complex terrain due to the variability (Hutchinson, 1998). But recently, the Intergovernmental Panel on Climate Change stated that rainfall trends are decreasing, and spatial distribution of rainfall is also changing worldwide due to climate changes (IPCC,2013). The impact of climate change is noticed over smaller spatial scales, in terms of changing spatio-temporal patterns of rainfall (Sawant et al., 2015). The northern Ahmednagar district is under the influence of monsoon circulation, rainfall is highly erratic and sharply declined from west to east direction (Sasane, 2016). The spatial distribution of rainfall and rainfall variability steadily decreases from west to east under the influence of altitude over the north Ahmednagar district (Patil and Sasane, 2013). Altitude is one of the key factors affecting the distribution of rainfall in hilly areas (Taher and Alshaikh, 1998). Recently, interpolation techniques have emerged as the best tool for the study of the distribution of rainfall in highland areas. In mountainous and hilly areas data collection is quite difficult due to rigid topography where the interpolation method plays playing significant role in mapping (Collins and Bolstad 1996). Several scholars used the IDW interpolation method for the mapping of rainfall distribution (Singh & Chowdhury 1986; Lebel et al. 1987). To examine the orographic effects on the distribution of rainfall person correlation coefficients (r) and linear regression models are the statical techniques commonly used. The linear regression model showed a correlation between the rainfall and elevation (Abdul Ghani et al., 2018)

The unique physiographic features of the Mula River basin and its surrounding hilly regions along the Western Ghat border generally affect the rainfall quantity and distribution patterns. The basin has an east-west alignment of ranges and hills in the northwest. The rainfall distribution in the basin during the southwest monsoon season is determined by the direction of monsoon winds which is controlled by physiographic conditions. The changes in the rainfall distribution are a combined effect of relief, slope, altitude, and wind movement over the basin. The presence of elevated hill barriers causes heavy rainfall in northwest highland areas and the rain shadow effect is more predominant resulting sharp decline in rainfall in eastwards. Therefore, the precent study is trying to explain the elevation effect on the distribution of rainfall in the Mula River catchment area by applying Person correlation coefficients and a linear regression model.

2. Study Area

The Mula River catchment area is located from 19°08' N to 19°32' N latitude and 73°42' E to 74°45' E longitude (Figure 1). The shape of catchment area is funnel-shaped and covers a 2919.55 sq. km catchment area of the north Ahmednagar district an elevation range between 643 to 1564 m above sea level. December is the coldest month at only 11.54°C and May is the hottest month at 34.68°C. The average rainfall is 880 mm and variation ranges between 1564 mm at Harishchandragad located on Kokan Kada to 605 mm at Pachegaon situated on the Mula-Pravara confluence in the plain area. Mula River is the main drainage system, it rises on the southern slope of Harishchandragad. About 25 km, Mula flows parallel to the Pravara River up to Kotul. After that, it flows southeast direction downstream through hilly areas. Mula Dam is constructed on the Mula River with a storage capacity of 23 TMC at Mulanagar in Rahuri tahsil. The water reservoir is known as Dnyaneshwar Sagar providing irrigation facilities to Rahuri, Newasa, Shevgaon, and Pathardi tahsils. After completing a 145 km journey from its source Mula joins Pravara at the village of Pachegaon and Mula-Pravara flows towards the northeast.

