

# The Relationship between Precipitation and Elevation of the Watershed in the Khirthar National Range

ABDUL GHANI SOOMRO\*, MUHAMMAD MUNIR BABAR\*, ARSHAD ASHRAF\*\*, AND ANEELA MEMON\*

RECEIVED ON 24.05.2018 ACCEPTED ON 30.10.2018

## ABSTRACT

Precipitation plays a pivotal role in the evolution of the ecosystems. Many watersheds in Pakistan and particularly in parts of Sindh are ungagged, which urge to estimate the precipitation and other parameters using feasible models for effective planning and management of water resources. Regression analysis is usually employed to understand the hydro-climatic relationships of a watershed. The present study is aimed to investigate the relationship between precipitation and elevation through developing linear regression models for various levels of precipitation data and map their spatial variability in the KNR (Khirthar National Range), Sindh, Pakistan. The precipitation data of 7 meteorological stations covering the study area were used with DEM (Digital Elevation Model) data of 90 m resolution for altitudinal trend analysis. The results of the linear regression model showed a close relationship between the precipitation of various time-scales and elevation, i.e. coefficient of determination  $R^2$  values ranging within 0.8206-0.9604. The correlation was significant at  $P < 0.05$  for mean annual, mean monthly, and mean seasonal (Rabi) precipitation. The spatial variation in precipitation was between 127.78-697.98 mm at annual and from 10.84-58.09 mm at mean monthly level. The lapse rate of increase in precipitation with elevation was 27.03 mm per 100 m for annual and 2.24 mm per 100 m for monthly level. At seasonal level, precipitation varied from 24.17-137.87 mm during Rabi (winter) and between 105.78-525.36 mm during Kharif (summer) season. Similarly, the monsoon precipitation (July-September) ranged between 92.24-359.93 mm in the study area. The higher precipitation estimated over elevated areas of the region at seasonal and annual levels needs to be harvested through adopting adequate water management techniques for improving agriculture productivity in the downstream areas.

**Key Words:** Precipitation, Elevation, Watershed, Digital Elevation Model, Regression Analysis, Khirthar National Range.

## 1. INTRODUCTION

Assessing and forecasting spatial variation and the potential of precipitation play a major role in planning and management of water resources to provide for the diversity of activities of

human beings, socio-economic, hydrology, and ecology [1-3]. Many studies have investigated the relationship among spatial-temporal distribution of precipitation versus elevation features [4-10] geographical location [7-8]

Authors E-Mail: (ag2005parc@gmail.com, mmunirbabar.uspcasw@faculty.muet.edu.pk, muhammad\_ashraf63@yahoo.com, aneelahameem@gmail.com)

\* US-Pakistan Center for Advanced Studies in Water, Mehran University of Engineering & Technology, Jamshoro, Pakistan.

\*\* Pakistan Agricultural Research Council, Islamabad, Pakistan.

surface grade [4,6-9] wind velocity and direction, variation of temperature [4,6,10-11] closeness of water bodies, such as sea, ocean or reservoirs [4,6-7] to discover the relationship among altitudinal distributions of normal annual, bi-season, and mean monthly precipitation for various regions of the globe through development of linear regression techniques coupled with GIS (Geographic Information System) approaches. Those experiments have established excellent consequences such as [7]; they estimated the best forecaster of precipitation variation. Bassist and Bell [4] revealed through their research that the applied techniques have enhanced the relationship of altitude, worked on the variables, which belong to the spatial distribution of yearly and mean precipitation. Konrad [6] concluded that elevation was associated strongly with concerning light-shower precipitation patterns; however, the closeness to water bodies was linked to the heavy precipitation patterns. Hayward Clarke [5] estimated the relationship between precipitation, elevation, and sea distance by interpreting many regression models. They did investigations on the relationship between monthly precipitation versus elevation using the regression model and found strong relation for rain gauging stations as compared to coastal gauging stations. Katsoulis et. al. [12] discovered spatial-temporal variations of rainfall in Greece, describing the change between the wetter western (windward) and the drier eastern Greece (leeward), although there was minimal quantity of rainfall over the Greek Islands. Pedgley [13] reported that rainfall in the mid-latitudes is associated closely with the flat topography near to the rain-gauge. Chaun and Lockwood [14] selected an average elevation for the rain gauge within an 8 km radius of the gauging station and revealed strong relation within elevation and precipitation. Hill et. al. [15] preferred normal altitudes in a 4 km<sup>2</sup> grid during the observation of radar and orographic experiment. Konrad [6] used the average altitude within a 10x10 km<sup>2</sup> grid; he revealed a strong relationship of altitude and event basis

precipitation. Johansson and Chen [16] re-managed the sample and used altitude from a 50 km<sup>2</sup> area into a strip of a 4 km<sup>2</sup> of the resolution, the results showed influences of wind on the distribution of rainfall slightly, overall found good the relationship of altitude and precipitation in the study area. Gouvas et. al. [17] explored the variable of neighboring elevation of gauging stations and found better results, during enhancement of precipitation in hilly areas compared to elevation of the gauging station itself. Alijani [10] estimated an average elevation for a 2½ km<sup>2</sup> radius of study area around the precipitation gauging position, which revealed the suitable relationship of altitude within the spatial distribution of precipitation in the mountainous range of study area.

