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Flood Risk Mapping with Entropy Based Methods

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Abstract. The inevitable effects of global warming on meteorological elements are intensely experienced as hydro-meteorological extremes such as floods and drought. While dealing with the destructive consequences of climate change today, accurate evaluation of hydrological data and future forecasts are becoming more vital in making the most efficient decisions for the safety of the environment and living things, as well as the management of water resources. Using long-term precipitation data from 37 meteorological stations in the Gediz Basin, the intensity variability index (IVI), based on intensity entropy (IE), has been used to quantify the variability in observed precipitation. Following the definition of precipitation variations by indices, the regions that could get excessive amounts of precipitation based on probability were determined using index-based maps created according to these indices. The generated entropy-based maps will be an effective tool in the scope of decision-makers' planning in the fight against climate change and flood risk.

Keywords: Gediz Basin, Variability Index, Entropy, Precipitation.

1 Introduction

The most efficient methods for obtaining information about meteorological processes are observation of hydrological processes, which is one of the most significant issues addressed within the context of water resources management. The complexity and stochasticity of water supply systems make it necessary to deal with uncertainty and variability as the key issues. As a result, determining how to assess the measured data is critical.

In order to evaluate potential water resources and analyze environmental changes, it is essential to investigate long-term time series of hydro-meteorological variables [1,2]. Determining the spatial and temporal characteristics of precipitation is essential to assess the regional impacts of climate change and water resources management [3]. The response of the hydrological cycle to climate change and its impact on the variability and availability of water resources on a regional and global scale can be understood by considering spatial and temporal differences in rainfall regimes [4]. The concept of

entropy, which is defined by "information theory" can be defined as the the amount of information gained ≡ reduction of uncertainty through observations [5]. Theory of Information [6] showed us that entropy is a value that can be determined by knowing or calculating the probability distribution function or probability density function of a random variable given in discrete or discrete or continuous form [7]. In the present study, entropy-based methods chosen to evaluate spatial and temporal variability precipitation data by considering the deficiencies in the datasets and Entropy-based indices were used to make the spatial assessment in a major basin as a whole.

2 Study Area

The presented study is carried out in scope of the Gediz basin within the borders of the Aegean Region. The basin is located in between 38° 04' - 39° 13' north latitudes and 26° 42' - 29° 45' east longitudes, constituting 2.17% of Turkey with a total area of 1,703,394 ha [8]. Within the boundaries of the basin, new stations were opened and some of them were relocated under the responsibility of the State Meteorological Service (TSMS). For these and similar reasons, the data recording start dates of the stations vary. As a result, data were collected from 37 stations belonging to the basin by observing between the year when each station started to serve and 2022. In this study, stations with short-term records were excluded in order to more precisely reflect the basin because long-term precipitation data works better in this context.

