SWIM and Horizon 2020 Support Mechanism

Working for a Sustainable Mediterranean, Caring for our Future

Drought Hazard analysis in the Amman-Zarqa catchment

Consultation Workshop "Roadmap for developing a Drought Risk Management Plan in the Amman-Zarqa catchment", 28 November 2018

Ayaas Hotel, Amman - Jordan

Presented by:

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This Project is funded by the European Union

Measures within a Drought Risk Management Plan (DRMP)

RAINFALL DATA

- **Objective:** To construct one rainfall dataset for the whole of the catchment.
- **Total number of rainfall stations:** 26 rainfall stations in the A-Z area.
- **Spatial distribution:** See map.
- **Temporal distribution:** Data for 53 hydrologic years (from 1964-65 to 2016-17). Additionally Amman Airport Rainfall Station from 1938 (80 years).

This Project is funded by the European Union

QUALITY CHECK FOR RAINFALL DATA

- Outliers: Outliers are data that are higher than the value defined as the average plus (often) two times the standard deviation of the sample. The outliers are not necessary erroneous, check for data.
- Correlation matrix: Correlation matrix between all annual and monthly rainfall values between all stations. Check for rainfall stations with constant low correlation values especially with the adjacent stations.
- Double Mass Curves: Perform double mass curves analysis to further evaluate data consistency in rainfall stations.
- Understand reasons for inconsistency: For rainfall station with certain fashion of inconsistency, check the station's log for certain changes (e.g. change of the rain recorder).

QUALITY CHECK FOR RAINFALL DATA

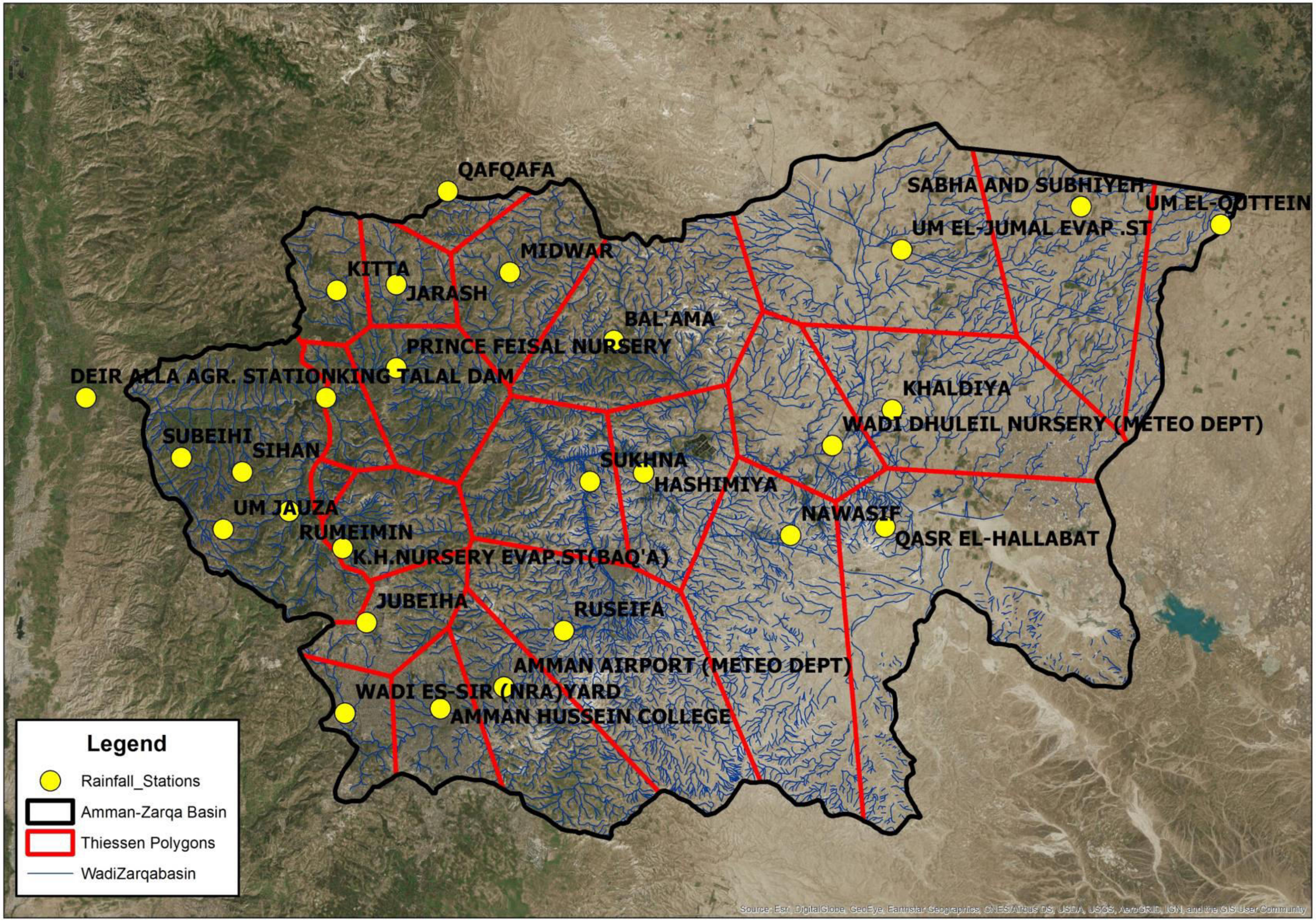
- **Data gap filling:** The base stations should have all datasets filled for all months of the finally selected time analysis. Certain, sparse, gaps can be filled according the correlation equation.
- **Data extension:** Reliable rainfall station with time of operation less than the defined one can be extended to the required one according to the correlation analyses.
- **Define the altitude rainfall lapse rate:** For the computation of the surface rainfall, the rate of change between rainfall and elevation must be defined with satisfactory correlation coefficients.

QUALITY CHECK FOR RAINFALL DATA

- Spatial Integration of Point Rainfall: The transition from point to surface rainfall can be done by means of the Thiessen polygons (very easy in GIS applications).

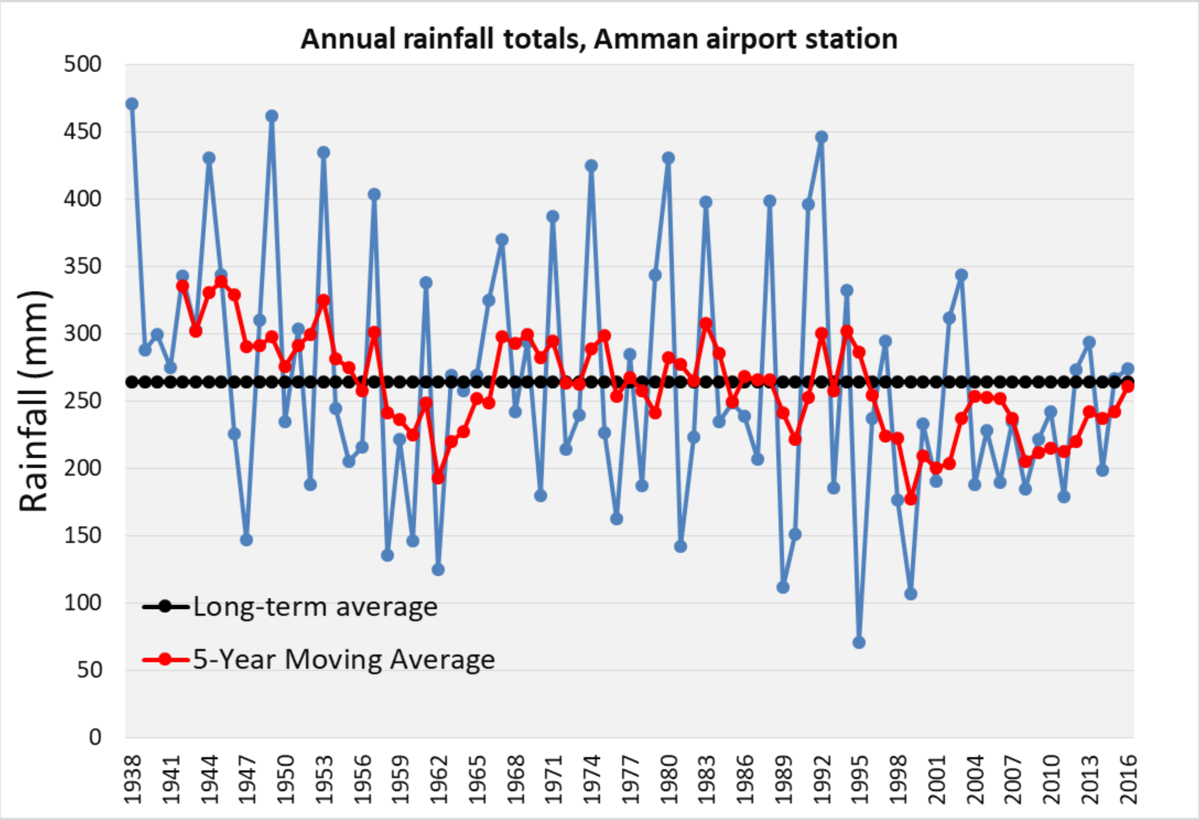
This Project is funded by the European Union