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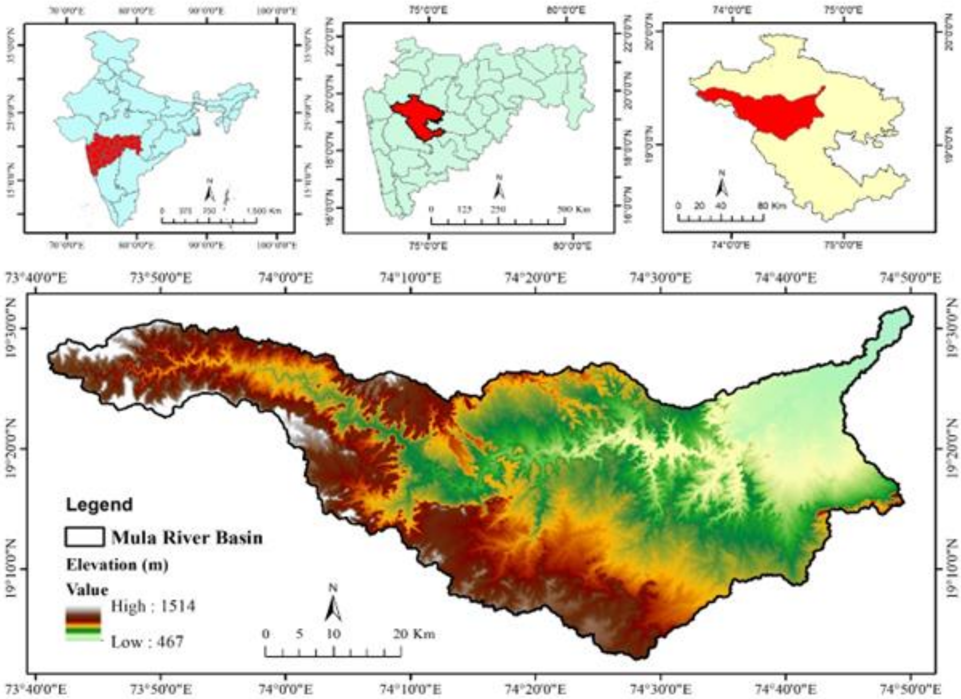

Figure 1: Location of Mula River Basin

3. Objective

To examine the orographic effects on the distribution of rainfall in the Mula River catchment area, Maharashtra.

4. Database and Methodology

Database

The rainfall statistics of 30 locations located in the Mula River catchment were obtained for the last 43 years (1980 – 2023) from the Indian Meteorological Department, Pune & Mula Irrigation.

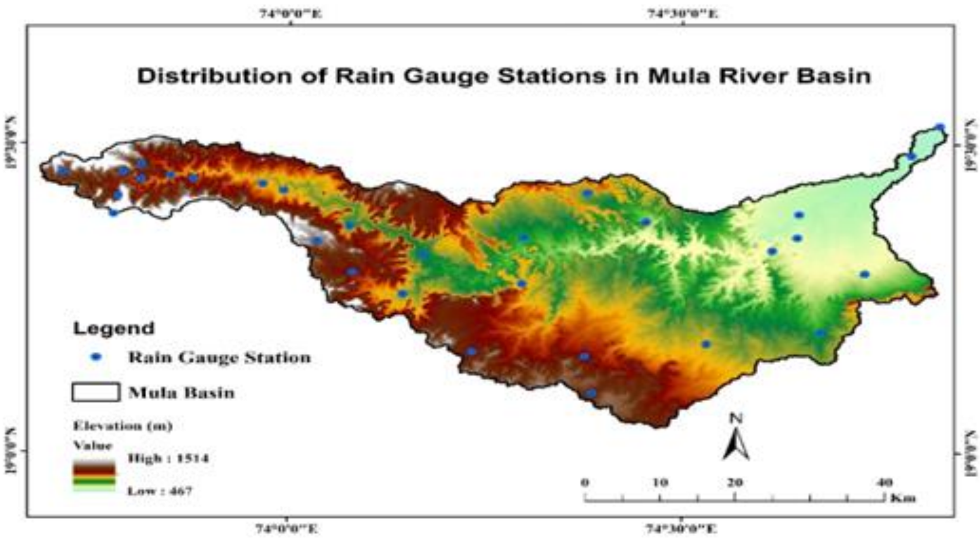

Figure 2: Rain Gause Stations in Mula River Basin

5. Methodology

The annual rainfall records of 30 stations distributed in the Mula River basin for a period of 43 years (1980 – 2023) have been compiled (Figure 2). The orographic effect on the spatial distribution of rainfall was calculated by applying Pearson's Coefficient of Correlation method using collected data.

$$\mathbf{r} = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{(n(\Sigma x^2) - (\Sigma x)^2)(n \times (\Sigma y^2) - (\Sigma y)^2)}}$$

The value of the coefficient of Correlation (r) ranges between -1 to +1, where -1 indicates a strongly negative correlation while +1 indicates a strongly positive correlation and 0 indicates, no correlation.

