Presenting a Model for Predicting Meteorological and Hydrological Drought Risk by Statistical Methods under the Influence of Climate Change (Case study: Afin Catchment Area)

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1. Introduction

Drought is a common, natural climate phenomenon on the earth with various effects on the economic, social, and environmental aspects of life. The impact of drought on agriculture, water access, and socioeconomic activities of the region depends on various physiological, environmental, and social factors. Due to declined rainfall in specific and efficient periods, drought could lead to water scarcity. Hydrological drought is defined as the reduction of available water in all its forms (Ma, Ren, Singh, Yuan, Chen, Yang, & Liu, 2016). Climate change could influence the frequency and severity of droughts. Therefore, drought vulnerability depends on several factors, such as topographic features, development of soil, land, and water resources, groundwater utilization, and the regional water demand for domestic, industrial, and agricultural activities. Since these impacts may be local or regional, it is difficult to evaluate the effects of drought on various sectors. Risk is often recognized as the combined probability of a specific event (e.g., drought) and its negative consequences. Risk is defined as the endangerment of a system, which could often be the environment, where drought is interpreted as an environmental risk. The response of the environment to a hazard depends on the severity of the hazard and environmental properties, which could be classified into four categories of economic, social, physical, and environmental factors. The previous studies in this regard have mainly introduced economic and social factors as the risk factors for the occurrence of droughts. In the aforementioned studies, field questionnaires have not been used to assess drought vulnerability, while in the present study, the main research instrument was a questionnaire to estimate drought vulnerability. The present study aimed to assess the risk status of drought in a region in Iran based on observational data and the climatic downscaled data obtained from the

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coordinated regional climate downscaling experiment (CORDEX) project in order to predict the risk of drought.

2. Study Area

Afin sub-basin covers an area of 655 square kilometers. The Afrin basin is between 33 degrees and 42 minutes north to 33 degrees and 58 minutes north and 52 degrees 35 minutes east to 53 degrees and 31 minutes north. Khoshbakht river is the permanent river of this basin and part of a larger sub-basin known as Esfedan, which is connected to Zuzan (northeast) and Khaf salt pan. It is also connected to Qaen (northwest), Sharokht (southeast), and Saddeh and Birjand (southwest). The average precipitation in Afin sub-basin is approximately 156.4 millimeters, and the average temperature in the region is 14.7°C (Figure 1).

Based on the climate classification methods proposed by Amberje, the climate of Afin sub-basin is arid-cold. The arid-cold climate of the area is suitable for the growth of barberries. The economy of the village in the vicinity of Afin sub-basin has historically relied on agriculture, especially the cultivation of barberries. In fact, most of Iran's barberry is produced in this region.

3. Materials and Methods

At the first stage, the standardized precipitation evapotranspiration index (SPEI), effective reconnaissance drought index (eRDI), and standardized runoff index (SRI) were applied as the hydrological indices in this regard. The base period was the year 1983, and the utilized data included the monthly data on the average maximum temperature, average minimum temperature, mean surface air temperature, precipitation, and river flow data of Khoshbakht River in Afin sub-basin. Drought Hazard is defined as the probability of drought occurring at various levels of severity. In the current research, the probability of drought occurrence, and the probability of drought occurrence in each drought class was calculated using the normal z-score table. Vulnerability is a set of economic, social, and environmental conditions, which determine the sensitivity of an environment to risk. In the present study, a questionnaire consisting of 35 items was prepared in order to identify the extent of the impact of each vulnerability factor, and exploratory factor analysis and confirmatory factor analysis were applied to determine the vulnerability level of the selected area. Risk is defined as the result of the interactions between a system (environment), natural hazards, and socioeconomic vulnerability relative to the risk. The level of drought risk could be estimated after calculating the drought hazard and its vulnerability based on the definition of risk. In order to access the required meteorological data in the future (as mentioned in the Methodology section) and due to the level of access to the CORDEX project data, only three models of GFDL-ESM2M, CNRM-CERFAC, and ICHEC-EC-EARTH were selected in the current research since all the required meteorological parameters must have historical data, RCP4.5, and RCP8.5. In the present study, the IHACRES model was utilized to obtain the future runoff data. Since the vulnerability level obtained by the questionnaire was considered constant over time in the modeling of drought risk, hazard modeling was carried out. After the prediction of the hazard, future drought risk was estimated by multiplying the vulnerability value as described in the previous section. Two methods were exploited for the modeling of the drought risk, including the bootstrapped quantile regression (500 repetitions) and loess nonparametric regression.