Meteorological drought – Overview of Rainfall Stations in the Amman-Zarqa Basin



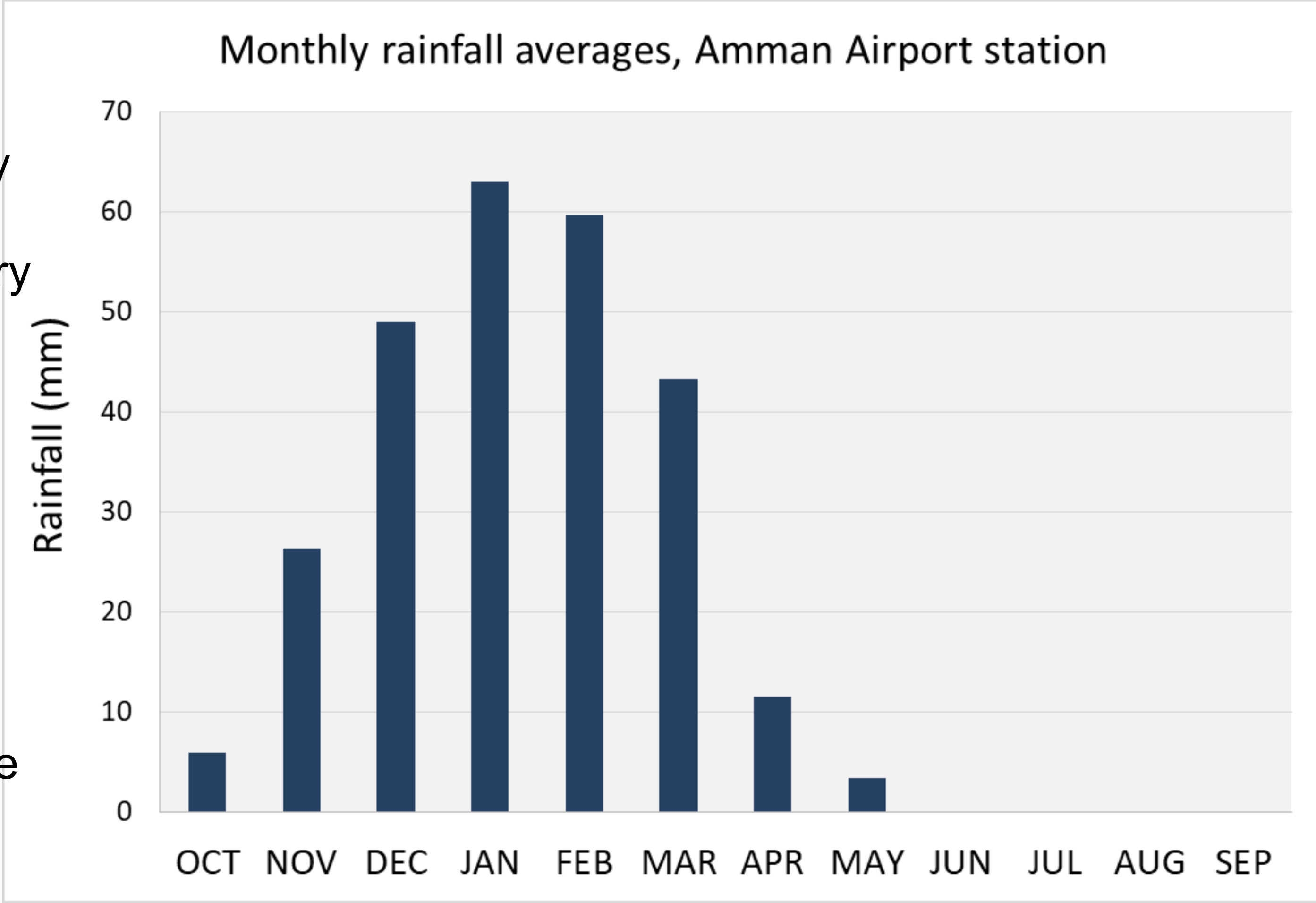
Meteorological drought – Overview of long-term rainfall behavior

- Historical record of long term rainfall at Amman 1938-2016
- A mild but consistent drop during the last 15 years
- A few periods with very low rainfall (worse in 1995) are followed on average by wet years
- This behavior is expected to be revealed by the indices taking into account rainfall at the annual and across annual scales (SPI-12, SPI-24 etc).

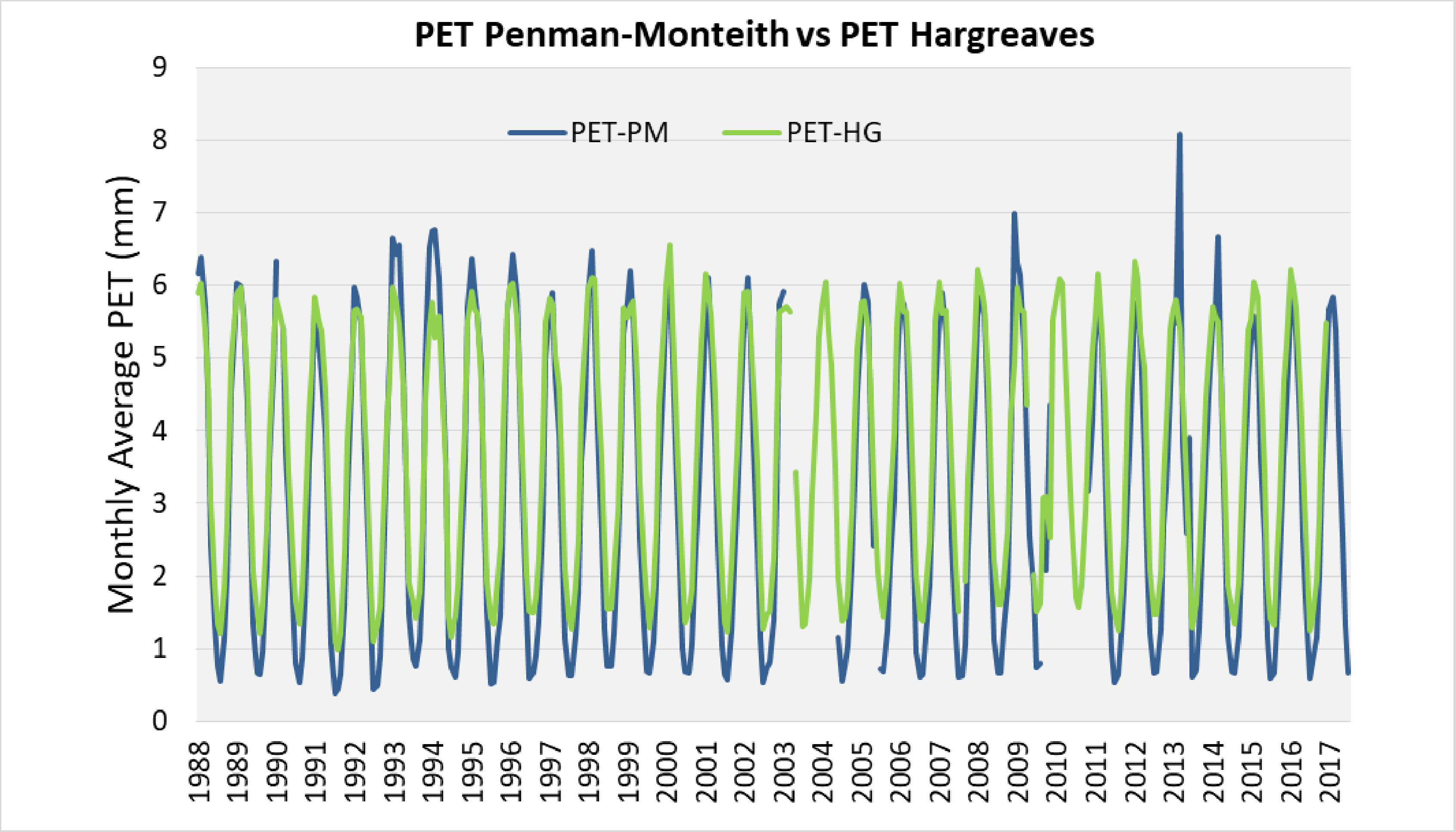


Meteorological drought – Overview of long-term rainfall behavior

- Historical record of monthly rainfall at Amman 1938-2016
- Rainfall shows a very seasonal behavior
- January and February are the wettest months
- June to September are always dry
- This behavior is expected to be revealed by the indices taking into account rainfall at the monthly scales (SPI-3, SPI-6 etc)



Penman-Motheith & Hargreaves PET comparison



Drought vs Water Scarcity

1. Water Scarcity

Water scarcity occurs where there are insufficient water resources to satisfy longterm average requirements. It refers to longterm water imbalances, combining low water availability with a level of water demand exceeding the supply capacity of the natural system.

