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Wet and dry spell feature charts for practical uses

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Abstract

Water resources management is dependent on wet and dry spells occurrences in an alternative manner. Therefore, information about their probabilistic occurrence frequencies and statistical parameters are the most required quantities for optimum and well-balanced operations for water demand. Among the most important dry spells are the meteorological (precipitation) and hydrological (runoff, stream flow, reservoir level, ground water level, etc.) drought occurrences and their future expectations under a certain level of risk (exceedance probability) or return period, which is the inverse of the risk. Firstly, this paper presents detection of wet and dry spell parameters among which are the duration, maximum surplus or deficit, magnitude, and intensity. Secondly, a set of *beneficial* charts is presented in the new graphical form for each dry (wet) spell characteristic versus different risk levels (0.50, 0.20, 0.10, 0.04 0.02, 0.01, 0.004 and 0.002) corresponding to return periods (2-year, 5-year, 10-year, 25-year, 50-year, 100-year, 250-year and 500-year). These applications of the methodology are presented for New Jersey Statewide annual precipitation and Danube River annual discharge records each with more than 100 years records. Finally, it is found that the mathematical relationship between each wet and dry spell parameter and the return periods abide with exponential function, which appears on semi-logarithmic papers as straight lines. Consequently, it can be generalized for the study area that any drought (wet) parameters variation with the return period appears as exponential function for hydro-meteorological records.

Keywords Dry (wet) spell · Drought · Duration · Intensity · Magnitude · Return period · Risk

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1 Introduction

There are many methodological approaches for reduction of the flood (wet spell) and drought (dry spell) effects scientifically to a certain extent, but nature continues to break records, especially coupled with the global warming and climate change impacts due to the greenhouse gas (GHG) emissions into the atmosphere. These instances of breaking records are rather rare, but continuously expected in the hydro-meteorological data, and especially, in their reflections in the future due to the anthropogenic activities. On the other hand, flood and drought occurrences may inflict the society in short time as consequences of meteorological events and comparatively long time due to climate change impact. There are various researches on dry and wet spell methodologies in scientific disciplines, Yu et al. (2019) and Ojara et al. (2020).

In characterizing a drought, it is critical to recognize conceptual and operational definitions (Wilhite and Glantz 1987). The same identification is feasible for wet spell. The early drought definitions started conceptually by considering droughts as either long period of dry spell or amount of hydro-meteorological record to be lower than an assigned level. Conceptual drought definitions do not depend on the whole-time series of hydro-meteorological record, but commonly used simple definitions about drought have described either based on time a specific duration or variable amount with reference to a base level. These definitions are rather subjective and cannot be applied universally. For instance, in their textbook, (Linsely et al. 1959) stated that a drought is a sustained period without significant rainfall.

On the other hand, the first quantitative drought calculations appeared in the probability and statistics domains for operationally assessment. For example, Gumbel (1963), based on the streamflow records, wrote that a drought is the smallest annual value of daily streamflow. Subsequently, Palmer (1965) considered a drought as a significant deviation from the normal hydrologic conditions of an area. Yevjevich (1967) is also one of the first researchers, who mentioned that there are various drought definitions, which make drought research uniformity rather distinctive from each other. He suggested droughts based on a time series record and a truncation level, which separated the whole record into wet (surplus) and dry (deficit) spells. This was operational type of drought assessment including identification of drought duration, severity, magnitude, and intensity. Only, operationally defined droughts provide useful numerical information about drought risk concerning its duration, magnitude, and intensity. This point has been emphasized by (Mishra and Singh 2010) in their review article. Dabanli et al. (2017) also investigated southern oscillation and drought relationship in recent temporal research. Yevjevich's definition has stimulated researchers further for probabilistically, statistically, simulationally and analytically methodologies and numerous authors have contributed to drought analyses among whom are Green (1970), Şen (1976), Dracup et al. (1980), Alyamani and Sen (1997), Şen and Boken (2005), Şen et al. (2017), Li et al. (2017), Almazroui and Islam (2019) and Şişman (2019).

A high number of various methods such as drought indices among which Standardized Precipitation Index (SPI) (McKee et al. 1993), Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al. 2010) and Multivariate Standardized Drought Index (MSDI) Hao and AghaKouchak (2013), and Severity Duration and Frequency (SDF) curves have been developed for drought assessment by Dalezios et al. (2000), Çetin et al. (2018) and Çavuş and Aksoy (2019). SPI has the advantage among them due to the requiring only precipitation data for calculations and can be compared between regions with different climatic zones (Zhang et al. 2017; Faiz et al. 2018; Bhunia et al. 2020).

