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Determination of Markov Chain Transition Probabilities for Daily Rainfall Data in Jordan

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Abstract

This study aims to determine Markov chain transition probabilities for daily rainfall data of 39 meteorological stations across Jordan. Two states were imposed to the chains, namely dry and wet, and first order was used as the dependence structure. This leads to four transition probabilities for each station in each month, namely dry-to-dry (p_{dd}), dry-to-wet (p_{dw}), wet-to-dry (p_{wd}), and wet-to-wet (p_{ww}). In the end of the study, it is concluded that $p_{dd} > p_{dw}$ for all stations in all months, and $p_{ww} \geq p_{wd}$ in only 15.1% of the times, which are concentrated in the middle of the rainy season (i.e., December–March) at North of Jordan. Also, all months tend to be dry in the long term, especially October, November, April, and May. Most of the expected dry spell lengths range from 5 to 100 days, while the expected wet spell lengths range mostly from 1 to 2 days, which indicates the tendency of the Jordanian weather to be dry across the country.

Keywords: rainfall; daily rainfall ;Markov chain; transition probabilities; equilibrium probabilities; spell lengths;Jordan.

1. Introduction

1.1. Overview

Markov chain is widely used in the prediction of the occurrence of daily rainfall events on the basis of past observed data. It can be applied in different orders depending on the temporal extent of the effect of the state of a certain day. Zero-order Markov chain assumes no dependence in the states of the days along the rainfall sequence. First-order means that the state of a day is affected by the state of one preceding day. Second-order means that the state of a day is affected by the state of two preceding days, and so on. First order is a convenient choice to use in modeling rainfall [1, 2, 3, 4, 5, 6, 7, 8, 9, 10] [11, 12, 13, 14, 15, 16, 17].

Different resolutions of rainfall can be simulated in a Markov chain, e.g., seasonal, monthly, daily, or hourly. Simulation of daily rainfall is commonly used and sufficiently useful for hydrological and agricultural applications [3, 18, 5, 6, 19, 10, 20, 11, 12, 21] [22, 23, 13, 24, 14, 15, 16, 17].

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In a Markov chain, rainfall volumes are classified into states. Two states of dry and wet is a commonly selected choice in rainfall modeling, where dry refers to days of precipitation lower than or equal a small number (e.g., zero or 0.1 mm) and wet refers to days of precipitation amounts greater than that number [1, 2, 3, 18, 25, 4, 26, 10, 20, 11] [12, 21, 22, 23, 13, 24, 14, 15, 16, 17]. Depending on the observed data, the probability of each state to be followed by a certain state is calculated. These probabilities are called transition probabilities since they describe the probability of the transition from a state to a state. Transition probabilities are put in a matrix called transition probability matrix. For instance, for a two-state Markov chain, the probability matrix includes dry-to-dry, dry-to-wet, wet-to-dry, and wet-to-wet transition probabilities (i.e., p_{dd}, p_{dw}, p_{wd}, and p_{ww}, respectively). From this matrix can the weather tendency be concluded whether it is more to the dry or to the wet state.

However, Markov chain behaves poorly in long dry spells and when variations in seasonal trends of rainfall exist. Consequently, researchers have developed several improvements to Markov chain in order to handle these limitations [1, 2, 4, 7, 20, 11, 22, 13, 24]. These improvements are out of the scope of this paper.