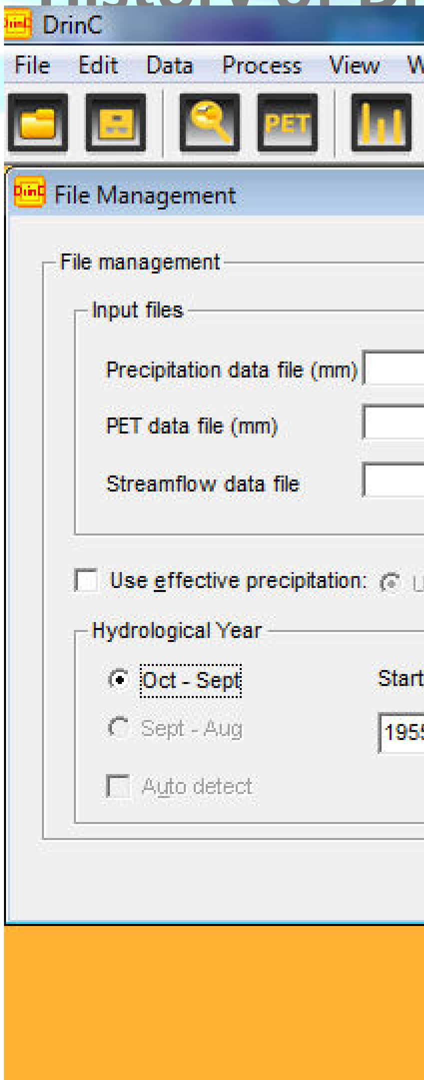
2. Drought

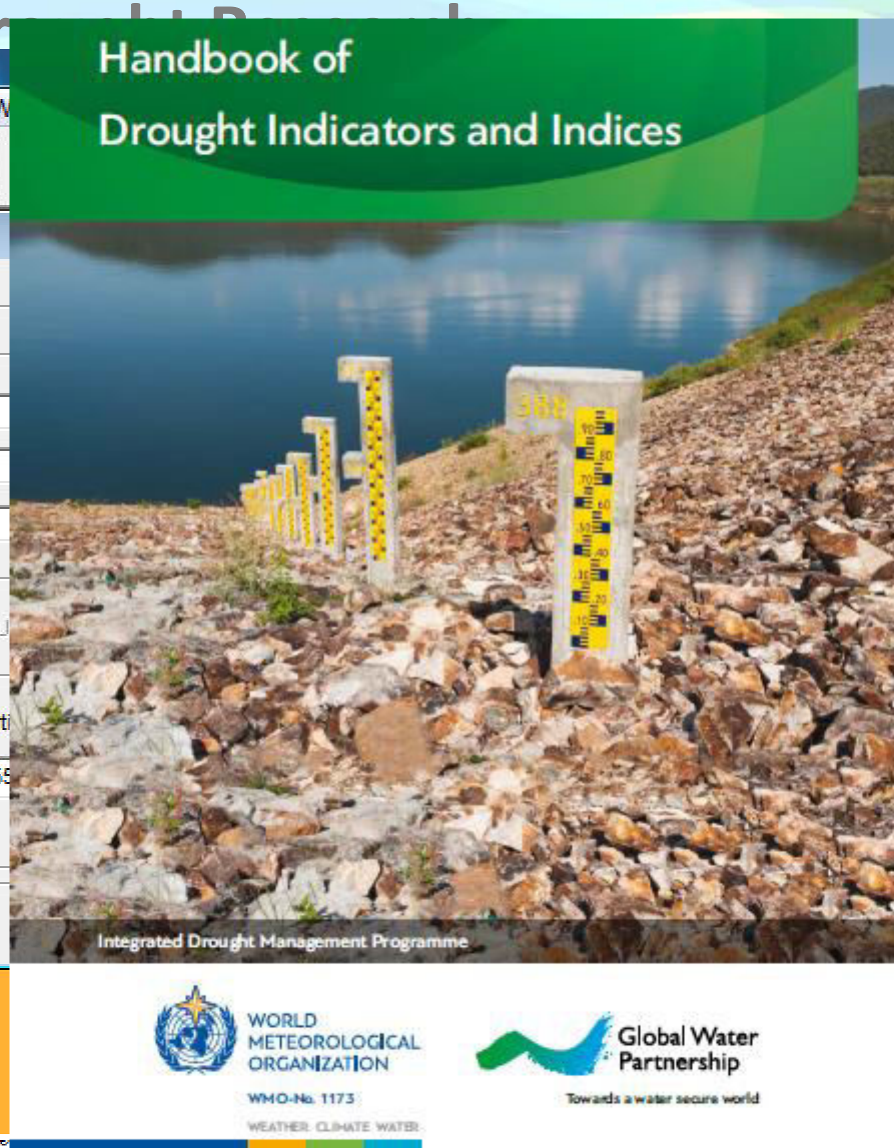
Natural occasional (random) temporary state of continuous reduction in rainfall and water availability with respect to normal values, covering a significant period of time and covering a wide area. It is caused by natural causes.

3. Water Scarcity and Drought

Water scarcity and drought are different phenomena although they are liable to aggravate the impacts of each other. In some regions, the severity and frequency of droughts can lead to water scarcity situations, while overexploitation of available water resources can exacerbate the consequences of droughts. Therefore, attention needs to be paid to the synergies between these two phenomena, especially in river basins affected by water scarcity.

History of Drought Research





PDSI reveals a fairly linear trend resulting from trends in precipitation and surface temperature and an El Niño–Southern Oscillation (ENSO)-induced mode of mostly interannual variations as the two leading patterns. The

Drought Hazard Indicator based on Rainfall (Standardized Precipitation Index, SPI*n*)

1. General Introduction

For the SPI calculation, the long-term precipitation record for a desired period is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (McKee et al. 1993; Edwards and McKee 1997).

2. Drought Classification according to SPI

SPI values	Classification
2.0 or more	Extremely Wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately Wet
-.99 to .99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Severely Dry
-2 or less	Extremely Dry

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Drought Hazard Indicator based on Rainfall (Standardized Precipitation Index, SPI*n*

3. Main characteristics of SPI

- The SPI is uniquely related to probability, so it changes while the whole data set is changing.
- Simplicity of use since it needs only rainfall data.
- Its variable time scale, which allows it to describe drought conditions important for a range of meteorological, agricultural, and hydrological applications. This temporal versatility is also helpful for the analysis of drought dynamics, especially the determination of onset and cessation, which have always been difficult to track with other indices.

4. Limitations of SPI

The SPI calculated in this way has the following disadvantages:

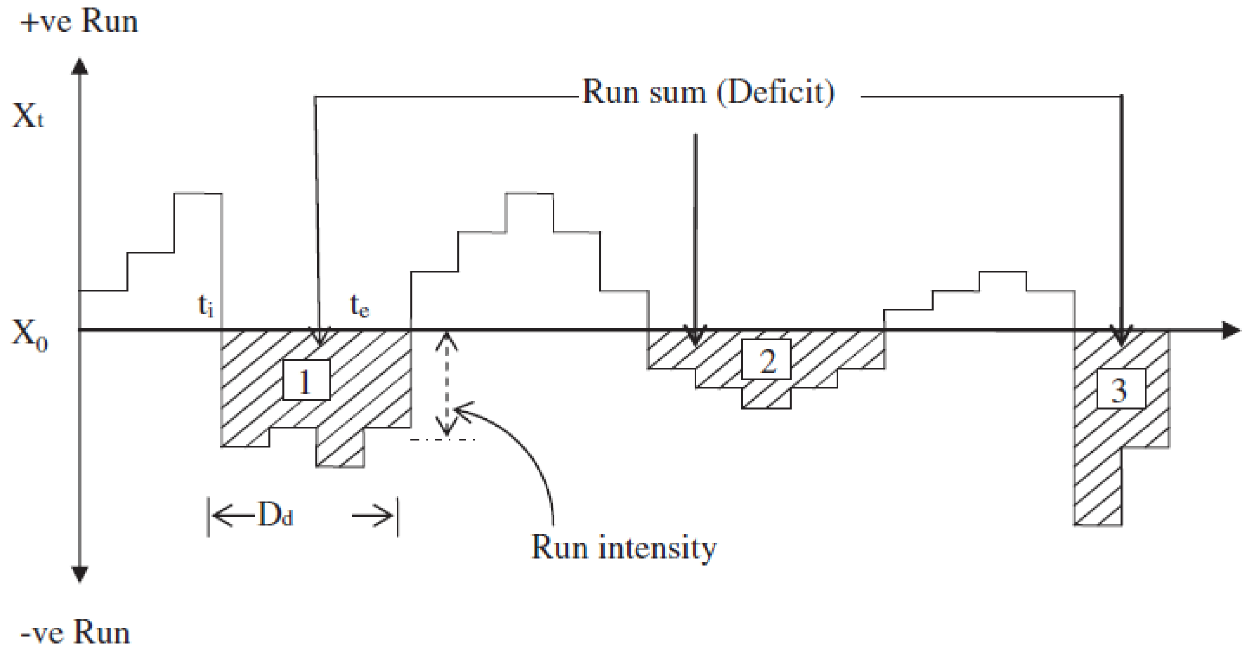
- A suitable theoretical probability distribution can be found to model the raw precipitation data. An associated problem is the quantity the data using at least 30 years of high-quality data.
- A serious problem may arise when applying the SPI at short time scales (1, 2, or 3 months) to regions of low seasonal precipitation. In these cases, misleadingly large positive or negative SPI values may result.

Drought Intensity, Duration and Magnitude

5. Drought definition according to SPI

According to the SPI, **a drought event occurs when the index continuously reaches an intensity of -1.0 or less**. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues.

Drought magnitude is the positive sum of the SPI for each month during the drought event.



1. Drought with the highest severity;
2. Drought with the longest duration;
3. Drought with the highest intensity

6. Time-Scale Variability of SPI

Soil moisture conditions respond to precipitation anomalies on a relatively short timescale. Groundwater, streamflow and reservoir storage reflect the longer-term precipitation anomalies. So, for example, one may want to look at a

- **1- or 2-month SPI** for **meteorological drought**,
- **1-month to 6-month SPI** for **agricultural drought**,
- **6-month up to 24-month SPI or more** for **hydrological drought analyses and applications (flow in reservoirs, groundwater aquifers, etc)**.