The main purpose of this paper is to provide dry (wet) spell future assessments based on dry (wet) spell components such as drought (wet) duration, maximum deficit (surplus), drought (wet) magnitude and intensity of drought (wet). To this end, the drought (wet) model charts for practical uses are developed and the mathematical relationships between the return period and each dry (wet) spell components have been represented. A case study on the hydro-meteorological records has been applied to show the overall results of the proposed methodology.

2 Basic concepts, definitions and methodology

There are different methodological assessment ways for the future performances of hydro-meteorological records that are dependent on the historical behaviors. Although, the historical records of any hydro-meteorological record may be extended to future periods, as for the wet and dry spells are concerned, they occur rather independently from each other and hence, the probabilistic and statistical methods are sufficient for their future behavior predictions. Figure 1 represents dry spell components of hydro-meteorological record with a truncation level, which may correspond to any practically significant level such as water demand or some statistical quantity such as the arithmetic average or its percentages.

1. In this figure only dry spell components are shown, which are the drought duration, D_D, maximum deficit, M_D, drought magnitude, D_M and intensity of drought, I_D in Figs. 1a-d, respectively. The geometrical description in Fig. 1 can be expressed in sequence linguistically for each component as follows. Drought duration, D_D: It may not be possible to express by single mathematical equation, but it is the time period between a down-crossing and up-crossing instances on the truncation level as shown in Fig. 1a. For instance, in the figure there are 8 dry spells with different drought durations. Hence, drought durations have a rather random appearance, and therefore, their treatment is possible through the probabilistic and statistical methodologies,
2. Maximum deficit, M_D: There is only one such a quantity within each dry spell, which is equal to the maximum deficit as shown in Fig. 1b. The sequence of maximum deficits also abides with uncertainty in a random fashion,
3. Drought magnitude, D_M: This is equal to the successive summation of the deficits during each dry spell as shown in Fig. 1c. It is the quantity that shows the total deficit during any dry spell,
4. Intensity of drought, I_D: It is the ratio of drought magnitude to drought duration, and hence, indicates the uniform amount of deficit during each dry spell. It is the amount of deficit per time unit (day, month, or year).

After the information about the linguistically interpretation of dry spell component, one can write a computer program as a simple software that takes into consideration all these four steps leading to their numerical calculations. After the extraction of four dry spell components' numerical sequences on a given record with truncation level as shown in Fig. 1, one can then exploit probabilistic and statistical features of each component in order to reach at dry (wet) spell characteristic charts including meaningful descriptions depending on risk levels that are useable in practical applications. The following steps are also necessary for construction of these charts.