Recently, Subyani [2] proposed that the use of a “Z” variable with elevation in the range of 2 ½ km<sup>2</sup> enhanced the forecasting results by interpolation techniques. A linear regression model gradually shows the differences between independent and dependent variables, which can be used for the estimation of spatial data [18-19]. The study regarding the relationship between precipitation and altitude is extremely important to comprehend hydro-climatology in watershed mountainous areas for better water resources **management**. Regression investigation concerns the study of association amongst quantitative variables with the object of classifying, assessing, and validating the relationships, a technique known as a linear regression model would be the best option. Accordingly, the goal of the current research is to discover and comprehend the relationship between elevation and precipitation at annual, seasonal (winter, summer, and monsoon) monthly time-scales. The study is focused on to analyze relationship between precipitation and elevation; develop linear regression equation, and to map spatial extent of precipitation concerning altitude through geo-statistical modeling approaches for the KNR, Sindh province.

## 2. MATERIALS AND METHOD

### 2.1 Study Area

The study area KNR lies between longitudes 67.028-68.307°E and latitudes 24.767-27.900°N in the southwest of Sindh province, Pakistan (Fig. 1). It consists mainly of mountainous terrain/topography stretching over an area of about 22,000 km<sup>2</sup>.

The area comprises of the western part of Dadu District, which is famous for Gorakh Hill Station at an altitude of 1,734 m. There are three of the most significant natural reservoirs are located in the foot hills of the study area, i.e. Hamal Lake in district Qambar Shahdad Kot, Manchar Lake in district Jamshoro, Pakistan, which is one of the largest lakes in the Asia and Keenjhar Lake situated in district Thatta. Torrential floods feed that through a several spates.

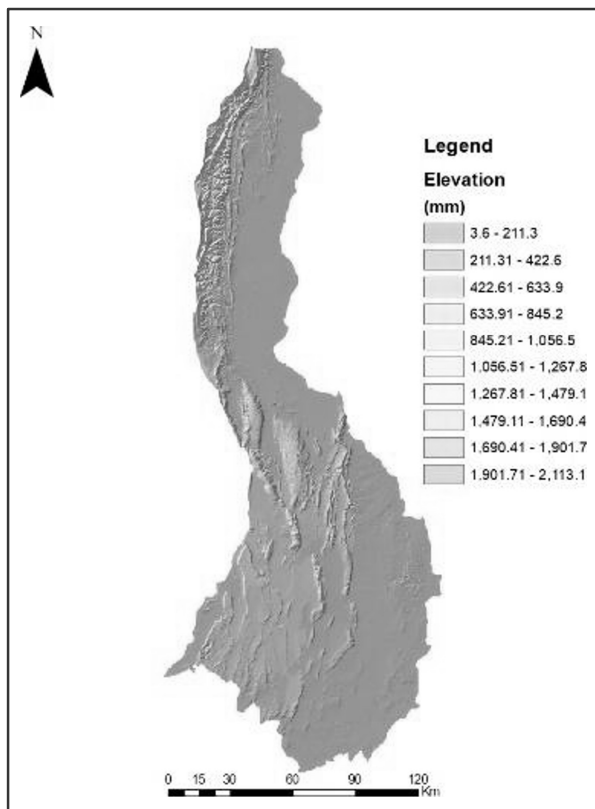


FIG. 1. ELEVATION MAP OF THE STUDY AREA

The community living in the area earns its livelihood from rain-fed agriculture employing spate irrigation techniques. Physiographically the area consists of numerous watersheds that are further divided into several sub-basins and streams.

### 2.2 Climate in Khirthar National Range

The concerning source of water resources in the area is rainfall; which has an average annual downpour from 135-358 mm. The northern part of the study area has annual rainfall ranging from 147-300 mm, with average annual evaporation of more than 4,000 mm. The annual rainfall in the central areas varies between 147 and 240 mm with an evaporation rate of 1800-3000 mm, while in the southern part average annual rainfall exceeds 200 mm with the evaporation of approximately 4,000 mm. The monsoon period comprised mainly of months of July, August, and September, receives the majority of the rainfall of a year. The average wind velocity in the southern part is 10 km/hr, which diminishes steadily towards the northern parts of the study area. The annual temperature ranges from 0-25°C in the winter season while the temperature varies from 26-50°C in the summer season [20] of the study area.

### 2.3 Data Collection

The precipitation data of 7 rain gauge stations for variable time-series 1957-2013 were collected from PMD (Pakistan Meteorological Department), WAPDA (Water Power Development Authority), and PARC (Pakistan Agricultural Research Council). The two rain gauge stations, i.e. TBK (Thana Boula Khan) (Elev: 249.02 m), and Gaj Guest House (Gaj) (Elev: 96.31 m), lie within the study area, while the rest gauge stations, i.e. Lasbella (Elev: 22.86 m), Larkana (Elev: 42.36 m), Hyderabad (Elev: 26.51 m), Barkhan (Elev: 1097 m) and Zohb (Elev: 1405 m), are located in the surroundings of the area (Fig. 2).

The seasonal data were categorized into two seasons, winter (Rabi cropping season from October–March) and summer (Kharif cropping season from April–September). The authors calculated the mean annual, mean monthly, mean Rabi corresponding with use of 7 rain gauge stations, while the result of mean Kharif and monsoon precipitation has been achieved by using of 6 rain gauge stations excluding by Zhob rain gauge station. In this study, it is tried to achieve suitable results by using 6 or 7 number of gauging stations. The DEM consisting of elevation information regarding the surface of the earth was applied to the executive altitude classification and grade of KNR, Sindh Province. Subarna et. al. [21] The DEM with a 90 m spatial resolution used for this study is the outcome of the remote sensing mission named SRTM (Shuttle Radar Topography Mission).