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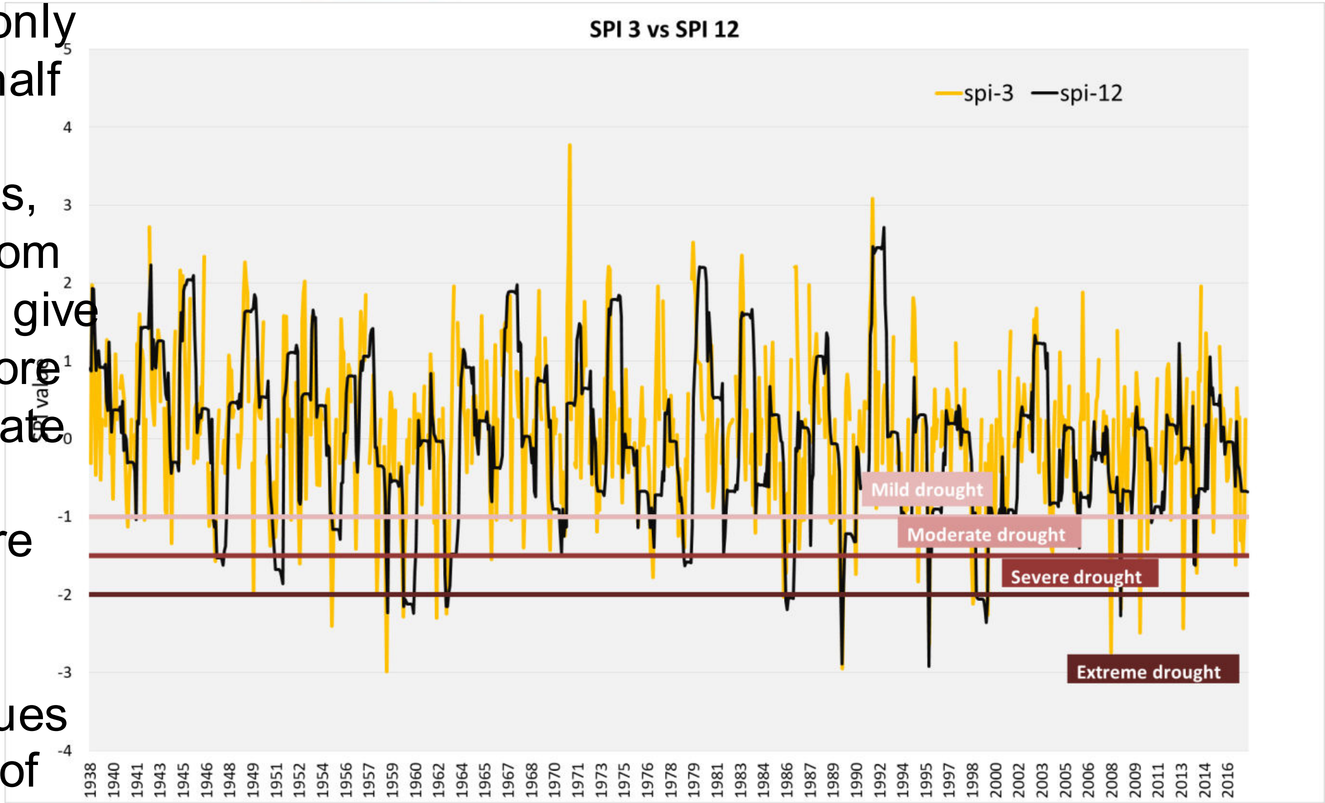
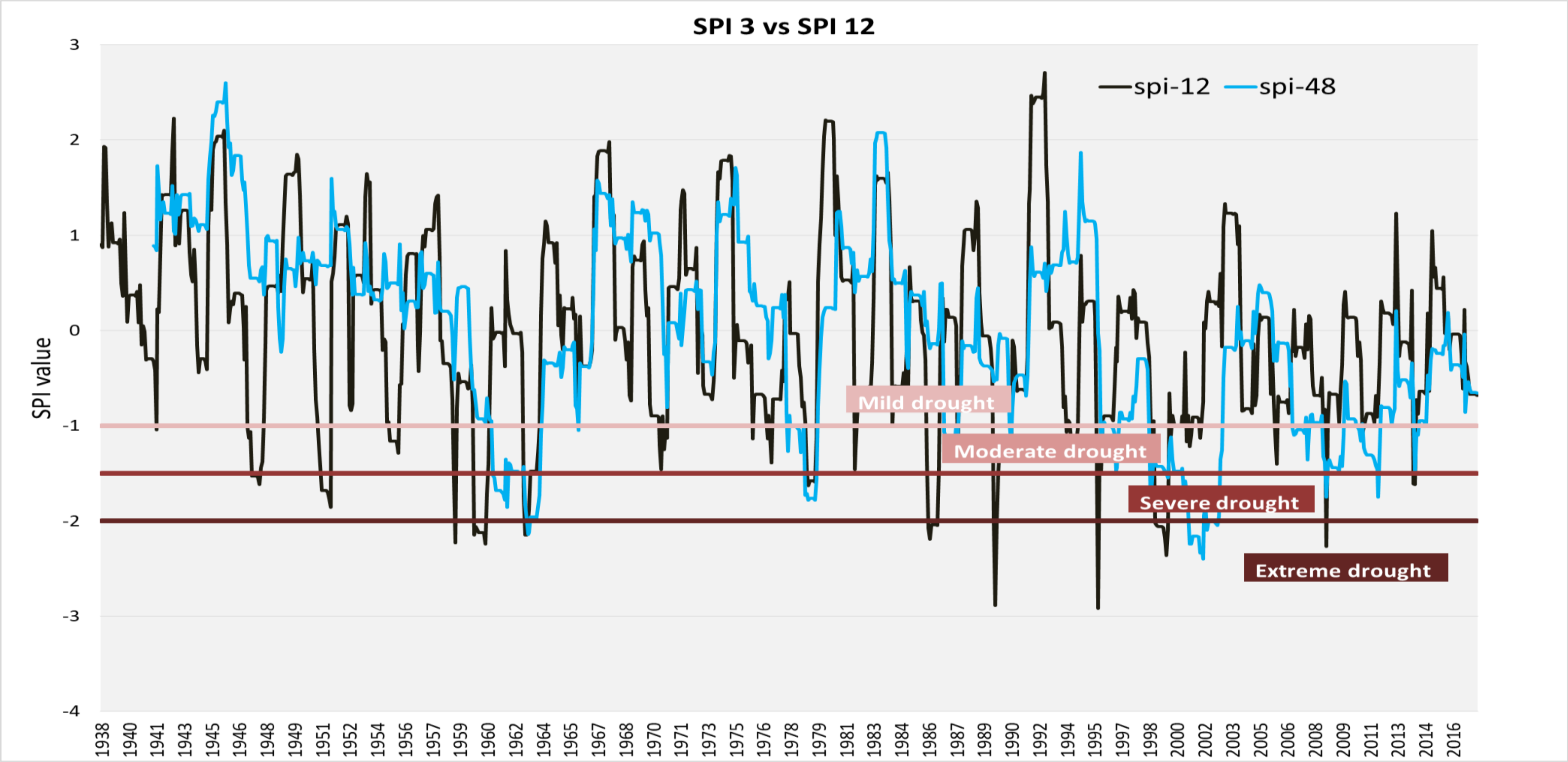
Amman Airport –SPI 3 & SPI-12 (1938-2017)

- In Jordan, due to the absence of rainfall from June to September, SPI-3 is only informative for the first half of the year.
- For generally dry periods, even small deviations from the long term mean, will give large SPI values, therefore SPI-3 is not an appropriate measure of drought
- It is important to compare the SPI3 with longer timescales
- Very negative SPI-3 values can occur in the middle of generally wet periods, and likewise, very positive SPI-3 values may occur in the middle of long-term drought periods.



Amman Airport –SPI 12 & SPI-48 (1938-2017)



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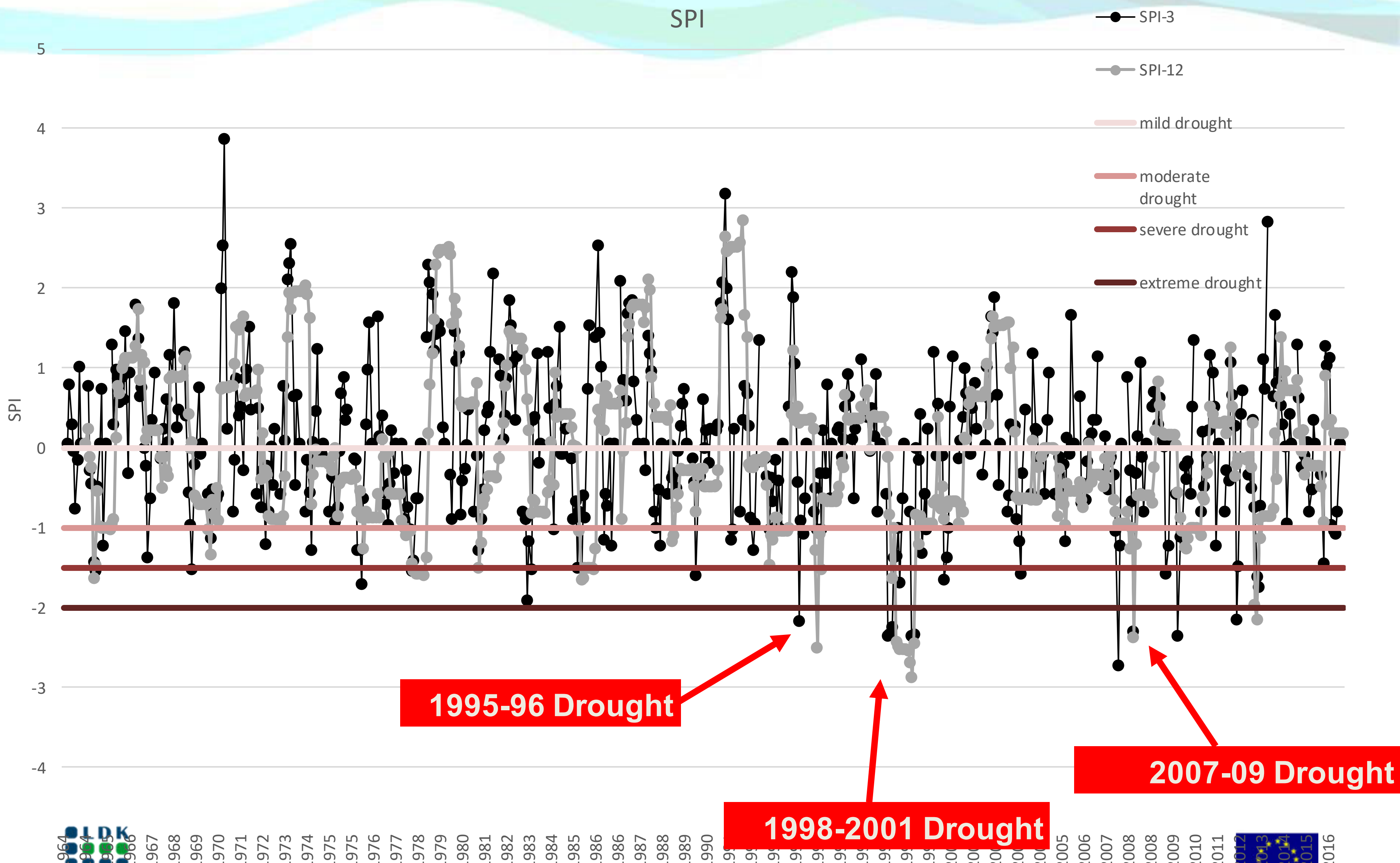
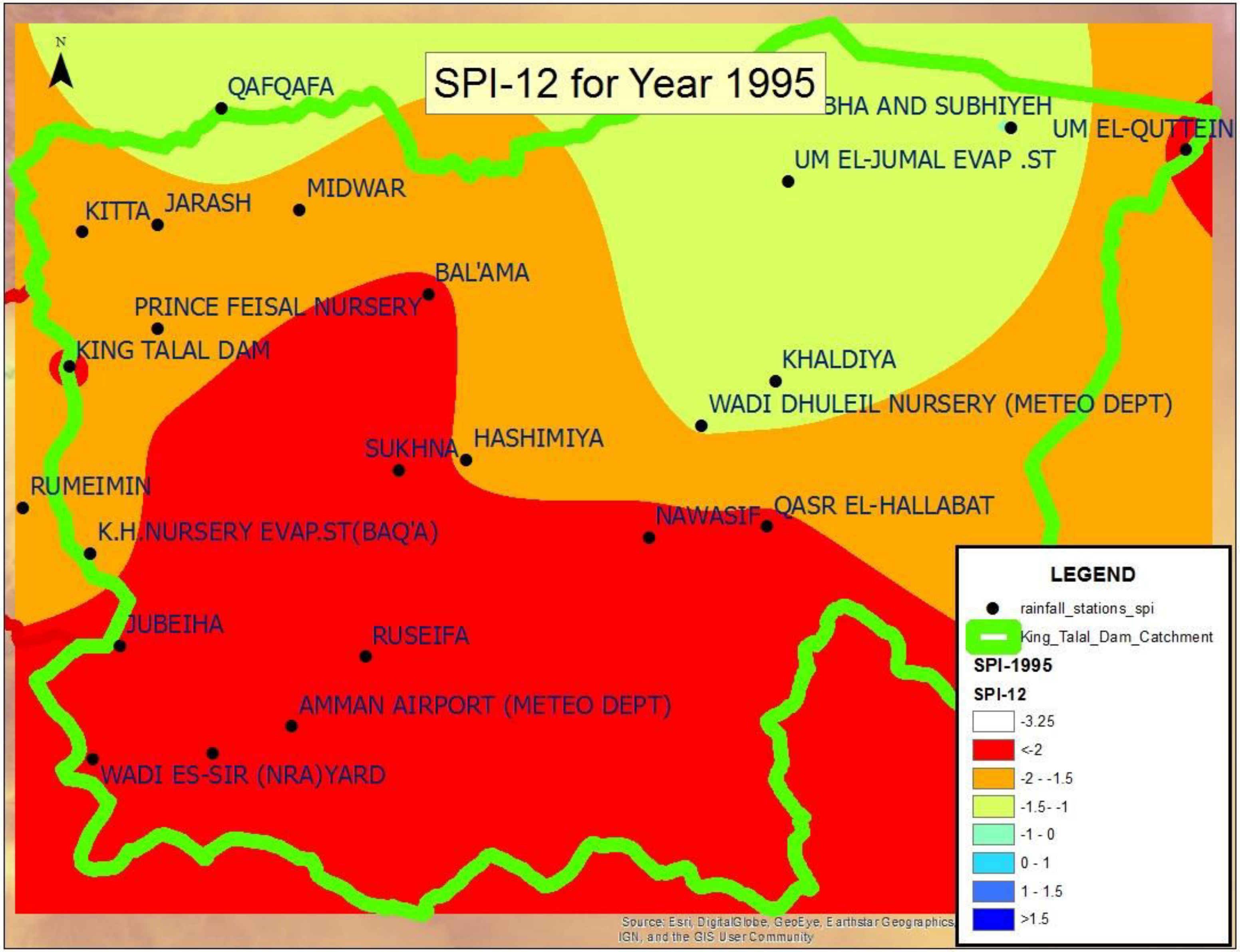
Amman Zarqa Basin - SPI 3 & SPI-12 (1965-2017)



