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Discussions

Interactive comment on "Characteristics and controlling factors of the drought runoff coefficient" *by* Rei Itsukushima

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Response to Reviewer

I wish to express my appreciation to the reviewer for insightful comments on my paper. The comments have helped me significantly improve the paper.

General comment: The paper by Itsukushima aims to quantify and model the relationship between drought conditions and controlling factors based on geology, land use, and topography. This would have been an interesting topic, but the research does not do what is promised. The analysis used average annual discharge divided by average annual precipitation, which clearly is not the same as drought. Average annual Q/P includes both high- and low-flow periods and the annual timescale is too long for many

droughts. This is unfortunately not the only misunderstanding in the paper. Terms are mixed up, a whole body of literature is missed, important factors are left out of the analysis, and the work does not lead to new insights. This paper cannot be accepted for publication in HESS. I explain my rejection below and give more detailed comments in the attached file. Throughout the paper there is confusion between annual discharge, low flow and drought, both in the literature review and in the analysis. The paper analyses aver- age annual discharge, but talks about drought and low flows. The literature about drought cited in the Introduction is not relevant for the current work on runoff coeffi- cients. Contrary to the claim of the author that this is the first attempt to study the relationship between runoff coefficient and controlling factors, there are already many papers doing this. For example, Berger & Entekhabi (2001), Laaha & Blöschl (2006), Merz & Blöschl (2009), Carey et al. (2010), Sawicz et al. (2011), Ali et al. (2012) and papers by the same and other authors. The probabilistic approach of looking at different return period is maybe new, but the calculation, interpretation and discussion of what this means is unsatisfactory. It is unclear how the runoff coefficient is calcu- lated for each occurrence probability? Have you just divided the 400yr discharge by the 400yr precipitation? Why? What does this mean? Other methodological flaws include: using different time period of data for precipitation and discharge to compute the runoff coefficient, as the meteorological input might be completely different between these periods, and not taking any climate-related factors into account, as the differences identified in the paper seem (at least partly) to be a function of ET and snow, which are related to latitude and altitude. The analysis should be completely redone and extended. The framework of Wagener et al. (2007) could be a useful guidance. Finally, the discussion section just mentions a random selection of papers, without thorough synthesis of what the results of this study mean and how they compare to the large body of existing literature on this topic. The discussion and conclusion also contain a lot of misunderstandings and misinterpretations.

Response: According to your comments, I have mainly corrected as follows. Details of the correction are described in the specific comments.

ãČżMethod I have clarified the calculation method of drought runoff coefficient of each occurrence probability. Further, I added the specific definition of the low-flow, high and low frequent drought. ãČżResults Based on the definition of the low-flow, high and low frequent drought, I classified the calculation results of runoff coefficient for each occurrence probability into categories of the low-flow, high and low frequent drought. In addition, I added the significant test among three groups for each occurrence probability. ãČżDiscussion Based on the manuscripts introduced by the reviewer, I substantially changed the discussion section to secure the synthesis.

Specific comment: 1. Mention the case study region in the abstract somewhere. The results might be specific to the region.

Response: As requested, I added the explanation of the research region as follow.

Line 10-13 I calculated the drought runoff coefficient for six types of occurrence probability based on past observation data of annual total discharge and precipitation in the Japanese archipelago where multiple climate zones exist.

2. Unclear what you mean with these terms. Are you looking at drought, low flow or minimum flow? What is the drought runoff coefficient? What do you mean with high and low frequency drought?

Response: As pointed out, the definition of low flow, high frequent drought, and low frequent drought was lacked. Therefore, I have defined these terms based on the previous researches as follow. Furthermore, I have classified the calculation results of each occurrence probability based on the definition. Line 106-110 Numerous definitions of hydrological drought have been proposed (Wilhite & Glantz, 1985; Wilhite, 2000). In this study, with reference to Whipple (1966) and Changnon (1980), I defined discharge less than the average annual total discharge as low flow and drought less than the 75% of the average annual total discharge. Furthermore, a discharge of 50%–75% of the average annual total discharge was defined as high-frequency drought, and a discharge of less than 50% was defined as low-frequency drought.