After correlation analysis, a linear regression model was applied to determine the degree of relationship between elevation (independent variable) and rainfall (dependent variable). The regression equation is as follows.

$$y = a + bx$$

The accuracy level of predicted values (y) is determined by utilizing the standard error (SE) method. The standard error (SE) of the regression has been calculated by the following equation.

$$\text{Standard Error} = \frac{1 - \boldsymbol{r}^2}{\sqrt{n}}$$

The smaller value of standard error (SE) indicates a lesser error, which means that data points are closer to the regression line.

6. Results and Discussion

The Mula River basin can be broadly divided into three zones, the hilly and plain areas. Threaten rain gauge stations are located in the hilly zone (upper basin), Ten stations in the Plateau zone and seven in the plain zone (Figure 2). The distribution of rainfall on a temporal scale has been examined by using the IDW method in ArcGIS.

Table 1: Annual rainfall in Mula River Basin: 1980-2023

S. No.	Rain Gauge	Zone	Latitude	Longitude	Rainfall
1	Harischandragad	Hilly zone	19.38637358	73.77653003	1564
2	Bhramanwada	Hilly zone	19.3432277	74.03559359	886
3	Kumshet	Hilly zone	19.45386637	73.71162591	1542
4	Panchanai	Hilly zone	19.4157375	73.78204888	1428
5	Kanhoor Pathar	Hilly zone	19.09767983	74.38596279	811
6	Ane	Hilly zone	19.16415111	74.2331733	874
7	Silwandi	Hilly zone	19.44372952	73.87768131	1356
8	Dhamanvan	Hilly zone	19.46654573	73.81180071	1552
9	Takali Dhokeshwar	Hilly zone	19.157207	74.3766775	828
10	Belapur	Hilly zone	19.29272958	74.08107308	965
11	Sisvad	Hilly zone	19.44294738	73.81230127	1486
12	Khadki	Hilly zone	19.44909288	73.84889656	1465
13	Ambit	Hilly zone	19.45412281	73.78876633	1533
14	Kotul	Plateau zone	19.43556049	73.96603116	844
15	Pokhari	Plateau zone	19.27436239	74.2963212	867
16	Dhawalpuri	Plateau zone	19.17697939	74.53074862	799
17	Bori	Plateau zone	19.42499641	73.99289775	881
18	Bota	Plateau zone	19.2576379	74.14489329	940
19	Varvandi	Plateau zone	19.42194022	74.37919932	828
20	Pimpaldhari	Plateau zone	19.36779918	74.07733257	979
21	Gargaon	Plateau zone	19.32195107	74.17056849	944
22	Vilad	Plateau zone	19.19569405	74.67568993	776
23	Sakur	Plateau zone	19.34933656	74.29852217	859
24	Mhaisgaon	Plain zone	19.37467989	74.4541075	808
25	Mulanagar	Plain zone	19.32806392	74.61454501	726
26	Vambori	Plain zone	19.29089746	74.73197227	742
27	MPKV	Plain zone	19.34923516	74.64638178	707
28	Pachegaon	Plain zone	19.52975706	74.8272869	605
29	Rahuri	Plain zone	19.38677416	74.64839601	696
30	Manjari	Plain zone	19.48197726	74.79155257	643

(Source: Indian Meteorological Department, Pune & Mula Irrigation Department, Rahuri)