Amman Zarqa Basin - SPI 3 & SPI-12 (1965-2017)



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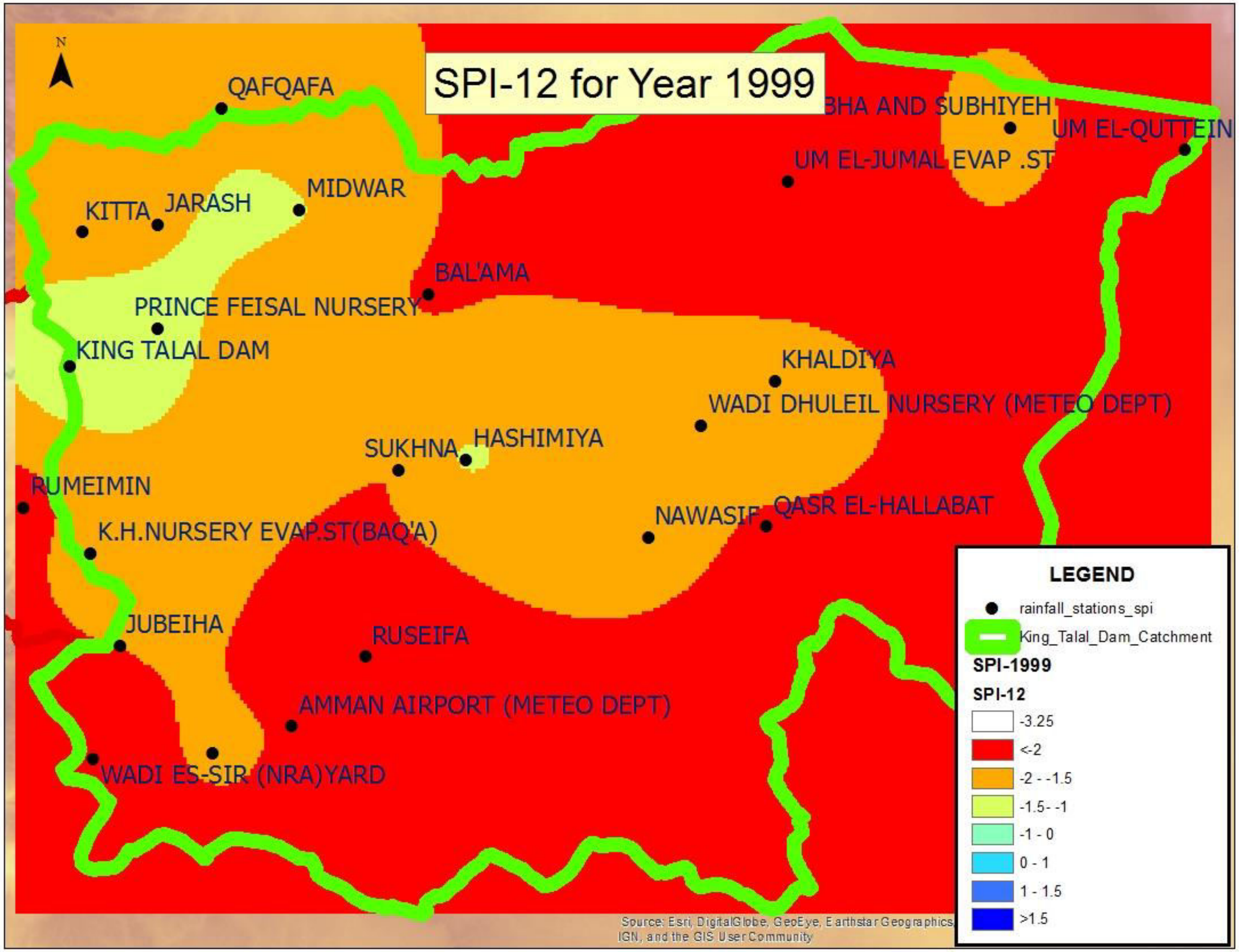
Amman Zarqa Basin - SPI 3 & SPI-12 (1965-2017)



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Reconnaissance Drought Index (RDI)

1. Introduction

The Reconnaissance Drought Index (RDI) was developed to approach the water deficit in a more accurate way, as a sort of balance between input and output in a water system (Tsakiris and Vangelis 2005; Tsakiris et al. 2007c). It is based both on cumulative precipitation (P) and potential evapotranspiration (PET), which are one measured (P) and one calculated (PET) determinant.

2. Calculation

The initial value (αk) of RDI is calculated for the i-th year in a time basis of k (months) as follows:

$$\alpha_k^{(i)} = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} PET_{ij}}, \; i = 1(1)N \;\; \text{and} \;\; j = 1(1)k$$

in which Pij and PETij are the precipitation and potential evapotranspiration of the j-th month of the i-th year and N is the total number of years of the available data.

Reconnaissance Drought Index (RDI)

2. Calculation

The values of α_k follow satisfactorily both the lognormal and the gamma distributions in a wide range of locations and different time scales, in which they were tested (Tigkas 2008; Tsakiris et al. 2008). By assuming that the lognormal distribution is applied, the following equation can be used for the calculation of RDIst:

$$RDI_{st}^{(i)} = \frac{y^{(i)} - \overline{y}}{\hat{\sigma}_y}$$

in which $y^{(i)}$ is the $\ln(\alpha_k^{(i)})$, y is its arithmetic mean and σ_y is its standard deviation.

In case the gamma distribution is applied, the RDIst can be calculated by fitting the gamma probability density function (pdf) to the given frequency distribution of α_k (Tsakiris et al. 2008; Tigkas 2008). For short reference periods (e.g. monthly or 3-months) which may include zero values for the cumulative precipitation of the period, the RDIst can be calculated based on a composite cumulative distribution function including the probability of zero precipitation and the gamma cumulative probability.

Reconnaissance Drought Index (RDI)

3. Categorization

Positive values of RDIst indicate wet periods, while negative values indicate dry periods compared with the normal conditions of the area. Drought severity can be categorised in mild, moderate, severe and extreme classes, with corresponding boundary values of RDIst (-0.5 to -1.0), (-1.0 to -1.5), (-1.5 to -2.0) and (< -2.0), respectively.

RDI values	Classification
2.0 or more	Extremely Wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately Wet
-.99 to .99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Severely Dry
-2 or less	Extremely Dry

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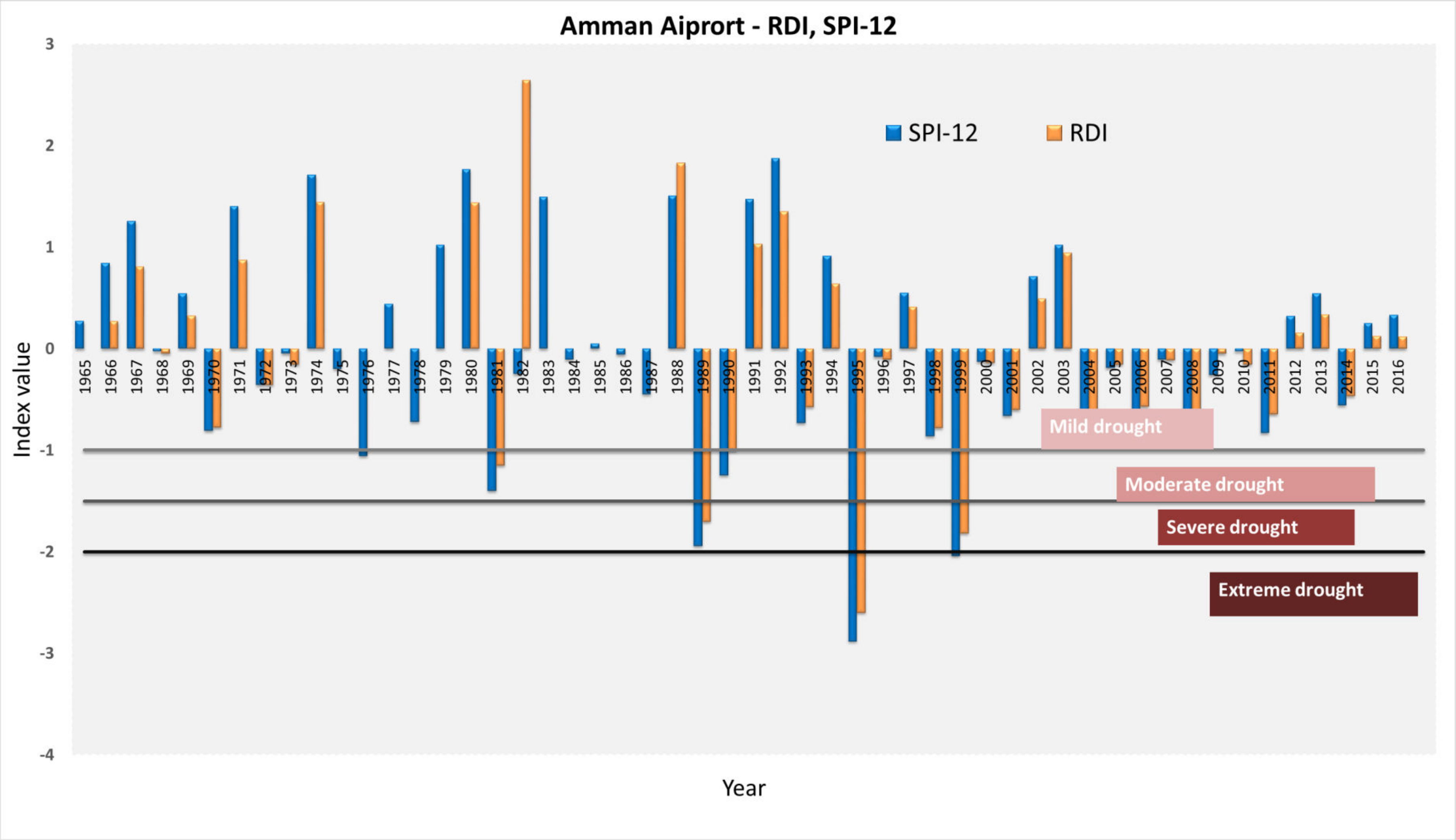
Amman Airport –SPI-12 & RDI (1965-2017)



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Drought Hazard Index (DHI)

1. First Step

The **12-month Standard Precipitation Index (SPI-12)** is proposed as the basis for the analysis of the meteorological drought episodes since it can capture long-term precipitation patterns usually associated with streamflows, reservoir levels and groundwater levels as water level fluctuations are very sensitive.