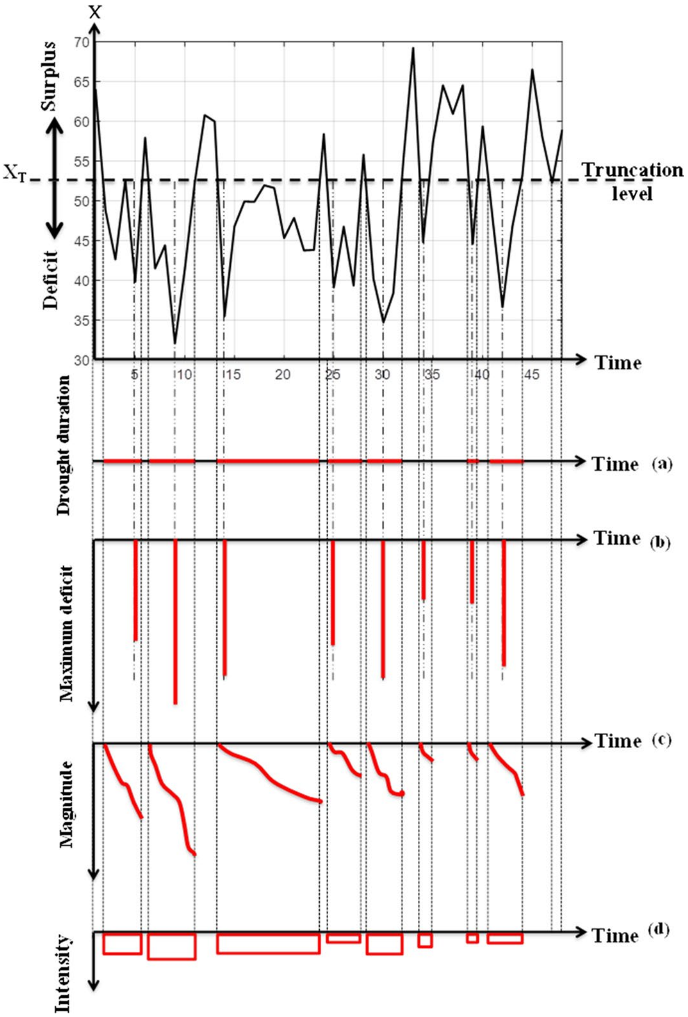


Fig. 1 Wet and dry spell components

- First, sort each dry spell component in ascending order, for instance, D_{D1}, D_{D2}, …, D_{Dn} where D_{D1} is the minimum drought duration, D_{DN} is the maximum drought duration and n is the number of dry spell time period,
- Secondly, each value in ascending series is numbered as $m=1, 2, \ldots, n$, where m is the position in the sorted sequence, for instance, $m=1$ is the smallest position,
- The exceedance probability of dry (wet) spell components in ranked series is determined with the following equation, $0<P_m<1$

$$P_m = \frac{m}{n+1} \tag{1}$$

- The dry (wet) spell components scattering graph for components such as drought duration, maximum deficit, etc. versus the probability is obtained.

Fig. 2 Location map of New Jersey and Danube River Basin

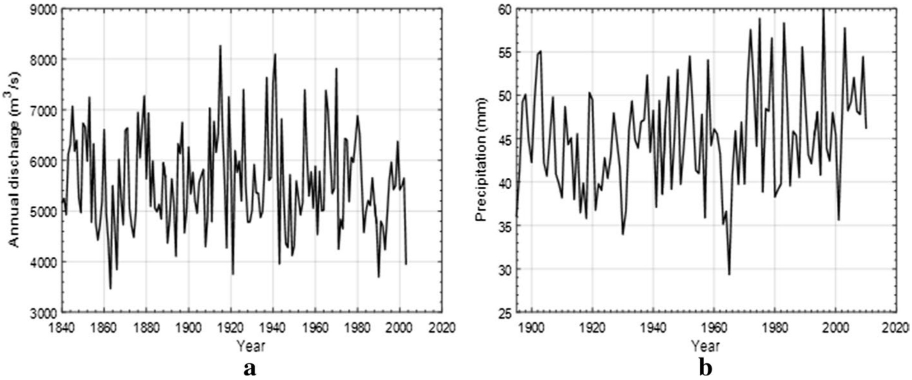


Fig. 3 Time series, **a** Danube River discharges, **b** New Jersey Statewide precipitation

- Finally, the best theoretical PDF among a set of functions Weibull, Pearson, Gamma, Log-normal are matched to the scatter points using the least squares methodologies.

Since the theoretical PDF is now available, one can make future predictions not on real-time trend basis but on different future risk levels as will be explained in the case study section of this paper. A set of practically useable return periods are considered as 2-year, 5-year, 10-year, 25-year, 50-year, 100-year, 250-year and 500-year with their corresponding risk levels (exceedance probabilities) as 0.50, 0.20, 0.10, 0.04, 0.02, 0.01, 0.004 and 0.002, respectively.

3 Results and discussion

The explanations in the previous section are applied to two more than 100-year record sites, which are the Danube River annual average discharge measurements at Orshava station in Romania with records from 1840 up to 2003. Another very long record location is the New Jersey Statewide annual average precipitation records from 1895 to 2010 in USA. The locations of each region are shown in Fig. 2. The time series of records at these stations are presented in Fig. 3.

In the planning of water structures and future projections regarding water resources, the aforementioned recurrence intervals (return period) are generally taken into account. Figure 4 indicates the dry spell components of Danube River discharge records including their values corresponding to risk levels. In general, Weibull PDF has emerged as the most suitable model for the exceedance probability variation against drought duration, maximum deficit, drought magnitude and intensity variables for Danube River discharge records. These graphs provide dry components characterization for identified return periods. In other words, if the return period is given, then one can obtain the values of dry spell components.

