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Scaling Behaviour of Twenty Catchments in New South Wales in Relation to Regional Flood Frequency Analysis

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Abstract

Flooding remains a major concern for New South Wales (NSW), Australia, impacting infrastructure, communities, and ecosystems. This paper investigates the scaling behaviour of 20 catchments in state of NSW, examining the relationship between catchments area (A) and peak discharge (Q) and the scaling exponent that governs the relationship between catchment size and peak flow. The results show that the scaling exponent varies widely for the study catchments. The value of the scaling component varies in the range of -0.73 to 2.12 (mean = 0.50 and standard deviation = 1.16). The results show that the generally recommended exponent of 0.7 is not applicable to the study data set. The relative error of estimation of the highest flow in two of the ten paired catchments is in the range of -79% to 175% (mean = -6.72% and standard deviation of 73.31%). Further study is needed to validate the scaling exponent using a greater number of catchments across Australia. The first author has adopted a project-based learning method in understanding statistical hydrology concepts presented in this paper.

Keywords: Scaling, Regional floods, catchment, peak discharge, relative error.

1. INTRODUCTION

Flood is regarded as the costliest natural disaster in Australia. The average flood damage is about $8.8 billion per year in Australia (as of 2017) covering insured, tangible and intangible costs (CSIRO, 2024). About 28% of the land area of NSW is affected by flooding (SES NSW, 2024). To reduce the flood damage, engineers and scientists use a risk-based approach in the hydrologic design of infrastructure, for example they use 100-year flood or 1% annual exceedance probability (AEP) flood in designing small hydraulic structures.

The design flood is estimated at a given location by methods such as flood frequency analysis (FFA). However, FFA is applicable to only gauged catchments where adequate streamflow data is available; however, many catchments in Australia are ungauged similar to many other countries. For these ungauged catchments, regional flood frequency analysis (RFFA) is adopted to estimate design floods, which attempts to transfer flood data from gauged to ungauged catchments on the basis of regional homogeneity. Rahman et al. (2019) presented a RFFA technique in Australian Rainfall and Runoff (ARR) guideline for general use in Australia, which is based on a parameter regression technique (Haddad and Rahman, 2012).

This paper focuses on scaling issue in RFFA, i.e., how floods in catchments of different sizes are related.

Ishak et al. (2011) conducted a scaling study in NSW and stated that regional annual maximum flood (AMF) series follow a simple scaling property. Pandey (1998) studied the scaling behavior of flood data from Quebec and Ontario, Canada and showed that AMF series were different in terms of scaling property. He also stated that when the basin area increases, the variability of annual flood decreases. Dawdy and Gupta (1995) examined the regional skewness of the annual maximum flood data from USA and adopted scaling theory to explain the regional differences in skew across USA.

This study examines scaling behavior of twenty catchments in NSW using AMF data till 2023. It also explains the learning aspect of the first author via a project-based learning method.

2. MATERIALS AND METHODS

A total of 20 catchments (Table 1) was selected for this study from NSW state of Australia. These catchments are unregulated and there has been no land use change in these catchments during the streamflow data length. The catchment area ranges from 62 to 956 km^2. The mean annual flood (M) varies in the range of 15.72 m^3/s to 442.39 m^3/s, and the standard deviation of the AMF data falls in the range of 27.15 m^3/s to 483.5 m^3/s. The coefficient of variation (CV) of the AMF data varies from 83;9% to 221.24%.

Table 1. Summary of 20 selected catchments (M, SD and CV represent mean (M), standard deviation (SD) and coefficient of variation (CV) of AMF).

Station ID	Area (km^2)	M (m^3/s)	SD (m^3/s)	CV (%)
204037	62	52.59	57.38	109.12
204056	104	136.96	159.64	116.56
210011	194	274.75	308.26	112.2
210014	395	87.66	152.92	174.43
210079	956	254.37	351.53	138.2
210080	80	112.43	183.75	163.44
410038	411	50.16	42.08	83.9
410048	530	26.61	50.8	190.93
416020	402	92.91	130.65	140.62
416023	505	110.1	145.31	131.98
418005	259	39.85	76.26	191.38
418014	855	148.37	240.45	162.06
419010	829	151.66	181.54	121.68
419016	907	162.73	199.69	122.68
222016	155	15.72	27.55	173.92
222017	313	94.09	154.06	163.73
219022	202	123.64	164.77	133.27
219025	717	442.39	483.5	109.29
421026	883	88.65	177.18	199.84
421050	365	132.23	292.54	221.24

The applicability of the following scaling equation is examined in this study:

$$Q_2=Q_1(A_2/A_1)^a \tag{1}$$

where A_1 and A_2 are catchment areas of catchment 1 and catchment 2, respectively, and Q_1 and Q_2 are peak discharge (the highest flow value in a station's AMF series) for catchment 1 and catchment 2, respectively, and "a" is an exponent, which is generally smaller than 1 (its typical value is 0.7) (Ishak et al., 2011).

To assess the accuracy of prediction, relative error (RE) is estimated using predicted (based on Equation 1) and observed peak discharges:

$$\text{RE} = \frac{Q_{\text{predicted}} - Q_{\text{observed}}}{Q_{\text{observed}}} \times 100 \quad (2)$$

3. RESULT AND DISCUSSION

Table 2 shows that exponent "a" varies significantly from the expected value of 0.70. The variation of "a" is shown in Figure 1; it can be seen that "a" values range from -1.50 to 2.12, with a mean value of 0.50. Two of the catchments have "a" values closer to expected value of 0.70 (0.807 and 0.626, respectively).