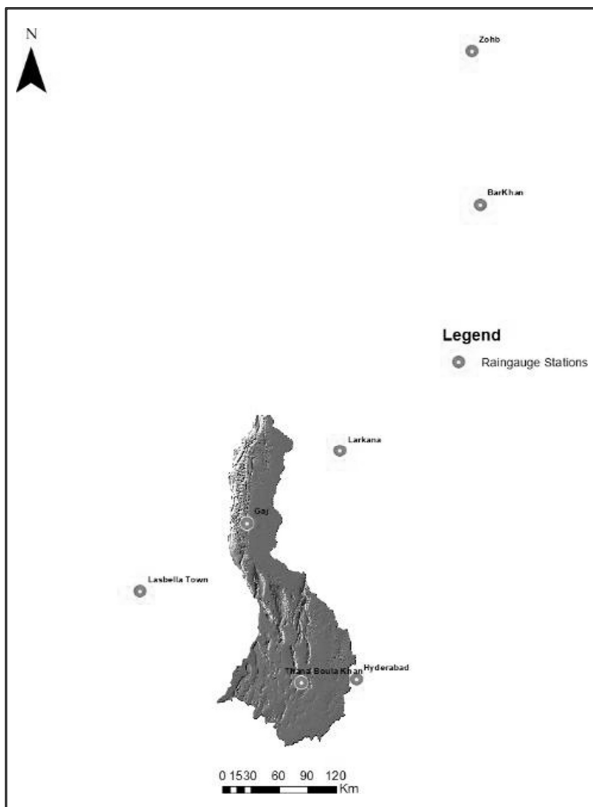


FIG. 2. RAIN GAUGE

## 2.4 Linear Regression Model

The statistical relationship between gauges lying within the study area and outside was calculated by using a linear regression equation [22-23]. LRM (Linear Regression Model) is a relatively simple and straight forward method for determination of precipitation variations concerning elevation. As the relationship between variables (elevation and precipitation) is different at each site [18], thus, the technique was used to develop an individual equation for each scenario (winter, summer, annual, mean monthly and monsoon). The raster calculator was used through map algebra by using spatial analyst tool and was used to generate a raster map of the precipitation distribution for each scenario. The resultant precipitation trends were interpreted with elevation retrieved from SRTM, DEM, similar to a study conducted in southern Nevada, the USA on establishing individual rainfall relationships with altitude for the area with insufficient gauging stations [24].

The coefficient of determination ( $R^2$ ) showed the relationship between both variables. It is a quantity of how suitably the regression line signifies the data. If the regression line passes precisely through every point on the scatter plot, it would be able to explain all of the variations. If it is suitable, it provides the proportion of the variance of a “dependent variable” and “independent variable” respectively [25]. Consequently, precipitation at variable levels versus altitude was predicted by developing individual equations for each scenario [22]. This allows us to estimate how confidently one can be in developing a forecast from a convinced model/graph [25]. The developed elevation map was made using the SRTM, DEM 90m spatial resolution [21] in the ArcMap ver.10.30.1 version (Fig. 1). Subsequently, a linear regression equation between precipitation and DEM was developed for each feature, which was used for spatial precipitation mapping using the raster calculator function of ArcMap software. Output results showed spatial variation of precipitation in the context of elevation in the study area. Similarly, linear regression models and raster maps were developed for each time-scales of precipitation.

### 3. RESULTS

The results of the linear regression model showed a close relationship between the precipitation at various levels and the elevation of the study area as indicative from the coefficient of determination  $R^2$  values range of 0.8206-0.9604 Figs. 3(a-c) and Table 1). The correlation was significant at  $P < 0.05$  for mean annual, mean monthly, and mean seasonal (Rabi) precipitation. The spatial distribution of various levels of precipitation in the study area is shown in Fig. 4(a-c). At the annual level, precipitation indicated variation 127.78 mm in the low lands to 697.98 mm at higher altitudes in the west and northwest of study area.

Similarly, precipitation exhibited an increase from 10.84-58.09 mm towards the west and northwest of the study area at the mean monthly level shown in Fig. 4(a). The lapse rate of increase in precipitation with elevation was

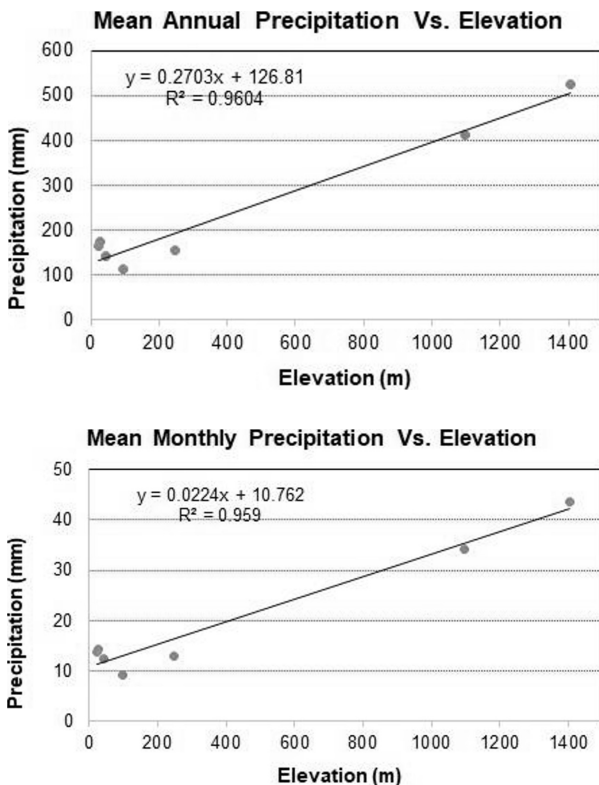


FIG. 3(a). RELATIONSHIP OF MEAN ANNUAL AND MONTHLY PRECIPITATION WITH ELEVATION IN THE STUDY AREA

27.03 mm per 100 m for mean annual and 2.24 mm per 100 m for mean monthly level (Table 1). For summer (Kharif) season, precipitation indicated an increase form 105.78 mm in the lower valleys to 525.36 mm at higher altitudes in the study area. For winter (Rabi) season precipitation