The model for Danube River shows that in the 100-year return period, the longest possible dry spell (drought) duration that may occur will be 6.49 years (see Fig. 4a). The maximum deficit that can be seen in any 1 year during this period is estimated as 2333 m^3/s. Successive summation of the deficits predictions has been calculated similarly for the same return period time. According to the model results presented in Fig. 4c, the maximum drought magnitude value has been determined as 6170 m^3/s for 100 years return period time. Finally, the largest drought intensity value for the 100-year return period was determined as 1840 $m^3/s/year$ (see Fig. 4d).

As for the drought components of New Jersey Statewide annual precipitation record in Fig. 5 presents each one of them. For the New Jersey Statewide annual precipitation record, drought duration abides with the Weibull PDF, whereas all the other three

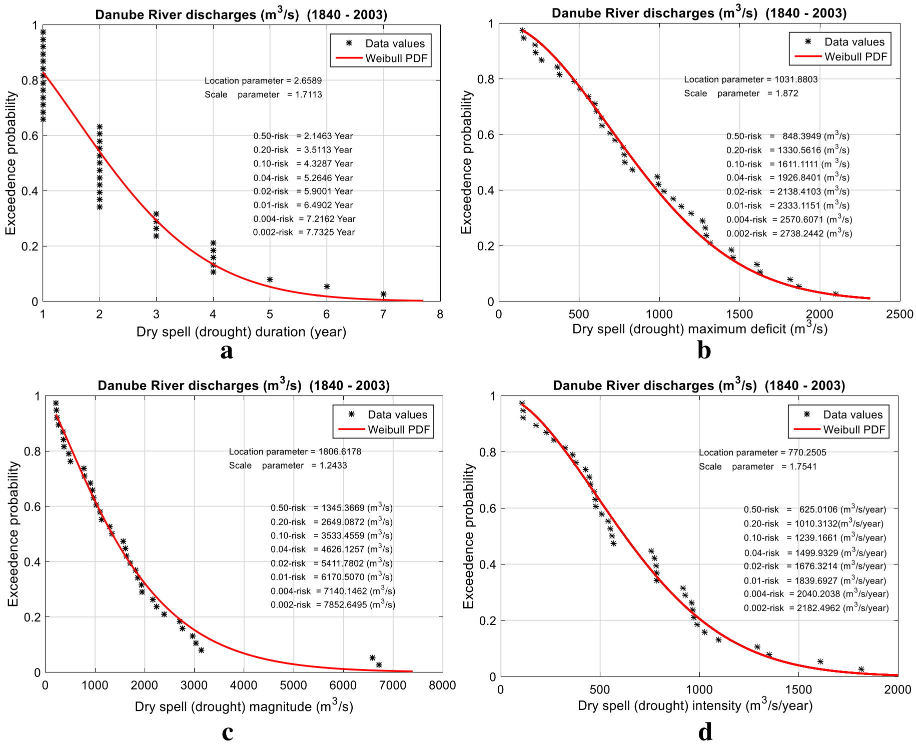


Fig. 4 Dry spell components of Danube River **a** drought duration, **b** maximum deficit, **c** drought magnitude, **d** drought intensity