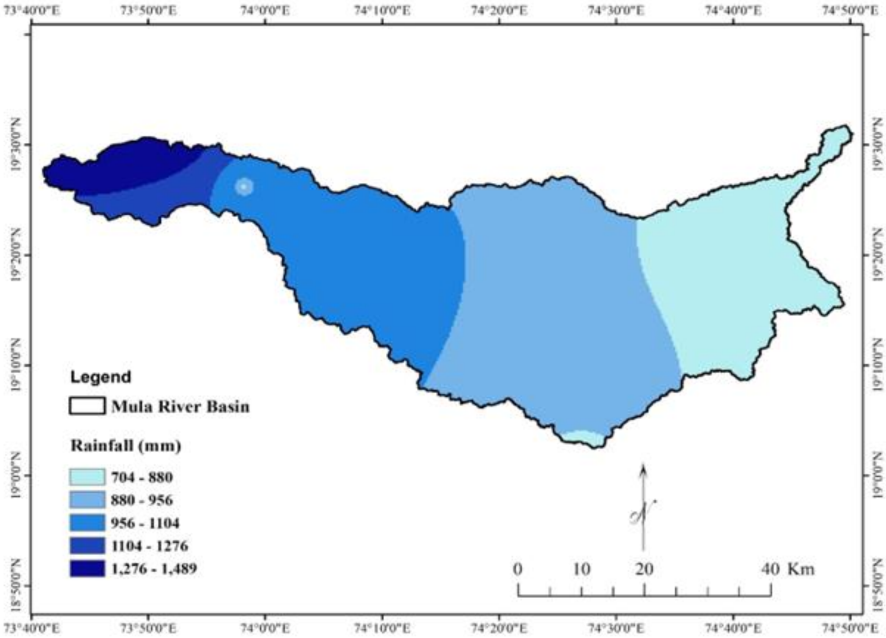

Figure 3: Spatial distribution of rainfall in Mula River catchment area

The Mula River basin is divided into five rainfall zones, very high (Above 1276 mm), high (1104 -1276 mm), medium (956 -1104 mm), low (880 -956 mm), and very low (below 880 mm). The rainfall distribution in the basin indicates high rainfall in the northwestern part of the basin and it sharply declines towards the east. The rainfall variation ranges between 1564 mm at Harishchandragad located on Kokan Kada to 605 mm at Pachegaon situated on Mula-Pravara confluence in the plain area. It is mainly due to the southwest monsoon winds. In general, the annual rainfall pattern indicates that heavy rainfall is experienced on the windward side and the amount of rainfall is dropping towards the leeward side of the Western Ghat ranges.

Table 2: Correlation of elevation and rainfall in Mula River Basin: 1980-2023

Rain Gauge Stations	Zone	Latitude (°)	Longitude (°)	Elevation (m)	Rainfall (mm)
Harischandragad	Hilly zone	19.38637358	73.77653003	1422	1564
Bhramanwada	Hilly zone	19.3432277	74.03559359	916	886
Kumshet	Hilly zone	19.45386637	73.71162591	874	1542
Panchanai	Hilly zone	19.4157375	73.78204888	863	1428
Kanhoor Pathar	Hilly zone	19.09767983	74.38596279	847	811
Ane	Hilly zone	19.16415111	74.2331733	806	874
Silwandi	Hilly zone	19.44372952	73.87768131	786	1356
Dhamanvan	Hilly zone	19.46654573	73.81180071	785	1552
Takali Dhokeshwar	Hilly zone	19.157207	74.3766775	780	828
Belapur	Hilly zone	19.29272958	74.08107308	779	965
Sisvad	Hilly zone	19.44294738	73.81230127	765	1486
Khadki	Hilly zone	19.44909288	73.84889656	764	1465
Ambit	Hilly zone	19.45412281	73.78876633	761	1533
Kotul	Plateau zone	19.43556049	73.96603116	700	844
Pokhari	Plateau zone	19.27436239	74.2963212	689	867
Dhawalpuri	Plateau zone	19.17697939	74.53074862	685	799
Bori	Plateau zone	19.42499641	73.99289775	682	881
Bota	Plateau zone	19.2576379	74.14489329	674	940
Varvandi	Plateau zone	19.42194022	74.37919932	660	828
Pimpaldhari	Plateau zone	19.36779918	74.07733257	648	979
Gargaon	Plateau zone	19.32195107	74.17056849	623	944
Vilad	Plateau zone	19.19569405	74.67568993	609	776
Sakur	Plateau zone	19.34933656	74.29852217	605	859
Mhaisgaon	Plain zone	19.37467989	74.4541075	578	808
Mulanagar	Plain zone	19.32806392	74.61454501	565	726
Vambori	Plain zone	19.29089746	74.73197227	558	742
MPKV	Plain zone	19.34923516	74.64638178	540	707
Pachegaon	Plain zone	19.52975706	74.8272869	531	605
Rahuri	Plain zone	19.38677416	74.64839601	516	696
Manjari	Plain zone	19.48197726	74.79155257	496	643