Added references Changnon, S. A.: Removing the confusion over droughts and floods: The interface between scientists and policy makers, Water Int., 5, 10-18, 1980. Whipple, W., Jr.: Regional drought frequency analysis, Proc. ASCE, 92 (IR2) (June), 11–31, 1966. Wilhite, D.A.: Drought as a Natural Hazard: Concepts and Definitions. Drought Mitigation Center Faculty Publications. 69, 2000.

3. Do you mean increase in socio-economic drought related to an increase in demand due to population growth?

Response: This research deals with the future drought risk due to both of population growth and climate change. In this section, I mentioned about the drought due to climate change, therefore, I changed the description as follow.

Line 46-48 However, future prediction of drought aggravation due to climate change and population growth in central Africa (Ahmadalipour et al., 2019) and increasing drought duration and severity in the interior southwest of the United States (Andreadis & Lettenmaier, 2006) have been reported.

4. For clarification, I suggest to add a definition of low flow above, when you define drought.

Response: As pointed out, the definition of low flow, high frequent drought, and low frequent drought was lacked. Therefore, I have defined these terms based on the previous researches as follow. Furthermore, I have classified the calculation results of each occurrence probability based on the definition.

Line 106-110 Numerous definitions of hydrological drought have been proposed (Wilhite & Glantz, 1985; Wilhite, 2000). In this study, with reference to Whipple (1966) and Changnon (1980), I defined discharge less than the average annual total discharge as low flow and drought less than the 75% of the average annual total discharge. Furthermore, a discharge of 50%–75% of the average annual total discharge was defined as high-frequency drought, and a discharge of less than 50% was defined as low-frequency drought.

5. Add papers by Laaha & Bloschl.

As requested, I added the papers by Laaha & Bloschl as reference.

Line 56-59 For research on flow regime, the factors influencing low flows strongly related to drought have been investigated, through focusing on watershed area, watershed elevation, ratio of urban area or forest cover, and geology (Mushiake et al., 1981; Zecharias & Brutsaert, 1988; Vogel & Kroll, 1992; Laaha & Blöschl, 2005; 2006).

Added references Laaha, G., and Blöschl, G.: 2005. Low flow estimates from short stream flow records - A comparison of methods. J. Hydrol., 306 (1-4), 264-286, 2005. Laaha, G., and Blöschl, G.: A comparison of low flow regionalisation methods-catchment grouping. J. Hydrol., 323 (1-4), 193-214, 2006.

6. What exactly do you mean by "10% occupancy by a dam watershed, is this the area of the reservoir itself or the area of a subcatchment in which a dam is located? Is area the best criterion? How do you know that effects of regulation are negligible when the dam area is less than 10%?

Response: The threshold of 10 % indicates an area of sub-catchment of the dam. There are few watersheds which have abundant discharge data without dam due to active water resource development. Therefore, we used the data of observation stations whose watershed was subject to under 10 % to secure the number of stations. As requested, I added the explanation of dam watershed and getting information of watershed of dams as follow.

Line 75-78 To extract stations where the impact of flow regime regulation due to a dam is small, observation stations whose watershed was subject to over 10% occupancy by the area of a sub-catchment in which a dam is located were excluded (Fig. 1). The information about the sub-catchment areas of dams was obtained from the Japan Dam Foundation (2019).

Added reference Japan Dam Foundation.: Dam year directory, 2019.

7. Why annual? Not low flow. . .

As requested, I added the explanation of the using annual total discharge as the indicator to calculate the drought runoff coefficient as follow.

Line 80-84 Propagation of a precipitation anomaly to the streamflow was explained by the yearly scale (Changnon, 1987; Van Loon, 2015), I used the annual total discharge as the indicator to calculate the drought runoff coefficient. Annual discharge was frequently used as the evaluation indicator of drought (Agnew &Warren, 1996; McMahon & Finlayson, 2003; Henny et al., 2007; Lorenzo-Lacruz et al., 2010).