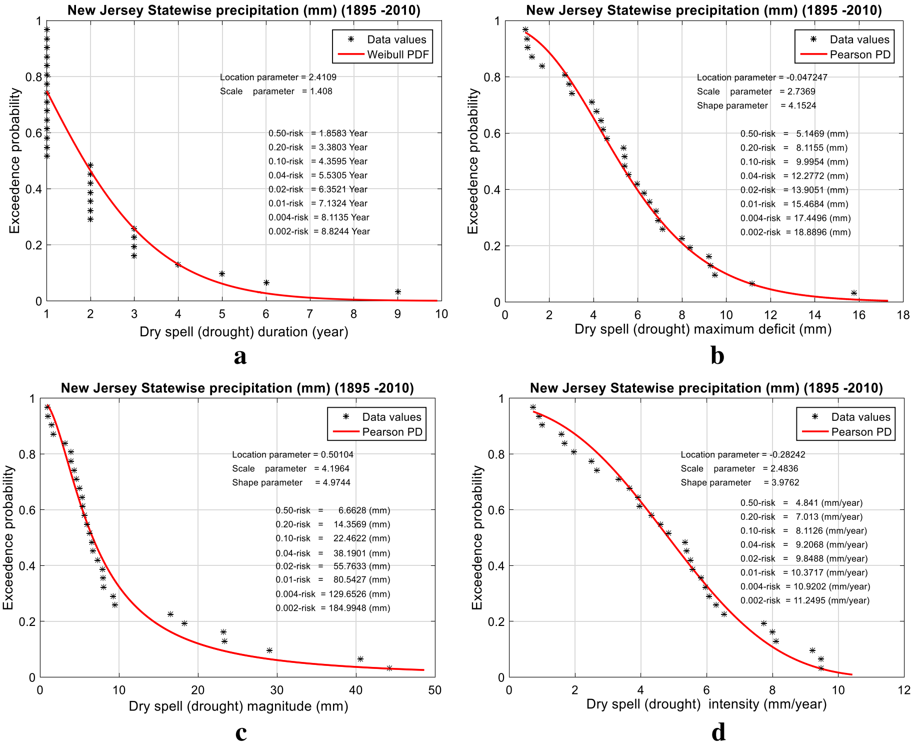


Fig. 5 Dry spell components of New Jersey Statewide **a** drought duration, **b** maximum deficit, **c** drought magnitude, **d** drought intensity

drought components appear to match with three-parameter Gamma PDF, which is referred to in the literature also as the Pearson PDF.

The collective numerical values of different wet and dry spell components are presented in Table 1. The drought (wet) spell components of Danube River and New Jersey Statewide data are evaluated for risk level (return period) identifications. It is noticed that the drought (wet) period duration expectation occurs close to each other for the same return period in Danube River. On the other hand, New Jersey Statewide' drought duration for the same periods are longer than wet duration. Particularly, this situation is clearly seen in return periods of 25–50–100–250–500 years.

If the model results are evaluated in terms of drought maximum deficit and wet spell maximum surplus, it is expected that the floods will be more important compared to the drought that will occur with the same risk levels in any year. For instance, while the drought maximum deficit is 2333 m^3/s, wet spell maximum surplus is 9973 m^3/s, which is possible in any year for 100-year return period. If the New Jersey Statewide drought maximum deficit and wet spell maximum surplus models is evaluated, it will be determined that the wet spell values calculated for the same risk are significantly higher than the dry spells. This result shows the importance of floods that may occur due to climate change effect for the region. For example, while the wet spell maximum surplus value is 25.95 mm, drought maximum deficit value is 12.27 mm for 25-year return period.

Table 1 Wet and dry spell component values versus risk levels

Spell type	Location	Return period (year)							
		2-year	5-year	10-year	25-year	50-year	100-year	250-year	500-year
		Risk level (exceedance probability)							
		0.50	0.20	0.10	0.04	0.02	0.01	0.004	0.002
Dry	Danube River	Drought duration (year)							
		2.00	3.51	4.32	5.26	5.90	6.49	7.21	7.73
		Drought maximum deficit (m^3/s)							
		848	1331	1611	1927	2138	2333	2571	2738
		Drought magnitude (m^3/s)							
		1345	2649	3534	4626	5412	6170	7140	7853
		Drought intensity (m^3/s/year)							
		625	1010	1239	1500	1676	1840	2040	2182
	New Jersey Statewide	Drought duration (year)							
		1.85	3.38	4.35	5.53	6.35	7.13	8.11	8.82
		Drought maximum deficit (mm)							
		5.14	8.11	9.99	12.27	13.90	15.46	17.44	18.88
		Drought magnitude (mm)							
		6.66	14.35	22.46	38.19	55.76	80.54	129.65	184.99
		Drought intensity (mm/year)							
		4.84	7.01	8.11	9.21	9.85	10.37	10.92	11.25
Wet	Danube River	Wet spell duration (year)							
		1.78	3.24	4.17	5.28	6.06	6.80	7.73	8.41
		Wet spell maximum surplus (m^3/s)							
		625	1490	2155	3043	3720	4401	5306	5993
		Wet spell magnitude (m^3/s)							
		908	2781	4357	6543	8244	9973	12,288	14,058
		Wet spell intensity (m^3/s/year)							
		504	1111	1555	2129	2557	2980	3532	3947
	New Jersey Statewide	Wet spell duration (year)							
		1.86	2.47	2.73	2.98	3.12	3.24	3.37	3.45
		Wet spell maximum surplus (mm)							
		5.76	13.13	18.66	25.95	31.46	36.95	44.21	49.70
		Wet spell magnitude (mm)							
		4.70	9.29	12.42	16.29	19.08	21.78	25.23	27.76
		Wet spell intensity (mm/year)							
		3.53	7.15	9.65	12.77	15.03	17.23	20.06	22.14

The graphs and their values in Figs. 4 and 5 can be converted to more practical uses into a set of other graphs as shown in Figs. 6 and 7 for Danube River discharge and New Jersey Statewide precipitation records, respectively. It is observed that each one yields to a straight-line on a semi-logarithmic paper with return periods on the logarithmic horizontal axis. The longest drought and wet spell duration expectation times are close to each other in the same return period for Danube River according to the model presented in Fig. 6a.