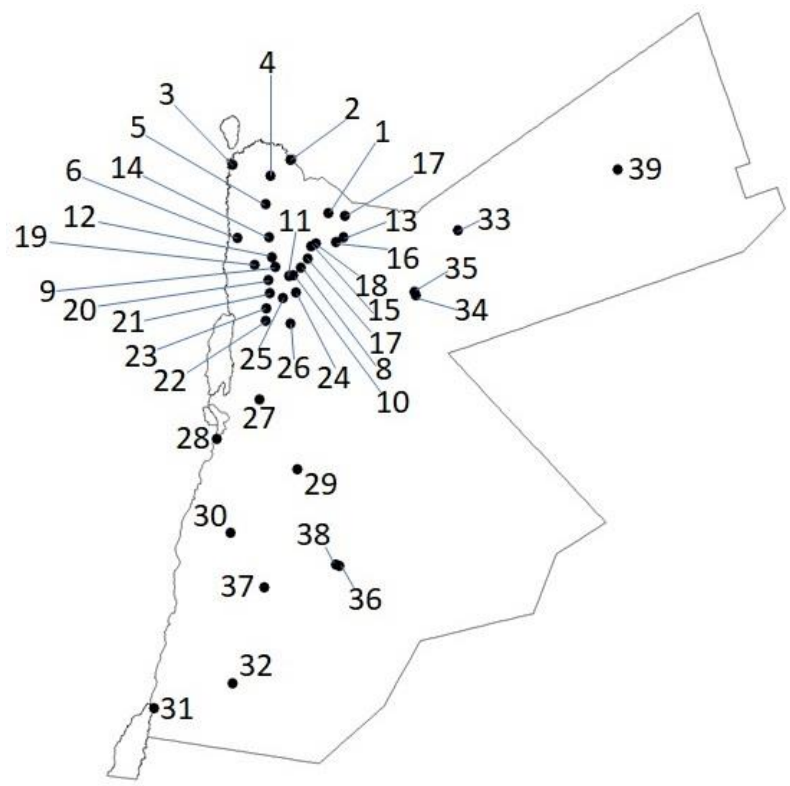
1.2. Study area

This study includes 39 rainfall stations across Jordan, of which the IDs, names and locations are shown in Figure 1. As a summary of their descriptive information, the years of record of the stations range from 22 to 78 years, except one station that has only 9 years of record. In more detail, 15% of the stations have 78 years of record, 33% more than 70, 40% more than 60, and 60% 50 years or more.

All rainfall precipitation records are from October to May, except one record in June for Ras Muneif evaporation station. The number of rainy days in each month. These records are all in October and May, which are the beginning and the end of the rainy season, respectively.

1.3. The significance of the paper

Research in Jordan lacks focus on rainfall stations. One previous research paper was found to study 13 meteorological stations in Jordan [27]. Another paper studied 6 stations [2]. Other research papers were found to study only 3 stations [28, 1]. This paper studies 39 stations across Jordan.



#	ID	Name	#	ID	Name
1	AD0019	Mafraq Airport	21	AN0003	Na'ur
2	AD0021	Turra	22	CC0001	Madaba
3	AD0032	Baqura	23	CC0004	Mushaqqar
4	AE0002	Irbid	24	CD0001	Sahab
5	AH0003	Ras Muneif	25	CD0002	Yaduda
6	AL0010	Deir Alla	26	CD0005	Jiza
7	AL0015	Zarqa	27	CD0010	Rabba
8	AL0016	Ruseifa	28	CF0006	Ghores-Safi
9	AL0018	Jubeiha	29	CF0007	Hasa
10	AL0019	Amman Airport	30	DA0002	Shaubak
11	AL0020	Ain Ghazal	31	ED0001	Aqaba
12	AL0035	Baq'a	32	ED0012	Ram
13	AL0048	Khaldiya	33	F 0002	H5
14	AL0053	King Talal Dam	34	F 0003	Azraq Police Post
15	AL0054	Hashimiya	35	F 0009	Azraq Evap. Station
16	AL0055	Wadi Dhuleil			
17	AL0059	Um El-Jumal	36	G 0002	Jafr Police Post
18	AL0066	Khirebit Es Samra	37	G 0003	Ma'an
19	AM0001	Salt	38	G 0008	Jafr Evap. Station
20	AN0002	Wadi Es-Sir	39	H 0001	H4

Figure 1: The 39 rainfall stations included in this study across Jordan.

