EXPERT FACILITY ACTIVITY NO: EFS-PS-1

MAINSTREAMING DROUGHT RISK MANAGEMENT

DELIVERABLE 2 (FINAL REPORT)

SWIM and Horizon 2020 Support Mechanism

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THE SWIM AND H2020 SUPPORT MECHANISM PROJECT (2016-2019)

The SWIM-H2020 SM is a Regional Technical Support Program that includes the following Partner Countries (PCs): Algeria, Egypt, Israel, Jordan, Lebanon, Libya, Morocco, Palestine, [Syria] and Tunisia. However, in order to ensure the coherence and effectiveness of Union financing or to foster regional co-operation, eligibility of specific actions will be extended to the Western Balkan countries (Albania, Bosnia Herzegovina and Montenegro), Turkey and Mauritania. The Program is funded by the European Neighbourhood Instrument (ENI) South/Environment. It ensures the continuation of EU's regional support to ENP South countries in the fields of water management, marine pollution prevention and adds value to other important EU-funded regional programs in related fields, in particular the SWITCH-Med program, and the ClimaSouth program, as well as to projects under the EU bilateral programming, where environment and water are identified as priority sectors for the EU co-operation. It complements and provides operational partnerships and links with the projects labelled by the Union for the Mediterranean, project preparation facilities in particular MESHIP phase II and with the next phase of the ENPI-SEIS project on environmental information systems, whereas its work plan will be coherent with, and supportive of, the Barcelona Convention and its Mediterranean Action Plan.

The overall objective of the Program is to contribute to reduced marine pollution and a more sustainable use of scarce water resources. The Technical Assistance services are grouped in 6 work packages: WP1. Expert Facility, WP2. Peer-to-peer experience sharing and dialogue, WP3. Training activities, WP4. Communication and visibility, WP5. Capitalizing the lessons learnt, good practices and success stories and WP6. Support activities.

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Disclaimer:

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1 INTRODUCTION

1.1 BACKGROUND

The present document is part of the Work package (WP)1 "Expert Facility" and more specifically activity number EFS-PS-1 “Mainstreaming Drought Risk Management”. The activity falls under the water component theme of the SWIM-H2020 “Assessment of water resources’ vulnerability and related risks” and aspires overall to support drought risk mainstreaming in Palestine by providing technical assistance and capacity building, through the following sub-activities.

a. Mapping of groundwater resources vulnerability and risk with respect to the reduction of groundwater recharge (as a direct impact of reduced rainfall/drought and urbanization/reduction of open spaces and land use change), mapping of rain-fed agricultural land vulnerability and risk related to reduction in rainfall;
b. Support aspects of mainstreaming drought/water scarcity into the legal framework on Disaster Risk Management (currently under development) and provide capacity building to water service providers and stakeholders;
c. Capacity Building on the cost of environmental degradation, and on measurement tools for economic impacts for climate change.

The implementation of these three sub-activities is of high relevance to the Country’s Strategic Framework; namely the National Water Policy and Strategy (NWPS) (June 2013), which addresses drought under the “Alleviation of Climate Change and Flood Risks” and stipulates the necessity to formulate reliable water protection zones based on detailed and advanced vulnerability assessment for all major water resources and study the effect of urbanization on the water resources and investigate the possible pollution that can be caused.

The first and second interrelated sub-activities aim to support national and local authorities of Palestine in the development of the drought regulatory framework as an essential element in drought management and in formulating water protection zones and defining drought vulnerability. They will provide capacity building on the legal framework developed with emphasis on the local level.

The third sub-activity aims to build the capacity of the relevant staff, such as planning officials and high-level staff with regards to the methodologies used for assessing the cost of environmental degradation.

1.2 OBJECTIVES

The activity’s main objectives are the following:

1) To support Drought Risk Management Mainstreaming (DRMM) by (a) developing drought risk profiles based on the mapping and assessment of the drought hazard and associated vulnerability, and (b) by assisting the Palestinian Water Authority (PWA) staff and stakeholders in mainstreaming

drought risk management, into the legal framework on Disaster Risk Management. This action will support the achievement of SDG 1 that focused on minimizing the poverty level, SDG 2: Zero hunger, and SDG 13: Climate action to improve the agricultural production, since the existence of a robust system for drought risk characterization on the one hand (incorporating vulnerabilities), and of a drought regulatory framework can help mitigate these issues.

2) To develop a robust methodology for carrying out vulnerability assessments of groundwater resources. The availability of such an assessment will provide decision-makers with options to evaluate and modify existing policies and to implement measures to improve groundwater resource management as Palestine is working to achieve the SDG Goal 6 that focuses on ensuring access to safe water for all.

Specifically, the activity aims to:

- Assess the drought hazard and the vulnerability to drought and water scarcity through a set of indicators, following a robust methodological framework. As rainfed agriculture is a sector already under stress, the vulnerability framework will include this sector in its analysis;
- Develop Drought Risk Profiles for 2 pilot areas, laying out a clear methodology that can be replicated in other areas;
- Create a knowledge base of scientific data and information on available surface and groundwater sources and the water use and demand of each sector
- Draft a methodology for assessing groundwater vulnerability and defining groundwater protection zones. Implement this methodology in 2 pilot areas;
- Set-up participatory approaches with the stakeholders towards the establishment of a Aquifer Protection Advisory and Review Committee (APARC) on one hand, and towards the development of a regulatory/legal framework for Drought Risk Management Mainstreaming (DRMM);
- Train staff on the costs of environmental degradation (assessment methodologies and tools);
- Build capacity of the PWA staff and other stakeholders on DRMM.

1.3 SCOPE OF THIS REPORT

The scope of this report corresponds to task 2 of the Terms of Reference; executed by the Consultants as listed below:

Task 2: Development of a Drought and Water Scarcity Risk Profile in 2 pilot areas

This included:

- Drought Hazard Mapping using relevant indicators (subject to data availability).
- Assessment of the water resources and key components (i.e. water availability per sources, water use per sector, water needs, unmet demand, etc.)
- Drought and water scarcity vulnerability assessment using relevant indicators (subject to data availability). The vulnerability assessment includes rainfed agricultural lands as these have

already been identified as areas of stress and potentially highly impacted by drought. It is required that at least 1 of the 2 pilot areas includes such type of land.

- Synthesize the Drought Risk Profile (DRP)

Expected outcome:

- Data collected for the Drought Hazard and Vulnerability analysis (and the relevant indicators), and the various water resources components (water availability per source, water use per sector, etc.)
- Development of Drought Risk Profile (drought hazard and vulnerability) in the 2 pilot areas

Droughts are recognized as an environmental disaster and have attracted the attention of environmentalists, ecologists, hydrologists, meteorologists, geologists and agricultural scientists. Droughts occur in virtually all climatic zones, such as high as well as low rainfall areas and are mostly related to the reduction in the amount of precipitation received over an extended period of time, such as a season or a year. Temperatures; high winds; low relative humidity; timing and characteristics of rains, including distribution of rainy days during crop growing seasons, intensity and duration of rain, and onset and termination, play a significant role in the occurrence of droughts. In contrast to aridity, which is a permanent feature of climate and is restricted to low rainfall areas (Wilhite, 1992), a drought is a temporary aberration. Often there is confusion between a heat wave and a drought. Chang and Wallace (1987) have emphasized the distinction between heat wave and drought, noting that a typical time scale associated with a heat wave is on the order of a week, while a drought may persist for months or even years. The combination of a heat wave and a drought has dire socio-economic consequences.

Due to the growth of population and expansion of agricultural, energy and industrial sectors, the demand for water has increased many folds and even water scarcity has been occurring almost every year in many parts of the world. Other factors, such as climate change and contamination of water supplies, have further contributed to the water scarcity. In recent years, floods and droughts have been experienced with higher peaks and severity levels. The period between extreme events seems to have become shorter in certain regions. Lettenmaier et al. (1996) and Aswathanarayana (2001) have made references to this change in the occurrence of extreme hydrologic events.

Droughts are complex hazardous recurrent phenomena affecting most parts of the world. The impacts of droughts are economic, environmental and social. These impacts are more crucial on the climatic zones suffering from permanent water scarcity. They are also more severe for the affected systems which are not protected from these events. Over the past few decades, droughts have dramatically increased in intensity and frequency. It is estimated that in Europe between 1976 and 2006 the total costs associated with drought episodes amounted to 100 billion euros, whereas the number of people affected by droughts was increased by almost 20%. Recent studies reveal that in areas such as the Mediterranean, more frequent and intense drought episodes are expected in the next decades (CEC 2007). This has put pressure on governments and institutions to provide measures in order to mitigate the impacts of future droughts.

The droughts are generally classified into four categories (Wilhite and Glantz, 1985; American Meteorological Society, 2004), which include:

(i) Meteorological drought is defined as a lack of precipitation over a region for a period of time. Precipitation has been commonly used for meteorological drought analysis (Pinkeye, 1966; Santos, 1983; Chang, 1991; Eltahir, 1992). Considering drought as precipitation deficit with respect to average values (Gibbs, 1975), several studies have analysed droughts using monthly precipitation data. Other approaches analyse drought duration and intensity in relation to cumulative precipitation shortages (Chang and Kleopa, 1991; Estrela et al., 2000).