Added reference Agnew, C., and Warren, A.: A framework for tackling drought and land degradation. Journal of Arid Environments. 33 (3), 309-320, 1996. Changnon S. A.: Detecting drought conditions in Illinois. Illinois State Water Survey Champaign, Circular 169, 1987. Henny, C. J., Hill, E. F., Grove, R. A., and Kaiser, J.L.: Mercury and Drought Along the Lower Carson River, Nevada: I. Snowy Egret and Black-Crowned Night-Heron Annual Exposure to Mercury, 1997–2006. Archives of Environmental Contamination and Toxicology. 53(2), 269-280, 2007. Lorenzo-Lacruz, J., Vicente-Serrano, S. M., López-Moreno, J. I., Beguería, S., García-Ruiz, J. M., and Cuadrat, J.M.: The impact of droughts and water management on various hydrological systems in the headwaters of the Tagus River (central Spain). Journal of Hydrology, 386(1-4), 13-26, 2010. McMahon, T.A., and Finlayson, B.L.: Droughts and antiâĂŘdroughts: the low flow hydrology of Australian rivers. Freshwater Biology. 48 (7), 1147-1160, 2003. Van Loon, A.F.: Hydrological drought explained. WIREs Water. 2, 359-392, 2015.

8. Why where these probability distributions used? Why are they suitable for the data? Please add a table of advantages and disadvantages of using these distributions for the calculation of low flow return flows.

Response: As requested, I added the references which explain the advantages and disadvantages of these hydrological frequency analysis (in line 93-95).

Added reference Etoh, T., Murota, A., and Nakanishi, M.: SQRT-Exponential Type Distribution of Maximum. Hydrologic Frequency Modeling. 253-264, 1987. Griffis, V. W.: Flood Frequency Analysis: Bulletin 17, Regional Information, and Climate Change, Ph. D. Dissertation, Cornell University, 2006. Griffis, V. W., and Stedinger, J. R.: Log-Pearson type 3 distribution and Its application in flood frequency analysis. I: Distribution characteristics. Journal of Hydrologic Engineering. 12(5), 482-491, 2007. Interagency Committee on Water Data.: Guidelines for Determining Flood Flow Frequency: Bulletin 17 B (revised and corrected), Hydrology Subcommittee, Washington, D. C., 1-28, 1982. Ishihara, T., and Takase, N. The logarithmic-normal distribution and its solution based on moment method. Transactions of the Japan Society of Civil Engineers. 47, 18-23, 1957. Stedinger, J.R., Vogel, R. M., and Foufoula-Georgiou.: Frequency analysis of extreme events, Chap. 18, Handbook of Hydrology, (Ed.) Maidment, D. R., McGraw-Hill., NewYork, 1993. Takara, K.: Frequency analysis of hydrological extreme events and how to consider climate change. The Nineteenth IHP training course (International Hydrological Program), 2009. Takara, K., and Tosa, K.: Application of probability distributions with lower and upper bounds to hydrologic frequency analysis. Proceedings of hydraulic engineering, JSCE. 43, 121-126, 1999. Takara, K., and Takasao, T.: Comparison of parameter estimation methods for hydrologic frequency analysis model. Proceedings of hydraulic engineering, JSCE. 34, 7-12, 1990. Yue, S., Ouarda, T. B. M. J., Bobée, B., Legendre, P., and Bruneau, P.: The Gumbel mixed model for flood frequency analysis. Journal of Hydrology. 226(1-2), 88-100, 10.1016/S0022-1694(99)00168-7 1999.

9. For precipitation and discharge? Same 30 year period used between stations and between P and Q?

Response: As for the precipitation amount, same 30 year period was used between stations. Further, the observation period of rainfall and discharge are overlapped.

10. In Table 1 I noticed that you only used 30yr for P, whereas you used various time periods for Q. If you do this, you cannot compare P and Q or calculate a runoff coefficient as they are derived from different time period with different meteorological input.