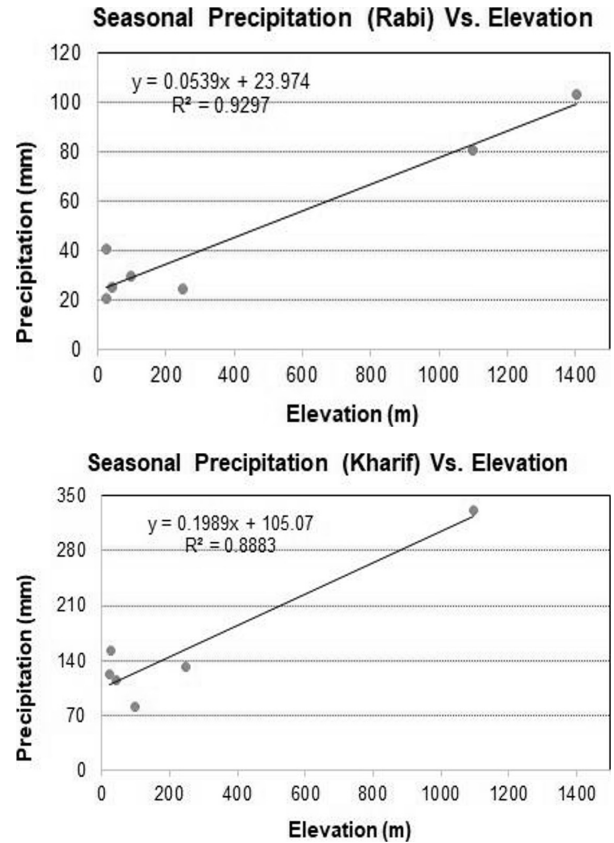


FIG. 3(b). RELATIONSHIP OF MEAN SEASONAL PRECIPITATION (RABI AND KHARIF) VS. ELEVATION IN THE STUDY AREA

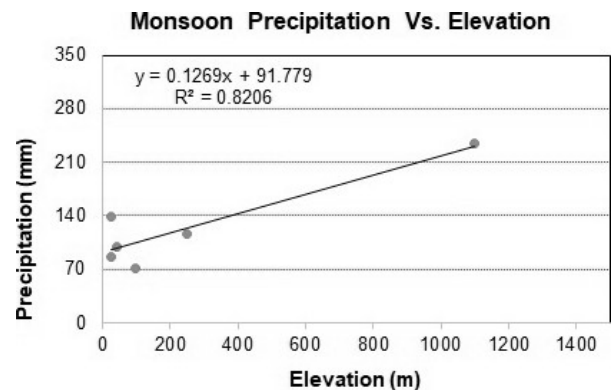


FIG. 3(c). SCATTERPLOT OF MONSOON PRECIPITATION (JULY-SEPTEMBER) VS. ELEVATION IN THE KNR WATERSHED

varied from 24.17 mm in the lower valleys to 137.87 mm at higher altitudes (Fig. 4(b)). The altitudinal increase in precipitation was at a rate of about 19.89 mm per 100 m for summer (Kharif) and 5.39 mm per 100 m for winter (Rabi) season (Table 1). Overall, the difference between lower and higher altitudes precipitation seems pronounced during both the seasons. The monsoon precipitation of July-September period also showed an increasing trend with the elevation towards the west and northwest of the study area. The precipitation increases from 92.24-359.93 mm towards west and northwest of the study area during this period (Fig. 4(c)). The rate of increase in precipitation with elevation was 12.68 mm per 100 m (Table 1). The results of Kharif and Monsoon precipitation compiled by the inclusion of 6 gauging stations which shown good results of Correlation of Determination Value 0.8883 and 0.8206, as shown in Seasonal precipitation Kharif Fig. 3(b) and Monsoon Precipitation Fig. 3(c), due to good correlations the Zhob gauging stations were excluded for both trends.

Variations of significant correlation were found between the lowest and higher elevations.

#### 4. DISCUSSION

The empirical equation of the LRM showed a strong relationship between precipitation and elevation in the watershed of the KNR.

The correlation results between the two parameters indicated  $R^2$  (coefficient of determination) value of 0.9604 for mean annual and 0.959 for monthly levels, 0.929 for winter (Rabi), 0.888 for summer (Kharif) and 0.8206 for precipitation of monsoon. The analysis is based on the time-series precipitation data of 7 meteorological stations (at variable elevations between 22-1405 m). The data of all 7 stations has been utilized for mean monthly, mean annual, Rabi trends. However, the data for 6 rain gauge stations have been used for monsoon and Kharif trend due to the good correlation of determination values received by excluding the gauging station of Zhob.