The 12-month SPI allows for the comparison of the cumulative precipitation of 12 consecutive months every year within the selected study period. It presents the advantage of eliminating seasonality (applicable in smaller temporal scales) and capturing signals of distinctive wet or dry trends. Based on the values of the SPI-12 the drought episodes within the reference period can be been identified in each rain gauge. A drought episode is identified when the SPI-12 first falls below zero (onset of the episode) and continuous to increase reaching a value equal or less than -1. When SPI-12 reaches again its first positive value this event has ended. If an SPI-12 value equal or less than -1 has not been reached, then this event is not characterized as drought (i.e. it is just low precipitation event but cannot be characterized as a drought episode).

Drought Hazard Index (DHI)

2. Second Step

The second step involved the post-processing of the SPI-12 results to derive four new sub-indicators that can reflect the magnitude, severity, duration, and recurrence of the drought hazard in each rain gauge. The focus of this meta-analysis is to derive operational indicators each one reflecting common drought hazard characteristics, easy to reproduce, and blend into a Drought Hazard Index. The following sub-indicators have been defined, to be computed at each rain gauge.

Following the calculation of the four sub-indicators for each rain gauge, a classification must be elaborated, assigning four classes and relevant 1-4 scores (less to more significant) across all gauges and for the same time periods.

Drought Hazard Index (DHI)

2. Second Step

FRQ: **Number of drought episodes (events) observed** within the reference period (expressed as absolute number or as % over the total duration of the period of analysis). This sub-indicator is used as metrics of "recurrence".

FRQ24: **Number of drought episodes with duration greater than 24 months,** within the reference period. This sub-indicator is used as a sensible descriptor of prolonged drought and thus metrics of "severity".

DMmax: **Maximum drought magnitude observed** within the reference period. This subindicator is used as metrics of "magnitude".

dmax: **Maximum duration (in months) among the drought episodes observed** within the reference period. This sub-indicator is used as metrics of "duration".

Drought Hazard Index (DHI)

3. Classification and scores of the drought hazard sub-indicators for a 50-year reference period

Classification thresholds for each sub-indicator				
FRQ *Number of episodes (% over the years of the period)*	**FRQ24** *Number of episodes with d>24 months*	**DMmax** *Maximum Magnitude*	**dmax** *Maximum duration*	**Assigned Score / Class**
1 – 2 (≤5%)	1	1 ≤ 35.0	24 – 36	1
3 – 5 (5.1% - 10%)	2	35.1 – 50.0	37 – 48	2
6 – 10 (10.1% - 20%)	3	50.1 – 70.0	49 – 60	3
11 - 20 (> 20%)	≥ 4	≥ 70.1	≥ 61	4

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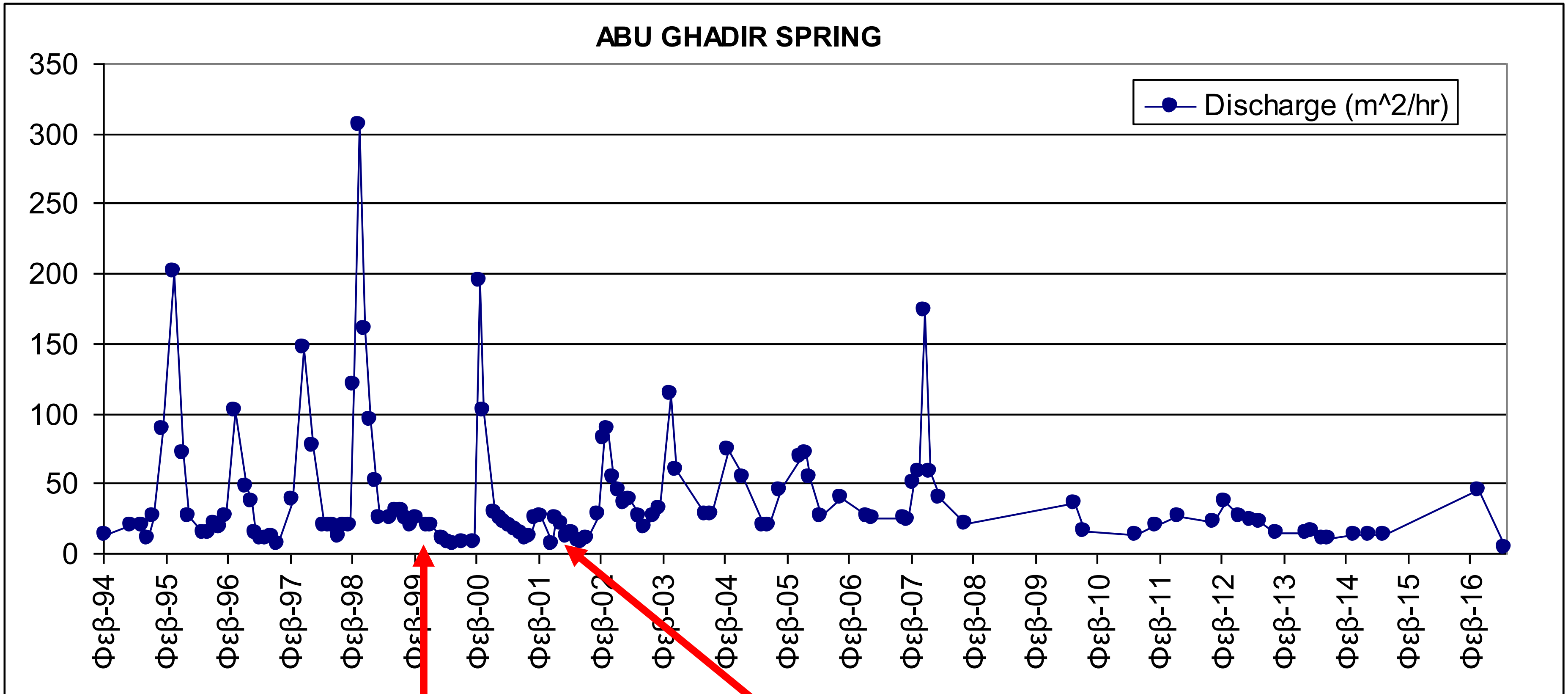
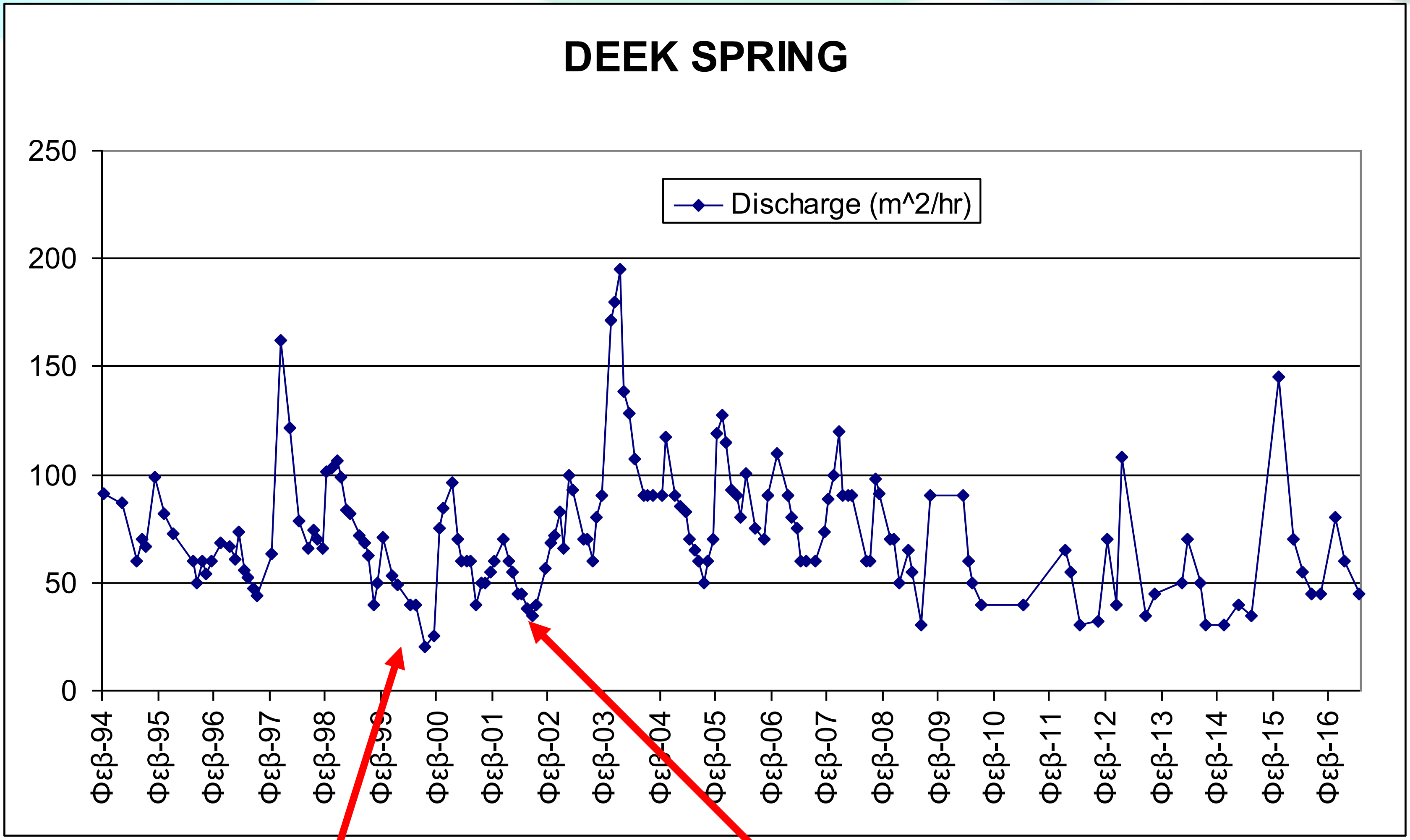
Spring Runoff and Drought Periods