Response: As requested, I added the explanation of the adequateness of the method. In order to calculate the most probable numerical value among the limited information, the probability distribution that best fits P and Q is adopted. The result of statistical analysis and calculation indicates the adequacy of this method. In addition, previous research revealed that the stability of reproduction statistics increased if the samples are more than about 30. Therefore, I adopted the method.

Line 98-102 Data from observation stations with an observation period of over 30 years were used based on the research result, which indicates that the stability of reproduction statistics increases if the samples are more than about approximately 30 (Takara & Kobayashi, 2009).

Added reference Takara, K., and Kobayashi, K.: Hydraulic analysis methods suitable to the sample size of extreme events. Annual journal of hydraulic engineering, JSCE. 53, 205-210, 2009.

11. Why this method?

Response: As requested, I added the explanation of the reason for the adaptation of this method.

Line 100-102 A sample of the average depth of rainfall over the watershed area was calculated using a Voronoi diagram for objectively considering the area effect of the rainfall at the watersheds.

12. How is this the drought runoff coefficient if you just divide the annual values?

Response: As you have pointed out, the explanation was insufficiently. I modified the calculation of drought runoff coefficient as follow.

Line 104-106 The drought runoff coefficient of each occurrence probability for the 44 watersheds was calculated using the following equation: Qn / (Pn * A) (Qn: estimated total discharge of each occurrence probability, Pn: estimated precipitation amount of each occurrence probability, n = 2, 10, 30, 50, 100, and 400, A: watershed area).

13. Also, from Table 1 it seems that the discharge and precipitation values had different units. This means that you do not get a dimensionless coefficient if you divide them.

Response: I calculated the drought runoff coefficient by dividing total discharge (m3) by catchment area (m2) and rainfall (m). I modified the calculation of drought runoff coefficient as follow.

Line 104-106 The drought runoff coefficient of each occurrence probability for the 44 watersheds was calculated using the following equation: Qn / (Pn * A) (Qn: estimated total discharge of each occurrence probability, Pn: estimated precipitation amount of each occurrence probability, n = 2, 10, 30, 50, 100, and 400, A: watershed area).

14. What do you mean? How did you increase / decrease the variables?

Response: I used the stepwise selection method proposed by Efroymson (1960). I modified the sentence and added a reference as follows.

Line 147-149 I compared the obtained Akaike information criteria (AIC) (Burnham & Anderson, 2002) of each model by the stepwise selection method (Efroymson, 1960).

Added reference Efroymson M. A.: Multiple regression analysis. In: Ralston A, Wilf HS, editors. Mathematical methods for digital computers. New York: Wiley; 1960.

15. Following the methodology you did not calculate drought, only annual streamflow.

Response: As pointed out, the definition of low flow, high frequent drought, and low frequent drought was lacked. Therefore, I have defined these terms based on the previous researches as follow. Furthermore, I have classified the calculation results of each occurrence probability based on the definition.

Line 106-110 Numerous definitions of hydrological drought have been proposed (Wilhite & Glantz, 1985; Wilhite, 2000). In this study, with reference to Whipple (1966) and Changnon (1980), I defined discharge less than the average annual total discharge as low flow and drought less than the 75% of the average annual total discharge. Furthermore, a discharge of 50%–75% of the average annual total discharge was defined as high-frequency drought, and a discharge of less than 50% was defined as low-frequency drought.

Line 161-165 From the calculation of the total discharge of each occurrence probability, the percentage to the average annual discharge was 96%, 67%, 56%, 53%, 48%, and 42% for the occurrence probability of 2, 10, 30, 50, 100, and 400 years, respectively. Therefore, the total discharge of the occurrence probability of 2 years corresponded to the low-flow; 10, 30, and 50 years corresponded to the high-frequency drought; and 100 and 400 years corresponded to the low-frequency drought.

16. Show clustering results.

Response: Clustering results were shown in Figure 2. Further, I have added the explanation of clustering results as follows.

Line 167-168 From seriation and clustering using the drought runoff coefficient for each occurrence probability based on NMDS, the 44 stations were classified into three groups (Group A, B, and C, as shown in Fig. 2).

