SWIM and Horizon 2020 Support Mechanism

Working for a Sustainable Mediterranean, Caring for our Future

# Mainstreaming Drought Risk Management, with a focus on proactive measures

## Technical training on drought monitoring and early warning system in Amman-Zarqa Basin (AZB), 23-26 July, 2018

## Ministry of Water and Irrigation, Amman – Jordan

Presented by:

**Mr. Demetris ZARRIS,** NKE Drought Hazard

This Project is funded by the European Union

# SWIM-H2020 SM in a Snapshot

## SWIM and Horizon 2020 Support Mechanism

**Working for a Sustainable Mediterranean, Caring for our Future**

## Profile

The **SWIM-H2020 SM Project**, funded by the European Union, aims to contribute to reduced marine pollution and a sustainable use of scarce water resources in the Mediterranean Region with emphasis on the **countries of North Africa and the Middle East (Algeria, Egypt, Israel, Jordan, Lebanon, [Libya], Morocco, Palestine, [Syria] and Tunisia).**

## Components of the Project

The Project is the continuation and merging of two successful previous EU-funded service contracts, Horizon 2020 Capacity Building/Mediterranean Environment Programme (H2020 CB/MEP) (2009-2014) and the Sustainable Water Integrated Management Support Mechanism (SWIM SM) (2010-2015).

This Project is funded by the European Union

# SWIM-H2020 SM

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## The Project is to:

- Provide tailored and targeted technical assistance at national level based on partners' requests through an Expert Facility;
- Organize regional (or sub-regional) peer-to-peer seminars and webinars;
- Conduct on-site training courses and study tours;
- Capitalize on the lessons learnt, good practices and success stories;
- Support logistically and technically the Horizon 2020 Initiative's Steering Group & Sub Groups and the Meetings of the Union for the Mediterranean's Water Experts Group.

# SWIM-H2020 SM Expected Results



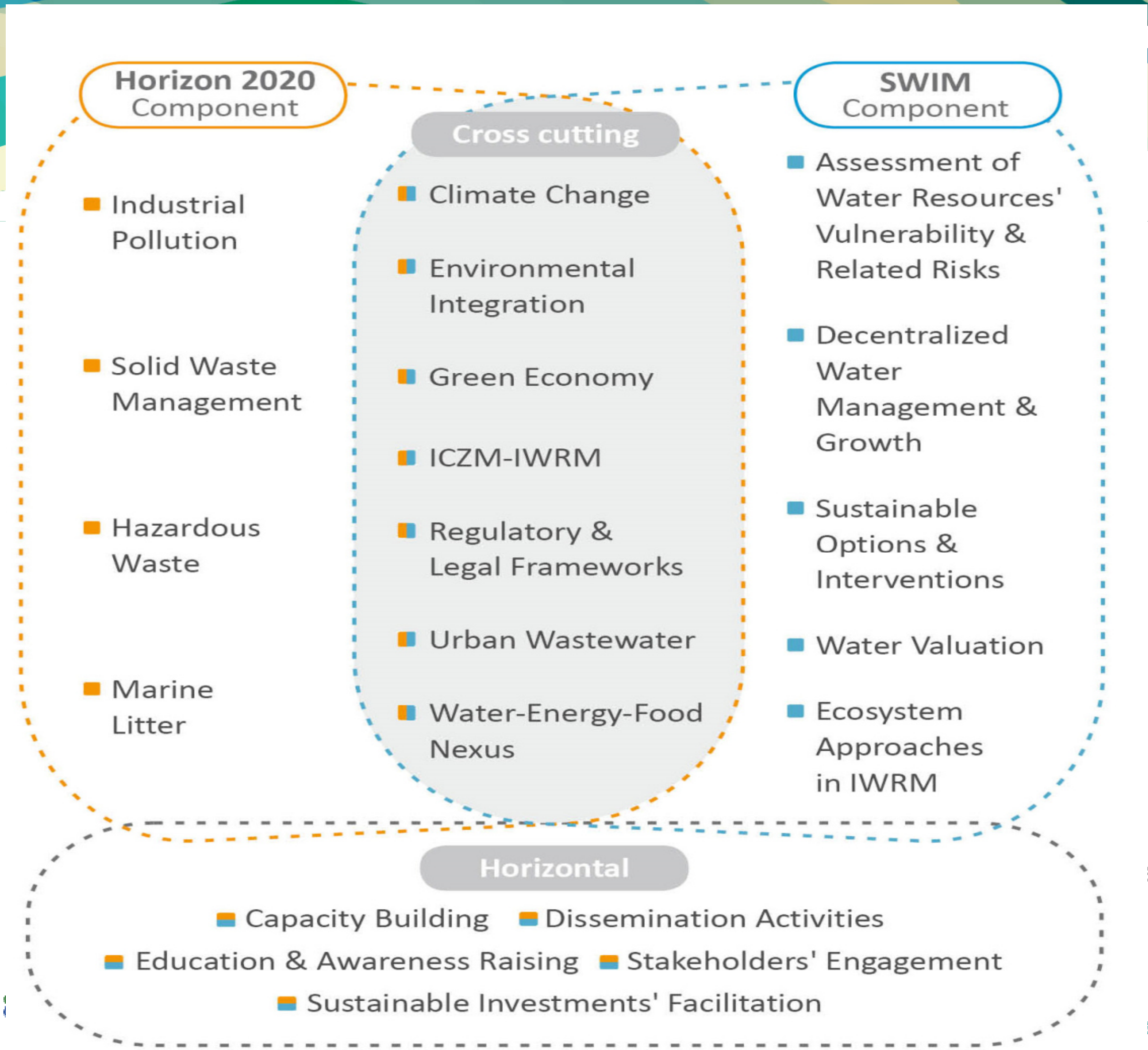
## In order to Achieve:

- Positive changes in the design and implementation of the relevant national institutional, policy and regulatory frameworks;
- Enhancement of partner countries' capacity to promote investment and business opportunities for properly managing municipal waste, industrial emissions and waste water;
- Facilitation of access to finance for selected sustainable investment projects;
- Strengthening of regional coherence and cooperation in approaches to marine pollution prevention and control, and sustainable water management;
- Identification, testing and sharing of best practices and success stories;
- Use of research results in policy making – enhancement of more sustainable practices.

# SWIM-H2020 SM Themes

SWIM and Horizon 2020 Support Mechanism

for our Future




an Union

# Framework of Cooperation

The project is based on synergies, which are further developed and supported through:

● **The SWIM-H2020 SM Focal Points (FPs)** in the Ministries in charge of Water and Environment of the Partner Countries, which also constitute the SWIM-H2020 SM Steering Committee.

● **Regional bodies forming the Institutional Partners** of the Project, namely:

- the **Union for the Mediterranean (UfM)**, assisting on issues linked with the draft Strategy for Water in the Mediterranean, the Water Strategy in the Western Mediterranean (5+5), projects and investments related with Mediterranean pollution Hot Spots.
- the **Mediterranean Action Plan of UNEP (UNEP/MAP)**, supporting activities related to the Land Based Sources (LBS), the Hazardous Wastes and Integrated Coastal Zone Management (ICZM) Protocols of the Barcelona Convention as well as the revised National Action Plans (NAPs).

