Quantile regression analysis: A novel approach to determine distributional changes in rainfall over Sri Lanka

Chandrasekara, S.S.K*, Sumiya, Uranchimeg**, Hyun-Han Kwon***

Abstract

Extreme hydrological events can cause serious threats to the society. Hence, the selection of probability distributions for extreme rainfall is a fundamental issue. For this reason, this study was focused on understanding possible distributional changes in annual daily maximum rainfalls (AMRs) over time in Sri Lanka using quantile regression. A simplified nine-category distributional-change scheme based on comparing empirical probability density function of two years (i.e. the first year and the last year), was used to determine the distributional changes in AMRs. Daily rainfall series of 13 station over Sri Lanka were analyzed for the period of 1960-2015. 4 distributional change categories were identified for the AMRs. 5 stations showed an upward trend in all the quantiles (i.e. 9 quantiles: from 0.05 to 0.95 with an increment of 0.01 for the AMR) which could give high probability of extreme rainfall. On the other hand, 8 stations showed a downward trend in all the quantiles which could lead to high probability of the low rainfall. Further, we identified a considerable spatial diversity in distributional changes of AMRs over Sri Lanka.

Keywords: Quantile regression, hydrological extremes, Sri Lanka

1. Introduction

Sri Lanka, a tropical country, is highly vulnerable to impacts of climate change. Recent studies on local, regional and global climate suggest that, the general pattern of rainfall over Sri Lanka is undergoing changes due to climate change (Climate Change Secretariat, 2015). Despite the small size of Sri Lanka, differences in the magnitude and pattern of rainfall trends have been observed from different parts of Sri Lanka. Studies comparing the mean annual rainfall of recent and earlier periods, suggested that average rainfall is more likely to have a decreasing trend (Basnayake, 2007; Chandrapala, 2007; Jayatilake et al., 2005). Punyawardena et al., (2013) observed that heavy rainfall events have become more frequent in central highlands during the recent years. However, many researchers seem to agree that the variability of rainfall has increased over time, especially in minor cultivation season (Yala season) (Chandrapala 2007; Eriyagama et al., 2010; Punyawrdena et al., 2013). Further, the intensity and the frequency of the extreme events such as floods and droughts have increased during recent times (Imbulana et al., 2006; Ratnayake and Herath, 2005).

* Member · Ph.D. Student, Dept. of Civil Engineering, Chonbuk National Univ. · E-mail : sewwandhi@jbnu.ac.kr
**Member · Ph.D. Student, Dept. of Civil Engineering, Chonbuk National Univ. · E-mail : sumya963@jbnu.ac.kr
***Corresponding Author · Member · Professor, Dept. of Civil Engineering, Chonbuk National Univ. · E-mail : hkwon@jbnu.ac.kr

2. Data and Methodology

The original data contained of daily rainfall records for the period of 1960 to 2015, which were observed in 28 stations in Sri Lanka. Out of 28 stations, 13 rainfall stations were selected by quality assessment criteria such as record length and the proportion of the missing values. Monthly total rainfall of each station were compared with CRU 3.4 precipitation data and the stations which are highly correlated with CRU 3.4 data were finally selected for the further analysis. Data are available at https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_3.22/.

Among various trend analysis approaches, we focused on understanding possible distributional changes of AMRs over time in Sri Lanka using quantile regression. Quantile regression was introduced by Koenker and Basset (1987) to better identify distinct changes in time series data at any percentile values. Further, this study adopted a systematic approach introduced by Shiau and Huang (2015) to examine the distributional changes in AMRs and further used to categorize the changes into certain classes. In this study, the 9 quantiles were selected for the study (i.e. from 0.05 to 0.95 with an increment of 0.01 for the rainfall index). A simplified nine-category distributional-change scheme based on comparing empirical probability density function (PDF) of two years (i.e. the first year and the last year), was used to determine the distributional changes in AMRs.

3 Results

4 distinct distributional change categories were identified for the AMRs (Table 1).

Table 1: Distributional categories for the stations

Category	Changes of quantile regression lines	Stations
I	Upward convergent line	Hambanthota, Nuwara Eliya
III	Upward divergent lines	Katugasthota, Badulla, Anuradhapura
VII	Downward convergent lines	Maha-Iluppallama, Trincomalee,

5 stations showed an upward trend in all the quantiles for the rainfall index. A decreasing trend of the AMRs was observed for 8 stations. (Table 1).