Table 1: Number of rainy days in each month for each station

Name	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Name	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Mafraq Airport	92	181	312	403	368	238	107	44	Na'ur	86	253	477	537	539	424	176	40
Turra	68	162	294	370	331	260	125	25	Madaba	77	264	455	544	511	405	141	39
Baqura	95	249	381	447	386	320	117	28	Mushaqqar	36	94	185	248	249	148	35	11
Irbid	149	318	513	609	569	483	224	69	Sahab	41	151	252	346	303	198	81	11
Ras Muneif	139	268	433	492	435	393	180	46	Yaduda	6	56	116	125	120	103	36	11
Deir Alla	122	279	458	559	488	411	160	53	Jiza	45	147	275	367	310	227	71	12
Zarqa	68	191	312	414	359	279	95	42	Rabba	58	209	380	473	442	335	121	18
Ruseifa	55	166	303	385	340	264	85	28	Ghores-Safi	25	51	96	145	131	89	38	5
Jubeiha	107	326	536	665	602	508	202	61	Hasa	22	61	68	104	81	82	24	6
Amman Airport	137	354	600	734	712	564	255	99	Shaubak	67	150	278	382	305	251	112	26
Ain Ghazal	4	18	51	57	65	46	22	10	Aqaba	27	47	105	119	87	77	45	9
Baq'a	86	196	350	413	413	316	119	39	Ram	8	14	21	43	24	23	13	2
Khaldiya	29	77	112	173	154	98	33	18	H5	64	162	251	304	310	227	111	49
King Talal Dam	46	146	242	300	310	218	68	21	Azraq Police Post	15	28	42	48	25	40	12	5
Hashimiya	30	94	141	174	182	115	45	15	Azraq Evap. Station	33	79	131	199	153	112	49	20
Wadi Dhuleil	52	134	236	312	301	208	71	23	Jafr Police Post	13	33	37	34	29	30	24	5
Um El-Jumal	49	160	250	320	288	210	85	26	Ma'an	52	86	138	218	171	152	57	26
Khirebit Es Samra	35	87	161	188	190	95	29	8	Jafr Evap. Station	21	19	28	35	32	27	18	4
Salt	105	302	526	618	610	503	196	64	H4	104	154	253	292	272	236	157	81
Wadi Es-Sir	100	277	520	587	545	431	190	41									

2. Methodology

The main concept of the Markov chain is the prediction of the state of a day based on the state of the previous day(s). Previous studies showed the validity of the first-order Markov chain for daily rainfall precipitation data [9], which means that the state of a day is dependent on the state of its previous day, not days. Two states are applied for Markov chain in this study: dry and wet. Dry state refers to the days that have zero rainfall precipitation depth. Wet state refers to the days that have rainfall precipitation depths greater than zero. Since two states are used, four transition probabilities (TPs) result for the model: dry-to-dry, dry-to-wet, wet-to-dry, and wet-to-wet. These probabilities are calculated using the following formulae:

$$p_{dd} = \frac{n_{dd}}{n_d} \tag{11}$$

$$p_{dw} = \frac{n_{dw}}{n_d} \tag{12}$$

$$p_{wd} = \frac{n_{wd}}{n_w} \tag{13}$$

$$p_{ww} = \frac{n_{ww}}{n_w} \tag{14}$$

where p_{dd}, p_{dw}, p_{wd} and p_{ww} are the dry-to-dry, dry-to-wet, wet-to-dry and wet-to-wet transition probabilities, respectively; n_{dd}, n_{dw}, n_{wd} and n_{ww} are the number of dry-to-dry, dry-to-wet, wet-to-dry and wet-to-wet days, respectively; and n_d and n_w the number of dry and wet days, respectively. By definitions, the following formulae can be concluded:

$$n_d = n_{dd} + n_{dw} \tag{15}$$

$$n_w = n_{wd} + n_{ww} \tag{16}$$

$$p_{dd} + p_{dw} = 1 \tag{17}$$

$$p_{wd} + p_{ww} = 1 \tag{18}$$

These formulae were used as a final check for the model.

Consequently, equilibrium probabilities (EPs) can be calculated using the following equations [6]:

$$\pi_d = \frac{1 - p_{ww}}{(1 - p_{dd}) + (1 - p_{ww})} \tag{19}$$

$$\pi_w = \frac{1 - p_{dd}}{(1 - p_{dd}) + (1 - p_{ww})} \quad (20)$$

where π_d and π_w are the equilibrium probabilities of a dry and wet day, respectively.

Since first order is assumed, the expected lengths of dry and wet spells can be calculated through the following equations, respectively [5]:

$$E(d) = \frac{1}{1 - p_{dd}} \quad (21)$$

$$E(w) = \frac{1}{1 - p_{ww}} \quad (22)$$

Weather cycle (WC) can then be calculated as:

$$WC = E(d) + E(w) \quad (23)$$

3. Results and Discussion

Half of the transition probabilities is shown in Table 2. The other half can be calculated through equations 17–18. It can be noticed that $p_{dd} > 0.5$ (i.e., $p_{dd} > p_{dw}$) for all stations in all months, and $p_{wd} > 0.5$ (i.e., $p_{wd} > p_{ww}$) for all stations in October, April, and May, except Ram station in May where $p_{wd} = 0.5$ (i.e., $p_{wd} = p_{ww}$). In November, $p_{wd} > 0.5$ (i.e., $p_{wd} > p_{ww}$) for all stations except Ras Muneif and Ain Ghazal. In December, $p_{wd} > 0.5$ (i.e., $p_{wd} > p_{ww}$) for all stations except Baqura, Irbid, Ras Muneif, Deir Alla, Amman Airport, Ain Ghazal, Baq'a, and Wadi Es-Sir. In January, $p_{wd} > 0.5$ (i.e., $p_{wd} > p_{ww}$) for all stations except Baqura, Irbid, Ras Muneif, Deir Alla, Jubeiha, Amman Airport, Ain Ghazal, Baq'a, King Talal Dam, Salt, Wadi Es-Sir, Mushaqqar, and Rabba. In February, $p_{wd} > 0.5$ (i.e., $p_{wd} > p_{ww}$) for all stations except Mafraq Airport, Baqura, Irbid, Ras Muneif, Deir Alla, Jubeiha, Amman Airport, Ain Ghazal, Baq'a, King Talal Dam, Salt, Na'ur, Mushaqqar, and Rabba. In March, $p_{wd} > 0.5$ (i.e., $p_{wd} > p_{ww}$) for all stations except Baqura, Irbid, Ras Muneif, Deir Alla, Jubeiha, Amman Airport, Ain Ghazal, Baq'a, and King Talal Dam.

The equilibrium probability of a dry day for each month in each station (i.e., π_d) is shown in Table 3. It can be concluded form the table that all values of π_d are greater than 0.65, and that in October, November, April, and May, they are all greater than 0.80. This indicates the tendency of those month to be dry in the long term. As noticed form the equations 19–20, the equilibrium probability of a wet day (i.e., π_w) can be calculated through the equation $\pi_d + \pi_w = 1$ [6].

Expected dry and wet spell lengths (SLs) are shown in Table 4. All stations show higher dry spell lengths than wet spell lengths for all months. Dry spell lengths range from 5 to 1000 days, while wet spell lengths from 1 to 2 days, except Amman Airport station that has a wet spell length of 3 days in February. The wide variety in the dry spell lengths can be summarized as follows. Dry spells in October range from 15 to 167 days, with 76.9%

being less than 60 days; in November, they range from 8 to 100 days, with 79.5% being less than 25 days; in December, they range from 5 to 71 days, with 79.5% being less than 20 days; in January, they range from 5 to 62 days, with 89.7% being less than 25 days; in February, they range from 5 to 62 days, with 87.2% being less than 20 days; in March, they range from 6 to 77 days, with 87.2% being less than 25 days; in April, they range from 12 to 100 days, with 76.9% being less than 40 days; in May, they range from 26 to 1000 days, with 61.5% being less than 100 days. Weather cycle for each month–station crosscheck can be calculated using equation 23.