● **Relevant EU Institutions** (including DG ENV, NEAR, Research, MARE, etc.) such as the European Investment Bank (EIB) which coordinates the Mediterranean Hot Spots Investment Programme II (MeHSIP II) and **Agencies** such as the European Environment Agency (EEA), which coordinates the Shared Environmental Information System (SEIS) South.

● **Other Regional Initiatives and Projects** (SwitchMed, CLIMA South, etc.).

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# SWIM-H2020 SM Identity

## SWIM and Horizon 2020 Support Mechanism

**Working for a Sustainable Mediterranean, Caring for our Future**

### Partner countries:

Algeria, Egypt, Israel, Jordan, Lebanon, [Libya], Morocco, Palestine, [Syria], Tunisia
Participation of Albania, Bosnia Herzegovina, Mauritania, Montenegro and Turkey in regional activities will be considered.

### Contracting Authority:

Directorate-General for Neighborhood and Enlargement Negotiations (DG NEAR)

### SWIM-H2020 SM Team:

Mr. Stavros Damianidis, Project Director
Prof. Michael Scoullos, Team Leader
Mrs. Suzan Taha, Water Expert
Mr. Ismail Anis, Environment Expert

### Duration:

39 months (2016-2019)

### Budget:

6.625.000 Euros

This Project is funded by the European Union

# SWIM-H2020 SM Consortium

## SWIM and Horizon 2020 Support Mechanism

Working for a Sustainable Mediterranean, Caring for our Future

LDK Consultants S.A. (Leader)
LDK Consultants Europe S.A.

Arab Countries Water Utilities Association (ACWUA)

Arab Network for Environment and Development "RAED“

Association of Cities & Regions for Recycling and Sustainable Resource Management (ACR+)

Catalan Waste Agency (hosting institution of Regional Activity Centre for Sustainable Consumption and Production (SCP/RAC))

EEIG UT – SEMIDE

GLOBE ONE LTD

Haskoning DHV Nederland B.V.

Mediterranean Information Office for Environment, Culture and Sustainable Development (MIO - ECSDE)

Milieu Ltd

National and Kapodistrian University of Athens (UoA)

Umweltbundesamt GmbH

WS Atkins International Ltd

## RAINFALL DATA

- Objective: To construct one rainfall dataset for the whole of the catchment.
- Total number of rainfall stations: The total number of rainfall stations in the catchment must be satisfactory.
- Spatial distribution: Rainfall stations should have a satisfactory distribution across the catchment both in the horizontal but also in all parts of the catchment's elevation.
- Temporal distribution: Dataset for all stations should cover a satisfactory length in time so as to be representative for all historic climatic regimes.

# QUALITY CHECK FOR RAINFALL DATA

- **Level of aggregation:** Understand your primary data. The original time step (daily, accumulated across days with rainfall) and construct monthly timeseries. Decide on the time frame duration according to data availability.
- **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.

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## QUALITY CHECK FOR RAINFALL DATA

- Correlation matrix: Correlation matrix between all annual rainfall and monthly values between all stations. Define rainfall stations with constant high correlation values especially with the adjacent stations. Select the ones as base 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).

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# 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.

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## 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).

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# COMPUTATION OF THE POTENTIAL EVAPOTRANSPIRATION

- Quality Check of the associated data: Data for PET are often vast and demanding. Temperatures, relative humidity, wind speed (height of 2m) and sunshine duration, for a satisfactory meteorological stations number for a time duration is rare even in developed countries.
- Variety of Methods: According to necessary data, methods of computing PET can be very complex (e.g. the Penman-Monteith) to very simple (e.g. Blaney-Criddle).

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# PENMAN -MONTEITH

•Developed by Howard Penman in 1948 (later modified by John Monteith et al. to yield the Penman–Monteith model)
•Well established and a basis for further theoretical development in the field of evaporation research
•Basically a combination of turbulent transfer and energy-balance approaches (3 equations)

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## PENMAN -MONTEITH

$$ET_{ref} = \left( \frac{\Delta (R_n - G) + K_{time}\, \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma \left( 1 + \frac{r_s}{r_a} \right)} \right) / \lambda$$

| | | |
|---|---|---|
| ρ | = | Density of the air |
| c | = | Specific heat of the air |
| ea | = | Saturation vapor pressure at mean air temperature |
| es | = | Saturation vapor pressure at dew point |
| rs | = | Total surface resistance |
| ra | = | Aerodynamic resistance |
| λ | = | Latent heat of vaporization |
| γ | = | Psychrometric constant |
| Δ | = | Rate of change of es with temperature |

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# HARGREAVES

$$ET_o = 0.0023\,(T_{max} - T_{min})^{0.5}\,(T_{mean} + 17.8)\,R_a$$

**Originally developed in 1975**

solar radiation and temperature data inputs

**Updated in 1982 and 1985**

**Grass reference ET (ETo)**

**Can be used to compute daily estimates**

solar radiation estimated from extraterrestrial radiation **Rn=So/λ, So: extraterrestrial radiation ($kg/m^2d$) – λ: latent heat (kJ/kg) ---- depending on latitude and longitude**

# HARGREAVES

- Simple, easy to use
- Minimal data requirements—maximum and minimum air temperature
- Better predictive accuracy in arid climates than modified Blaney-Criddle
    - Max-min temperature difference
    - Extra-terrestrial radiation

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# 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.

# Types of Drought

## 1. Meteorological

Meteorological drought is usually an expression of precipitation's departure from normal over time.

## 2. Hydrological

Hydrological drought refers to deficiencies in surface and subsurface water supplies.

## 3. Agricultural

Agricultural drought occurs when there isn't enough soil moisture to meet the needs of a particular crop.

## 4. Socioeconomic

Socioeconomic drought occurs when physical water shortage affect supply and demand of economic goods.

# Measures within a Drought Risk Management Plan (DRMP)



A Drought Risk Management Plan should contain:

- Indicators: Each drought phase is defined by indicators and thresholds establishing the onset, ending, and severity levels of the exceptional circumstances (prolonged drought)
- Measures to be taken in each drought phase in order to prevent deterioration of water status and to mitigate negative drought effects.

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# The Decile Index

## 1.Description

In this approach suggested by Gibbs and Maher (1967) and widely used in Australia (Coughlan, 1987), monthly precipitation totals from a long-term record are first ranked from highest to lowest to construct a cumulative frequency distribution. The distribution is then split into 10 parts (tenths of distribution or deciles).