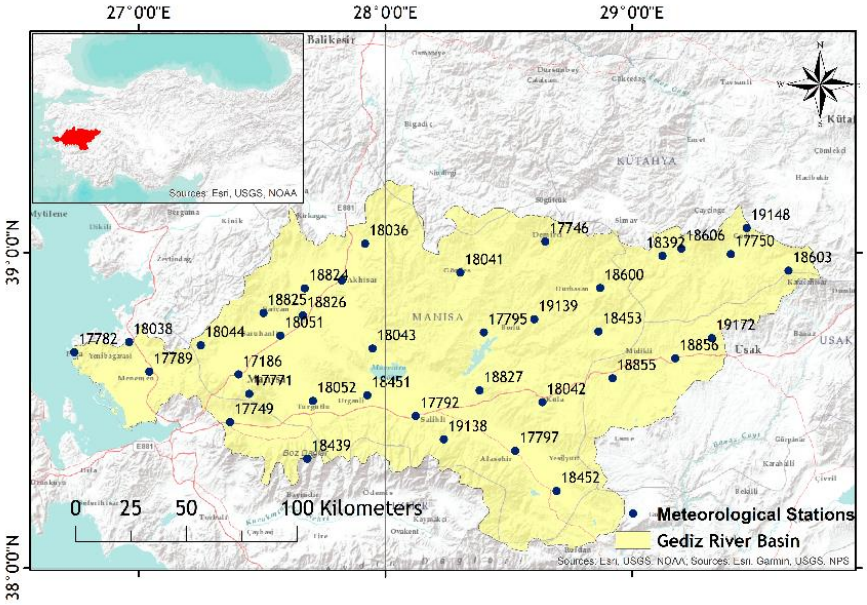


Fig 1. Gediz Basin and the station locations of TSMS.

3 Method

Entropy measures for analysis of precipitation were defined as marginal entropy (ME), intensity entropy (IE), apportionment entropy (AE) and decadal apportionment entropy (DAE) (Mishra et al. 2009). In the presented study, it is aimed to analyze in terms of intensity and the intensity entropy (IE) values are calculated and evaluated by indices.

Index of Variability (IV), calculated by the difference of entropy values from the maximum entropy value, gives information about the variability characteristics of the analyzed time series. The variability will increase as the IV value rises. The variability of a time series is measured using indices based on entropy values computed from annual, seasonal, monthly, or daily time series. Spatial and temporal variability can be compared based on these calculated indices.

The Index of Variability (IV) is defined as the difference between the maximum possible entropy (max H) and the entropy determined from a single time series and is calculated by Equation 1.

$$\mathrm{IV} = (\max H) - H \tag{1}$$

Shannon entropy gets its greatest value when the variable has a uniform distribution. As a result, the range of variation of H is [0, log N]. R is the difference between the random variable's lowest and highest values in the current data set, as represented by Equation 2 [9].

$$maxH = \log(R) \tag{2}$$

It is known as the Intensity Variability Index (IVI) when IV is derived from the intensity entropy, and the higher the IV value (hence the IVI value), the higher the variability is defined.

4 Application

Each station's annual total daily precipitation series is collected and sorted in ascending order. The class range $\Delta x = 3$ was chosen after considering the suggested formulas, and as a result, class number were obtained of minimum 5. The Intensity Entropy method was applied after the frequency analysis of the provided data was finished and the statistical characteristics were obtained considering the temporal and spatial evaluation of the existing long-term precipitation data. IV values were calculated according to equation (1), and maximum entropy values were calculated using equation 2. The intensity entropies and index values calculated on the long-term daily precipitation data of the stations. Table 1 presents the results of the analysis. Figure 2 compares the annual and seasonal IVI values of the basin with each other. Annual analysis of basin shows that the southern part of the basin has high IVI values and therefore high variability. It

is also seen from spring and winter spatial distribution maps that IVI values are at the lowest and therefore uncertainty is higher.

Table 1. Intensity Entropy (IE) and Intensity Variability Indices (IVI) calculated from long-term precipitation data of The Gediz Basin