4. Results and Discussion

Correlation-coefficient (R), explanation coefficient (R2), and Nash-Sutcliffe coefficient (NS) were used to assess the predictive ability of the climate models. After correction, the combined model for the precipitation and temperature parameters was determined using the weighted average method and Bayesian approach. According to the obtained results, the ICHEC-EARTH model had the highest coefficient as an integrated model based on the RCP4.5 scenario. Based on the two scenarios, the amount of runoff will have no significant changes in the upcoming years. Increased temperature and the subsequent probability of excessive rainfall in the studied area may be the reason for the lack of runoff in the upcoming years. Based on the completed questionnaires, the vulnerability score was 0.53 for Afin sub-basin, which indicated that about half of the sub-basin vulnerability was due to the economic, social, and environmental factors of the sub-basin. Furthermore, the vulnerability value was considered to be a mediator of the sensitivity of the mentioned factors. According to the results based on the mentioned meteorological drought indices, most variations in the drought risk were observed in winter. The results of drought risk assessment indicated that most variations in the frequency of droughts occurred in winter compared to the base season. On the other hand, the SRI findings showed no significant risk of severe droughts in any of the time scales within the next three periods based on the RCP4.5 and RCP8.5 scenarios.

5. Conclusion

The present study aimed to provide a model to predict the drought risk status in the future in the form of a case study of Afin sub-basin in Iran based on the meteorological drought indices of SPEI and eRDI and hydrological drought index of SRI. In general, the obtained results could be summarized as follows:

- SPEI and eRDI had the same performance in estimating the frequency of drought events, while eRDI showed higher drought intensity compared to SPEI, which could be due to the use of effective precipitation as an input in this index. In addition, SPI and eRDI indicated approximately equal drought severity.
- A slight increase was observed in the runoff of the future years based on the RCP8.5 scenario.
- Based on the meteorological drought indices, the possibility of highly severe droughts within the next 27 years is lower compared to the mid and far future periods.
- The meteorological drought indices showed that most drought changes in the investigated time scales occur in winter.

Keywords: Drought Hazard, Drought Vulnerability, Drought Risk, Climate Change

References (In Persian)

Jabbari Noghabi, H., & Jabbari Noghabi, M. (2007). نکاتی چند در مورد برآورد حجم نمونه و معرفی نرم افزار مربوطه. [A few tips on estimating sample size and introducing relevant software.] *Student Journal of Statistics, 4*, 13-21.

Khalil, N., Rezaee Pazhand, H., Derakhshan, H., & Davari, K. (2017). توسعه چارچوبی برای ارزیابی ریسک خشکسالی کشاورزی بر گندم دیم. [Development of a framework for agricultural drought risk assessment on rain fed wheat]. *Iranian Water Resources Research, 14*, 59-70.

Mosaedi, A., Kavakebi, G., & Abdolahhzade, Z. (2011). *آزمون آماری آشکارسازی تغییرات اقلیمی براساس من-ویتنی در شهر مشهد.* [Climate change detection based on Mann-Whitney statistical test in Mashhad. Paper presented at First National Conference on Meteorological and Agricultural Water Management.

References (In English)

Anderson-cook, C. M., & Prewitt, K. (2005). Some guidelines for using nonparametric methods for modeling data from response surface designs. *Journal of Modern Applied Statistical Methods, 4***,** 12, 106-119.

Apurv, T., & Cai, X. (2019). Evaluation of the stationarity assumption for meteorological drought risk estimation at the multi-decadal scale in contiguous United States. *Water Resources Research, 55*(6), 5074-5101.

Arnell, N. W. (1999). The effect of climate change on hydrological regimes in Europe: A continental perspective. *Global Environmental Change, 9***,** 5-23.

Bachmair, S., Svensson, C., Prosdocimi, I., Hannaford, J., & Stahl, K. (2017). Developing drought impact functions for drought risk management. *Natural Hazards and Earth System Sciences, 17***,** 1947-1960.

Chopra, P. (2006). Drought risk assessment using remote sensing and GIS: a case study of Gujarat. University of Twente International Institute for Geo-Information Science and Earth ObservationITC.

Efron, B. (2000). The bootstrap and modern statistics. *Journal of the American Statistical Association, 95***,** 1293-1296.

Fan, G., Zhang, Y., He, Y., & Wang, K. (2017). Risk assessment of drought in the Yangtze river delta based on natural disaster risk theory. *Discrete Dynamics in Nature and Society,*.2017. 1-7.

Fox, J. & Weisberg, S. 2018. An R companion to applied regression, Sage Publications.

Hashemi-ana, S. K., Khosravi, M. & Tavousi, T. 2015. Validation of AOGCMs capabilities for simulation length of dry spells under the climate change in Southwestern area of Iran. *Open J Air Pollut, 4***,** 76-85.

Kim, H., Park, J., Yoo, J. & Kim, T.-W. (2015). Assessment of drought hazard, vulnerability, and risk: a case study for administrative districts in South Korea. *Journal of Hydro-environment Research, 9***,** 28-35.

Lin, M.-L. & Chen, C.-W. (2011). Using GIS-based spatial geocomputation from remotely sensed data for drought risk-sensitive assessment. *International Journal of Innovative Computing, Information and Control, 7***,** 657-668.

Lubis, M., Taki, H., Anurogo, W., Pamungkas, D., Wicaksono, P. & Aprilliyanti, T. (2017). *Mapping the distribution of potential land drought in Batam Island using the integration of* *remote sensing and geographic information systems (GIS).* Paper presented at IOP Conference Series: Earth and Environmental Science,. IOP Publishing, 98(1), 012012.

