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APPLICATION OF NONSTATIONARY IN CLIMATE VARIABILITY – A CASE STUDY OF SOUTH PUNJAB, PAKISTAN

[a] Muhammad Usman Khan, [b] Mudassar Iqbal*, [c] Noor Muhammad Khan

a: Centre of Excellence in Water Resources Engineering, UET., Lahore, Pakistan, usmank4773@gmail.com
b: Centre of Excellence in Water Resources Engineering, UET., Lahore, Pakistan, mudassar@cewre.edu.pk
c: Centre of Excellence in Water Resources Engineering, UET., Lahore, Pakistan, noorkhan@uet.edu.pk
*Corresponding author: Email ID: mudassar@cewre.edu.pk

Abstract- The rate of change in the planet's environment has been inconsistent. One of the main reasons is believed to be vital changes caused by human in the climate. Recent innovations in time series investigation of hydro-climatological parameters have contributed to the belief that the effects of nonstationarity are considerable enough to call the validity of conventional stationary methods into question. The goal of this study was to assess the nonstationary variability in Southern Punjab using nonstationary parameters for the historical era (1970-2015). Generalized Extreme Value, GEV, Gumbel, GUM, Normal, NOR and Lognormal, LOGNOR were used as the frequency analysis probability functions. The findings of the nonstationarity variability influences across the Southern Punjab showed a variety of variations, such as an increase or reduction in the return level of extreme rainfall. Upon an evaluation of NLLH value, GEV offered the best match compared to other distributions. In Bahawalnagar, Bahawalpur, Multan, Rahim Yar Khan, and DG Khan, the yearly nonstationary consequences for the 100-year return level were 15.2, 8.7, 58.3 18.7 and 20% respectively. The evidence also showed that extreme precipitation appears to be increasing during the historical period, which increases floods. Overall, nonstationarity variations demonstrated the importance of adopting climate change into hydraulic structure design.

Keywords- Climate change, GEV, Nonstatioinarity, Precipitation, Probability Distributions

1 Introduction

In meteorology, atmospheric sciences, and other closely related fields, extreme weather or climate play a fundamental role. One of the primary regulating factors affecting the world climate is solar radiation. The overall equilibrium of incoming – outgoing radiation (long wave radiations) has been thrown off due to increased aerosol and greenhouse gas concentration [1]. The presence of these elements in a place over an extended length of time controls its climate. The amount of longwave radiation emitted from the earth's surface fluctuates as a result of changes in land use patterns, such as the removal of forests, which influence carbon dioxide (CO_2) emission levels and surface albedo. [2]. The nature of precipitation is also shifting as a result of rising temperatures, with northern regions increasingly seeing more rainfall than snowfall [3]. The occurrence of summer days and soaring temperatures is increasing while the number of winter days is dwindling [4]. Aziz adopts a fixed and nonstationary recurrence technique to analysis the fluctuating irregularity in annual rainfall as well as extraordinary rainfall in Turkey. The findings have been presented in Turkey as nonstationarity influence plans, which offer information on the inconsistent nature of the severity of impacts such as effect kinds, such as an increase or reduction in the next phase of excess precipitation [5]. The number of hot and cold days as well as the frequency and intensity of hydro-climatological extremes, increased globally between 1950 and 2010. Severe extreme temperatures, droughts, flooding, and precipitation have all been more often during the past century [6]. Indicating that the characteristics (of location, shape and scale) of fundamental distributions might shift over time and contradicting the theory of stationarity becomes incorrect, the existence of climate change and variables related to land use may modify the probability of hydrological severe occurrences [7]. Since the top and bottom tails of distributions are connected to disasters such flooding and drought, respectively, they are important for the preparation and administration of water resources [8].

Despite the possibility that the professional has never acknowledged the existence of nonstationarity in hydrological operations, they have chosen the fixed assumption as a logical approach to address assessments of future conditions of the framework based on empirical evidence [9]. Many previous researchers have shown how this dread of stationarity (such as the idea of regular intervals) could be hazardous as a result of climate transformation. Later, it is predicted that the frequency of extraordinary precipitation events would rise, and neglecting these developments will lead to the mistake of excessive events. No matter what, using limitations recognize the stationarity that accepts no change after given amount of time [10]. The idea of stationarity in hydro-climatological variables is regarded to be invalidated by large human caused shifts in the Earth's climate, which modify the means and extremes of precipitation [11]. Sertac, [12] adopted a nonstationary GEV distribution in a region where floods occur on a yearly basis. They established that nonstationary levels were lower than stationary levels. Due to this local and global development, the stationarity theory has come under heavy criticism. Keeping this in mind, several studies have attempted to investigate the viability of this idea in flood regimes in numerous geographic locations across the world considering the impact of natural climatic variation [13–15] or changes in land use [16].

The forecasting of weather is primarily used to predict the condition of the environment's changes in the near future, from a few minutes to hours, days to seasons, and it requires improved precision and reliability. Global circulation models are frequently used for generating climate predictions, which provide an overall picture of weather conditions over a longer time horizon, such as fifty or one hundred years. In this work, nonstationary variability in return levels of significant precipitation at the selected stations was measured across the historical (1970–2015) and projection (2020–2100) periods using a nonstationary frequency analysis technique. Nonstationarity analysis comprised on the normal and lognormal distributions in addition to the well-known generalized extreme value (GEV) and Gumbel distributions. In this regard, the present research shows how probability distribution functions may be used to quantify nonstationarities in return level of extreme precipitation.