		Autumn		Winter		Spring		Summer		Annual	
ID	Station Name	IE	IVI	IE	IVI	IE	IVI	IE	IVI	IE	IVI
17750	Gediz	1.98	4.17	2.36	3.81	2.19	3.36	1.52	4.40	2.10	4.07
18392	Pazarlar	1.42	3.67	1.94	3.78	1.68	3.49	1.35	3.38	1.62	4.09
17184	Akhisar	2.39	3.80	2.93	4.25	2.46	3.99	1.26	4.49	2.50	4.68
18036	Akhisar/Karaköy	1.01	4.92	2.01	4.23	1.50	3.88	0.73	5.40	1.35	4.89
17186	Manisa	2.51	4.33	3.09	4.26	2.55	3.95	1.32	4.47	2.64	4.71
17746	Demirci	1.64	4.21	2.47	3.38	2.12	3.57	1.17	4.48	1.94	3.92
17771	Şehzadeler/Spil	1.45	5.09	2.66	3.90	1.82	4.22	0.79	4.87	1.75	4.81
17792	Salihli	2.06	3.86	2.64	3.51	2.25	3.60	1.26	4.84	2.23	3.93
17795	Köprübaşı	1.25	4.32	1.86	3.96	1.56	3.51	0.96	4.46	1.44	4.38
17797	Alaşehir	1.06	4.84	1.64	3.99	1.39	4.11	0.72	4.73	1.24	4.65
18041	Gördes	1.06	4.82	1.85	4.21	1.55	3.48	0.90	4.80	1.38	4.68
18042	Kula	0.96	4.45	1.80	3.71	1.54	3.49	0.90	4.80	1.35	4.71
18043	Gölmarmara	0.98	4.44	1.83	4.34	1.41	3.91	0.74	5.02	1.28	4.88
18044	Yunusemre/Çakmak	1.10	4.07	2.07	3.98	1.50	3.43	0.66	4.19	1.38	4.67
18052	Turgutlu	1.19	4.28	2.12	4.12	1.49	3.77	0.66	5.38	1.46	4.78
18451	Ahmetli	1.11	4.31	1.83	4.49	1.49	3.34	1.21	3.32	1.45	4.88
18452	Sarıgöl	0.92	5.62	1.66	4.15	1.39	3.19	0.88	4.61	1.25	5.29
18453	Selendi	1.22	4.45	1.84	4.37	1.70	3.65	1.45	4.50	1.58	4.62
17749	Kemalpaşa	1.15	4.78	2.28	4.48	1.50	4.02	0.64	4.78	1.47	5.30
18439	Kemalpasa/Ovacık	1.23	4.90	2.52	4.46	1.73	4.57	0.84	5.03	1.65	5.33
17782	Foça Toprak Su	1.06	5.37	2.12	3.81	1.32	4.45	0.34	3.52	1.30	5.13
17789	Menemen	1.06	5.49	2.05	4.25	1.34	4.38	0.37	5.18	1.28	5.27
18603	Gediz/Murat Dağı	1.28	3.78	1.88	3.81	1.54	3.91	1.21	4.45	1.50	4.19
18606	Şaphane	1.24	3.68	1.82	3.80	1.55	3.48	1.32	3.06	1.51	4.11
19148	Gediz/Yaylaköy	1.02	3.56	1.53	2.68	1.41	3.24	1.29	4.15	1.35	4.08
18855	Eşme/Delibaşlı	0.91	4.45	1.62	3.17	1.48	3.25	0.95	4.05	1.29	4.07
18856	Uşak Tekstil OSB	0.92	4.09	1.68	3.25	1.56	3.05	1.05	3.98	1.36	3.66
19172	Uşak/Selvioğlu	1.01	4.39	1.75	3.31	1.61	3.25	1.08	3.87	1.41	3.99
18824	Akhisar/Mecidiye	0.99	5.08	1.94	4.46	1.31	3.75	0.65	3.85	1.28	5.11
19139	Demirci/İçikler	0.90	3.46	1.70	3.14	1.44	3.24	0.94	3.56	1.29	3.56
18827	Salihli/İğdecik	0.94	4.69	1.77	3.46	1.43	3.28	0.72	4.04	1.27	4.36
19138	Salihli/Çalkadoğanlar	0.93	3.62	1.94	4.37	1.32	3.47	0.77	4.29	1.31	5.00
18051	Saruhanlı	1.06	4.53	2.00	4.35	1.47	3.77	0.71	5.04	1.38	4.97
18825	Saruhanlı/Sarıçam	0.91	4.61	1.98	3.95	1.27	4.43	0.65	3.34	1.27	4.46
18826	Saruhanlı/Tirkeş	1.01	4.72	1.95	4.21	1.32	3.76	0.64	4.42	1.29	4.88
18600	Selendi/Tavak	1.04	4.51	1.70	3.87	1.52	3.53	1.08	3.98	1.37	4.20
18038	Aliağa/Bozköy	1.03	4.90	2.13	3.91	1.35	4.01	0.47	4.48	1.31	4.72