Table 2 : Markov chain transition probabilities

Station name	TP	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Mafraq Airport	p_{dd}	0.957	0.914	0.865	0.807	0.831	0.893	0.95	0.977
	p_{ww}	0.315	0.37	0.462	0.453	0.522	0.412	0.346	0.227
Turra	p_{dd}	0.965	0.921	0.863	0.842	0.844	0.896	0.949	0.985
	p_{ww}	0.25	0.364	0.429	0.495	0.489	0.485	0.432	0.08
Baqura	p_{dd}	0.956	0.892	0.841	0.801	0.832	0.87	0.947	0.986
	p_{ww}	0.379	0.494	0.553	0.55	0.588	0.534	0.41	0.286
Irbid	p_{dd}	0.947	0.89	0.823	0.797	0.797	0.846	0.924	0.969
	p_{ww}	0.396	0.487	0.536	0.583	0.599	0.561	0.469	0.188
Ras Muneif	p_{dd}	0.935	0.881	0.801	0.787	0.796	0.828	0.914	0.976
	p_{ww}	0.403	0.504	0.545	0.596	0.593	0.547	0.428	0.283
Deir Alla	p_{dd}	0.955	0.901	0.844	0.814	0.826	0.865	0.944	0.978
	p_{ww}	0.352	0.452	0.514	0.556	0.559	0.513	0.412	0.226
Zarqa	p_{dd}	0.976	0.942	0.905	0.876	0.877	0.919	0.966	0.985
	p_{ww}	0.191	0.356	0.372	0.408	0.376	0.387	0.211	0.19
Ruseifa	p_{dd}	0.981	0.942	0.902	0.88	0.874	0.92	0.972	0.99
	p_{ww}	0.236	0.307	0.376	0.423	0.374	0.402	0.318	0.25
Jubeiha	p_{dd}	0.965	0.913	0.855	0.823	0.825	0.866	0.943	0.982
	p_{ww}	0.271	0.472	0.499	0.54	0.543	0.504	0.406	0.328
Amman Airport	p_{dd}	0.958	0.903	0.846	0.813	0.806	0.862	0.927	0.968
	p_{ww}	0.307	0.46	0.54	0.578	0.601	0.553	0.412	0.253
Ain Ghazal	p_{dd}	0.981	0.963	0.878	0.859	0.839	0.891	0.935	0.962
	p_{ww}	0	0.529	0.529	0.536	0.594	0.522	0.364	0.1
Baq'a	p_{dd}	0.959	0.918	0.859	0.835	0.83	0.883	0.949	0.982
	p_{ww}	0.306	0.444	0.501	0.535	0.576	0.532	0.395	0.308
Khaldiya	p_{dd}	0.971	0.933	0.905	0.846	0.857	0.913	0.972	0.983
	p_{ww}	0.172	0.338	0.357	0.347	0.386	0.278	0.273	0.176
King Talal Dam	p_{dd}	0.975	0.934	0.89	0.874	0.857	0.911	0.964	0.99
	p_{ww}	0.283	0.473	0.492	0.543	0.558	0.518	0.324	0.333
Hashimiya	p_{dd}	0.971	0.925	0.882	0.856	0.848	0.909	0.956	0.985
	p_{ww}	0.2	0.404	0.39	0.408	0.47	0.377	0.178	0.133

Wadi Dhuleil	p_{dd}	0.976	0.941	0.895	0.864	0.866	0.913	0.968	0.989
	p_{ww}	0.288	0.388	0.403	0.449	0.482	0.413	0.338	0.261
Um El-Jumal	p_{dd}	0.971	0.917	0.88	0.853	0.86	0.906	0.96	0.983
	p_{ww}	0.163	0.35	0.42	0.478	0.497	0.438	0.365	0.077
Khirebit Es Samra	p_{dd}	0.965	0.923	0.87	0.856	0.839	0.928	0.969	0.992
	p_{ww}	0.143	0.322	0.4	0.457	0.468	0.389	0.103	0.125
Salt	p_{dd}	0.971	0.91	0.852	0.832	0.821	0.864	0.94	0.981
	p_{ww}	0.362	0.397	0.476	0.518	0.541	0.487	0.352	0.297
Wadi Es-Sir	p_{dd}	0.97	0.922	0.852	0.825	0.815	0.879	0.944	0.984
	p_{ww}	0.36	0.469	0.513	0.511	0.494	0.494	0.416	0.146
Na'ur	p_{dd}	0.972	0.926	0.853	0.838	0.828	0.882	0.945	0.986
	p_{ww}	0.291	0.443	0.46	0.488	0.521	0.495	0.381	0.225
Madaba	p_{dd}	0.974	0.924	0.874	0.846	0.832	0.889	0.958	0.986
	p_{ww}	0.224	0.413	0.466	0.48	0.454	0.457	0.355	0.179
Mushaqqar	p_{dd}	0.969	0.928	0.87	0.83	0.821	0.904	0.969	0.991
	p_{ww}	0.25	0.404	0.476	0.532	0.566	0.493	0.2	0.273
Sahab	p_{dd}	0.981	0.942	0.898	0.865	0.87	0.921	0.967	0.995
	p_{ww}	0.22	0.397	0.381	0.445	0.439	0.374	0.346	0.273
Yaduda	p_{dd}	0.993	0.946	0.884	0.876	0.864	0.898	0.965	0.986
	p_{ww}	0.333	0.446	0.457	0.48	0.467	0.456	0.417	0.182
Jiza	p_{dd}	0.986	0.951	0.924	0.887	0.898	0.931	0.977	0.995
	p_{ww}	0.267	0.286	0.425	0.381	0.384	0.339	0.268	0
Rabba	p_{dd}	0.98	0.93	0.877	0.844	0.846	0.889	0.959	0.993
	p_{ww}	0.345	0.435	0.492	0.514	0.532	0.463	0.397	0.278
Ghores-Safi	p_{dd}	0.987	0.973	0.954	0.932	0.932	0.959	0.98	0.997
	p_{ww}	0.24	0.255	0.312	0.345	0.344	0.337	0.237	0.2
Hasa	p_{dd}	0.989	0.956	0.953	0.933	0.942	0.95	0.981	0.995
	p_{ww}	0.409	0.267	0.294	0.365	0.333	0.378	0.208	0.167
Shaubak	p_{dd}	0.969	0.93	0.885	0.842	0.847	0.899	0.954	0.987
	p_{ww}	0.299	0.36	0.45	0.492	0.416	0.454	0.402	0.192
Aqaba	p_{dd}	0.99	0.982	0.969	0.955	0.966	0.972	0.982	0.997
	p_{ww}	0.185	0.17	0.343	0.185	0.218	0.169	0.133	0.222
Ram	p_{dd}	0.993	0.988	0.981	0.97	0.978	0.982	0.989	0.999
	p_{ww}	0.125	0.214	0.19	0.349	0.208	0.304	0.231	0.5
H5	p_{dd}	0.976	0.946	0.923	0.905	0.889	0.924	0.96	0.983
	p_{ww}	0.188	0.34	0.39	0.395	0.381	0.33	0.27	0.224
Azraq Police Post	p_{dd}	0.988	0.978	0.969	0.964	0.979	0.976	0.989	0.995
	p_{ww}	0.2	0.214	0.286	0.271	0.24	0.4	0.083	0
Azraq Evap. Station	p_{dd}	0.979	0.952	0.935	0.899	0.905	0.938	0.973	0.989
	p_{ww}	0.091	0.203	0.359	0.377	0.288	0.268	0.265	0.25