2 Study Area and Data

The research was carried out in South Punjab, Pakistan (Figure 1) considering the meteorological stations Dera Ghazi, DG Khan, Multan, MTN, Bahawalnagar, BHN, Bahawalpur, BHP, and Rahim Yar Khan, RY Khan. For the historical period (1970-2015), the impacts of nonstationarities upon annual and seasonal maximum precipitation (MP) were evaluated. Although the region is primarily flat, there are a few hilly areas in the far north and south-west sides.

The observed data of daily precipitation was collected from Pakistan Meteorological Department (PMD) for the duration of 45 years (1971 to 2015).

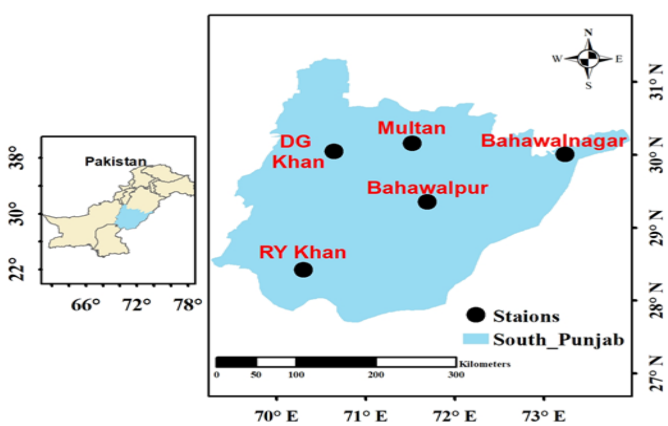

Figure 1: Geographical location of South Punjab with meteorological stations.

3 Research Methodology

3.1 Stationary and Non-Stationary Frequency Analysis.

The parameters of the GEV and GUM are designed to be time dependent by incorporating time as a covariant so that may be used under nonstationary settings [12]. This study makes use of both stationary and nonstationary (GEV, GUM, NORM, and LOGNORM) frequency analysis distributions. Equation (1) represents the GEV cumulative distribution function's nonstationarity form.

$$F\,(z,\,\theta_t) = \;exp\;exp\;\left\{-\left[1+\,\varepsilon\,\left(\frac{z\,-\,\mu_t}{\sigma_t}\right)\right]^{\frac{-1}{\varepsilon}}\right\} \qquad (1)$$

Here, the location parameter has been modified to μ_t= μ1+ μ2*t and the scale parameter is changed to σ_t= σ1+ σ2*t. In this case, the location and scale parameters (μ1 (μ2) and σ1 (σ2)) are intercept (slope) values respectively. For a specific period of time, t serves as descriptive covariant of time, making μt and σ_t nonstationary. The negative log likeli-hood function was minimized using the MLLE to assess distributional parameters. For a stationary and non-stationary variant of the GEV distribution, the likelihood functions may be represented by equations (2) and (3), respectively.

$$l\,(\mu,\sigma,\varepsilon,x)\;=\;-\,nlog\,\sigma\;-\;\left(\frac{1}{\varepsilon}+1\right)\sum_{i=1}^{n} log\;\;log\;\left[1+\,\varepsilon\,\left(\frac{x_i\,-\,\mu}{\sigma}\right)\right]-\sum_{i=1}^{n} log\;\left[1+\,\varepsilon\,\left(\frac{x_i\,-\,\mu}{\sigma}\right)\right]^{\frac{-1}{\varepsilon}} \quad (2)$$

$$l\,(\mu_{,t}\;\sigma_t,\varepsilon)\;=\;-\,n\;log\,\sigma\;-\;\left(\frac{1}{\varepsilon}+1\right)\sum_{i=1}^{n} log\;\left[1+\,\varepsilon\,\left(\frac{x_i\,-\,\mu_i}{\sigma_i}\right)\right]-\sum_{i=1}^{n} log\;\left[1+\,\varepsilon\,\left(\frac{x_i\,-\,\mu_i}{\sigma_i}\right)\right]^{\frac{-1}{\varepsilon}} \quad (3)$$

Different packages are used to determine the estimation of parameters of the frequency analysis probability functions. In order to compute the values of the parameters of the GUM and GEV functions using the maximum likely-hood estimation (MLLE) approach, we selected the "ISMEV" package in R programming [13]. The same procedure was performed for parameter calculation of the NOR and LOGNOR functions.

In the equation, the variations of nonstationarities are expressed as percentage fluctuations between 100-year non-stationary and stationary return values.

$$Nonstationary\;impacts = \frac{nonstationary\;RL - stationary\;RL}{stationary\;RL} * 100 \qquad (4)$$

An increasing (decreasing) variation of nonstationarity states the condition of higher (lower) return levels. Higher (lower) return levels indicate that the risk of an extreme event occurring during a certain return period has increased (decreased) because of nonstationarity.