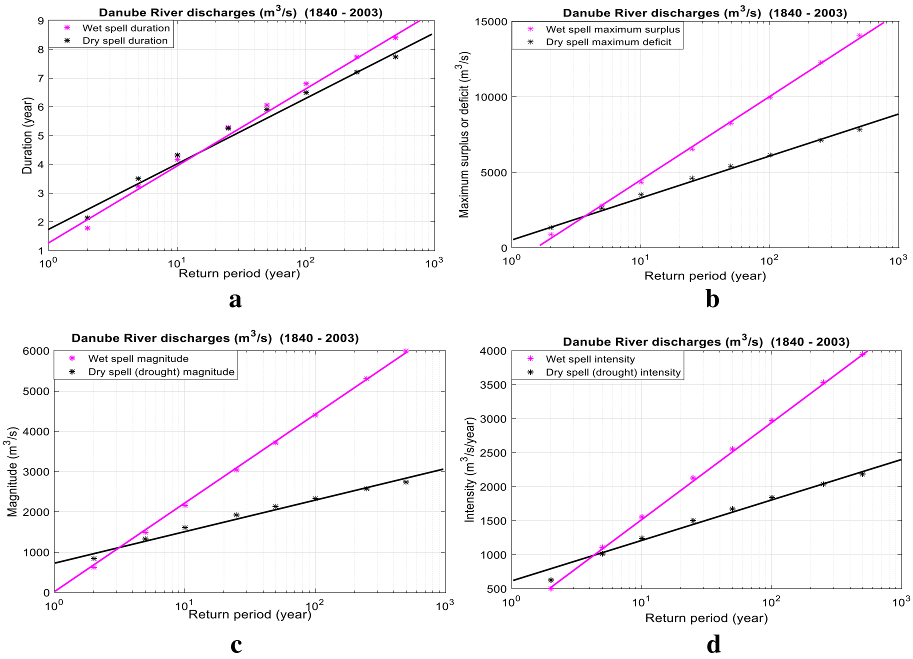


Fig. 6 Danube River discharge **a** drought duration, **b** maximum deficit, **c** drought magnitude, **d** drought intensity

It was observed that the value of drought (wet spell) characteristics such as maximum deficit (surplus), magnitude and intensity are closed to each other in short return period times. However, as the return periods increase, the wet spell values are much larger for drought spell in Fig. 5. Similar comments can be derived from New Jersey model graphs in Fig. 7.

The mathematical expression between the return period, *R*, and one of the wet or dry spell component is represented by, *C*, in which has a semi-logarithmic form as,