(ii) Hydrological drought is related to a period with inadequate surface and subsurface water resources for established water uses of a given water resources management system. Streamflow data have been widely applied for hydrologic drought analysis (Dracup et al., 1980; Sen, 1980; Zelenhasic and Salvai, 1987; Chang and Stenson, 1990; Frick et al., 1990; Mohan and Rangacharya, 1991; Clausen and Pearson, 1995). From regression analysis relating droughts in streamflow to catchment properties, it is found that geology is one of the main factors influencing hydrological droughts (Zecharias and Brutsaert, 1988; Vogel and Kroll, 1992).

(iii) Agricultural drought, usually, refers to a period with declining soil moisture and consequent crop failure without any reference to surface water resources. A decline of soil moisture depends on several factors which affect meteorological and hydrological droughts along with differences between actual evapotranspiration and potential evapotranspiration. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant and stage of growth, and the physical and biological properties of soil. Several drought indices, based on a combination of precipitation, temperature and soil moisture, have been derived to study agricultural droughts.

(iv) Socio-economic drought is associated with failure of water resources systems to meet water demands and thus associating droughts with supply of and demand for an economic good (water) (AMS, 2004).

1.4 TARGET GROUP FOR THE ACTIVITY

The activity's target groups are the following:

- Palestinian Water Authority as the Water Sector Lead
- Ministries (Ministry of Agriculture, Ministry of Local Government, Ministry of Planning and Finance)
- Other services and authorities (Environment Quality Authority, Palestinian Energy Authority, Meteorological Department, Service Providers, Tubas Governorate, Jenin Governorate)
- Other stakeholders such as Local NGOs

2 PILOT GOVERNORATES OVERVIEW

Initially, during the kick-off meeting the two pilot Governorates have been selected:(a) Semi coastal of Tulkarem city and nearby localities of Tulkarem Governorate, and (b) Eastern slopes of Jenin: (Jalbon and Faqqoua) in Jenin Governorate. A short description of these pilot areas is presented as follows:

2.1 JENIN GOVERNORATE

The Jenin Governorate area is around 583 km^2, located in the northern part of the West Bank, on the northern tip of the main mountain range crossing the interior area of Palestine, with its north and east mountains extending towards Bissan and the Jordan Valley. Located next to the bottom of mountains overlooking the Marj Ibn Amer plain, the Governorate is a confluence of three environments [mountainous, valleys (Aghwar) and plains]. It is bordered by the Nablus Governorate to the south, the Tulkarem Governorate to the south-west, the Tubas Governorate to the south-east, and the Green Line along the other borders.

The Jenin Governorate enjoys one of the richest and most fertile agricultural lands in the Palestinian territory, with deep soil in plain areas. The population of the Jenin Governorate is about 256,619 in 2007 (PCBS, Census 2007) with a 42% urban population, 54% rural, and 4% representing the inhabitants of the Jenin refugee camp. The population is spread across 80 localities, with 39,004 people living in Jenin city and 10,371 in Jenin refugee camp. There are five other towns with a population size exceeding 9000, namely: Qabatiya, Yamoun, Arraba, Yabad and Silat al-Harithiya, (PCBS, Census 2007). As such, 46% of the Governorate's population resides in six localities, in addition to the refugee camp. The local governance and administration of the Governorate consists of 12 Municipal Councils, 30 Village Councils and 34 Project Committees. However, there are a number of localities which have no local official administrative structure. (Ministry of Local Government records, 2007)

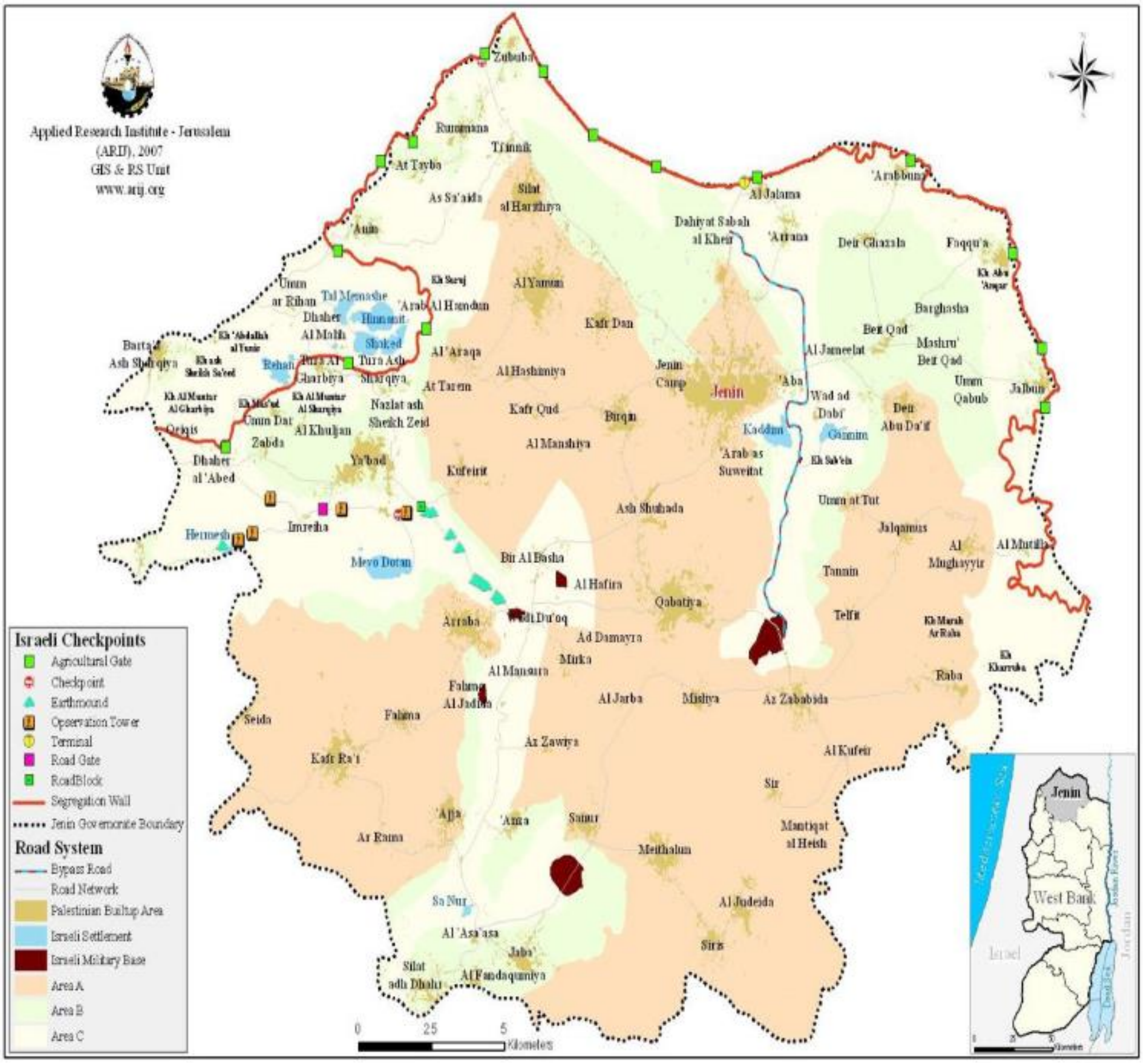


FIGURE 2-1: GENERAL MAP OF JENIN GOVERNORATE

The topography of the Jenin Governorate can be divided into three areas: (a) the eastern slopes, (b) mountain crests, and (c) western slopes. The eastern slopes are located between the Jordan Valley and the central highland. They are characterized by steep slopes which contribute to forming young wadis. Mountain crests form the watershed line and separate the eastern and western slopes. Altitudes range on average between 500 and 650 meters above sea level. The western slopes, characterized by gentle slopes, have elevation ranges between 100 and 400 meters above sea level. The elevation from sea level ranges from 7m to 465m with a mean elevation of 221 m. The landscape can be characterized by two main features: (1) rolling hills in the North-Eastern (NE), Eastern (E), and Southern (S) parts of the watershed; and (2) gently sloping wadies in the central and north-western parts. The soil is textured as silty clay.

Agriculture is the major land use activity in the Jalbon as the arable land is 93,758 dunums , 32,744 dunums are cultivated with fruit trees (mostly olives) and 61,014 with field crops and vegetables. Most of the agricultural land is rain-fed. The number of heads of small ruminants (sheep and goat) is 34,880 heads, cattle are 1,638 heads and chicken broilers are 1,490,950 (MoA, 2013).

The climate in Jenin district is governed by its position on the Mediterranean Sea, which is rainy moderate in winter, hot dry in summer, and the average rain in the district is about 528 mm. Average rainfall is decreasing from 778 mm at Um-Al Rehan village in the West to 286 mm in Raba village at the east, that is because the Western part is exposed to the wind comes from the sea. Figure 2-2 illustrates zonal rainfall in Jenin Governorate prepared by the Palestinian Hydrology Group (PWG).