Drought Magnitude (Kitta Station): 18.6

Drought Magnitude (Kitta Station): 14.1

Spring Runoff and Drought Periods



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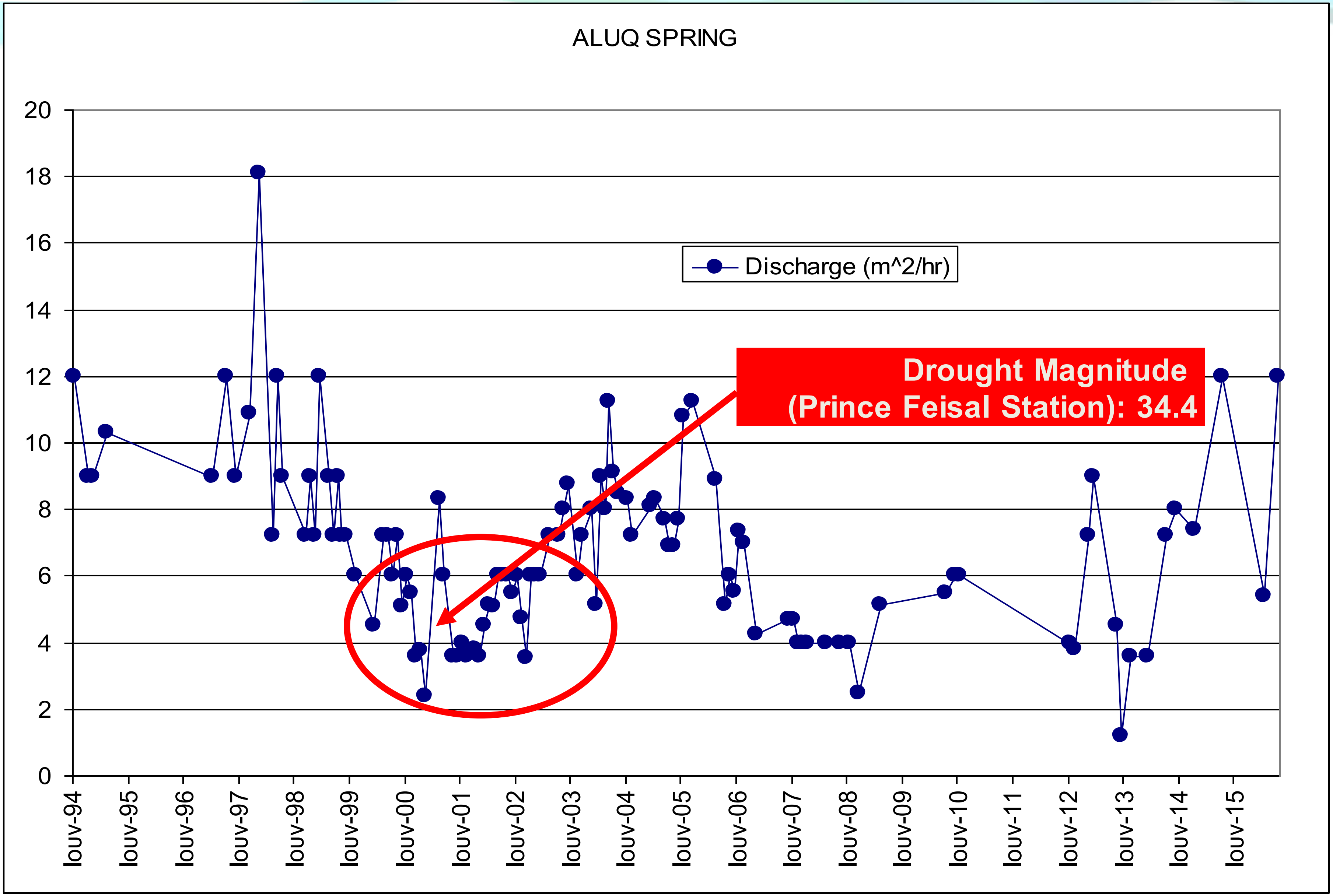

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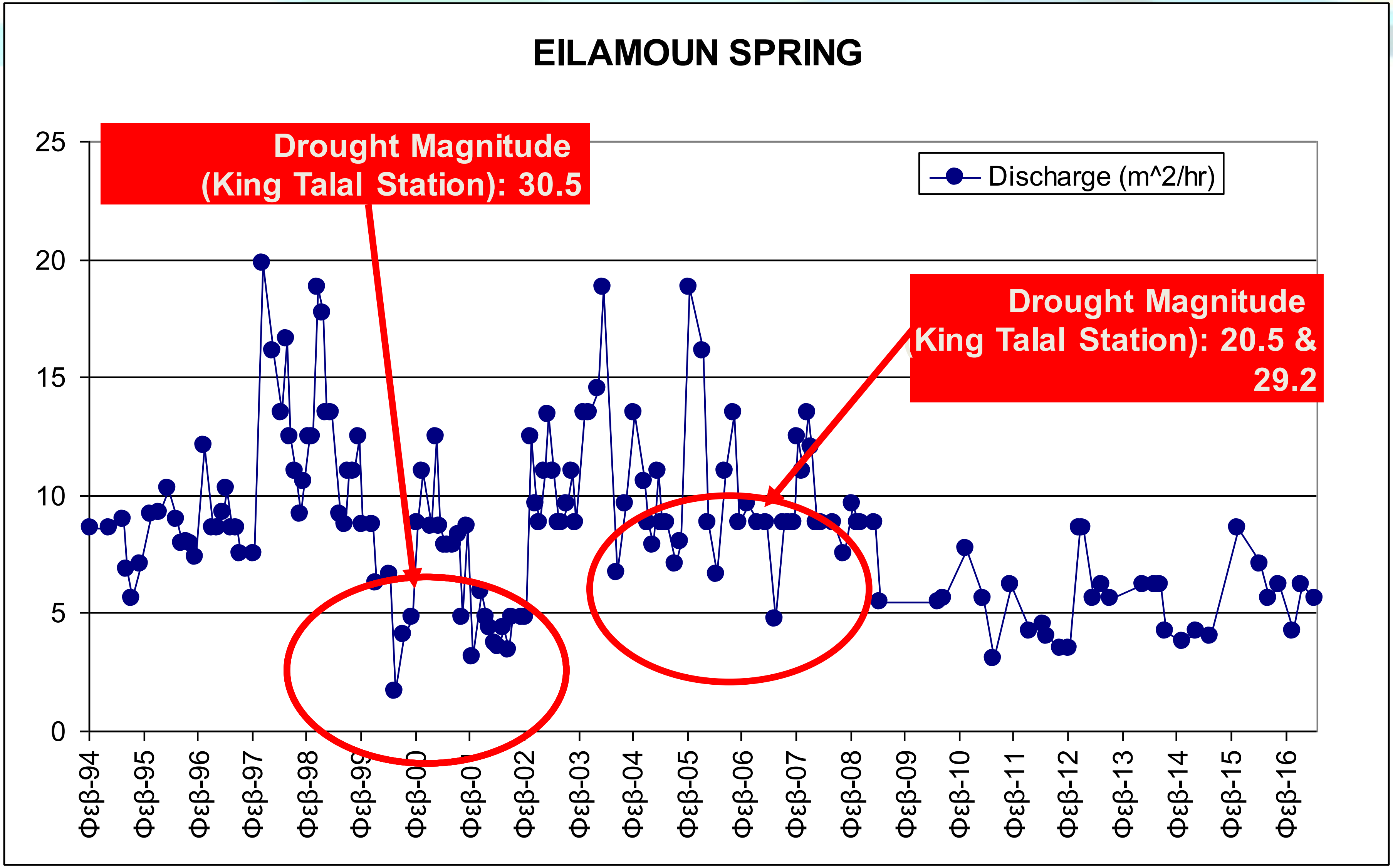

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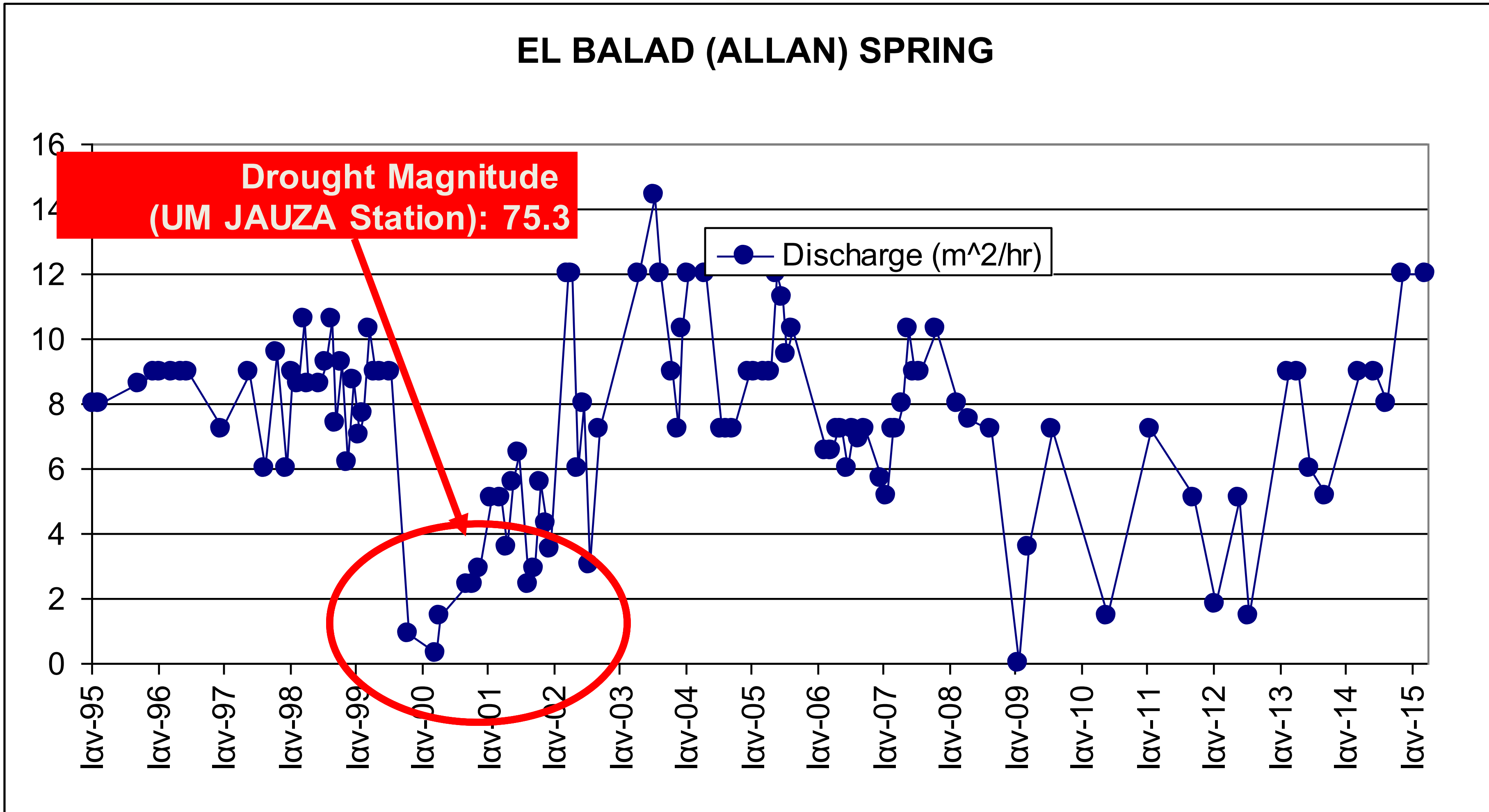
Spring Runoff and Drought Periods