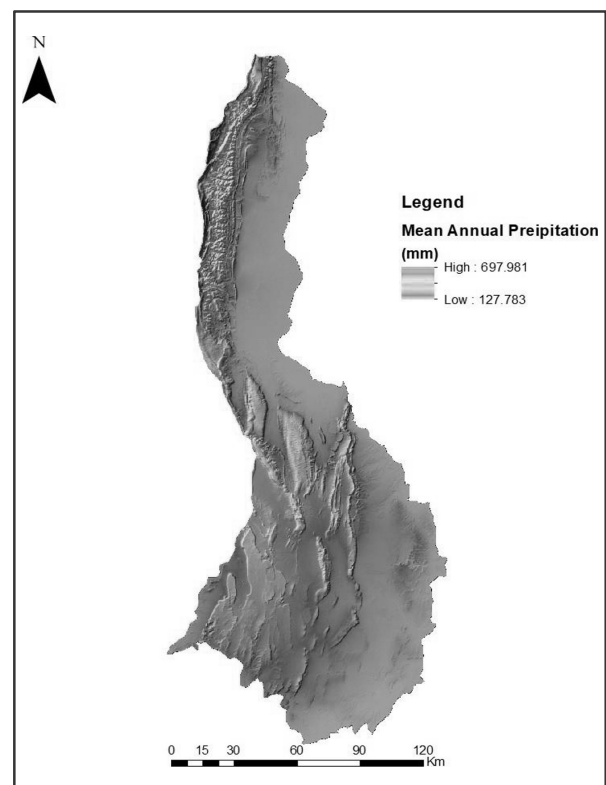
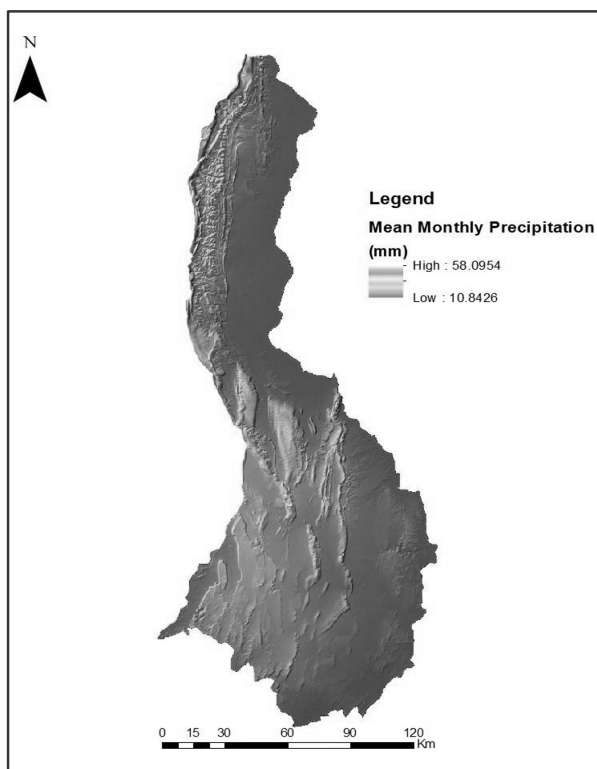
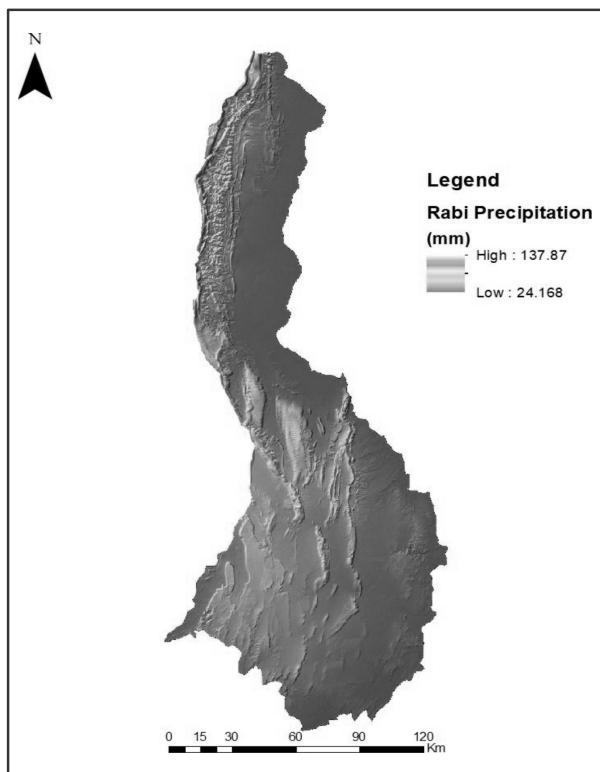


FIG. 4(a). MEAN ANNUAL AND MEAN MONTHLY PRECIPITATION IN THE STUDY AREA



As the area lacks higher altitude meteorological stations, e.g. at elevations exceeding 800 m, therefore, the stations surrounding the area with having the fair quality of records had been selected for this study. Most of the higher altitude stations lie sparsely in the western part of the study area, among which Barkhan station at 1097 m and Zhob station at 1405 m possessing sufficient span and quality of climate data were used to represent higher altitudinal climate in our analysis.