The first decile is the precipitation value not exceeded by the lowest 10% of all precipitation values in a record. The second decile is between the lowest 10 and 20% etc. Comparing the amount of precipitation in a month (or during a period of several months) with the long-term cumulative distribution of precipitation amounts in that period, the severity of drought can be assessed. The deciles are grouped into five classes, two deciles per class. If precipitation falls into the lowest 20% (deciles 1 and 2), it is classified as **much below normal**. Deciles 3 to 4 (20 to 40%) indicate **below normal precipitation**, deciles 5 to 6 (40 to 60%) indicate near normal precipitation, 7 and 8 (60 to 80%) indicate above normal precipitation and 9 and 10 (80 to 100%) indicate much above normal precipitation.

# 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). Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. Since SPI is normalised, wetter and drier climates can be represented in the same way.

## 2. SPI*n* represented by the Gamma distribution function

Thom (1958) found the gamma distribution to fit well to the climatological precipitation time series. The gamma distribution is defined by its frequency or probability density function:

$$g(x) = \frac{1}{\beta^{a}\Gamma(a)} x^{a-1} e^{-x/\beta}, \quad \text{for } x > 0$$

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

## 2. SPI*n* represented by the Gamma distribution function

in which $\alpha$ and $\beta$ are the shape and scale parameters respectively, x is the precipitation amount and $\Gamma(\alpha)$ is the gamma function. Parameters $\alpha$ and $\beta$ of the gamma pdf are estimated for each station and for each time scale of interest (1, 3, 6, 9, 12 months, etc.).

Since the gamma function is undefined for $x = 0$ and a precipitation distribution may contain zeros, The cumulative probability distribution is then transformed into the standard normal distribution to yield the SPI.

## 3. 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.

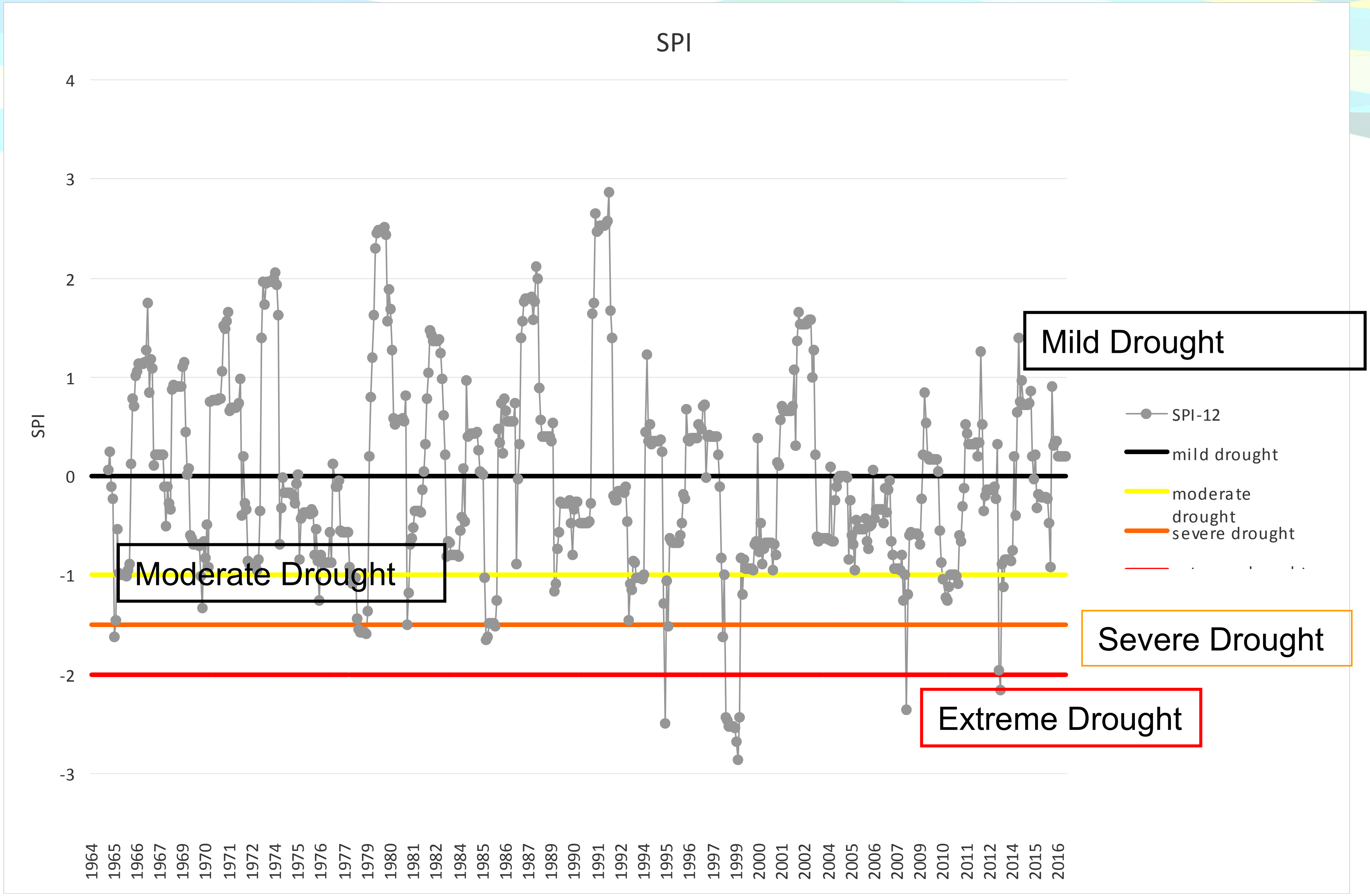
Drought magnitude is the positive sum of the SPI for each month during the drought event.

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

## 4. Drought Classification according to SPI

in which $\alpha$ and $\beta$ are the shape and scale parameters respectively, x is the precipitation amount and $\Gamma(\alpha)$ is the gamma function. Parameters $\alpha$ and $\beta$ of the gamma pdf are estimated for each station and for each time scale of interest (1, 3, 6, 9, 12 months, etc.).

| 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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Mild Drought
Moderate Drought
Severe Drought
Extreme Drought
SPI-12
mild drought
moderate drought
severe drought
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# Drought Hazard Indicator based on Rainfall (Standardized Precipitation Index, SPI*n*

## 4. Drought Categorization according to SPI

Depending on probabilities.

| SPI | Category | Number of times in 100 years | Severity of event |
|---|---|---|---|
| 0 to -0.99 | Mild dryness | 33 | 1 in 3 yrs. |
| -1.00 to -1.49 | Moderate dryness | 10 | 1 in 10 yrs. |
| -1.5 to -1.99 | Severe dryness | 5 | 1 in 20 yrs. |
| < -2.0 | Extreme dryness | 2.5 | 1 in 50 yrs. |

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

## 5. Main characteristics of SPI

The SPI calculated in this way has the following desirable traits:

•The SPI is uniquely related to probability.

•The precipitation used in SPI can be used to calculate the precipitation deficit for the current period.

•The precipitation used in SPI can be used to calculate the current percent of average precipitation for time period of i months.

•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.

•Its standardization, which ensures that the frequency of extreme events at any location and on any time scale are consistent.