4. Discussion and Conclusion

The stations which showed an increasing trend of the AMRs had rightward PDF for the distributional changes in the AMRs for 1960 and 2015 (figure 1 Left and Right). However, according to Wickramagamage (2016) except for Nuwara Eliya, 4 remaining stations (i.e. Hambanthota, Katugasthota, Badulla and Anuradhapura) had an increasing mean annual rainfall trend. We figured that in Nuwara Eliya station (figure 1 Left), the increasing trend of the lower quantiles of the AMRs would not impact on the trend of the mean annual or mean seasonal rainfall pentads of the station. However, Senalankadhikara and Manawadu (2010) identified, in terms of number of rainy days, Nuwara Eliya station showed an increasing trend. Further, Senalankadhikara and Manawadu (2010) showed annual total rainfall for all the mentioned stations had a decreasing trend in the time series using regression analysis approaches. Therefore, this study confirm that quantile regression could give comprehensive information on nonstationarity in hydrological extremes. Despite that, for all these 5 station, the increase in AMRs could lead to high probability associated with higher rainfall extremes. Moreover, the likelihood of extreme rainfall is high in the lower quantiles of AMRs for these 5 stations.

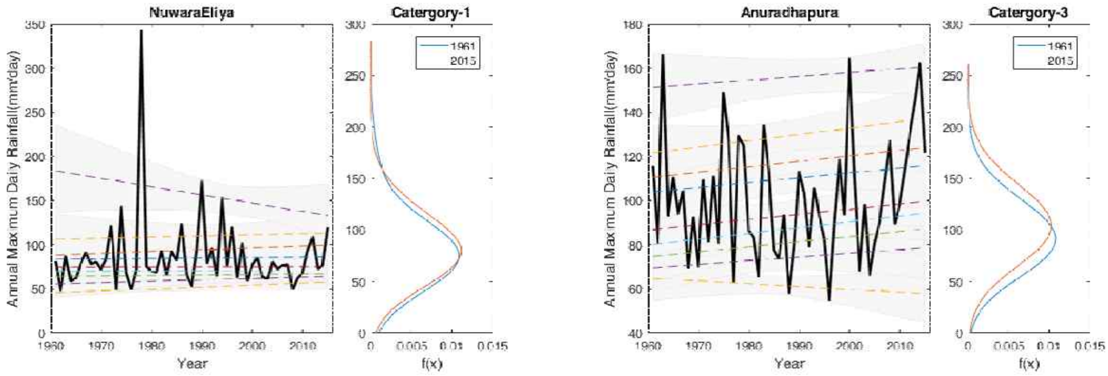

Figure: 1 Trends of the quantiles and PDFs for the Nuwara Eliya station-category I (Left) and Anuradhapura station - category III (Right)

On the other hand, the stations which showed a decreasing trend of the AMR had leftward PDF for the distributional changes in the AMRs for 1960 and 2015 (figure 2 Left and Right). Further, Manawadu (2008) also stated, due to global warming, the annual averages of the rainfall of the Northern region of Sri Lanka (i.e. Vavuniya (figure 2 Right) and Trincomalee) showed a decreasing trend. However, these 8 stations (i.e. Maha-Iluppallama ,Colombo, Trincomalee, Vavuniya, Galle, Katunayake, Batticaloa and Ratmalana) had an increasing trend in the mean annual and mean seasonal pentads based on an ordinary linear regression curves (Wickramagamage, 2016). We emphasized, using quantile regression to understand distributional changes in a rainfall index gives more information than the ordinary linear regression. It is because, for these stations some quantiles contribute much weight for the AMRs and it may not be detectable using ordinary regression approaches. Moreover, So et al. (2012) illustrated that the ordinary regression method is designed to estimate conditional mean (expectations) of the response variable while the quantile regression method allows flexibility to examine the trends at the quantiles of interest. Therefore, the presence of low AMRs for lower quantiles in these stations could lead to high probability for the lower rainfall extremes. On the other hand, special concern is in general needed when presence of high AMRs for highest quantiles. Because, these event could lead to high probability for the higher rainfall extremes.

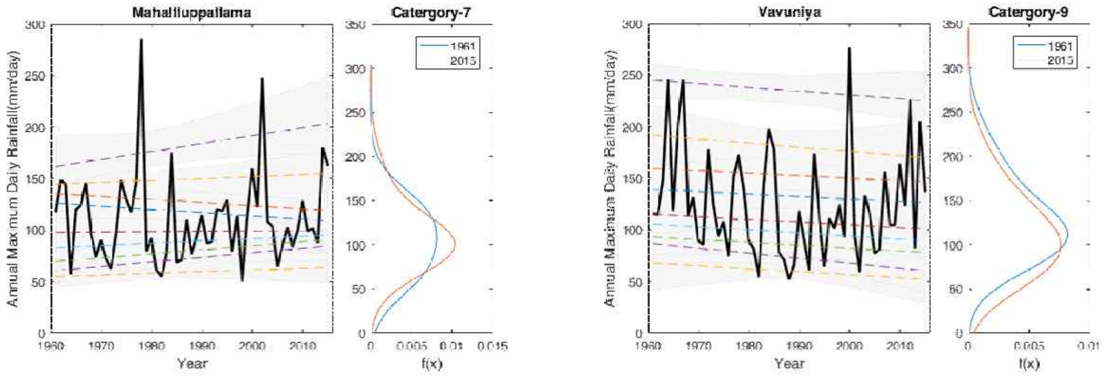

Figure: 2. Trends of the quantiles and PDFs for the Maha-Iluppallama station-category VII (Left) and Vavuniya station - category IX (Right)