Jafr Police Post	p_{dd}	0.994	0.985	0.983	0.983	0.984	0.985	0.989	0.997
	p_{ww}	0.154	0.212	0.162	0.088	0.069	0.1	0.167	0
Ma'an	p_{dd}	0.983	0.97	0.954	0.932	0.935	0.95	0.979	0.992
	p_{ww}	0.231	0.233	0.246	0.321	0.24	0.27	0.175	0.231
Jafr Evap. Station	p_{dd}	0.99	0.99	0.986	0.984	0.982	0.987	0.99	0.998
	p_{ww}	0.238	0.211	0.25	0.314	0.188	0.259	0.167	0.25
H4	p_{dd}	0.964	0.943	0.908	0.902	0.89	0.92	0.946	0.976
	p_{ww}	0.26	0.253	0.281	0.349	0.29	0.322	0.312	0.358

Table 3: Markov chain equilibrium probabilities

Station	EP	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Mafraq Airport	π_d	0.941	0.88	0.799	0.739	0.739	0.846	0.929	0.971
Turra	π_d	0.955	0.89	0.806	0.762	0.766	0.832	0.918	0.984
Baqura	π_d	0.934	0.824	0.738	0.693	0.71	0.782	0.918	0.981
Irbid	π_d	0.919	0.823	0.724	0.673	0.664	0.74	0.875	0.963
Ras Muneif	π_d	0.902	0.807	0.696	0.655	0.666	0.725	0.869	0.968
Deir Alla	π_d	0.935	0.847	0.757	0.705	0.717	0.783	0.913	0.972
Zarqa	π_d	0.971	0.917	0.869	0.827	0.835	0.883	0.959	0.982
Ruseifa	π_d	0.976	0.923	0.864	0.828	0.832	0.882	0.961	0.987
Jubeiha	π_d	0.954	0.859	0.776	0.722	0.723	0.787	0.912	0.974
Amman Airport	π_d	0.943	0.848	0.749	0.693	0.673	0.764	0.89	0.959
Ain Ghazal	π_d	0.981	0.927	0.794	0.767	0.716	0.814	0.907	0.959
Baq'a	π_d	0.944	0.871	0.78	0.738	0.714	0.8	0.922	0.975
Khaldiya	π_d	0.966	0.908	0.871	0.809	0.811	0.892	0.963	0.98
King Talal Dam	π_d	0.966	0.889	0.822	0.784	0.756	0.844	0.949	0.985
Hashimiya	π_d	0.965	0.888	0.838	0.804	0.777	0.873	0.949	0.983
Wadi Dhuleil	π_d	0.967	0.912	0.85	0.802	0.794	0.871	0.954	0.985
Um El-Jumal	π_d	0.967	0.887	0.829	0.78	0.782	0.857	0.941	0.982
Khirebit Es Samra	π_d	0.961	0.898	0.822	0.79	0.768	0.895	0.967	0.991
Salt	π_d	0.957	0.87	0.78	0.742	0.719	0.79	0.915	0.974
Wadi Es-Sir	π_d	0.955	0.872	0.767	0.736	0.732	0.807	0.913	0.982
Na'ur	π_d	0.962	0.883	0.786	0.76	0.736	0.811	0.918	0.982
Madaba	π_d	0.968	0.885	0.809	0.772	0.765	0.83	0.939	0.983
Mushaqqar	π_d	0.96	0.892	0.801	0.734	0.708	0.841	0.963	0.988
Sahab	π_d	0.976	0.912	0.859	0.804	0.812	0.888	0.952	0.993
Yaduda	π_d	0.99	0.911	0.824	0.807	0.797	0.842	0.943	0.983
Jiza	π_d	0.981	0.936	0.883	0.846	0.858	0.905	0.97	0.995
Rabba	π_d	0.97	0.89	0.805	0.757	0.752	0.829	0.936	0.99
Ghores-Safi	π_d	0.983	0.965	0.937	0.906	0.906	0.942	0.974	0.996