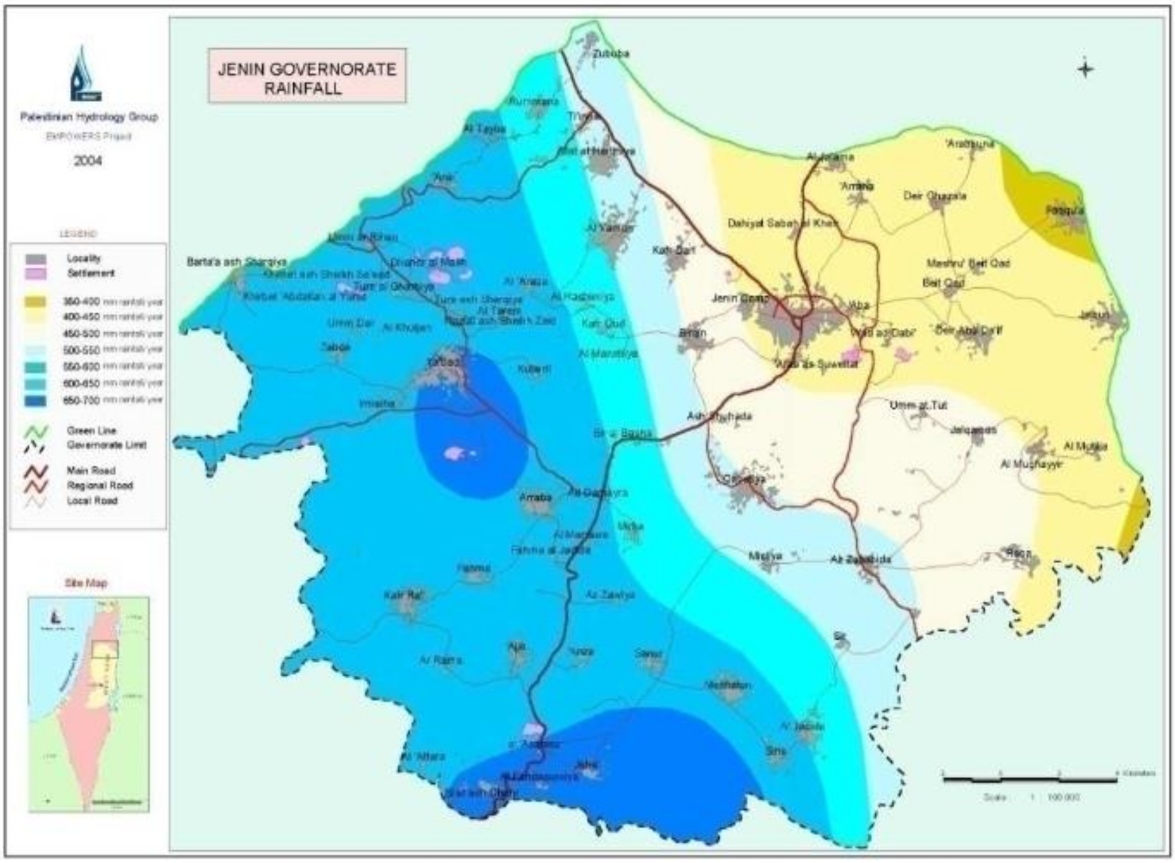


FIGURE 2-2: RAINFALL DISTRIBUTION MAP FOR JENIN (PHG, 2005)

2.1 TULKAREM GOVERNORATE

Tulkarem Governorate is located at the northwestern part of West Bank with a total surface area of nearly 268 square kilometers. 36% of this area is cultivated by permanent crops, while the Palestinian Built-up Area form 7.1%.

The name "Tulkarm" means the mount of vineyards. It is situated 17 km from the Mediterranean Sea and 125 meter above the sea level. The city is situated on the western edge of northern West Bank, about 15 kilometres west of Nablus further southwest of Jenin, total area is 32,610 dunums.

The total available area for agriculture is 10,814 dunum, whereby 10,383 dunum are cultivated with irrigated crops especially the fruit trees (3123 dunum), vegetables (2500 dunum), field crops (400 dunum), and rain-fed crops with 4000 for olive trees, 360 dunum for field crops. The number of small ruminants (sheep and goat) is 1,000 heads, cattle is 968 heads. Chicken Broilers is 52,000 (PWA, 2017). Tulkarm Governorate can be divided into three clusters as follows (Figure 2-3):

Cluster1 comprises the middle part of Tulkarm District and extends along the catchment area of Wadi Zeimar between Beit Leed in the East and Tulkarem in the West. The municipalities and villages included in this cluster include Anabta, Rameen, Bal'a, Beit Leed, Iktaba (considered as part of Tulkarem), Irtah (part of Tulkarem municipality), Kafr El Labad, Kafr Rumman (part of Anabta municipality), Nur Shams Camp, Shuweika (part of Tulkarem municipality), Thenabeh (part of Tulkarem municipality), Tulkarem and Tulkarem Camp.

Cluster 2 comprises the northern part of Tulkarm District and extends along the green line area of Al-Sharawiya between Qifeen in the north and Tulkarem in the South. The municipalities and villages included in this cluster include are Dir Al-Gosoun, Attil, Zeita, Illar, Syda, Al-Nazleh Al-Sharqiya, Al-Nazleh Al-Wusta, Al-Nazleh Al-Gharbiya, Qifeen, Baqa Al-Sharqiya, Akkaba, Nazlat Issa, Al-Masqufa, Al-Jarushiya.

Cluster 3 comprises the southern part of Tulkarm District and extends along the green line area of Al-Kafriyat between Qifeen in the north and Tulkarem in the South. The municipalities and villages included in this cluster included are Jibarah, Al-Ras, Kufr Soor, Koor, Kufr Jammal, Kufr Zibad, and Kufr Abboush.

These governorates share the same administrative borders in the northern part of the Palestine territory, as presented in the following map.

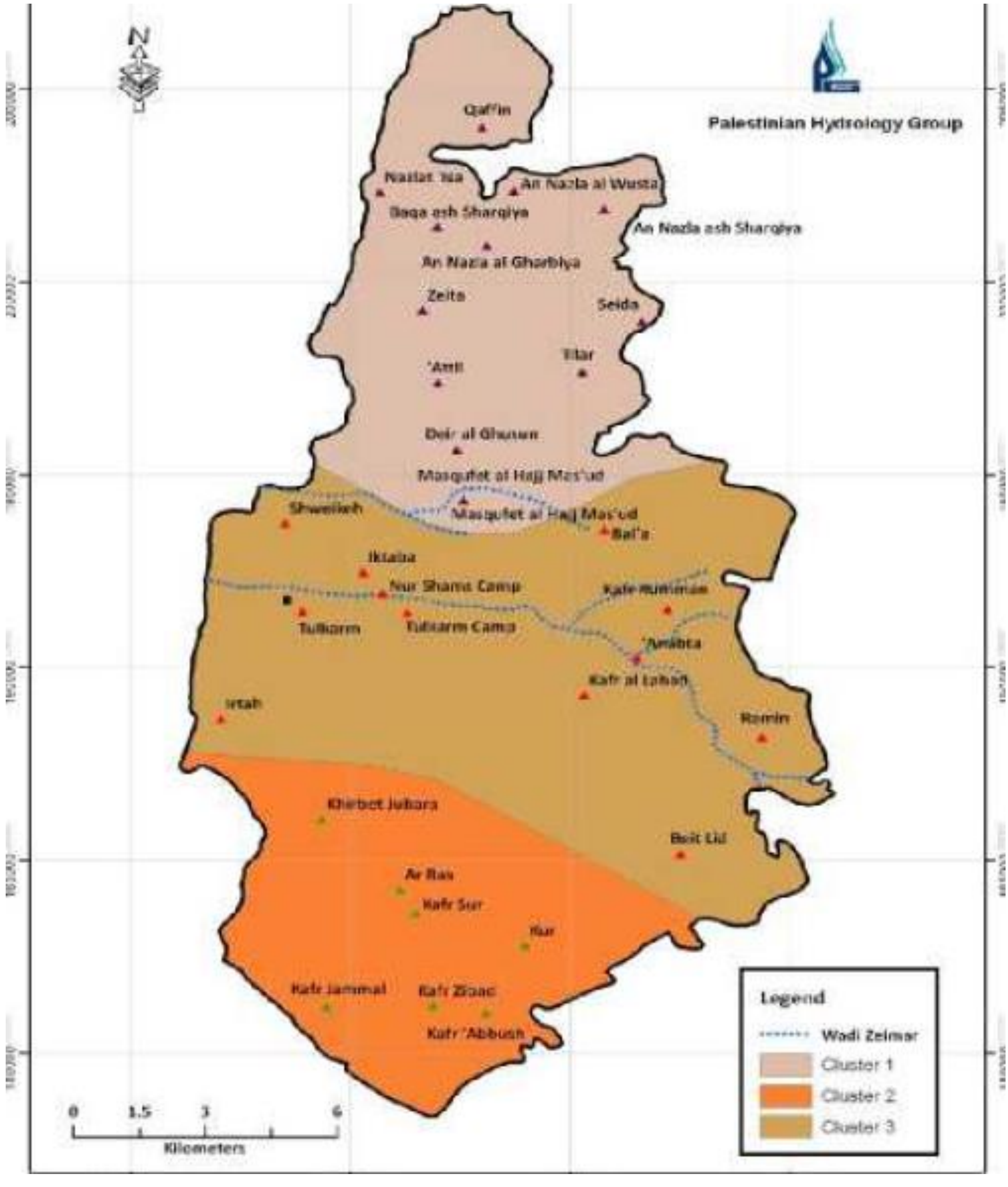


FIGURE 2-3: ADMINISTRATION MAP PF TULKARM GOVERNORATE

Hydrology and Climate: In general, Tulkarem Governorate belongs to the sub-tropical zone which is characterized by Mediterranean climate with long hot and dry summer, and short cool and rainy winter. Average temperature is ranging between 10.9 and 26.1 c˚ in January, and August respectively. The mean maximum temperature ranges from 13.3 (January) to 29.6ºC (August), while the mean minimum temperature is ranging between 8.6 ºC and 22.7 ºC for the same months.