Ma, M., Ren, L., Singh, V. P., Yuan, F., Chen, L., Yang, X. & Liu, Y. (2016). Hydrologic model-based almer indices for drought characterization in the Yellow River basin, China. *Stochastic Environmental Research and Risk Assessment, 30,* 1401-1420.

Mckee, T. B., Doesken, N. J. & Kleist, J. (1993). The relationship of drought frequency and duration to time scales. Proceedings of the 8th Conference on Applied Climatology,. American Meteorological Society Boston, MA, 179-183.

Meng Dai .,Shengzhi Huang ., Qiang Huang., GuoyongLeng .,Yi Guo ., Lu Wang ., WeiFang ., Pei Li ., Xudong Zheng (2020). Assessing agricultural drought risk and its dynamic evolution characteristics. *Agricultural Water Management, 231,* 106003.

Pandey, R. P., Pandey, A., Galkate, R. V., Byun, H.-R. & Mal, B. C. (2010). Integrating hydro-meteorological and physiographic factors for assessment of vulnerability to drought. *Water resources management, 24,* 4199-4217.

Pandey, S., Pandey, A., Nathawat, M., Kumar, M. & Mahanti, N. (2012). Drought hazard assessment using geoinformatics over parts of Chotanagpur plateau region, Jharkhand, India. *Natural hazards, 63,* 279-303.

Pei, W., Fu, Q., Liu, D., Li, T.-X., Cheng, K. & Cui, S. 2017. Spatiotemporal analysis of the agricultural drought risk in Heilongjiang Province, China. *Theoretical and Applied Climatology***,** 133, 151–164.

Prathumchai, K., Honda, K. & Nualchawee, K. (2001). Drought risk evaluation using remote sensing and GIS: a case study in Lop Buri Province. Paper presented at 22nd Asian conference on remote sensing, 9. Singapore

Reduction, U. N. S. F. D. (2007). Drought risk reduction framework and practices: Contributing to the implementation of the hyogo framework for action. UNISDR Geneva (CH).

Samani, Z. (2000). Estimating solar radiation and evapotranspiration using minimum climatological data. *Journal of irrigation and drainage engineering, 126***,** 265-267.

Shahidi, S. & Behrawan, H. (2008). Drought risk assessment in the western part of Bangladesh. *Natural Hazards, 46,* 391-413.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M. & Miller, H. L. (2007). Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change, 2007. Cambridge University Press, Cambridge.

Tigkas, D., Vangelis, H. & Tsakiris, G. (2017). An enhanced effective reconnaissance drought index for the characterisation of agricultural drought. *Environmental Processes, 4,* 137-148.

Tsakiris, G. (2007). Practical application of risk and hazard concepts in proactive planning. *European Water, 19***,** 47-56.

UNISDR, U. (2009). Terminology on disaster risk reduction. United Nations Office for Disaster Risk Reduction Geneva, Switzerland.

Valverde-arias, O., Garrido, A., Valencia, J. L. & Tarouis, A. M. (2018). Using geographical information system to generate a drought risk map for rice cultivation: Case study in Babahoyo canton (Ecuador). *Biosystems Engineering, 168,* 26-41.

Vicente-serrano, S. M., Begueria, S. & Lopez-moreno, J. I. (2010). A multiscalar drought index sensitive to global warming: The standardized precipitation evapotranspiration index. *Journal of Climate, 23,* 1696-1718.

Vicente-serrano, S. M., Begueria, S. & Lopez-moreno, J. I. (2010). A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. *Journal of Climate, 23,* 1696-1718.

Wentz, F. J., Ricciardulli, L., Hilburn K. & Mears, C. (2007). How much more rain will global warming bring? *Science, 31*(7), 233-235.

Wilhite, D. A., Hayes, M. J., Knutson, C. & Smith, K. H. (2000). Planning for Drought: Moving From Crisis to Risk Management 1. *JAWRA Journal of the American Water Resources Association, 36***,** 697-710.

Wu, H. & Wilhite, D. A. (2004). An operational agricultural drought risk assessment model for Nebraska, USA. *Natural Hazards, 33,* 1-21.

Yaduvanshi, A., Srivastava, P. K. & Pandey , A. (2015). Integrating TRMM and MODIS satellite with socio-economic vulnerability for monitoring drought risk over a tropical region of India. *Physics and Chemistry of the Earth, Parts A/B/C, 83***,** 14-27.

Yuan, X.-C., Zhou, Y.-L., Jin, J.-L. & Wei, Y.-M. (2013). Risk analysis for drought hazard in China: A case study in Huaibei Plain. *Natural Hazards, 67,* 879-900.

Zhiyong Wu ., Huating Xu .,Yuanyuan Li., Lei Wen ., Jianqiang Li., Guihua Lu., Xiaoyan Li (2018). Climate and drought risk regionalisation in China based on probabilistic aridity and drought index. *Science of the Total Environment, 612*, 513-521.