Hasa	π_d	0.982	0.943	0.938	0.905	0.92	0.926	0.977	0.994
Shaubak	π_d	0.958	0.901	0.827	0.763	0.792	0.844	0.929	0.984
Aqaba	π_d	0.988	0.979	0.955	0.948	0.958	0.967	0.98	0.996
Ram	π_d	0.992	0.985	0.977	0.956	0.973	0.975	0.986	0.998
H5	π_d	0.971	0.924	0.888	0.864	0.848	0.898	0.948	0.979
Azraq Police Post	π_d	0.985	0.973	0.958	0.953	0.973	0.962	0.988	0.995
Azraq Evap. Station	π_d	0.977	0.943	0.908	0.86	0.882	0.922	0.965	0.986
Jafr Police Post	π_d	0.993	0.981	0.98	0.982	0.983	0.984	0.987	0.997
Ma'an	π_d	0.978	0.962	0.943	0.909	0.921	0.936	0.975	0.99
Jafr Evap. Station	π_d	0.987	0.987	0.982	0.977	0.978	0.983	0.988	0.997
H4	π_d	0.954	0.929	0.887	0.869	0.866	0.894	0.927	0.964

Table 4: Expected dry and wet spell lengths (numbers are rounded to be integers to be expressive for numbers of days)

Station	SL	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Mafraq Airport	E(d)	23	12	7	5	6	9	20	43
	E(w)	1	2	2	2	2	2	2	1
Turra	E(d)	29	13	7	6	6	10	20	67
	E(w)	1	2	2	2	2	2	2	1
Baqura	E(d)	23	9	6	5	6	8	19	71
	E(w)	2	2	2	2	2	2	2	1
Irbid	E(d)	19	9	6	5	5	6	13	32
	E(w)	2	2	2	2	2	2	2	1
Ras Muneif	E(d)	15	8	5	5	5	6	12	42
	E(w)	2	2	2	2	2	2	2	1
Deir Alla	E(d)	22	10	6	5	6	7	18	45
	E(w)	2	2	2	2	2	2	2	1
Zarqa	E(d)	42	17	11	8	8	12	29	67
	E(w)	1	2	2	2	2	2	1	1
Ruseifa	E(d)	53	17	10	8	8	13	36	100
	E(w)	1	1	2	2	2	2	1	1
Jubeiha	E(d)	29	11	7	6	6	7	18	56
	E(w)	1	2	2	2	2	2	2	1
Amman Airport	E(d)	24	10	6	5	5	7	14	31
	E(w)	1	2	2	2	3	2	2	1
Ain Ghazal	E(d)	53	27	8	7	6	9	15	26
	E(w)	1	2	2	2	2	2	2	1