Average relative humidity reaches about 69 %. The minimum value of relative humidity is 62% which occurs in May during the Khamaseen weather. Maximum relative humidity of 76% is usually registered in February. Winds direction and velocities vary according to the seasons of the year. The main wind direction is from west, southwest and northwest. Variation during winter is associated with the pattern of depressions passing from west to east over the Mediterranean. The main winds in the area are the southwest and northwest winds with an annual average wind speed of 3.4 km per day, at a height of 2 meters from ground surface. The Khamaseen, desert storm, may occur during the period from March to June. During the Khamaseen, the temperature increases, the humidity decreases and the atmosphere becomes hazy with dust of desert origin and eastern prevailing winds.

Rainfall in Tulkarem area usually begins in October and continues through May. About 60% of the annual rainfall occurs between December and February, while 20% of annual rainfall occurs in October and November. The annual average of rainfall reaches 601 mm, while the maximum monthly rainfall recorded in December of about 436 mm. In general, rainfall average increases within the governorate towards the north where it reaches 650 mm (PNA & PHG, 2011).

Topography: Elevation is ranging between less than 50 meters above sea level (a.s.l) in the plain areas west of Tulkarem city to about 450 m above sea level in Bala'a area to the east (Figure 2-4).

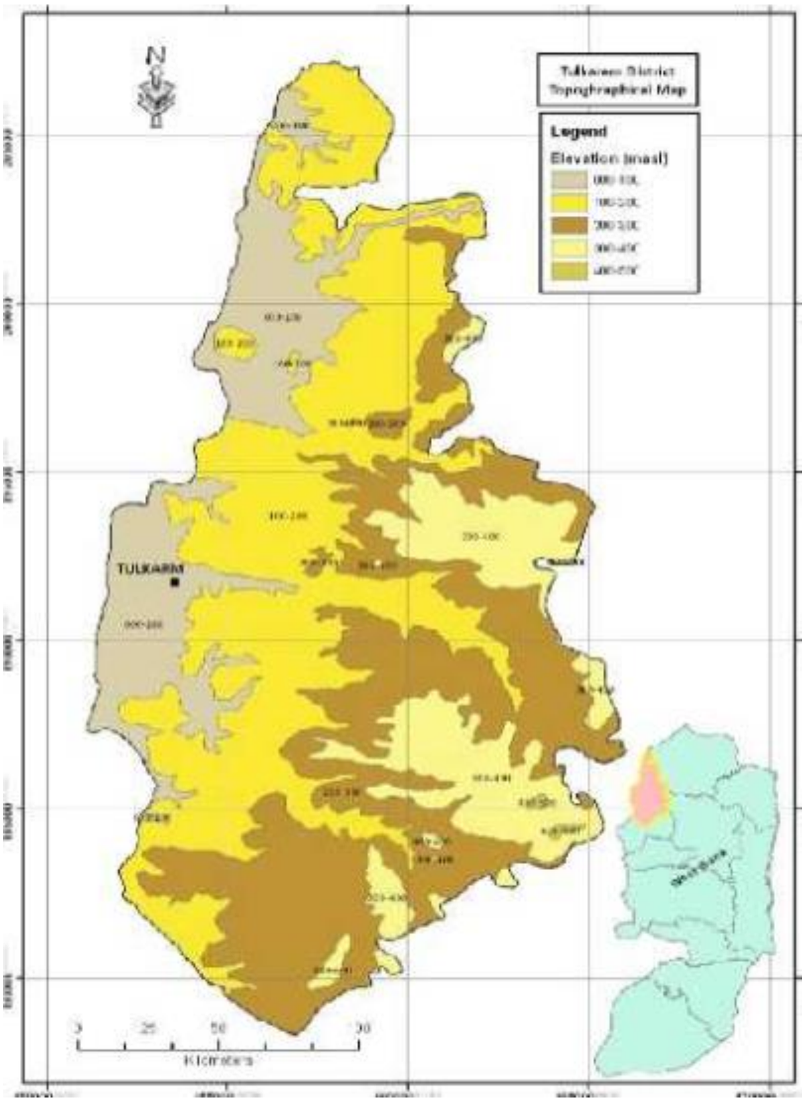


FIGURE 2-4: TOPOGRAPHY OF TULKARM GOVERNORATE

Soils: The major soil types in the governorate are Brown and Pale Rendzina which composes of chalk materials and has varying depth from 0.5 m to 2 m; Grumusols which has a dominant clay soil texture and is a characteristic of areas with smooth to gently sloping topography, and Terra Rosa which composes of carbonate in general and has depth vary from 0.5 – 2 m (Figure 2-5).

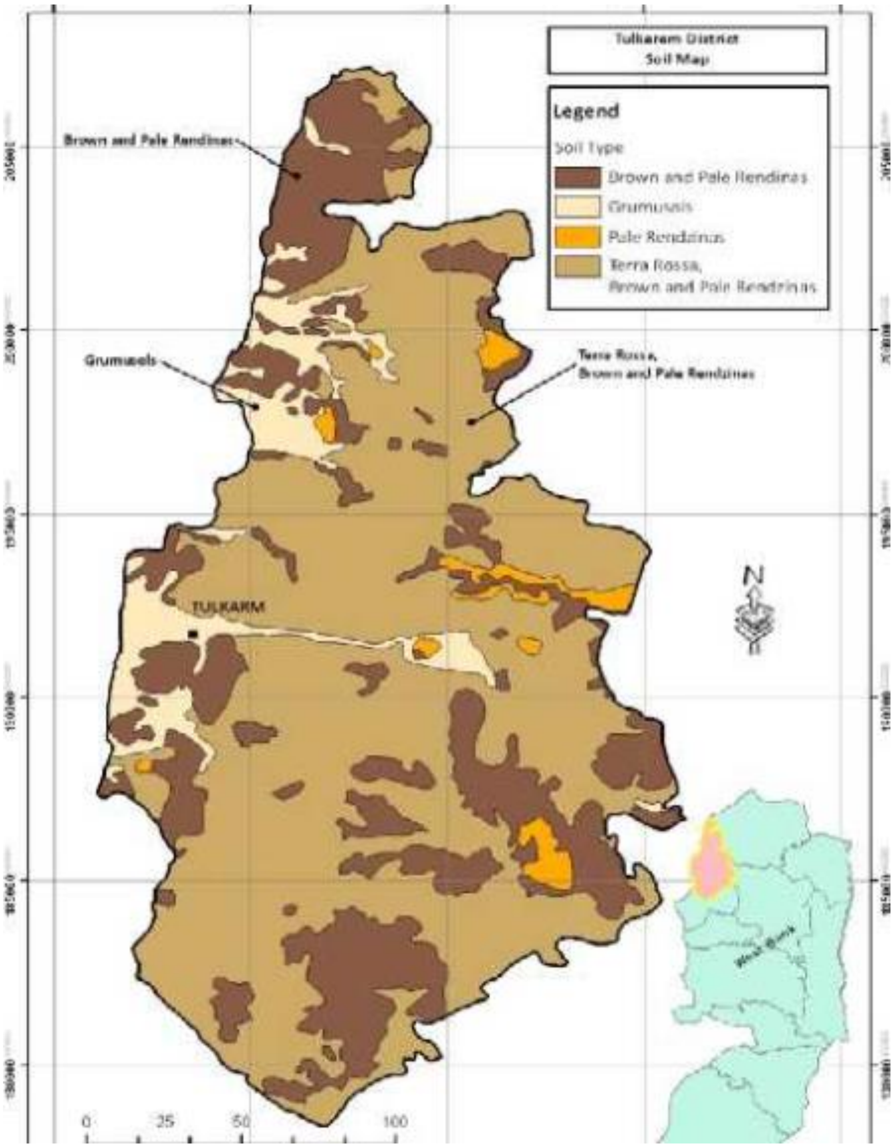


FIGURE 2-5: SOIL MAP FOR TULKARM GOVERNORATE

Geology and Hydrogeology: Tulkarm governorate area forms part of the western groundwater basin which is composed of two main sub aquifers namely upper and lower aquifers of Turonian – Cenomanian age and lower Cenomanian age respectively where, the groundwater flows towards the west (Figure 2-6). While the groundwater level in the area varies between 20-50 meters above sea level. The western aquifer basin is recharged mainly from precipitation falling on the mountains of West Bank while the historical outlets of the basin were through Ras Al Ain (Auja) (Yarkon) and Al Timsah (Taninim) springs and hence the Israeli named the basin Yarkon - Taninim Basin. The average value of recharge of the West Aquifer Basin was estimated by several studies to vary from 340- 360 cubic hectometers (cubic million) per year (hm^3/yr) and the most recent Israeli estimate of the basin is 425 hm^3/yr. Transmissivity of Western Basin aquifers is characterized by its high values -In some wells transmissivity reaches more than 100,000 m^2/day.