The results obtained were similar to other researchers who had achieved their successful goals as a case study, for instance, [24] established an individual rainfall relationship for southern Nevada for additional and determined and insufficient gauging stations and determined there was an obtained strong relationship between rainfall and altitude. Outcomes of this research resemble work performed by the various scientists in their investigations of subtropical regions such as the Himalayan, Peru rocky,

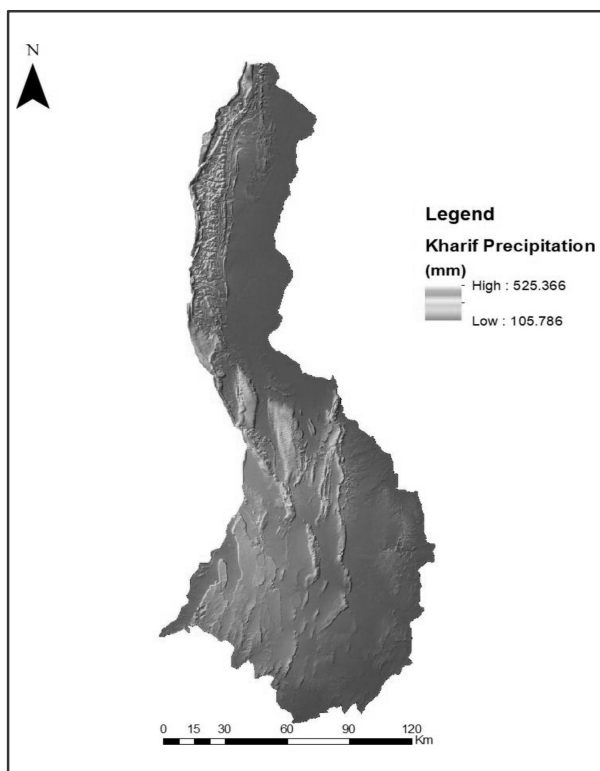


FIG. 4(b). SPATIAL PRECIPITATION DURING KHARIF AND RABI SEASON

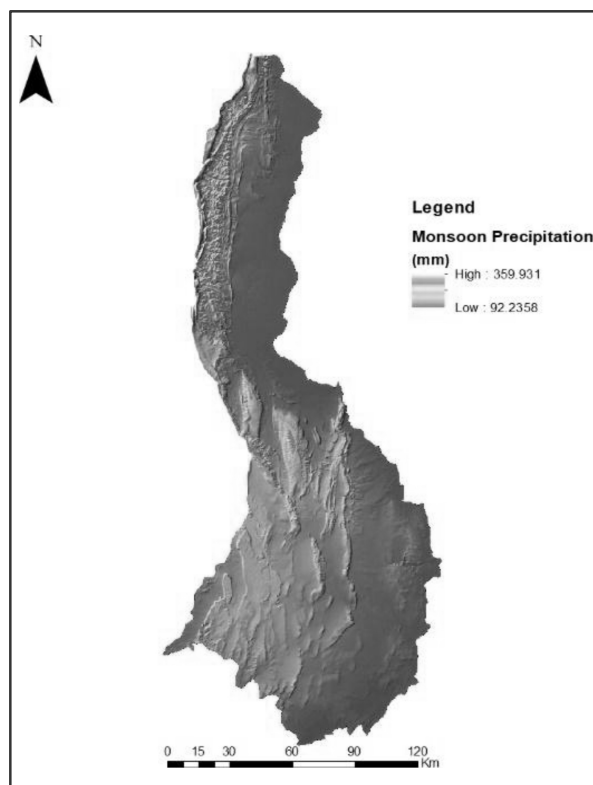


FIG. 4(c). MONSOON SEASON

hilly region, and tropical regions [26] and in the Cisangkuy Watershed Bandung reGENCY of Indonesia [21].

The results determined by an LRM shown the precipitation trend which increase in the mountainous area compared to low lying areas in the watershed of KNR. These types of discoveries express the physical association between elevation and precipitation [27-29], that has been explored by various researchers, who are engaged in several regions of the world [2,4,9-10,30-31]. The physical features of region effects on the precipitation trend have few references. However, in modern science, the modeling approaches to landscape elevation shows that the trend of precipitation and intensity depending on the feature and physiography of the area i.e. altitude, slope, and depressions [32].

The increased precipitation estimated over elevated areas at annual and seasonal levels in this study needs to be harvested by adopting adequate flood management techniques for improving agriculture productivity in the downstream. For example, hill-torrent water should be managed through establishing appropriate distribution/ water conservation structures for raising Rabi crops like wheat, gram, onions, oilseeds, fodder, and Kharif crops like sorghum and vegetables. Similarly, the high runoff generated during monsoon period can be harvested through constructing a series of storage dams helpful not only for groundwater recharge but also for meeting future

water requirements of irrigation/domestic use during water stressed/drought conditions.

The precipitation radar satellites make the researchers capable of concerning more research findings by adopting the new technology. Uneven variability in rainfall results in dangerous trends of floods and droughts, which damage the natural resources and the biodiversity [33]. During the last few decades, researchers observed that the variation trend of monsoon precipitation is a natural and shifting process globally, which will create pressure these susceptibilities challenges on food security [34]. The developed linear regression model obtained successful results as [35] optimized parameters by developing a linear model successfully to estimate the rainfall relationship in the eastern region of the Sierra Nevada Mountains. The study of the relationship between elevation and precipitation in the KNR authenticates the outcomes of results that were achieved as by [36]. He estimated the relationship between precipitation and elevation regressions to measure the monthly and annual precipitation over several regions of the United States and discovered strong relationships. Hanson et. al. [37] explained that the associations between rainfall and altitude for a hilly watershed in Idaho were highly influenced by weather. No doubt from the above reference, USA and Pakistan are situated in different regions, but the procedure of this study in the watershed of KNR, Sindh Province validates the results and shows a strong relationship between precipitation and elevation.