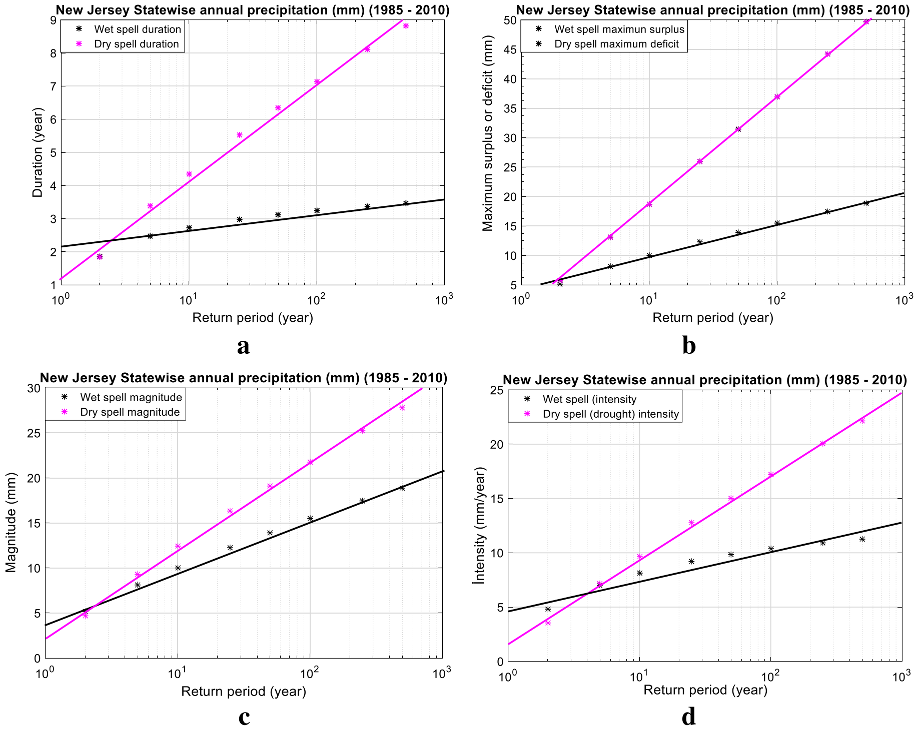
$$C = a + b \ln (R) \tag{2}$$

This can also be written in terms of the return period as a subject as follows.

$$R = \exp\left(\frac{C-a}{b}\right) \tag{3}$$

In these expressions, *b* is the slope of the straight lines on semi-logarithmic paper as in Figs. 6 and 7. The other constant, *a*, refers to intercept on the horizontal axis. On the semi-logarithmic paper, the slope can be calculated simply as the difference on the vertical axis corresponding to one cycle on the horizontal axis. The parameter estimations of each chart are given in Table 2 for wet and dry spell cases both in the Danube River and New Jersey State locations.

Last but not the least, after all what have been explained in this paper, a useful discussion for future recommendations is to incorporate climate change impact quantitatively on wet and dry spell return period calculations. In the classical return period assessments,



a **b** **c** **d**

Fig. 7 New Jersey Statewide precipitation **a** drought duration, **b** maximum deficit, **c** drought magnitude, **d** drought intensity

Table 2 Exponential model coefficients

Location	Spell type	Components	*a*	*b*
Danube river	Dry spell	Drought duration (year)	1.25	2.75
		Drought maximum deficit (m^3/s)	– 500	5500
		Drought magnitude (m^3/s)	0.00	2207
		Drought intensity ($m^3/s/year$)	50.00	1450
	Wet spell	Wet spell duration (year)	1.75	2.35
		Wet spell maximum surplus (m^3/s)	500	3600
		Wet spell magnitude (m^3/s)	780	795
		Wet spell intensity ($m^3/s/year$)	600	615
New Jersey State	Dry spell	Drought duration (year)	1.24	2.88
		Drought maximum deficit (mm)	0.65	19.40
		Drought magnitude (mm)	2.10	9.95
		Drought intensity (mm/year)	1.6	7.70
	Wet spell	Wet spell duration (year)	2.20	0.50
		Wet spell maximum surplus (mm)	3.15	5.95
		Wet spell magnitude (mm)	3.80	5.65
		Wet spell intensity (mm/year)	4.50	2.50

climate change trend slopes are not taken into consideration at all. Hence, the return period is considered as the reverse of risk level (Mishra and Singh 2010). For instance, if the risk level is $R = 0.01$ then its reverse as the return period is $T = 1/R = 100$-year. Mohorji et al. (2017) have suggested inclusion of the climate change trend slope in the calculation of the return period. Logically, increase in the precipitation and discharge record trends causes to more dangerous risky cases. It is recommended in this paper that in the future the trend slopes should be incorporated in the drought duration, intensity and magnitude calculations.

4 Conclusion

In this paper, wet and dry spell parameters (duration, maximum deficit, magnitude, and intensity) are analyzed based on two study areas, namely Danube River annual discharges and New Jersey Statewise annual precipitation records. A set of risk charts is presented in the new graphical form for each dry (wet) spell characteristic versus different return periods (risks) as 2-year (0.50 risk), 5-year (0.20 risk), 10-year (0.10 risk), 25-year (0.04 risk), 50-year (0.02 risk), 100-year (0.01 risk), 250-year (0.004 risk), and 500-year (0.002 risk). The reflection of the figure representations is given in a table form for practical uses. It is observed that the mathematical relationship between each wet and dry spell parameter and the return period abide with exponential functions, which appear as a straight-line on a semi-logarithmic paper. The necessary slope and intercept parameters are also provided for the study records. Consequently, this method can provide useful guidance to any drought (wet) parameters variation assessment study according to exponential function model for hydro-meteorological records.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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