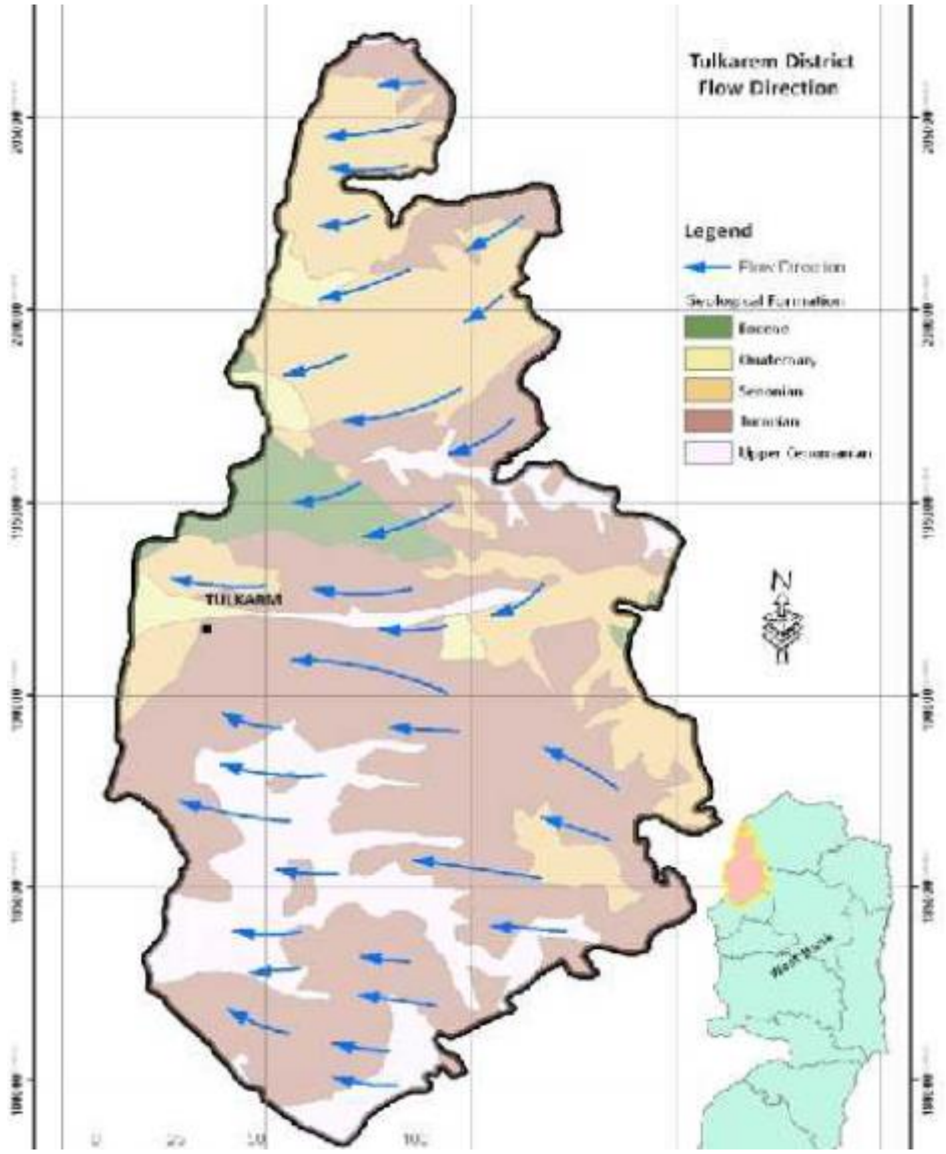


FIGURE 2-6: GROUNDWATER FLOW AND FORMATIONS

3 AVAILABLE DATA FOR DROUGHT ANALYSES

For drought analyses purposes, it is essential to gather all the relevant information. Rainfall is, obviously, the main drought factor, but also potential (or actual) evapotranspiration plays also a very important role. Potential Evapotranspiration (PET) is computed after meteorological information is also archived and processed. Meteorological variables necessary for PET calculations are: (a) Temperature (mean monthly or mean monthly maximum and minimum) (°C), (b) Relative humidity (%), (c) Wind Speed (m/s at 2 m height of the sensor), and (d) sunshine duration (h).

3.1 RAINFALL

Rainfall data are the main and primary information for studying drought hazard. PWA has submitted rainfall data in daily time steps for several rainfall stations gradually during the whole period of the activity duration. Data flow between PWA and the Consultant was not ideal: leaving the Consultant with idle time in waiting and working in full effort during the last days of the Expert Facility. Data flow is presented as follows:

- Daily rainfall data only for rainfall stations #1 & 2 (Table 3-1 below), one for Jenin and one for Tulkram Governorates were submitted on November 2017.
- After a series of appeals from the Consultants, PWA submitted daily rainfall data for all Palestinian rainfall stations (in pdf format) only for hydrologic years 2013-14, 2014-15 and 2015-16 on December 2017.
- Monthly rainfall data have been received from the Palestinian Meteorological Department in June 2018 (Rainfall Stations: Rumaneh1, Yabad1, Qabatya1, Atteel2, Burqa031, Tubas038, Tallu033, Hajja2). Data cover a time frame starting from calendar year 1980.
- Finally, complete rainfall daily data for all stations from Palestine Meteorological Department (PMD), were retrieved by the Consultant (the Drought Hazard NKE) during the Capacity Building Training Seminar on Drought Risk Management Mainstreaming (DRMM) on the 7th November 2018 directly from the PMD.

All together, data from 13 rainfall stations have been assembled. Almost all stations have no data between 1998-99 to 2004-05, mainly due to abnormal political situation of the intifada of the Palestinian people. General characteristics of the 13 rainfall stations are presented in Table 3-1 and are mapped in Figure 3-1.

TABLE 3-1: GENERAL CHARACTERISTICS OF THE RAINFALL STATIONS UNDER CONSIDERATION.

a/a	Station	Governorate	Year Start	Year End	X Coordinate	Y Coordinate	Elevation (m)
1	Khadouri Institute Tulkarem	Tulkarem	1968-69 & 2013-14	1996-97 & 2016-17	152,500	191,000	90
2	Jenin	Jenin	1995-96	2016-17	176,602	193,973	370
3	Rumaneh1	Jenin	1970-71	2016-17	169,881	214,633	160
4	JEN00001	Jenin	1969-70	2016-17	176,602	193,973	370
5	Qefeenmc	Tulkarem	1973-74	2016-17	158,283	204,130	130
6	Yabad1	Jenin	1969-70	2016-17	167,013	205,087	270
7	Qabatya1	Jenin	1969-70	2016-17	175,764	201,836	290
8	Atteel2	Tulkarem	1974-75	2016-17	156,746	197,218	100
9	Burqa031	Nablus	1974-75	2016-17	167,706	189,665	460
10	Tubas038	Tubas	1971-72	2016-17	182,669	189,237	260
11	Tallu033	Nablus	1974-75	2016-17	178,232	186,475	490
12	Hajja2	Qalqilya	1974-75	2016-17	162,484	178,649	410
13	Maithaloun	Jenin	1980-81	2012-13	176,800	194,800	360

Maithaloun, Jenin and JEN0001 rainfall stations are nearly at the same position, therefore JEN0001 station was preferred to be used for further analysis.