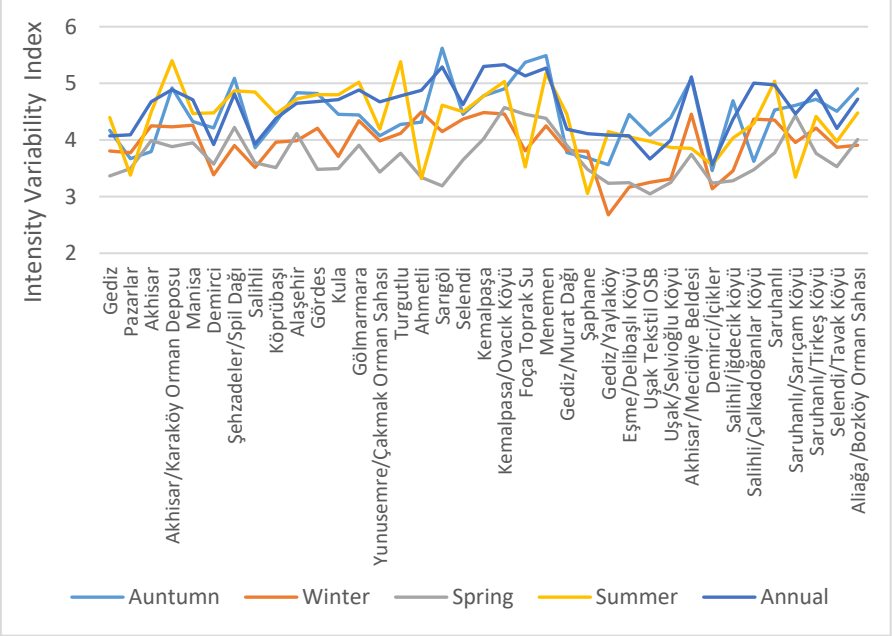


Fig 2. Comparison of Intensity Variability Indices (IVI) between annual and seasonal time series in the Gediz Basin

