Geostatistical Modeling to Predict Rainfall in Indian Himalayas of Uttarakhand

It is generally agreed that mountainous regions are of significant hydrological importance. In such areas with orographic rainfall effects, capturing the spatial variability of rainfall is a challenging task owing to (a) complex rainfall patterns due to undulating terrain (b) sparse rain gauge network and (c) non-stationarity in spatial relationship of rainfall and topographical variables. There are very few studies on spatial interpolation of rainfall in Indian Himalayas. Two important limitation of such studies are that (a) global approach for rainfall interpolation wherein single spatial interpolation technique is applied to the global dataset (b) use of conventional geostatistical techniques that assumes that stationary relationship of rainfall and topography. This research is an attempt to develop a novel approach for modeling orographic rainfall in complex terrain that can integrate the knowledge of spatially varying rainfall-elevation relationship with the uncertainty measurement feature of geostatistical technique. The study has been carried out in Central Himalayas which is bounded by the administrative boundary of Uttarakhand.

The first objective of this study aims at comparing the existing spatial interpolation techniques for prediction of rainfall. The univariate techniques, including ordinary kriging, simple kriging and universal kriging were compared with multivariate geostatistical method of ordinary cokriging (OCK). The topographical variables, elevation, slope and terrain ruggedness index (TRI) calculated from digital elevation model (DEM) were incorporated as auxiliary variables in ordinary cokriging. From the result, it was evident that geostatistical techniques that incorporates topographical variables performs better than univariate interpolation methods when the correlation is high (correlation coefficient, $r > 0.5$).

The second objective quantifies the impact of various topographical variables on the variability of rainfall in complex terrain. To analyze the impact of data homogeneity on correlation study, the rainfall data was clustered into lowland and upland data. An overall improvement of 5-20% was observed in rainfall estimation accuracy when the data was clustered based on homogeneity of the region in which gauges were installed. The study demonstrated that scaling down from global ordinary least square (OLS) to local geographically weighted regression (GWR) model decreases the unexplained variance in the rainfall-topography relationship significantly. The annual rainfall lapse rate was found in range of 0- 1.33 mm/m.

The third objective focuses on modeling of rainfall in complex terrain considering topographical influences. A novel spatial modelling framework, stratified GWR-residual kriging (s-GWRK) was developed as part of this research. s-GWRK model is hybrid of GWR and residual kriging and uses stratified (preprocessed) rainfall data. The prediction result of s-GWRK showed an improvement of 60% over OCK. The external validation of s-GWRK model was carried out using new validation dataset from two different mountainous regions of New Zealand and Bhutan.

The finding of the research was applied to develop a new method, **G**radient **a**nd **R**esidual **i**ntegrated **R**ank **O**rdering (GaRiRO) for ranking the stations in a monitoring network. GaRiRO can be used to prioritize the rain gauge stations for optimizing the existing network and selection of the best locations for installation of new gauges. Although initially aimed to assist hydrologists with a ranking scheme for rain gauge stations, it can be applied to any environmental, meteorological or hydro-meteorological monitoring network.