(Source: Indian Meteorological Department, Pune & Mula Irrigation Department, Rahuri)

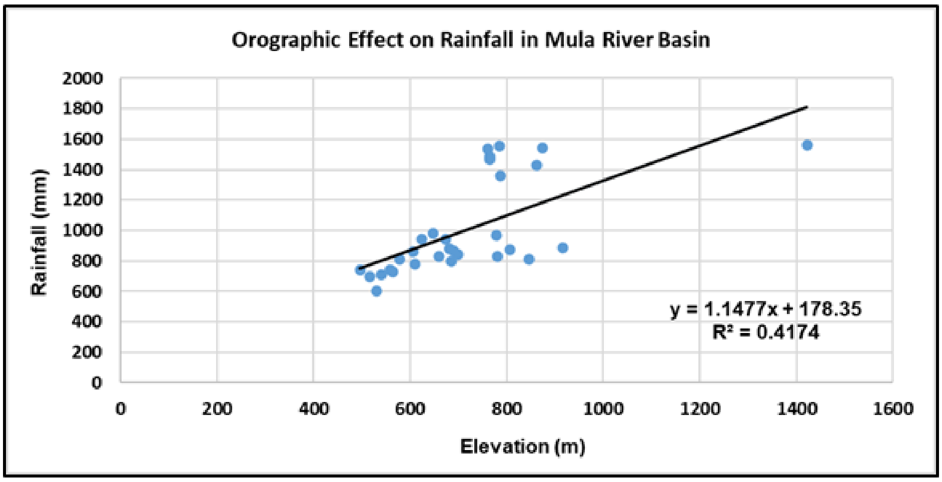

Figure 4: Orographic effect on the distribution of rainfall in the Mula River Basin

The correlation between elevation and rainfall is calculated by applying the Person correlation coefficient (r) method using the following formula.

$$\mathbf{r} = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{(n(\Sigma x^2) - (\Sigma x)^2)(n \times (\Sigma y^2) - (\Sigma y)^2)}}$$

r = 0.64

The calculated value of the Person correlation coefficient (r) is 0.64 which indicates the positive correlation between elevation and rainfall in the catchment area.

The coefficient of determination (R^2) is also calculated to determine the degree of correlation between elevation and rainfall and the value of R^2 0.4174 (41.74%) rainfall variation is explained by elevation in the Mula River basin.

The linear regression model was applied to estimate the rainfall (y) concerning elevation (x) in the study area. For that, the following equation is used.

y = a + bx
y = 1.1477x +178.35

The regression model indicates that an increase of 100 m elevation causes an increase of 114.77 mm of rainfall in the Mula River catchment area (Figure 4).

To understand the accuracy level of predicted rainfall (y) by regression model the standard error (SE) of the estimate method is applied using the following equation.

$$\text{Standard Error} = \frac{1 - \boldsymbol{r}^2}{\sqrt{n}}$$

SE= 0.1064

Thus, the final equation takes the form:

y = 1.1477x +178.35 ± 0.10

Fortunately, the standard error (SE) of the estimate of rainfall association with elevation is very low. The results indicate that rainfall depends on elevation because most parts of the basin are under hilly areas.

7. Conclusion

From the result, it can be calculated that the role of physiography is important in the distribution of rainfall and rainfall variability patterns in the entire Mula River basin. The effect of elevation on the amount of rainfall is most visible in the hilly zone of the northwestern parts of the basin where rainfall is quite high. The effect of Western Ghat ranges in northwestern areas is visible through the heavy rainfall. The deflection of southwest monsoon winds as they enter the funnel-shaped hilly zone, as a result, most parts recorded heavy rainfall. The basin physiography shows that the elevation has sharply declined from the northwest towards the east which also controls the amount of rainfall and variability of rainfall. Statistical analysis shows that the annual rainfall ranges between 1564 mm at Harishchandragad located on Kokan Kada to 605 mm at Pachegaon situated on the Mula-Pravara confluence in the lowland area. The regression model reveals that an increase of 100 m elevation causes an increase of 114.77 mm of rainfall. It can also be indicated that the amount of rainfall depends on elevation in the Mula River Basin.

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