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

## 5. Main characteristics of SPI

The SPI calculated in this way has the following disadvantages:

- The assumption that a suitable theoretical probability distribution can be found to model the raw precipitation data prior to standardization. An associated problem is the quantity and reliability of the data used to fit the distribution. McKee et al. (1993) recommend using at least 30 years of high-quality data.
- A second limitation of the SPI arises from the standardized nature of the index itself; namely that extreme droughts (or any other drought threshold) measured by the SPI, when considered over a long time period, will occur with the same frequency at all locations. Thus, the SPI is not capable of identifying regions that may be more 'drought prone' than others.
- A third 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 Hazard Indicator based on Rainfall (Standardized Precipitation Index, SPI*n*

## 5. Main characteristics of SPI

The SPI calculated in this way has the following desirable traits:

- 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, anywhere from 1-month to 6-month SPI for agricultural drought, and something like 6-month up to 24-month SPI or more for hydrological drought analyses and applications.
- 1-month SPI: A 1-month SPI map is very similar to a map displaying the percentage of normal precipitation for a 30-day period. In fact, the derived SPI is a more accurate representation of monthly precipitation because the distribution has been normalized. For example, a 1-month SPI at the end of November compares the 1-month precipitation total for November in that particular year with the November precipitation totals of all the years on record. Because the 1-month SPI reflects short-term conditions, its application can be related closely to meteorological types of drought along with short-term soil moisture and crop stress, especially during the growing season.

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

## 5. Main characteristics of SPI

The SPI calculated in this way has the following desirable traits:

• 3-month SPI: The 3-month SPI provides a comparison of the precipitation over a specific 3-month period with the precipitation totals from the same 3-month period for all the years included in the historical record. In other words, a 3-month SPI at the end of February compares the December–January–February precipitation total in that particular year with the December–February precipitation totals of all the years on record for that location. Each year data is added, another year is added to the period of record, thus the values from all years are used again. The values can and will change as the current year is compared historically and statistically to all prior years in the record of observation. A 3-month SPI reflects short- and medium-term moisture conditions and provides a seasonal estimation of precipitation. In primary agricultural regions, a 3-month SPI might be more effective in highlighting available moisture conditions

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

## 5. Main characteristics of SPI

The SPI calculated in this way has the following desirable traits:

• 6-month SPI: The 6-month SPI compares the precipitation for that period with the same 6-month period over the historical record. For example, a 6-month SPI at the end of September compares the precipitation total for the April–September period with all the past totals for that same period.

The 6-month SPI indicates seasonal to medium-term trends in precipitation and is still considered to be more sensitive to conditions at this scale than the Palmer Index. A 6-month SPI can be very effective in showing the precipitation over distinct seasons. For example, a 6-month SPI at the end of March would give a very good indication of the amount of precipitation that has fallen during the very important wet season period from October through March for certain Mediterranean locales. Information from a 6-month SPI may also begin to be associated with anomalous streamflows and reservoir levels, depending on the region and time of year.

## ASSIGNMENT ON SPI ANALYSIS

- TASK #1: Analyze SPI (SPI1, 3, 6, 12) for Amman Airport Rainfall Station with the WMO model from the hydrologic year 1937-38. Search for the drought periods and compute the drought magnitude. Compare different periods with droughts.
- TASK #2: Analyze SPI (SPI1, 3, 6, 12) for Amman Airport Rainfall Station with the WMO model from the hydrologic year 1964-65. Compare the results with the previous task.

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# Standardized Precipitation Evapotranspiration index (SPEI)

## 1. Introduction

Vicente-Serrano et al. (2010) formulated a new drought index [the standardized precipitation evapotranspiration index (SPEI)] based on precipitation and potential evapotranspiration (PET). The SPEI combines the sensitivity of the PDSI to changes in evaporation demand (caused by temperature fluctuations and trends) with the multitemporal nature of the SPI.

## 2. Calculation

The SPEI is based on the climatic water balance, that is, the difference between precipitation and PET:

$$D = P - PET,$$

Where P is the monthly precipitation (mm) and PET (mm) the potential evapotranspiration.

The difference D is then modeled exactly as the SPI.

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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 $\alpha_k$ 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 $\sigma_y$ 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 αk (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 |

## ASSIGNMENT ON RDI ANALYSIS

- TASK #1: Analyze RDI (RDI1, 3, 6, 12) for Amman Airport Rainfall Station with the DrinC model from the hydrologic year 1988-89. Search for the drought periods and compute the drought magnitude. Compare different periods with droughts.
- TASK #2: Analyze SPI (SPI1, 3, 6, 12) for Amman Airport Rainfall Station with the DrinC model from the hydrologic year 1988-89. Compare the results with the previous task.

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# Streamflow Drought Index (SDI)

## 1. Introduction

According to Nalbantis (2008), if a time series of monthly streamflow volumes $Q_{i,j}$ is available, in which i denotes the hydrological year and j the month within that hydrological year (j = 1 for October and j = 12 for September), $V_{i,k}$ can be obtained based on the equation:

## 2. Calculation

$$V_{i,k} = \sum_{j=1}^{3k} Q_{i,j} \quad i = 1, 2, \ldots \quad j = 1, 2, \ldots, 12 \quad k = 1, 2, 3, 4$$

in which Vi,k is the cumulative streamflow volume for the i-th hydrological year and the k-th reference period, k = 1 for October-December, k = 2 for October-March, k = 3 for October-June, and k = 4 for October-September.

Based on the cumulative streamflow volumes Vi,k, the Streamflow Drought Index (SDI) is defined for each reference period k of the i-th hydrological year as follows:

# Streamflow Drought Index (SDI)

## 2. Calculation

$$\mathrm{SDI}_{i,k} = \frac{V_{i,k} - \overline{V}_k}{s_k} \quad i = 1, 2, \ldots, \quad k = 1, 2, 3, 4$$

in which $V_k$ and $s_k$ are respectively the mean and the standard deviation of cumulative streamflow volumes of the reference period *k* as these are estimated over a long period of time.

According to Nalbantis and Tsakiris (2009), states (classes) of hydrological drought are defined for SDI in an identical way to those used in the meteorological drought indices SPI and RDI. Five states are considered, which are denoted by an integer number ranging from 0 (non-drought) to 4 (extreme drought) and are defined through the criteria

| State | Description | Criterion |
|---|---|---|
| 0 | Non-drought | $\mathrm{SDI} \geq 0.0$ |
| 1 | Mild drought | $-1.0 \leq \mathrm{SDI} < 0.0$ |
| 2 | Moderate drought | $-1.5 \leq \mathrm{SDI} < -1.0$ |
| 3 | Severe drought | $-2.0 \leq \mathrm{SDI} < -1.5$ |
| 4 | Extreme drought | $\mathrm{SDI} < -2.0$ |

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# ASSIGNMENT ON SDI ANALYSIS

- TASK #1: Analyze SDI (SDI1, 3, 6, 12) for Wadi Zerqa at New Jerash Bridge Station with the DrinC model from the hydrologic year 1988-89. Search for the drought periods. Compare different periods with droughts.