In few cases "a" is negative, which indicates that a drier larger catchment has a smaller peak AMF than the other paired smaller catchment, which is wetter. Station 204037 with catchment area of 62 km^2 has the highest negative relative error of -50.57%. Station 210011 with catchment area of 194 km^2 has the large positive relative error of 175.35%. Station 418005 with catchment area of 259 km^2 has the smallest relative error of -11.98%.

It can be seen that the relative error ranges from -11.98% to 175.35%, and absolute median relative error in flood peak estimation is 36.27%. This implies that if Equation 1 is used to estimate design flood estimates based on catchment area only, the expected error in estimation will be about 36%, which is very similar to other RFFA techniques. For example, Zalnezhad et al. (2023) noted that median relative error values are in the range of 32 to 48% for quantile regression technique in southeast Australia.

Table 2. Calculating value of exponent "a" (Equation 1) to match peak discharge between two catchments.

Station ID	Area (km^2)	Qobserved	Qpredicted	RE(%)	Matched discharge	Value of a to match discharge
204037	62	225.62	324.06	-50.57	654.85	2.06
204056	104	655.61				
210011	194	1349.9	2220.54	175.35	803.31	-0.73
210014	395	806.43				
210079	956	1324.02	233.20	-79.21	1121.27	0.067
210080	80	1121.97				
410038	411	201.4	240.64	-16.39	287.52	1.4
410048	530	287.81				
416020	402	562.33	659.69	11.21	593.97	0.24
416023	505	593.17				
418005	259	423.74	977.61	-11.98	1110.87	0.807
418014	855	1110.68				
419010	829	956.91	1019.08	21.97	836.16	-1.5
419016	907	835.51				
222016	155	177.12	289.68	-63.30	785.81	2.12
222017	313	789.21				
219022	202	797.02	1934.58	9.84	1761.47	0.626
219025	717	1761.29				
421026	883	1054.04	567.92	-64.18	1582.50	-0.046
421050	365	1585.67				

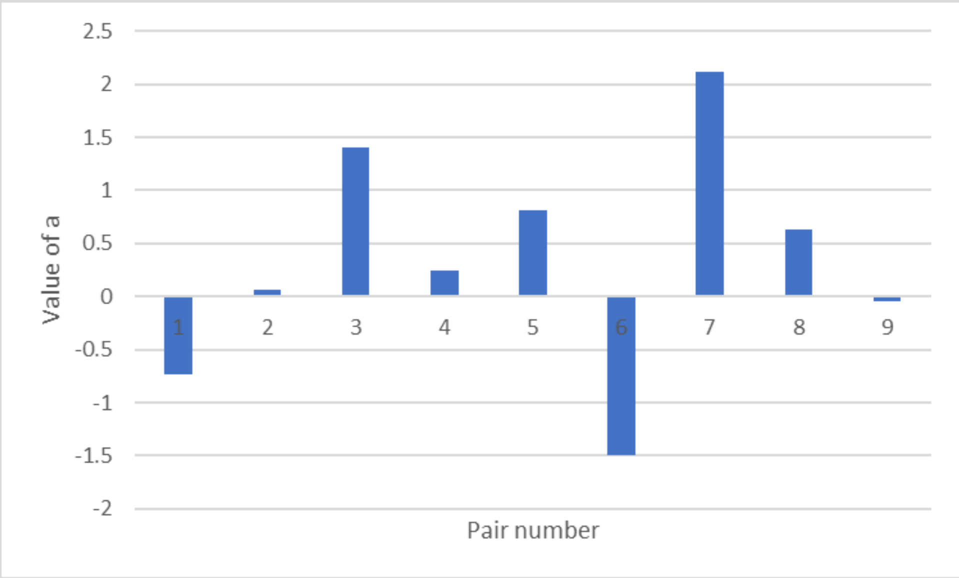

Figure 1. Value of exponent "a" (Equation 1) for ten pairs of catchments.

4. ENGINEERING EDUCATION ASPECTS

Statistical hydrologic teaching and learning have been examined by several authors. For example, Rahman et al. (2018) and Kelleher et al. (2024) advocated a blended learning approach. The first author of the paper adopted a project-based learning to learn statistical hydrology where she has been analyzing flood and catchment characteristics data from over 100 catchments in NSW. She is using Excel and R program to check and analyze the flood and catchment data. She is getting hands-on experience on RFFA model building and testing from her supervisory panel. The main challenges being faced by the first author include (i) learning basic hydrological terms related to RFFA research; (ii) understanding catchment characteristics that affect flood generation; (iii) understanding assumptions related to RFFA; (iv) learning computer programming in R to analyze a large set of hydrological data; and (v) learning research writing.

5. CONCLUSION

This study illustrates scaling behavior of the peak discharge in 20 catchments within the state of NSW. It shows that the scaling exponent "a" is widely different (-1.5 to 2.12) despite the assumption that it should be within 0.7 and 0.8. This initial finding needs to be tested using a larger data set across Australia. The first author of the paper is learning statistical hydrology using a project-based learning where she has been analyzing a large set of hydrological data to develop and test alternative RFFA models. Future study will focus on nested catchment-based scaling study using data from all the Australian states. Also, kriging and regression based approach will be tested using the nested catchment concept in RFFA.

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