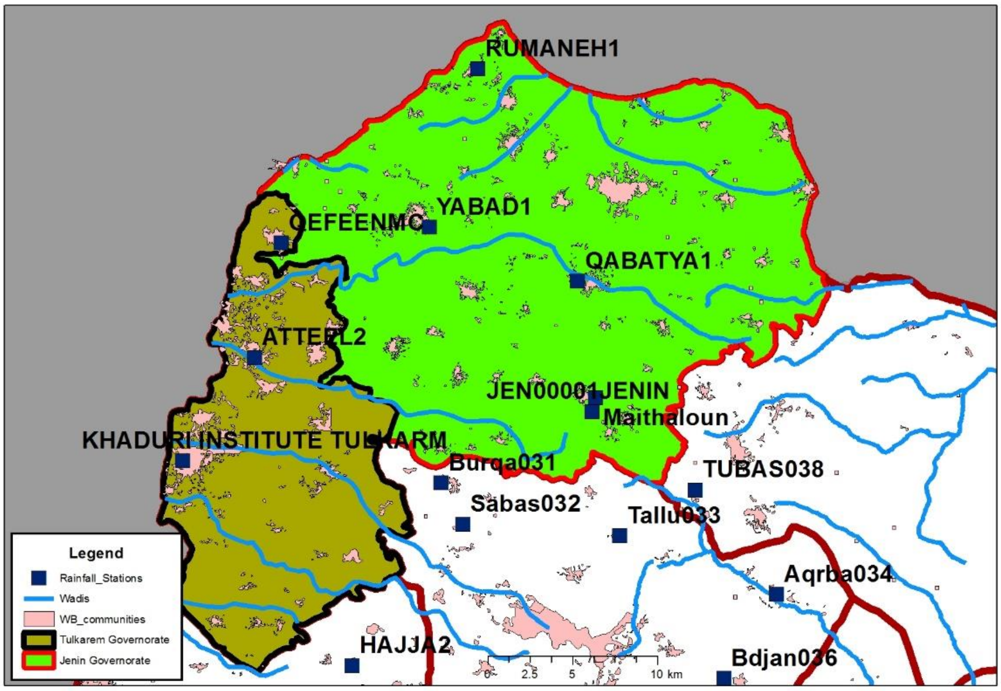


FIGURE 3-1: RAINFALL STATIONS IN JENIN & TULKARM GOVERNORATES AND ADJOINING AREAS

In order to simultaneously study drought occurrences, it is important to have rainfall data with common time frames across rainfall stations. Data sets of monthly rainfall are presented together in Table 3-2. Unfortunately, there is no a single rainfall station with complete data series, which makes the effort for gap filling very intensive. Most of the stations have a common period with no data (1998-2005), that induces a lot of uncertainties in the gap filling operation.

After all rain data are archived, then all typical statistical processes were carried out. These processes are:

1. 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. The most reliable rainfall stations are selected and listed in Table 3-4 with the criteria (a) have more original data, and (b) exhibit better regression coefficients on annual rainfall values with neighboring stations. These stations are illustrated in Figure 3-1.
2. Double Mass Curves: Perform double mass curves analysis to further evaluate data consistency in rainfall stations. Figure 3-2 presents an example of the double mass curves that generally illustrate coherent rainfall data between adjacent stations. **Data on x and y-axes represent cumulative annual rainfall values for the rainfall stations under consideration**.
3. 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 to the correlation equation. For processing purposes, a complete sample for six rainfall stations from the hydrologic year 1969-70 to 2016-17 was made, that means 48 years of data.
4. 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.

5. 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. However, it seems that there is no statistically significant correlation between altitude and annual rainfall depth (see Figure 3-3).

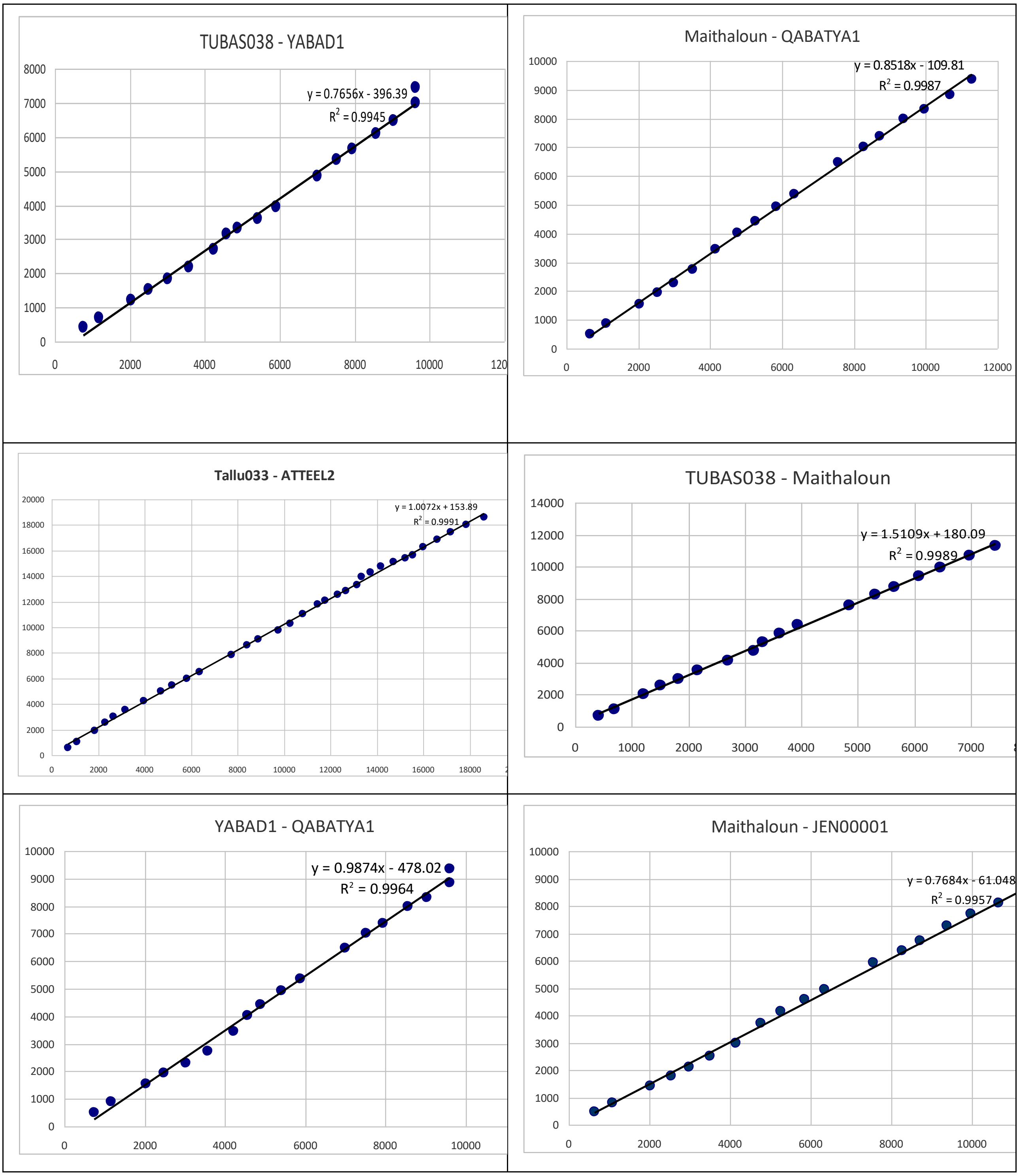


FIGURE 3-2: DOUBLE MASS CURVES FOR SOME RAINFALL STATIONS.

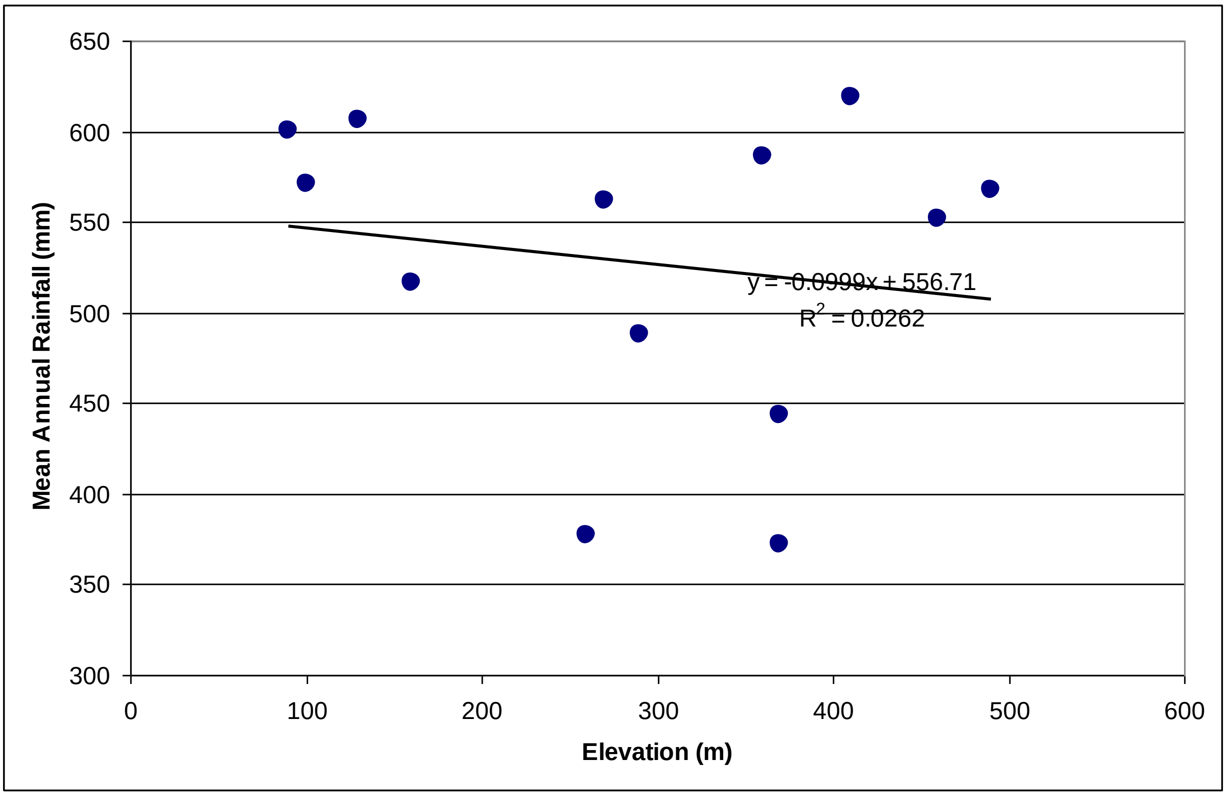


FIGURE 3-3: REGRESSION ANALYSIS BETWEEN RAINFALL DEPTH AND STATION ELEVATION

TABLE 3-2: RAINFALL DATA AVAILABILITY AMONG RAINFALL STATIONS (BLUE COLOUR WITH DATA)