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# Palmer's Drought Severity Index (PDSI)

## 1. Better suitable for Agricultural Drought

• **Origins:** Developed in the 1960s as one of the first attempts to identify droughts using more than just precipitation data. Palmer was tasked with developing a method to incorporate temperature and precipitation data with water balance information to identify droughts in crop-producing regions of the United States. For many years, PDSI was the only operational drought index, and it is still very popular around the world.

• **Characteristics:** Calculated using monthly temperature and precipitation data along with information on the water-holding capacity of soils. It takes into account moisture received (precipitation) as well as moisture stored in the soil, accounting for the potential loss of moisture due to temperature influences.

# Palmer's Drought Severity Index (PDSI)

## 1. Better suitable for Agricultural Drought

- **Input parameters:** Monthly temperature and precipitation data. Information on the waterholding capacity of soils can be used, but defaults are also available. A serially complete record of temperature and precipitation is required.
- Ranges from **–4** (extreme drought) to **+4** (extremely wet)
- Most widely used drought index in the US.
- Takes a supply-and-demand approach to the surface water balance.

| $X$ | Class |
|---|---|
| ≥ 4.00 | Extremely wet. |
| 3.00 to 3.99 | Very wet. |
| 2.00 to 2.99 | Moderately wet. |
| 1.00 to 1.99 | Slightly wet. |
| .50 to .99 | Incipient wet spell. |
| .49 to −.49 | Near normal. |
| −.50 to −.99 | Incipient drought. |
| −1.00 to −1.99 | Mild drought. |
| −2.00 to −2.99 | Moderate drought. |
| −3.00 to −3.99 | Severe drought. |
| ≦ −4.00 | Extreme drought. |

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# Soil Moisture Deficit Index (SMDI)

## 1. Better suitable for Agricultural Drought

- **Origins:** Developed from research at the Texas Agricultural Experiment Station, United States, by Narasimhan and Srinivasan in 2004.
- **Characteristics:** A weekly/monthly soil moisture product calculated at four different soil depths, including the total soil column, at 0.61, 1.23 and 1.83 m, and can be used as an indicator of short-term drought, especially using the results from the 0.61 m layer.
- **Input parameters:** Modelled data from a hydrologic model to compute soil water in the root zone on a daily basis.
- **Applications:** Useful for identifying and monitoring drought affecting agriculture.

# Soil Moisture Deficit Index (SMDI)

## 2. Calculation

- After daily soil water content has been computed, monthly (or weekly) values are derived. For every month a Soil Deficit value, is computed based on the median value (MSW), the long-term maximum (maxSW) and the long term minimum (minSW) value of the calculations.

$$\mathrm{SD}_{i,j} = \frac{\mathrm{SW}_{i,j} - \mathrm{MSW}_j}{\mathrm{MSW}_j - \mathrm{min}SW_j} \times 100, \quad \text{if } \mathrm{SW}_{i,j} < \mathrm{MSW}_j$$

$$\mathrm{SD}_{i,j} = \frac{\mathrm{SW}_{i,j} - \mathrm{MSW}_j}{\mathrm{max}SW_j - \mathrm{MSW}_j} \times 100, \quad \text{if } \mathrm{SW}_{i,j} > \mathrm{MSW}_j$$

- The SD values during a month will range between -100 and +100 stating very dry and very wet soil respectively. Drought occurs only when dryness continuous for a prolonged period of time that can affect crop yield in rainfed agriculture.

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# Soil Moisture Deficit Index (SMDI)

## 2. Calculation

• A transformation is being made in order to be compatible with the PDSI scale (-4----→+4) in the following way, where the SMDI is the Soil Moisture Deficit Index (where t is the number of months in our calculations)

$$\mathrm{SMDI}_j = \frac{\sum_{t=1}^{j} \mathrm{SD}_t}{25t + 25}$$

• For the first month of our sample $SMDI_{(1)}$ will be equal to $SD_1/50$.

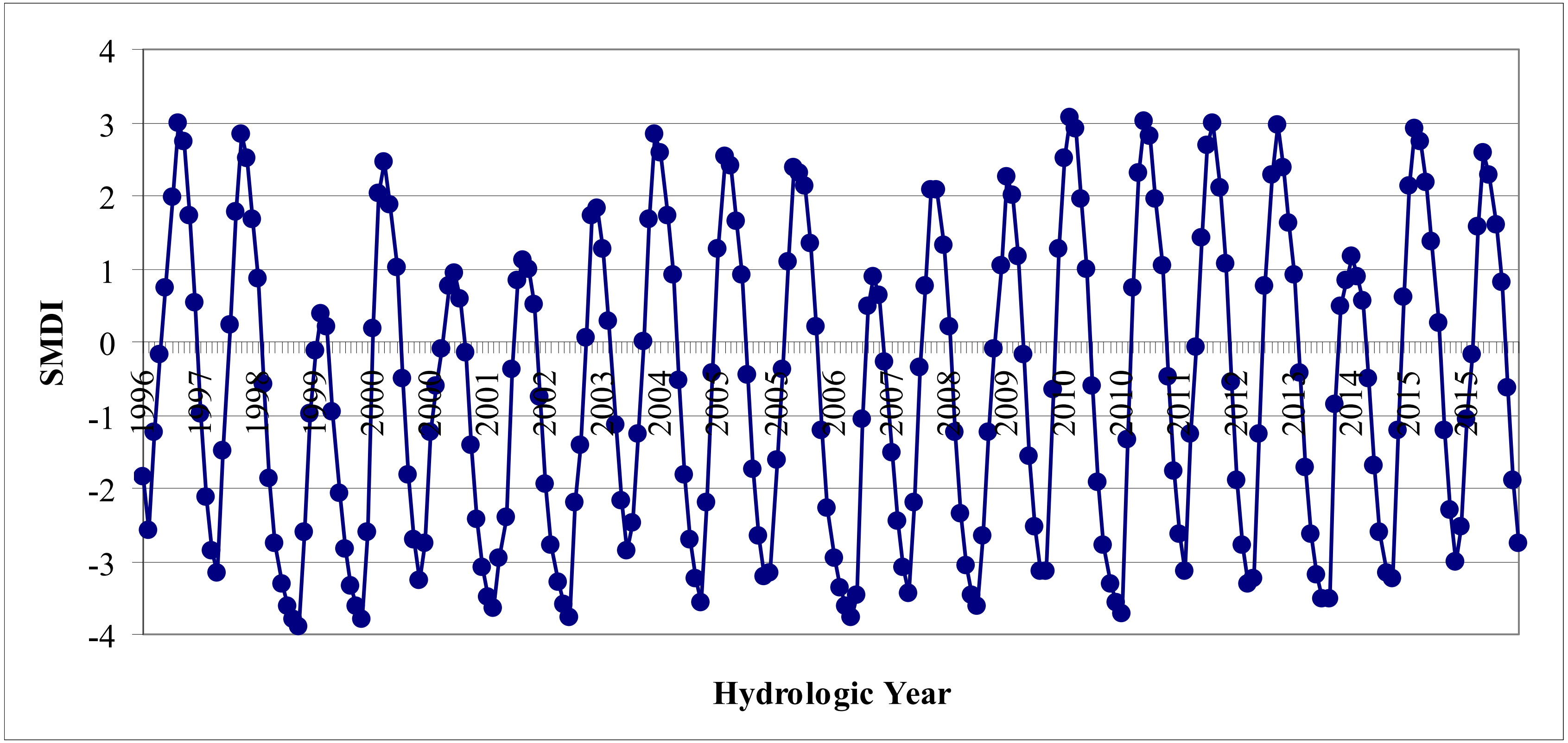
• The SMDI(j) is then calculated by the following equation:

$$\mathrm{SMDI}_j = 0.5\mathrm{SMDI}_{j-1} + \frac{\mathrm{SD}_j}{50}$$

# Soil Moisture Deficit Index (SMDI)

## 2. Calculation

-



# Soil Moisture Index (SMI)

## 1. Calculation

- Soil water, an integral part of the hydrologic cycle and water balance, for a given time period (t ):

$$\partial S/\partial t = P - ET - Ro - Dr$$

where $\partial S/\partial t$, P, ET, Ro, and Dr are the change in soil water, precipitation, evapotranspiration (ET), runoff and drainage for the same time period t. The soil water (S) is the equivalent depth of water:

$$S = \theta \, \Delta d$$

where $\theta$ is the average volumetric water content of the soil over a layer of soil and $\Delta d$ is the thickness of the soil layer

- The SMI is a continuous function and is scaled from 5.0 to −5.0, with 5.0 representing actual water content ($\theta$) at field capacity and −5.0 representing $\theta$ at wilting point.

# Soil Moisture Index (SDI)

## 1. Calculation

•The available water content ($F_{AW}$) in the soil is computed by the equation:

$$F_{AW} = (\theta - \theta_{WP})/(\theta_{FC} - \theta_{WP})$$

where θ is the measured volumetric soil water content; $\theta_{WP}$ is the volumetric soil water content at the wilting point; and $\theta_{FC}$ is the volumetric soil water content at field capacity. Note that $F_{AW}$ varies from 0 to 1 as θ varies from wilting point to field capacity. An SMI was desired which would attribute negative values of SMI to drought and positive values to lack of drought. It was decided to scale the SMI values from −5 to 5 as $F_{AW}$ changed from 0 to 1.

# Soil Moisture Index (SDI)

## 1. Calculation

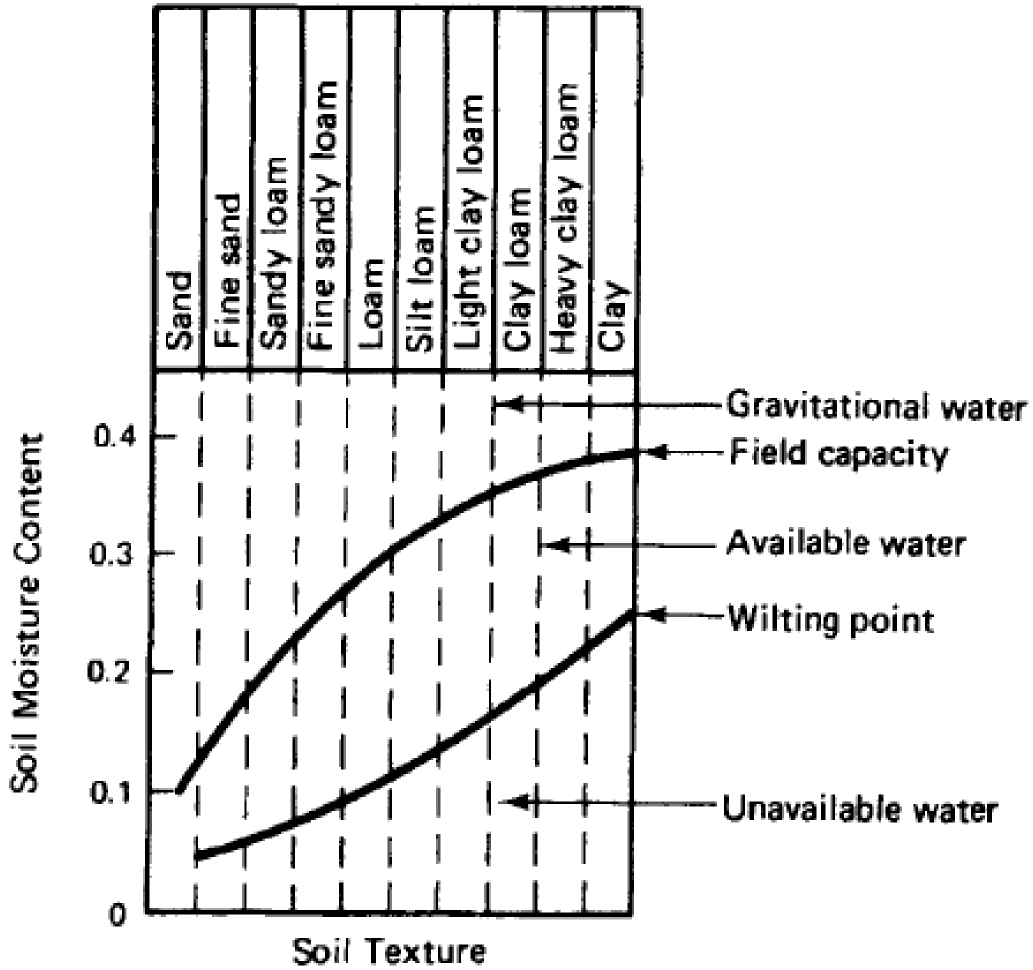
- This allows SMI to be written as follows:

$$SMI = -5 + 10\ F_{AW}$$

$$SMI = -5 + 10(\theta - \theta_{WP})/(\theta_{FC} - \theta_{WP})$$

When FAW is 0.5 the value of SMI is zero. Thus, an SMI value of 0.0 separates the stress (negative values) versus non-stress situations (positive values).