TABLE 1. LINEAR REGRESSION EQUATIONS ALONG WITH COEFFICIENT OF DETERMINATION VALUES BETWEEN VARIOUS PRECIPITATION DATA LEVELS AND ELEVATION

Level of Precipitation Data	Estimation of Linear Regression (X= Elevation, Y= Rainfall)	Correlation of Determination Value (R <sup>2</sup> )
Mean Annual	$y = 0.2703x + 126.81$	0.9604
Mean Monthly	$y = 0.0224x + 10.762$	0.959
Summer Season (Kharif)	$y = 0.1989x + 105.07$	0.888
Winter Season (Rabi)	$y = 0.0539x + 23.974$	0.929
Monsoon period (July-September)	$y = 0.1268x + 93.216$	0.8206



## 5. CONCLUSION

Regional climate trending is most important to exactly reproduce expected volume, intensity, and duration of precipitation events with spatial variation. Most of the hilly mountainous watershed areas of the country are ungauged and have no previous records whatsoever of precipitation runoff processes. As climate data is essential in numerous planning activities related to watershed management, but accurate data about the precipitation is rarely obtainable on micro to the macro level of watersheds. To overcome these types of complications, it is possible to generate precipitation data using LRMs coupled with RS and GIS technique, to identify the trend and estimate relationships between precipitation and elevation. The results of the LRM showed a close relationship between the precipitation and elevation, as indicative from  $R^2$  (coefficient of determination) values 0.86-0.96 for various precipitation levels. The correlation was significant at  $P < 0.05$  for mean annual, mean monthly, and mean seasonal (Rabi) precipitation. While the variation was found an increasing trend of precipitation from lowest to the highest elevation of watersheds in the KNR. The excessive runoff generated from increased precipitation at higher altitudes (e.g. during summer monsoon) should be conserved for sustaining agriculture and livelihood during water stressed/drought conditions in the region.

## ACKNOWLEDGEMENT

Authors are grateful to the Pakistan Meteorological Department, Water Power Development Authority, Water Wing, and Pakistan Agricultural Research Council, Sindh Irrigation Department, for providing meteorological data for this study. Finally, also acknowledged to USAID for offering scholarship to enhancing the higher degree of Ph.D. in the field Integrated Water Resources Management.

## REFERENCES

- [1] Abdullah, M.A., and Al-Mazroui, M.A., "Climatological Study of the Southwestern Region of Saudi Arabia-I Rainfall Analysis", *Climate Research*, Volume 9, No. 3, pp. 213-223, 1998.
- [2] Subyani, A.M., "Topographic and Seasonal Influences on Precipitation Variability in Southwest Saudi Arabia", *Journal of King Abdul-Aziz University*, Volume 11, pp. 89-102, Saudi Arabia, 1999.
- [3] Gouvas, M., Sakellariou, N., and Xystrakis, F., "The Relationship between Altitude of Meteorological Stations and Average Monthly and Annual Precipitation", *Studia Geophysica et Geodaetica*, Volume 53, No. 4, pp. 557-570, 2009.
- [4] Bassist, A., and Bell, G.D., "Statistical Relationships between Topography and Precipitation Patterns", *Journal of Climate*, Volume 7, pp. 1305-1315, 1994.
- [5] Hayward, D., and Clarke, R.T., "Relationship between Rainfall, Altitude and Distance from the Sea in the Freetown Peninsula, Sierra Leone", *Hydrological Sciences Journal*, Volume 41, No. 3, pp. 377-384, 1996.
- [6] Konrad, C.E., "Relationships between Precipitation Event Types and Topography in the Southern Blue Ridge Mountains of the Southeastern USA", *International Journal of Climatology*, Volume 16, No. 1, pp. 49-62, 1996.
- [7] Sevruk, B.K., Matokova-Sadlonova, and Toskano, L., "Topography Effects on Small-Scale Precipitation Variability in the Swiss Pre-Alps", *International Association of Hydrological Science Publication*, Volume 248, pp. 51-58, 1998.
- [8] Oettli, P., and Camberlin, P., "Influence of Topography on Monthly Rainfall Distribution Over East Africa", *Climate Research*, Volume 28, No. 3, pp. 199-212, 2005.
- [9] Buytaert, W., Celleri, R., Willems, P., Bièvre, B.D., and Wyseure, G., "Spatial and Temporal Rainfall Variability in Mountainous Areas: A Case Study from the South Ecuadorian Andes", *Journal of Hydrology*, Volume 329, No. 3-4, pp. 413-421, 2006.
- [10] Alijani, B., "Effect of the Zagros Mountains on the Spatial Distribution of Precipitation", *Journal of Mountain Science*, Volume 5, No. 3, pp. 218-231, 2008.
- [11] Prudhomme, C., and Reed, D.W., "Mapping Extreme Rainfall in a Mountainous Region Using Geostatistical Techniques", *International Journal of Climatology*, Volume 19, pp. 1337-1356, 1999.
- [12] Katsoulis, N.B., Pnevmatikos, J., and Antakis, V., "Spatial and Temporal Variation of Precipitation in Greece and Surrounding Regions Based on Global Precipitation Climatology Project Data", *Journal of Climate*, Volume 21, No. 6, pp. 1349-1370, 2008.
- [13] Pedgley, D.E., "Heavy Rainfalls Over Snowdonia", *Weather*, Volume 25, pp. 340-350, 1970.
- [14] Chaun, G.K., and Lockwood, J.G., "An Assessment of Topographical Controls on the Distribution of Rainfall in the Central Pennines", *Meteorological Magazine*, Volume 103, pp. 275-287, 1974.