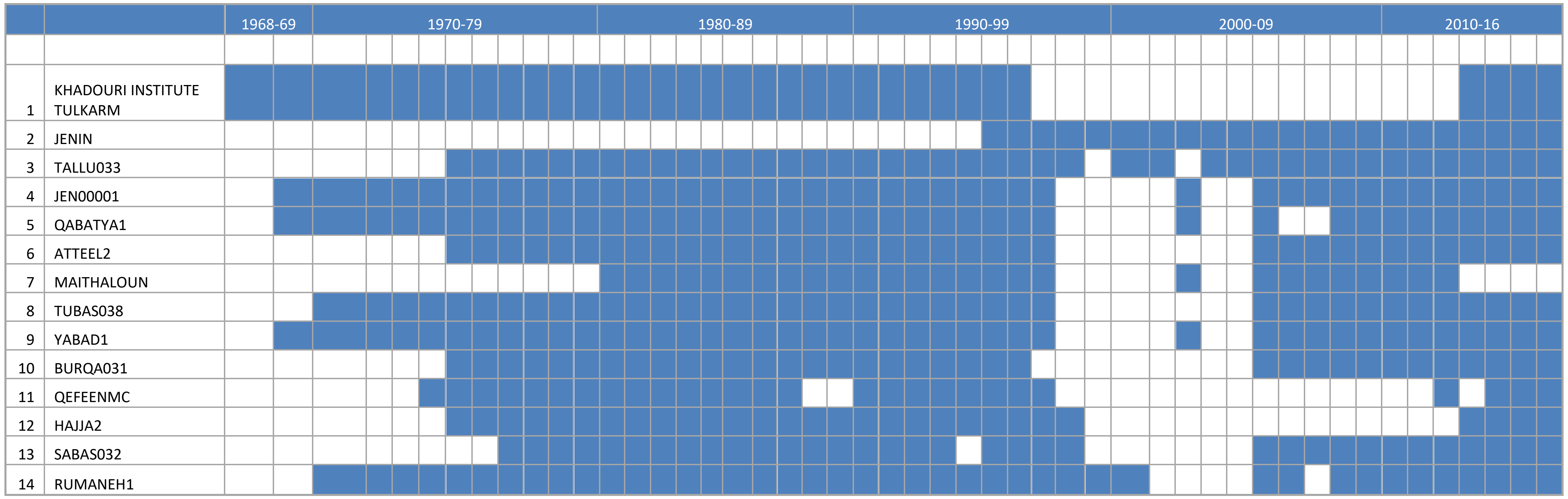


TABLE 3-3: CORRELATION COEFFICIENTS OF ANNUAL RAINFALL BETWEEN ALL RELEVANT STATIONS

RAINFALL STATION	GOVERNORATE	Tulkarem	Jenin	RUMANEH1	Burqa031	JEN00001	QEFEENMC	YABAD1	QABATYA1	Maithaloun	Sabas032	TUBAS038	ATTEEL2	Tallu033	HAJJA2
TULKAREM	TULK	1	0.612	0.402	0.350	0.868	0.845	0.813	0.888	0.876	0.328	0.844	0.928	0.860	0.843
JENIN	JENIN		1	0.537	0.146	0.576	0.639	0.507	0.653	-0.210	N/A	0.354	N/A	N/A	0.803
RUMANEH1	JENIN			1	0.375	0.336	0.354	0.454	0.592	0.288	0.404	N/A	0.493	0.512	0.337
BURQA031	OUT/CLOSE				1	0.255	0.232	0.280	0.346	0.137	0.436	N/A	0.268	0.185	-0.120
JEN00001	JENIN					1	0.893	0.762	0.860	0.713	0.384	0.578	0.924	0.888	0.918
QEFEENMC	TULK						1	0.751	0.857	0.621	0.218	N/A	0.927	0.817	0.813
YABAD1	JENIN							1	0.826	0.654	0.391	0.497	0.806	0.770	0.751
QABATYA1	JENIN								1	0.589	0.532	0.778	0.873	0.810	0.870
MAITHALOUN	JENIN									1	N/A	0.429	N/A	0.818	0.927
SABAS032	OUT/CLOSE										1	0.571	0.373	N/A	N/A
TUBAS038	OUT/CLOSE											1	0.822	0.822	0.888
ATTEEL2	TULK												1	0.857	0.900
TALLU033	OUT/CLOSE													1	N/A
HAJJA2	OUT/CLOSE														1

From Table 3-2 and

Table 3-3, it s evident that Tallu033 station will be used for filling the other stations because it exhibits the best regression coefficients and has the least of gaps in the data. After all the analyses, the following seven rainfall stations will be kept for further analyses. These stations are presented in Table 3-4. Three of them belong to Jenin Governorate, two belong to Tulkarm Governorate and two neighboring Governorates (Nablus and Tubas Governorates).

TABLE 3-4: FINAL LIST OF RAINFALL STATION FOR ANALYSIS

a/a	Station	Governorate	Year Start	Year End	X Coordinate	Y Coordinate	Elevation (m)	Annual Rainfall (mm)
1	Khadouri Institute Tulkarem	Tulkarem	1968-69	2016-17	152,500	191,000	90	570.6
2	JEN00001	Jenin	1969-70	2016-17	176,602	193,973	370	437.6
3	Qabatya1	Jenin	1969-70	2016-17	175,764	201,836	290	487.3
4	Atteel2	Tulkarem	1969-70	2016-17	156,746	197,218	100	564.3
5	Tubas038	Tubas	1969-70	2016-17	182,669	189,237	260	387.8
6	Tallu033	Nablus	1969-70	2016-17	178,232	186,475	490	572.7
7	Yabad1	Jenin	1969-70	2016-17	167,013	205,087	270	572.7

Even though, by plotting only the most reliable stations, it is not possible to provide a meaningful correlation between and elevation and annual rainfall as it is illustrated in Figure 3-4. If a meaningful correlation existed (i.e. linear regression coefficient more than 0.7), then surface rainfall should be corrected with the altitude – rainfall alternation.

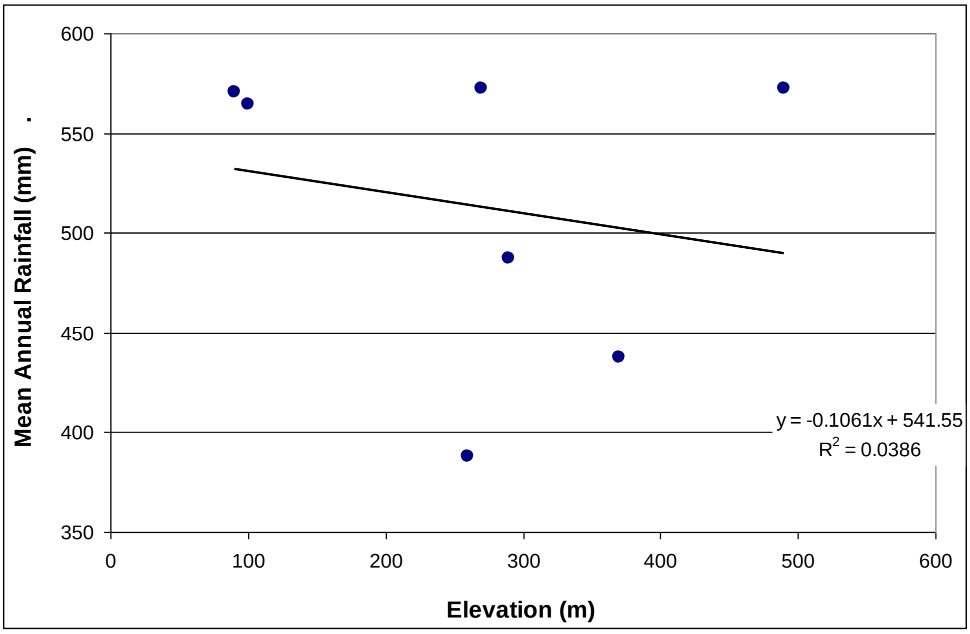


FIGURE 3-4: CORRELATION BETWEEN STATION ELEVATION AND MEAN ANNUAL RAINFALL FOR THE RAINFALL STATIONS UNDER FINAL CONSIDERATION.

In the following Tables (from Table 3-5 to Table 3-12) monthly rainfall data are presented and taken into consideration for the drought analyses in the following sectors of this report.