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Drought Hazard Index (DHI)

6. Classification of the DHI

DHI value	Score / Class
1.00 – 1.49	1 – low
1.50 – 1.99	2 – moderate
2.00 – 2.49	3 – severe
≥ 2.50	4 – extreme

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Drought Hazard Index (DHI)

Station_Na	FRQ	FRQ24	Drmax	dmax	Orienation
HASHIMIYA	7	2	84.71	67	C
SUKHNA	11	3	99.43	95	C
KHALDIYA	9	4	35	50	E
WADI DHULEIL NURSERY	9	4	79.07	70	E
BAL'AMA	11	4	41.12	62	N
MIDWAR	13	5	33.57	34	N
QAFQAFA	12	4	62.36	37	N
SABHA AND SUBHIYEH	7	5	38.37	40	NE
SUBEIHI	10	4	61.89	62	NE
UM EL-JUMAL EVAP .ST	11	4	55.63	29	NE
UM EL-QUTTEIN	8	5	59.65	57	NE
UM JAUZA	10	4	75.27	50	NE
BEIR EL-AD'AM	15	4	28.14	37	NW
JARASH	15	4	56.31	62	NW
KING TALAL DAM	12	4	47.75	41	NW
KITTA	14	2	42.46	36	NW
PRINCE FEISAL NURSERY	10	4	65.53	56	NW
RUMEIMIN	8	5	48.32	58	NW
NAWASIF	11	3	79.75	69	SE
QASR EL-HALLABAT	10	5	41.17	36	SE
AMMAN AIRPORT (METEO	13	3	45.11	39	SW
AMMAN HUSSEIN COLLEG	14	4	30.68	33	SW
JUBEIHA	14	3	39.6	36	SW
K.H.NURSERY EVAP.ST(BA	15	3	47.84	50	SW
RUSEIFA	11	2	55.99	59	SW
WADI ES-SIR (NRA)YARD	15	4	46.24	39	SW

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Drought Hazard Index (DHI)

5. Calculation of Composite DHI

It is determined that unequal weights for one of four subindicators (i.e. frequency of drought events is not that critical since most of them have low magnitudes). As follows, the sub-indicators are blended to derive a DHI value for each rain gauge for the entire study period (as well as for sub-periods if desired) based on the following equation:

$$DHI = (\theta_1 \times score_{FRQ}) + (\theta_2 \times score_{FRQ24}) + (\theta_3 \times score_{DM\max}) + (\theta_4 \times score_{d\max})$$

where θ_i are the weights of the sub-indicators (θ_1=0.1, θ_2-θ_4=0.3)

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Drought Hazard Index (DHI)

Station_Na	FRQ	FRQ24	Drmax	dmax	SCORE	CLASS
HASHIMIYA	3	2	4	4	3.3	4
SUKHNA	4	3	4	4	3.7	4
KHALDIYA	3	4	3	3	3.3	4
WADI DHULEIL NURSERY	3	4	4	4	3.9	4
BAL'AMA	4	4	4	4	4	4
MIDWAR	4	4	1	1	2.2	3
QAFQAFA	4	4	2	2	2.8	4
SABHA AND SUBHIYEH	3	4	2	2	2.7	4
SUBEIHI	3	4	3	4	3.6	4
UM EL-JUMAL EVAP .ST	4	4	3	1	2.8	4
UM EL-QUTTEIN	3	4	3	3	3.3	4
UM JAUZA	3	4	4	3	3.6	4
BEIR EL-AD'AM	4	4	1	2	2.5	4
JARASH	4	4	3	4	3.7	4
KING TALAL DAM	4	4	2	2	2.8	4
KITTA	4	2	2	1	1.9	2
PRINCE FEISAL NURSERY	3	4	3	3	3.3	4
RUMEIMIN	3	4	2	3	3	4
NAWASIF	4	3	1	4	2.8	4
QASR EL-HALLABAT	3	4	2	1	2.4	3
AMMAN AIRPORT (METI	4	3	2	2	2.5	4
AMMAN HUSSEIN COLLI	4	4	1	1	2.2	3
JUBEIHA	4	3	1	1	1.9	2
K.H.NURSERY EVAP.ST(B.	4	3	2	3	2.8	4
RUSEIFA	4	2	3	3	2.8	4
WADI ES-SIR (NRA)YARI	4	4	2	2	2.8	4

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Short – Term Drought Early Warning System for Amman

1. Rainfall Data on Amman Airport Station from 1937

- Analyses between the first two months of the hydrologic year and the 7 months with rainfall of a given year.
- Calculate deciles of the rainfall data for cumulative rainfall for October – November and October – April.
- Calculate the probability that when the cumulative rainfall for October – November period is below the lower 20% percentile (very dry conditions), the cumulative rainfall for October – April also is below the corresponding 20% lower percentile. This probability is calculated equal to 0.56.
- Calculate the probability that when the cumulative rainfall for October – November period is below the lower 30% percentile (also very dry), the cumulative rainfall for October – April also is below the corresponding 30% lower percentile. This probability is increased and calculated equal to 0.63.

Short – Term Drought Early Warning System for Amman

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1937	4.6	14	1.1	97	132.8	66.4	1.3	24.1	0	0	0	0	341.3
1938	0.2	121.5	28.2	24.8	79.4	84.8	4.3	0	0	0	0	0	343.2
1939	3.3	71.8	20.4	124.1	5.2	30	31.4	0	0	0	0	0	286.2
1940	8.4	42.7	59	61.6	22.4	24	6.2	0	0	0	0	0	224.3
1941	2.2	3.5	155.1	56.9	86.6	96.9	0.3	0	0	0	0	0	401.5
1942	54.6	27.8	18.6	105.4	50.5	86.7	34.3	2.3	0	0	0	0	380.2
1943	4.5	0.6	18.2	141.7	12.6	20.2	11.7	13	0	0	0	0	222.5
1944	0	136.8	94	100.2	105.5	19.3	4.6	19.6	0	0	0	0	480
1945	0	33.7	60.4	15.3	120.3	26.1	0.9	30.6	0	0	0	0	287.3
1946	0.2	3.5	29.2	65	8.2	21	8.6	1.4	0	0	0	0	137.1
1947	0	22.2	21	92.8	69.1	76.1	12.8	1.3	0	0	0	0	295.3
1948	2.1	12.4	44.3	74.9	123.9	116	52.5	2	0	0	0	0	428.1
1949	0	0	92.3	74.1	77.3	31.5	11.5	15.4	0	0	0	0	302.1
1950	0	16.7	8.2	28.1	60.3	15.4	0.3	0	0	0	0	0	129
1951	0.9	19.9	179.8	35.6	79.7	46.9	0.4	0	0	0	0	0	363.2
1952	8.5	3.9	12.3	29.3	81.3	168.5	1.8	0	0	0	0	0	305.6
1953	1.5	91.2	60.5	17.7	90.3	12.8	16.2	0	0	0	0	0	290.2
1954	3.2	37.1	67.5	13.7	15.8	17.4	4.5	0	0	0	0	0	159.2
1955	0.4	91	62	67.1	16.2	68.2	24.4	2.4	0	0	0	0	331.7

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
20% PERCENTILE	0.0	4.4	15.1	26.4	18.8	18.2	0.8	0.0	0	0	0	0	194.94

CONSULTANTS

DROUGHT MONITORING & PLANNING SYSTEM

ALERT LEVEL	MAIN INDEX
	SPI-12
ALERT OFF	> 0
LOW ALERT	-1 < SPI < 0
MODERATE ALERT	-1.5 < SPI < -1
HIGH ALERT	-2 < SPI < -1.5
EXTREMELY HIGH	< -2

LDK CONSULTANTS

DROUGHT MONITORING & EARLY WARNING SYSTEM

Month	SPI-3 & SPI-12	Early Warning System	Estimate Severe Irrigation Cuts to Farmers	Groundwater Bodies
OCT	SPI-12 Calculation - Implementation of Alert System SPI-3 for rainfed agriculture After the end of the drought event, Drought Magnitude is estimated and DHI is attributed.			Evaluation of annual variation (drawdown) of aquifer levels and spring discharge taking into account SPI 12 in selected wells and springs in each aquifer.
NOV		Calculate Rainfall Depth for Oct - Nov and calculate decile. If less than 20% then..	First Warning Issue to Farmers	
DEC		Calculate Rainfall Depth for Oct - Dec and calculate decile. If less than 20% then..	Update Warning Issue to Farmers	
JAN		Monitoring Storage in King Talal Dam and GW levels		
FEB			Update Warning Issue to Farmers	
MAR				
APR		Calculate Rainfall Depth for Oct - April and calculate decile. Storage in King Talal Reservoit	Final Issue to Irrigation Cut to Farmers.	
MAY				
JUN				
JUL				
AUG				
SEP				

SWIM and Horizon 2020 Support Mechanism

Working for a Sustainable Mediterranean, Caring for our Future

Thank you for your attention.

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