# Soil Physics



# Soil Physics

| | |
|---|---|
| Low infiltration rate | less than 15 mm/hour |
| medium infiltration rate | 15 to 50 mm/hour |
| high infiltration rate | more than 50 mm/hour |

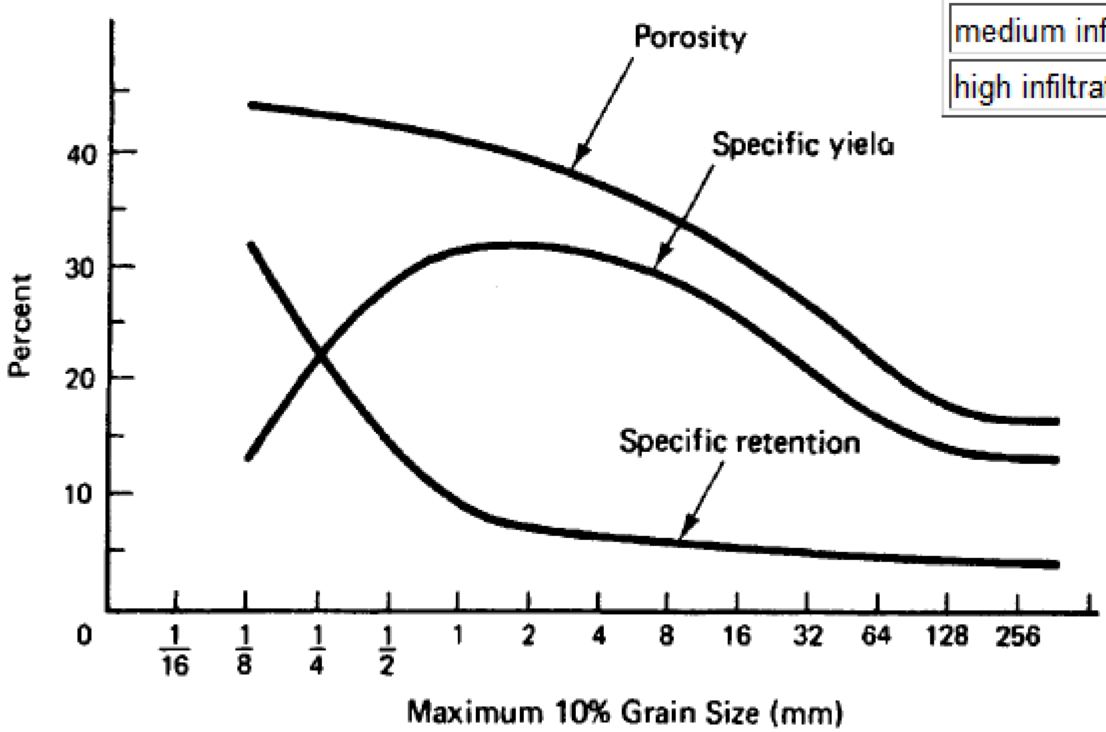



**FIGURE 3–10** Variation of specific retention, specific yield, and porosity with the grain size for which the cumulative total (starting with the coarsest material) reaches 10% of the total.

# Soil Physics

| Soil Texture | Porosity, cm³/cm³ | Saturated hydraulic conductivity (cm/hr) |
|---|---|---|
| Sandy | 0.437 | 21 |
| Loamy sand | 0.437 | 6.11 |
| Sandy loam | 0.453 | 2.59 |
| Loam | 0.463 | 1.32 |
| Silt loam | 0.501 | 0.68 |
| Sandy clay loam | 0.398 | 0.43 |
| Clay loam | 0.464 | 0.23 |
| Silty clay loam | 0.471 | 0.15 |
| Sandy clay | 0.43 | 0.12 |
| Silty clay | 0.479 | 0.09 |
| Clay | 0.475 | 0.06 |

# The HEC-HMS Soil Moisture Accounting (SMA) Model

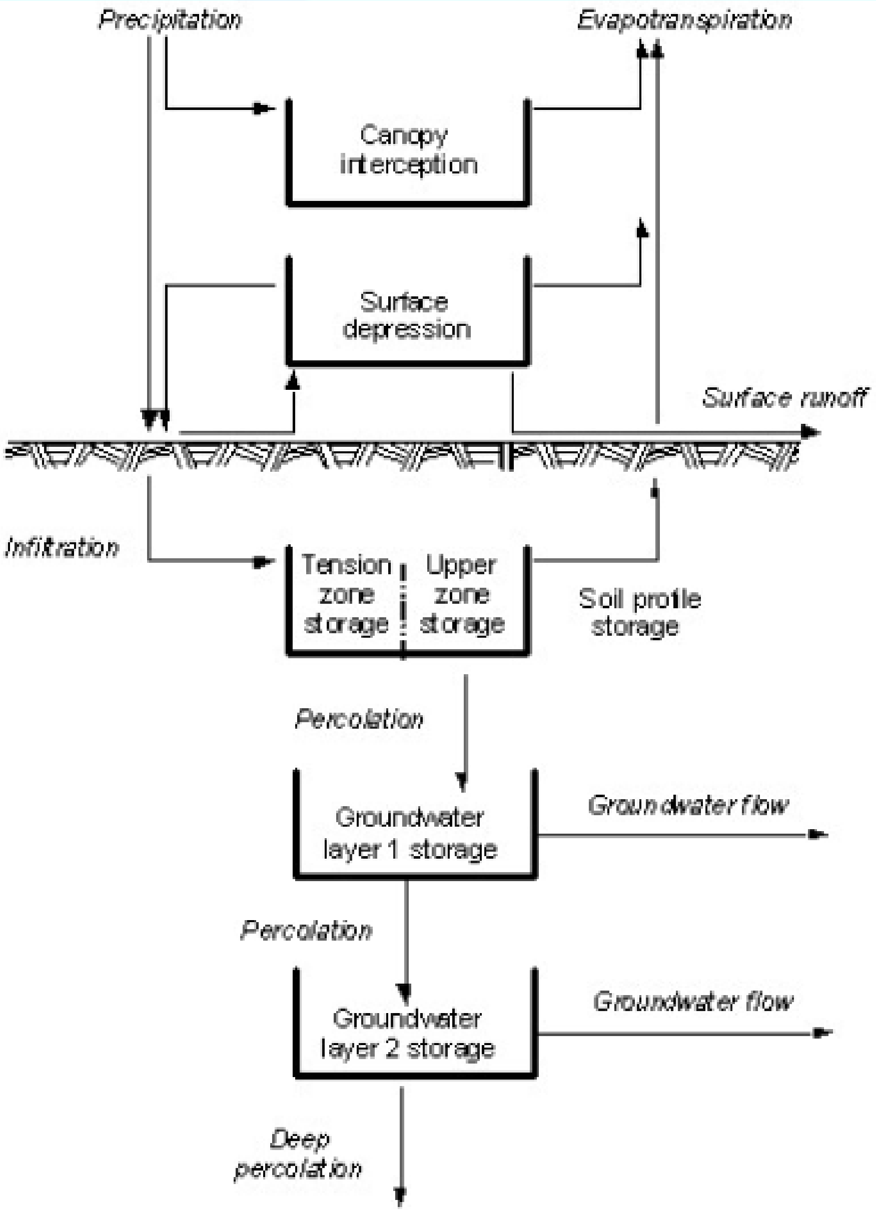



Table 1 Surface depression storage BENNET (1998)

| Description | Slope, % | Surface storage, mm |
|---|---|---|
| Paved impervious | NA | 3.2-6.4 |
| Steep | >30 | 1 |
| Moderate to gentle | 5-30 | 12.7-6.4 |
| Flat, furrow | 0-5 | 50.8 |

**Table 1.** Canopy Interception Values

| **Type of Vegetation** | **Canopy Interception** | |
|---|---|---|
| | **in.** | **mm** |
| General Vegetation | 0.05 | 1.270 |
| Grasses and Deciduous Trees | 0.08 | 2.032 |
| Trees and Coniferous Trees | 0.1 | 2.540 |

# Drought Early Warning Systems

## 1. Drought Probably Linked with General Atmospheric Circulation Patters

•Most of the research dealing with the coupling of atmospheric and hydrological systems has focused on the downscaling of large-scale GCM output, which can then be used as an input to regional hydrological models.