- [15] Hill, F.F., Browning, K.A., and Bader, M.J., "Radar and Rain Gauge Observations of Orographic Rain Over South Wales", *Quarterly Journal, Royal Meteorological Society*, Volume 107, No. 453, pp. 643-670, 1981.
- [16] Johansson, B., and Chen, D., "The Influence of Wind and Topography on Precipitation Distribution in Sweden: Statistical Analysis and Modelling", *International Journal of Climatology*, Volume 23, No. 12, pp. 1523-1535, 2003.
- [17] Gouvas, M., Sakellariou, N., and Xystrakis, F., "The Relationship between Altitude of Meteorological Stations and Average Monthly and Annual Precipitation", *Studia Geophysica et Geodaetica*, Volume 53, No. 4, pp 557-570, 2009.
- [18] Páez, A., "Anisotropic Variance Functions in Geographically Weighted Regression Models", *Geographical Analysis*, Volume 36, No. 4, pp. 299-314, 2004.
- [19] Mennis, J., "Mapping the Results of Geographically Weighted Regression", *Cartographic Journal*, Volume 43, No. 2, pp. 171-179, 2006.
- [20] PARC (Pakistan Agricultural Research Council), "Completion Report of NRDP on Water Management of Spate Irrigation Systems in Rod-Kohi areas of Pakistan Dadu Component", *Water Resources Research Institute, National Agricultural Research Center/Pakistan Agricultural Research Council*, 2010.
- [21] Subarna, D., Yanuar, M., Purwanto, J., Murti Laksono, K., and Wiweka, "The Relationship between Monthly Rainfall and Elevation in the Cisangkuy Watershed Bandung Regency", *International Journal of Latest Research in Science and Technology*, Volume 3, No. 2, pp. 55-60, March-April, 2014.
- [22] Fotheringham, A.S., Brunson, C., and Charlton, M., "Geographically Weighted Regression: The Analysis of Spatially Varying Relationships", *Wiley*, Chichester, UK, January, 2002.
- [23] Fotheringham, A.S., Bunson, C., and Charlton, M., "Quantitative Geography: Perspectives on Spatial Data Analysis", *Sage*, pp. 1-272, London, 2000.
- [24] French, R.H., "Precipitation in Southern Nevada", *ASCE Journal of the Hydraulics Division*, Volume 10, No. HY7, pp. 1023-1036, 1983.
- [25] Sari, B.G., Lúcio, A.D.C., Santana, C.S., Kryszun, D.K., Tischler, A.L., Drebes, L., "Sample Size for Estimation of the Pearson Correlation Coefficient in Cherry Tomato Tests", *Ciência Rural*, Santa Maria, Volume 47, No. 10, pp. e20170116, 2017.
- [26] Mair, A., and Fares, A., "Comparison of Rainfall Interpolation Methods in a Mountainous Region of a Tropical Island", *Journal Hydrological Engineering*, Volume 16, No.4, pp. 371-383, 2011.
- [27] Diskin, M.H., "Factors Affecting Variations of Mean Annual Rainfall in Israel", *Bulletin of the International Association of Scientific Hydrology*, Volume 15, No. 4, pp. 41-49, 1970.
- [28] Schermerhorn, V.P., "Relations between Topography and Annual Precipitation in Western Oregon and Washington", *Water Resources Research*, Volume 3, pp. 707-711, 1967.
- [29] Johansson, B., and Chen, D., "The Influence of Wind and Topography on Precipitation Distribution in Sweden: Statistical Analysis and Modelling", *International Journal of Climatology*, Volume 23, pp. 1523-1535, 2003.
- [30] Johnson, L., and Hanson, C.L., "Topographic and Atmospheric Influences on Precipitation Variability Over a Mountainous Watershed", *Journal of Applied Meteorology*, Volume 34, No. 1, pp. 68-87, 1995.
- [31] Naoum, S., and Tsanis, I.K., "Orographic Precipitation Modeling with Multiple Linear Regression", *Journal of Hydrologic Engineering*, Volume 9, No. 2, pp. 79-102, 2004.
- [32] WorldClim <http://www.worldclim.org/> Accessed in 23 November, 2012.
- [33] Khan, M.A., "Climate Change Research in Pakistan, Regional Conference on Climate Change: Challenges and Opportunities for South Asia", *Islamabad, Pakistan*, 2009.
- [34] Rasul, G., Mahmood, A., Sadiq, A., and Khan, S.I., "Vulnerability of the Indus Delta to Climate Change in Pakistan", *Journal of Meteorology*, Volume 8, No. 16, January, 2012.
- [35] Tung, and Yeou-Koung, "Point Rainfall Estimation for a Mountainous Region", *ASCE Journal of the Hydraulics Division*, Volume 109, No. HY10, pp. 1386-1393, 1983.
- [36] Daly, C., Nelson, R.P., and Phillips, D.L., "A Statistical-Topographic Model for Mapping Climatological Precipitation over Mountainous Terrain", *Journal of Applied Meteorology*, Volume 33, pp. 140-158, 1994.
- [37] Hanson, C.L., Morris, R.P., Engleman, R.L., Coon, D.L., and Johnson, C.W., "Spatial and Seasonal Precipitation Distribution in Southwest Idaho", *Science and Education Administration Publications*, pp. 1-15, 1980.