4 Results

4.1 Nonstationary Variations During the Historical Period (1970–2015) Annually

Maps of the nonstationarity variations during 100-year recurrence intervals using four probability distributions for annually max precipitation is shown in fig 2 (a). With a few notable differences, the study's findings show that all four distributions have revealed comparable implications for annual AMPs. There are a number of comparable consequence outcomes across the stations that are supported to varying degrees by all four probability functions. The findings demonstrated that positive nonstationary variations have been found for every station. The nonstationary generated by the GEV and LOGNOR probability distributions is shown to be greater in relation to the remaining two stations. Generally, the nonstationary variations from all four probability distributions have been found positive throughout all the stations.

Seasonally

Figure 2 (b) depicts the fluctuations of nonstationarity during 100-year recurrence intervals using four probability distributions for seasonally max precipitation. The evaluation of seasonal maximum precipitation reveals an overall trend of nonstationarity effect from each of the four distributions. However, minor variations have been found at few stations. Seasonal trends highlight the significance of periodicity on the amount of 100-year rainfall recurrence during a historic time period under changing climatic conditions. Seasonal analysis for winter and spring MP indicated that all four distributions have more or less similar impacts of nonstationarity throughout the seasons. The results also showed the positive impacts of nonstationarity at all stations. Moreover, in spring except for GEV the other three probability distributions have a negative effect on Rahim Yar Khan. The positive nonstationary impacts of summer MP are comparable to those of annual MP. This may because of majorly annual extreme precipitation occurred during the summer season. Seasonal MP for autumn has more positive impacts (up to 65%) utilizing the GEV at all stations. Positive impacts using the Gumbel distribution (up to 63%) were identified at all stations except Bahawalnagar where negative impacts of 9% were determined. Overall, higher return level values were anticipated in the autumn, although the effects varied among stations in other seasons.

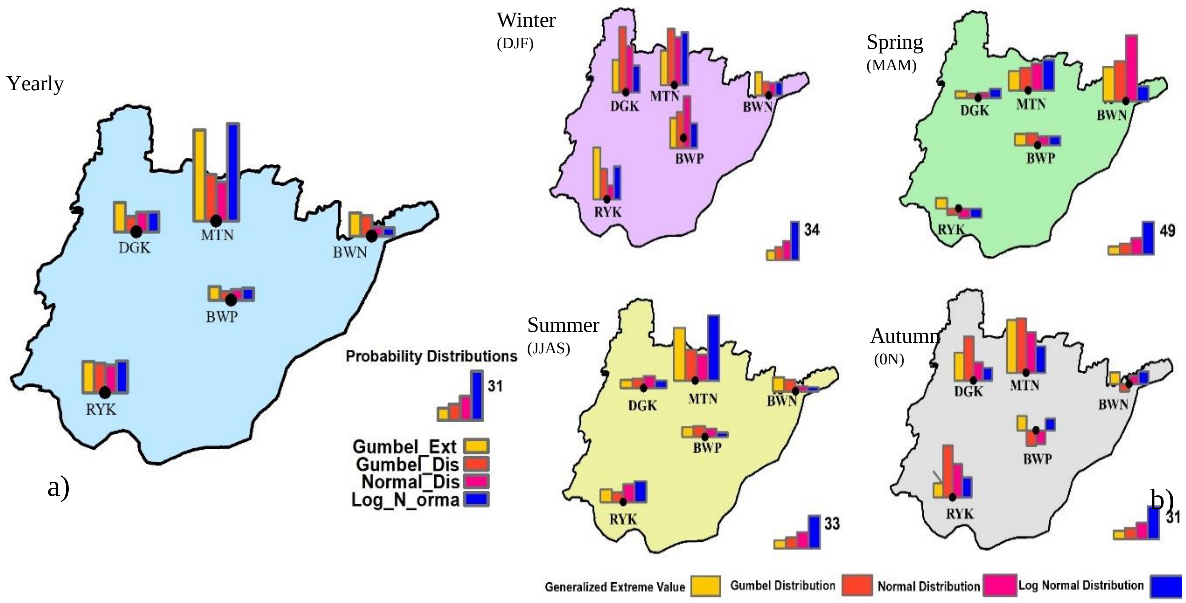

Fig:2 Fluctuations of Nonstationarity Variations during 100 – Year Recurrence Intervals Using Four Probability Distributions for Annual and Seasonal Max. Precipitation

5 Conclusions

Following conclusions can be drawn from the conducted study:

1 Analysis of historic data indicates that higher levels of severe precipitation were predicted over the winter at all stations. In the spring, variations of nonstationary are more prevalent in Multan and Bahawalnagar than at other sites, with the exception of Rahim Yar Khan, where negative variations of nonstationary have been observed.

2 The expected increasing nonstationary impacts. (10-60%) emphasized to adapt and integrate the climate change in design of hydraulic infrastructure.

The above outcomes strongly recommended nonstationary conditions to be implemented in future projects of water resources. The study, however, may be completed in the future by incorporating the other GCMs with their ensemble approach. Furthermore, nonstationarity of other meteorological variables such as temperature, required to be assessed for future research.

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