•Close relationships between rainfall/streamflow anomalies and indices based on Sea Level Pressure such as the El-Nino Southern Oscillation (ENSO) has been found.

•Example: The 2004/05 hydrological year (October 2004 to September 2005) was characterized by intense dry conditions affecting most of western Europe (35°–55°N and 10°W–10°E). In Iberia the drought affected every month of this period, with the southern half of Iberia receiving roughly 40% of the usual precipitation by June 2005. Moreover, this episode stands as the driest event in the last 140 yr, producing major socio-economic impacts particularly due to the large decrease in hydroelectricity and agricultural production in both Iberian countries (Portugal and Spain).

## 1. Drought Probably Linked with General Atmospheric Circulation Patters

•Example: The storm-track analysis reveals an impressive northward displacement of cyclone trajectories in the North Atlantic sector in winter months, resulting in an almost complete absence of cyclones crossing Iberia and western Europe.

•The land area surrounding the Mediterranean Sea has experienced 10 of the 12 driest winters since 1902 in just the last 20 years. A change in wintertime Mediterranean precipitation toward drier conditions has likely occurred over 1902–2010 whose magnitude cannot be reconciled with internal variability alone. Anthropogenic greenhouse gas and aerosol forcing are key attributable factors for this increased drying, though the external signal explains only half of the drying magnitude. Furthermore, sea surface temperature (SST) forcing during 1902–2010 likely played an important role in the observed Mediterranean drying, and the externally forced drying signal likely also occurs through an SST change signal.

## 1. Drought Probably Linked with General Atmospheric Circulation Patters

•The Mediterranean drying intensifies further when the Indian Ocean is warmed +0.5oC more than the remaining tropical oceans, an enhanced drying signal attributable to a distinctive atmospheric circulation response resembling the positive phase of the North Atlantic Oscillation.

# Drought Early Warning Systems

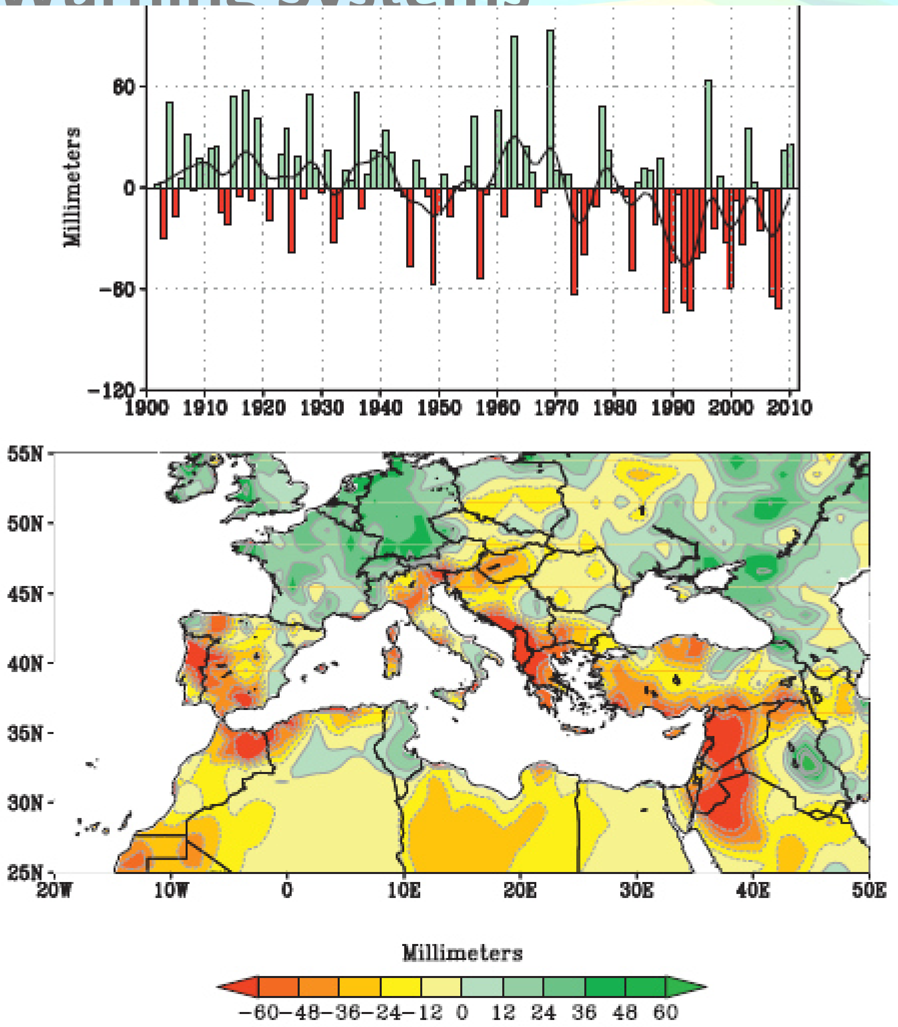



FIG. 1. (top) Observed time series of Mediterranean (30°–45°N; 10°W–40°E) cold season (November–April) precipitation for the period 1902–2010 and (bottom) the observed change in cold season

the observed change in cold season precipitation for the period 1971–2010 minus 1902–70.

# 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.

# Drought Hazard Indicators for Groundwater based on aquifer levels or spring runoff

## 1. Difficulties

Groundwater drought indicators is a very difficult subject especially where illegal or not monitored groundwater abstraction distort the meaning of the aquifer level. Usually a correlation between SPIn and aquifer level is searched to establish a link between SPI (rate of percolation) and groundwater levels.

A better correlation is found between SPI and spring runoff especially in areas with little upstream groundwater abstractions (SPI12 and 12 m-MA spring runoff in Cyprus).

# Drought Hazard Indicators based on remote sensing (e.g. NDVI)

## 1. Better suitable for Agricultural Drought

The Normalized Difference Vegetation Index (NDVI) is an index from remote sensing and airborne images that detect the level of moisture in the vegetation and the soil. Suitable only for rainfed agriculture and not for state irrigation schemes. Very effective on drought hazard mapping.

Its use depends on the country's capabilities on exploiting remote sensing sources.

SWIM and Horizon 2020 Support Mechanism

Working for a Sustainable Mediterranean, Caring for our Future

# Thank you for your attention.

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