There is a considerable spatial-temporal variability in distributional changes in AMRs over Sri Lanka. As an example, Maha-Iluppallama is a sub-station which is at the periphery of Anuradhapura district (i.e. administration unit which covers the Anuradhapura station) and the results revealed there is significant difference in terms of distributional changes in the AMRs (Figure 2. Left and figure 1. Right). Further, all the stations showed different features in distributional changes in AMRs. Therefore, we suggest understanding the distributional changes of the each quantile could give broader information on occurrence of hydrological extremes.

However, our study revealed the obtained trends for the rainfall are substantially different over the temporal scale (i.e. daily, monthly and annual), the period of data used and the approach used to determine the trend. Further, a robust relationship on hydrological extremes could be identified with consideration of distributional changes of the seasonal rainfall (i.e. monsoon seasons) over Sri Lanka.

Acknowledgement

This research was supported by a grant [MPSS-NH-2015-78] through the Disaster and Safety Management Institute funded by Ministry of Public Safety and Security of Korean government.

References

1. Basnayake, S. (2007). Future climate scenarios of rainfall and temperature for Sri Lanka. Paper presented at the 209th meeting of the E&E forum of the Tea Research Institute of SriLanka. Talawakele, SriLanka.
2. Chandrapala, L. (2007). Rainfall. In The National Atlas of Sri Lanka. Survey Department of Sri Lanka, Colombo, Sri Lanka: 58-59.
3. Climate Change Secretariat. (2015). National adaptation plan for climate change impacts in Sri Lanka. 2016 to 2025. Climate Change Secretariat. Ministry of Mahaweli Development Environment. Sri Lanka.
4. Eriyagama, N., Smakhtin, V., Chandrapala, L. and Fernando, K. (2010). Impacts of climate

change on water resources and agriculture in Sri Lanka: a review and preliminary vulnerability mapping. IWMI Research Report 135. International Water Management Institute. Colombo, Sri Lanka. DOI:10.5337/2010.211

5. Imbulana, K.A.U.S., Wijesekara, N.T.S. and Neupane, B.R. (2006). Sri Lanka Water Development Report 2010. UNESCO and Ministry of Irrigation and Water Resources Management, Colombo, Sri Lanka.
6. Jayatilake, H.M., Chandrapala, L., Basnayake, B.R.S.B. and Dharmaratne, G.H.P. (2005) Water Resources and Climate Change. In (Eds.) Wijesekara, S., Imbulana, K.A.U.S. and Neupane, B. Proceedings of the preparatory workshop on Sri Lanka national water development report. Ministry of Irrigation, Mahaweli and Rajarata Development, Colombo, Sri Lanka: 62-87.
7. Koenker, R. and Basset, G. (1978). Regression quantiles. Econometrica. 46 (1): 33-50.
8. Manawadu, L. and Fernando, N. (2008). Climate change in Sri Lanka. Review Journal of University of Colombo. 1(2), 2007/2008.
9. Punyawardena, B. V. R. and Premalal, K. H. M. S. (2013) Do trends in extreme positive rainfall anomalies in the Central highlands of Sri Lanka exist? Annals of the Sri Lanka, Department of Agriculture, 15: 1-12.
10. Ratnayake, U. and Herath, G. (2005). Changes in Water Cycle: Effect on Natural Disasters and Ecosystems. In Proceedings of the Preparatory Workshop on Sri Lanka National Water Development Report. Eds. Wijesekara, S., Imbulana, K.A.U.S. and Neupane, B. World Water Assessment Programme, Paris, France: 192-205.
11. Senalankadhikara, S. and Manawadu. L. (2010). Rainfall fluctuation and changing patterns of agriculture practices. Available at: http://publications.iwmi.org/pdf/H042865.pdf Accessed on 24th March, 2017.
12. Shiau, J.T. and Huang, W.H. (2015). Detecting distributional changes of annual rainfall indices in Taiwan using quantile regression. Journal of Hydro-environment Research. 9: 368-380.
13. So, B. J., Kwon, H.H. and An, J.H. (2012). Trend analysis of extreme precipitation using quantile regression. Journal of Korea Water Resources Association. 45 (8). 815-826. DOI: 10.374/JKWRA.2012.45.8.815
14. Wickramagamage, P. (2016). Spatial and temporal variation of rainfall trend of Sri Lanka. Theoretical and Applied Climatology. 125: 427-438. DOI:10.1007/s00704-015-1492-0