Baq'a	E(d)	24	12	7	6	6	9	20	56
	E(w)	1	2	2	2	2	2	2	1
Khaldiya	E(d)	34	15	11	6	7	11	36	59
	E(w)	1	2	2	2	2	1	1	1
King Talal Dam	E(d)	40	15	9	8	7	11	28	100
	E(w)	1	2	2	2	2	2	1	1
Hashimiya	E(d)	34	13	8	7	7	11	23	67
	E(w)	1	2	2	2	2	2	1	1
Wadi Dhuleil	E(d)	42	17	10	7	7	11	31	91
	E(w)	1	2	2	2	2	2	2	1
Um El-Jumal	E(d)	34	12	8	7	7	11	25	59
	E(w)	1	2	2	2	2	2	2	1
Khirebit Es Samra	E(d)	29	13	8	7	6	14	32	125
	E(w)	1	1	2	2	2	2	1	1
Salt	E(d)	34	11	7	6	6	7	17	53
	E(w)	2	2	2	2	2	2	2	1
Wadi Es-Sir	E(d)	33	13	7	6	5	8	18	62
	E(w)	2	2	2	2	2	2	2	1
Na'ur	E(d)	36	14	7	6	6	8	18	71
	E(w)	1	2	2	2	2	2	2	1
Madaba	E(d)	38	13	8	6	6	9	24	71
	E(w)	1	2	2	2	2	2	2	1
Mushaqqar	E(d)	32	14	8	6	6	10	32	111
	E(w)	1	2	2	2	2	2	1	1
Sahab	E(d)	53	17	10	7	8	13	30	200
	E(w)	1	2	2	2	2	2	2	1
Yaduda	E(d)	143	19	9	8	7	10	29	71
	E(w)	1	2	2	2	2	2	2	1
Jiza	E(d)	71	20	13	9	10	14	43	200
	E(w)	1	1	2	2	2	2	1	1
Rabba	E(d)	50	14	8	6	6	9	24	143
	E(w)	2	2	2	2	2	2	2	1
Ghores-Safi	E(d)	77	37	22	15	15	24	50	333
	E(w)	1	1	1	2	2	2	1	1
Hasa	E(d)	91	23	21	15	17	20	53	200
	E(w)	2	1	1	2	1	2	1	1
Shaubak	E(d)	32	14	9	6	7	10	22	77
	E(w)	1	2	2	2	2	2	2	1
Aqaba	E(d)	100	56	32	22	29	36	56	333
	E(w)	1	1	2	1	1	1	1	1

Ram	E(d)	143	83	53	33	45	56	91	1000
	E(w)	1	1	1	2	1	1	1	2
H5	E(d)	42	19	13	11	9	13	25	59
	E(w)	1	2	2	2	2	1	1	1
Azraq Police Post	E(d)	83	45	32	28	48	42	91	200
	E(w)	1	1	1	1	1	2	1	1
Azraq Evap. Station	E(d)	48	21	15	10	11	16	37	91
	E(w)	1	1	2	2	1	1	1	1
Jafr Police Post	E(d)	167	67	59	59	62	67	91	333
	E(w)	1	1	1	1	1	1	1	1
Ma'an	E(d)	59	33	22	15	15	20	48	125
	E(w)	1	1	1	1	1	1	1	1
Jafr Evap. Station	E(d)	100	100	71	62	56	77	100	500
	E(w)	1	1	1	1	1	1	1	1
H4	E(d)	28	18	11	10	9	13	19	42
	E(w)	1	1	1	2	1	1	1	2

4. Conclusions and Recommendations

4.1. Conclusions

$p_{dd} > p_{dw}$ for all stations in all months. $p_{ww} \geq p_{wd}$ in only 15.1% of the times, which are concentrated in the middle of the rainy season (i.e., December–March) at North of Jordan. In the long term, all months tend to be dry, especially October, November, April, and May.

The expected dry spell lengths range from 5 to 100 days, except 13 stations that have dry spell lengths greater than 100 days in May, while the expected wet spell lengths range from 1 to 2 days, except one station that has a wet spell length of 3 days in February.

4.2. Recommendations for Future Studies

- Nonparametric methods for data resampling (e.g., kernel and nearest-neighbor estimators) are recommended to use before studying the data.
- Spatial correlations of daily rainfall data are recommended to consider among the meteorological stations.

5. Ethical Statement

We will conduct ourselves with integrity, fidelity, and honesty. We will openly take responsibility for my actions, and only make agreements, which we intend to keep. We will not intentionally engage in or participate in any form of malicious harm to another person or animal.

6. Conflict of Interests

We declare that we have NO conflict of interests in the subject matter or materials discussed in this paper.

7. Data Availability Statement

The data associated with this paper are available with the authors and can be accessed if needed.

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