17. How were these selected?

Response: As you requested, I have added the explanation of the selecting method of variables as follow.

Line 137-138 From the permutation test (n = 999), controlling factors closely related to the classification of the drought runoff coefficient ($p < 0.01$) were presented as vectors.

18. What do you mean? Refer to Figure 3.

Response: As requested, I modified the sentence as follow.

Line 180-181 To compare the runoff coefficient among groups, the average value of the runoff coefficient was large in order of group A, B, and C in all occurrence probabilities. 19. Also, I do not think that the differences between the groups are statistically significant with this high amount of overlap between the groups. Needs to be tested.

Response: As requested, I have conducted the significant test among three groups for each occurrence probability. The results were added as follows.

Line 186-189 From the significant test among the three groups for each occurrence probability, a significant difference between groups A and C was confirmed in all occurrence probabilities ($p < 0.01$). In addition, a significant difference between groups A and B was confirmed in the occurrence probability of 10, 30, 50, 100, and 400 years ($p < 0.01$).

20. Move to figure caption

Response: As requested, I have moved the sentences to figure caption (Line 665-669).

21. Not surprising. Probably due to low ET?

Response: As pointed, this is due to the low ET. I have added the explanation and references as follow.

Line 234-235 This is also due to the low evapotranspiration in the high-latitude area (Ahn & Tateishi, 1994; Zhang et al., 2011).

Added reference Ahn, C-H., and Tateishi, R.: Development of Global Land Surface Evapotranspiration and Water Balance Data Sets. Journal of the Japan society of photogrammetry and remote sensing. 33, 48-61, 1994. Zhang, K., Kimball, J. S., Kim, Y., and Mcdonald, K. C.: Changing freeze-thaw seasons in northern high latitudes and associated influences on evapotranspiration. Hydrological Processes. 25(26), 4142-4151, 2011.

22. This is not relevant as you only looked at annual Q, not at droughts or seasonality.

Response: Based on your comment, I defined the low flow, drought runoff coefficient as follows.

Line 108-110 I defined discharge less than the average annual total discharge as low flow and drought less than the 75 % of the average annual total discharge. Furthermore, discharge of 50-75% of the average annual total discharge was defined as high-frequent drought, and discharge of less than 50% is defined as low-frequent drought.

23. Again, you are not researching drought.

Response: Based on your comment, I defined the low flow, drought runoff coefficient as follows.

Line 108-110 I defined discharge less than the average annual total discharge as low flow and drought less than the 75 % of the average annual total discharge. Furthermore, discharge of 50-75% of the average annual total discharge was defined as high-frequent drought, and discharge of less than 50% is defined as low-frequent drought.

24. What do you mean?

Response: As requested, I modified the sentences as follows.

Line 264-267 In the total discharge of occurrence probability of 2 and 10 years, geological factors and land use factors were selected as the controlling factors. These factors were closely related to the surface runoff or subsurface flow. In contrast, for the low-frequency drought, factors related to the larger time-scale hydrological cycle, such as ground water level, were apparently selected.

25. There is ample research on controlling factors of the runoff coefficient. You are not researching drought.

Response: As requested, I modified the sentence as follow.

Line 351-352 This manuscript reports the relationship between drought runoff and controlling factors (geological, land use, and topographical factors) in relation to the magnitude of occurrence probability.

26. Nothing new here.

Response: As requested, I modified the sentence as follow.

Line 366-367 Therefore, for effective water resource management, estimation of the drought runoff volume needs to consider precipitation pattern, geology, land use, and topography for corresponding to the magnitude of the drought.

27. Figure 2 How do you mean "for each occurrence probability"? You would get a different number for each probability and so a different figure. Or have you averaged all runoff coefficients for all probabilities?

Response: I used the dataset of runoff coefficient of six occurrence probability (2, 10, 30, 50, 100, and 400 year). I have modified the caption of Figure 2 as follows.

Line 656-657 Figure 2: Results of NMDS using the drought runoff coefficient of six occurrence probabilities (2, 10, 30, 50, 100, and 400 years). NMDS: non-metric multidimensional scaling

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