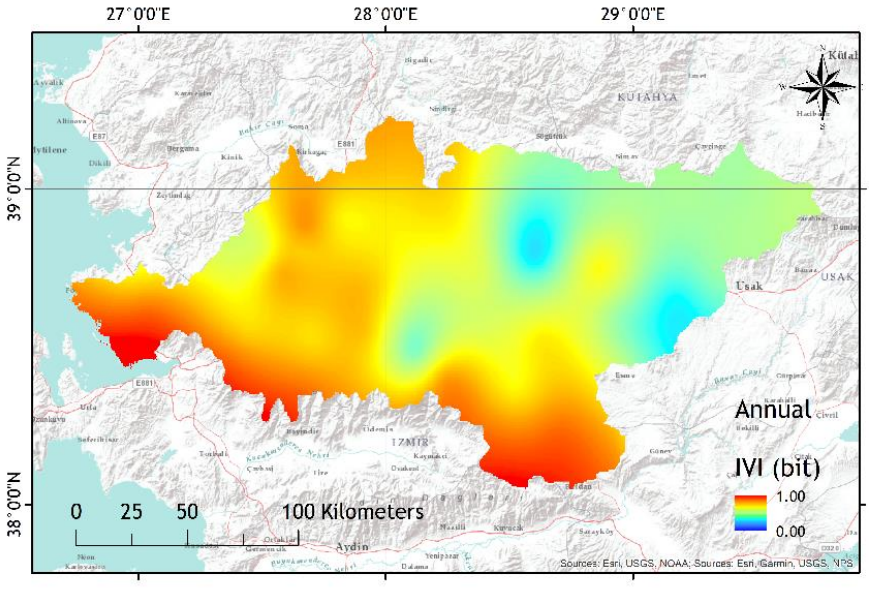
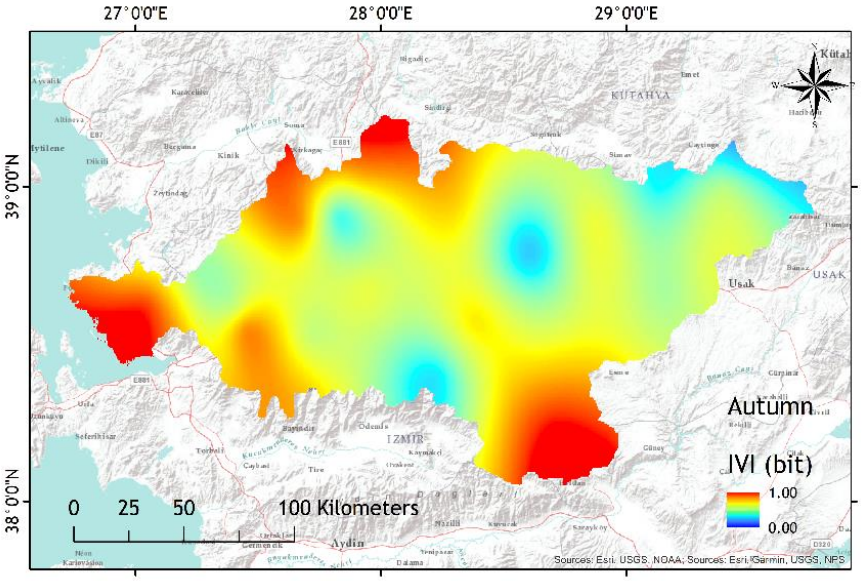
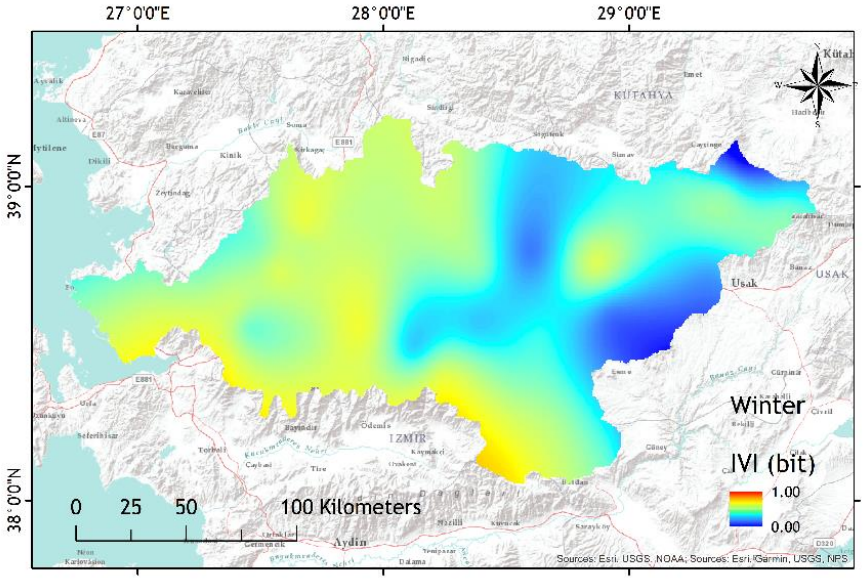


Fig. 3. Spatial distribution of Intensity Variability Indices (IVI) of precipitation time series in the Gediz Basin - Annual

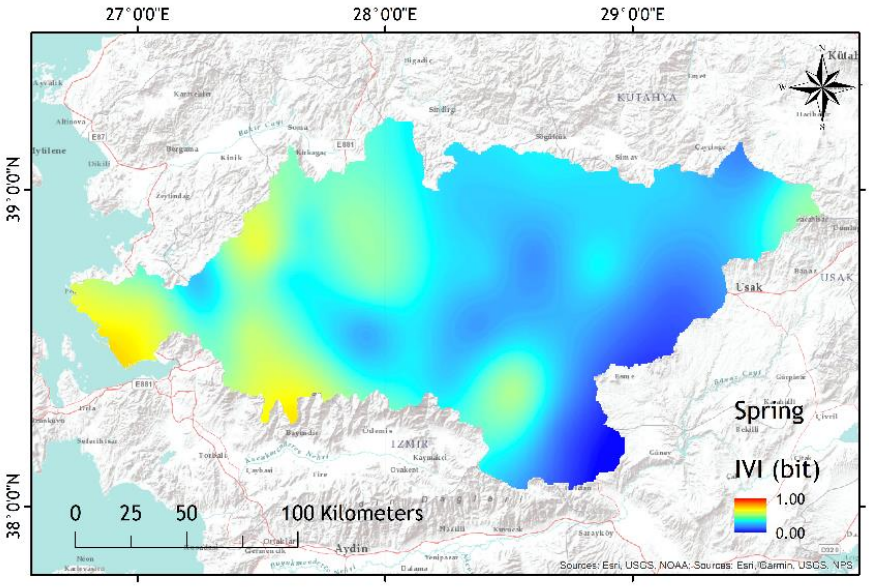


(a)

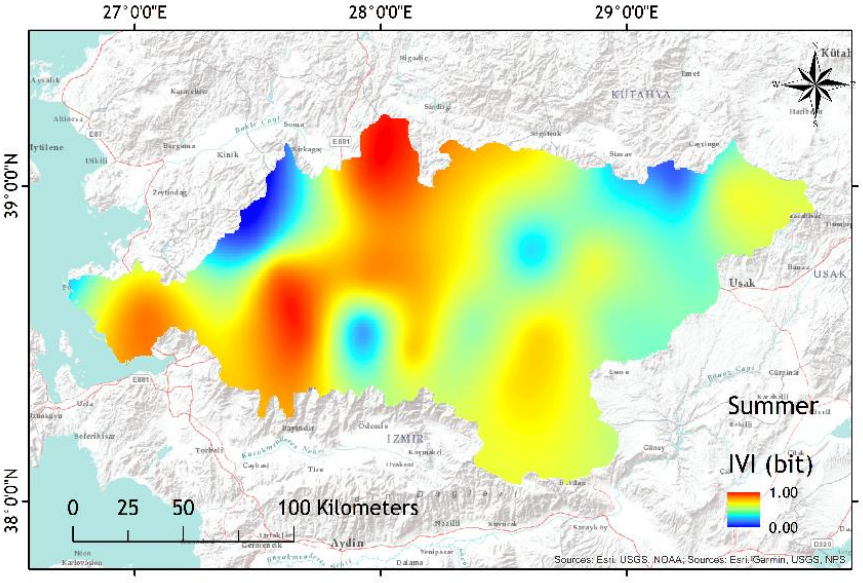


(b)

Fig. 4. Spatial distribution of Intensity Variability Indices (IVI) of precipitation time series in the Gediz Basin; (a) Autumn; (b) Winter



(a)



(b)

Fig. 5. Spatial distribution of Intensity Variability Indices (IVI) of precipitation time series in the Gediz Basin; (a) Spring; (b) Summer

5 Results and Concluding Remarks

In scope of the study, the whole basin is analyzed annually and seasonally, and a regional analysis is performed to create risk maps throughout the basin. In regions at risk for hazard, areas with high precipitation variability can be detected, and timely action plans can be developed. The precipitation variability profile in the region will have a significant influence in both present and future river basin management decisions, preventing construction in potentially dangerous locations and managing agricultural processes. The entropy-based maps obtained will be an effective instrument for researchers and policymakers dealing with climate change and flood risk.

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