TABLE 3-5: MONTHLY RAINFALL DATA VALUES FOR TULKARM (KHADOURI INSTITUTE TULKARM) RAINFALL STATION.

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	ANNUAL
1969-70	3.7	48.9	48.7	65.3	209.4	48.9	171.1	33.2	2.9	0	0	0	632.1
1970-71	1.1	7.4	39.5	91.9	114.2	140.3	55.3	112.9	0	0	0	0	562.6
1971-72	0	1.4	57.2	159.2	127.7	175	69	21.2	0.2	0	0	0	610.9
1972-73	0.6	4.4	79	60.1	151.5	17.8	88.8	9.7	18.1	0	0	0	430.0
1973-74	0	26.4	128.4	59.6	329.9	85.7	35.1	22.8	0.4	0	0	0	688.3
1974-75	0	0	39	173.6	108	166.5	53.4	3.6	1.6	0	0	0	545.7
1975-76	19.3	15.5	35.3	160.5	70.6	95.1	89.4	20.7	4.7	0	0	0	511.1
1976-77	0	39.1	230.1	100.6	111.7	64.5	168.5	85.5	1.1	1	0	0	802.1
1977-78	0	91.7	1.1	264.5	93.8	69.8	73.5	12	1.5	0	0	0	607.9
1978-79	0	36.1	10.6	126.2	92.2	24.9	45.1	3.7	0.3	0	0	1.2	340.3
1979-80	0	17.5	103.6	357.6	74.9	176.7	79.4	30.6	0.7	0	0	0	841.0
1980-81	0.8	4.9	6.1	172.2	308.7	85.1	37.3	28.9	1.5	1	0	0	646.5
1981-82	0	1	148.3	38.4	93.8	125.1	75.2	3.1	11.4	0	0	0	496.3
1982-83	0	0	137.7	137.2	182.8	199.6	119.8	18.5	19.7	0	0	0	815.3
1983-84	1	3	71.2	25.4	122.4	40.1	92.5	26.8	0	0.5	0	0	382.9
1984-85	0	23.2	25.2	77.9	123.3	171.8	5.8	26.7	0.5	0	0	0	454.4
1985-86	0	49.8	75.5	106.7	174.8	107.9	21.6	23	34.1	0	0	0	593.4
1986-87	10	70.9	260.3	177	109	37.2	119.3	1.5	0	0	0	0	785.2

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	ANNUAL
1987-88	0	44.2	12.5	234.6	101.6	167.2	86.7	7.2	0	0	0	0	654.0
1988-89	0	27.2	58.6	150.5	100	56.6	83.2	0	0	0	0	0	476.1
1989-90	0	27.6	95.1	189	149.6	155.4	48.1	30.8	0.5	0	0	0	696.1
1990-91	0	6.6	9.7	19.7	251.1	88.2	144.2	37.7	1	0	0	0	558.2
1991-92	0	8.3	220.7	436.4	277.6	390	30	8	9.1	6.2	0	0	1386.3
1992-93	0	0	50.5	316.1	122.3	77.7	60.7	2	5.7	0	0	0	635.0
1993-94	0	18.7	18.4	21.6	228.5	92.6	0	0	0	0	0	0	379.8
1994-95	0	33.7	217.3	258.7	73	123.3	39.7	21.5	0	0	1.5	0	768.7
1995-96	0	2	94.6	63.1	163.5	23.7	144.7	11.5	0	0	0	0	503.1
1996-97	0	0	7	98.5	138.5	173.6	196	0	0	0	0	0	613.6
1997-98	0.0	21.1	52.8	221.3	184.8	72.6	137.3	0.0	0.0	0.0	0.0	0.0	690.0
1998-99	0.0	0.0	21.3	73.0	131.0	53.8	32.4	19.6	0.0	0.0	0.0	0.0	331.1
1999-00	0.0	0.0	19.9	100.9	256.1	52.1	64.8	3.2	0.0	0.0	0.0	0.0	497.0
2000-01	0.0	46.0	20.6	94.2	68.5	87.5	0.0	0.0	0.0	0.0	0.0	0.0	316.9
2001-02	0.0	32.1	50.8	142.6	144.1	39.3	58.2	24.4	2.6	0.0	0.0	0.0	494.2
2002-03	0.0	8.0	63.8	237.3	108.9	308.2	185.3	36.1	0.0	0.0	0.0	0.0	947.7
2003-04	0.0	0.0	33.8	97.6	145.5	84.6	0.0	0.0	0.0	0.0	0.0	0.0	361.5
2004-05	0.0	0.0	93.0	58.5	128.9	123.3	0.0	0.0	2.7	0.0	0.0	0.0	406.4
2005-06	0.0	9.1	40.0	102.6	83.3	95.3	0.0	58.4	0.0	0.0	0.0	0.0	388.6
2006-07	0.0	0.0	16.5	84.1	109.1	87.0	0.0	0.0	0.0	0.0	0.0	0.0	296.8
2007-08	0.0	0.0	80.1	111.1	130.8	85.9	18.3	0.0	0.4	0.0	0.0	0.0	426.6
2008-09	0.0	0.0	16.1	166.4	33.1	249.8	68.8	16.6	0.0	0.0	0.0	0.0	550.7
2009-10	0.0	47.9	99.6	109.9	98.5	178.5	0.0	0.0	4.5	0.0	0.0	0.0	539.0
2010-11	0.0	10.4	15.8	213.0	107.0	82.1	76.7	35.6	6.0	0.0	0.0	0.0	546.5
2011-12	0.0	8.1	113.5	65.7	126.0	150.6	75.0	0.0	0.0	0.0	0.0	0.0	538.8
2012-13	0.0	6.5	44.3	123.2	341.0	54.0	0.0	39.7	5.2	0.0	0.0	0.0	613.9
2013-14	0	9	5.2	303.3	12.5	5	92.5	0	33	0	0	0	460.5
2014-15	0.5	27.5	161.5	33.3	222.5	209.2	18.3	47.5	0	0	0	0	720.3
2015-16	0	64.5	57.8	47.3	128.6	87.3	30.1	11.9	0	0	0	0	427.5
2016-17	0	0	0	289.7	60.2	61.5	6.8	0.5	0	0	0	0	418.7
AVER	0.8	18.7	68.5	142.0	142.2	111.4	64.5	18.7	3.5	0.2	0.0	0.0	570.6
ST. DEV.	3.1	21.9	64.5	94.3	73.0	75.5	53.6	22.8	7.7	0.9	0.2	0.2	192.7
C. VAR.	4.1	1.2	0.9	0.7	0.5	0.7	0.8	1.2	2.2	5.0	6.9	6.9	0.3

AVER: Average Value, ST. DEV: Standard Deviation, C.VAR.: Coefficient of Variation

TABLE 3-6: MONTHLY RAINFALL DATA VALUES FOR JININ RAINFALL STATION

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	ANNUAL
1995-96	0	0	0	0	0	42	115.5	20.4	0	0	0	0	177.9
1996-97	0	35.4	24.1	51.6	92.3	151.4	85.3	10.1	0	0	0	0	450.2
1997-98	0	9.2	48.9	150.2	115.3	73	0	16.7	4	0	0	0	417.3
1998-99	0	0	0	0	62.7	34.9	54.2	21	0	0	0	0	172.8
1999-00	0	0	3.5	46	253.5	42.1	53	2.9	0	0	0	0	401.0
2000-01	0	55.3	0	0	64.2	67	4.6	0	10.9	0	0	0	202.0
2001-02	0	9.8	19.4	0.5	149.2	36.2	44.3	0	6.6	0	0	0	266.0
2002-03	0	0	0	41.6	*78.6*	205.2	130.7	25.1	0	0	0	0	481.2
2003-04	0	18	34	94.1	169.7	94.6	8.1	14.9	1.1	0	0	0	434.5
2004-05	0	0	86.2	43.9	116.1	139.9	15.5	3	9.8	0	0	0	414.4
2005-06	0.3	22.8	42.7	76.9	87.6	73.8	10.2	76.4	0	0	0	0	390.7
2006-07	0	0	0	0	30.1	120.1	59.7	10.3	7.3	0	0	0	227.5
2007-08	0	0	70.5	56.8	100.6	74.5	11.1	0	1.3	0	0	0	314.8
2008-09	0	15.3	14.1	69.7	27.7	214.7	47.8	7	0	0	0	0	396.3
2009-10	0	57.7	88.6	149	58.3	125.3	16.4	0.4	0	1.1	0	0	496.8
2010-11	0	4.3	0	161.9	93.5	95.3	92.8	37.4	5.7	0	0	0	490.9
2011-12	0.4	0	88.8	32.2	167.2	118.6	50.6	0	0	0	0	0	457.8
2012-13	0	30.6	67.6	122.8	258.7	18.1	3.8	24.8	0.4	0	0	0	526.8
2013-14	0	6.8	0.2	167.2	6.7	5.9	75.9	3.9	22.5	0	0	0	289.1
2014-15	3	16.5	142.1	20.9	139.8	185.6	14.4	57.8	0.2	0	0	0	580.3
2015-16	0	46.3	36.5	48.5	146	67.6	25.6	9	3.9	0	0	0	383.4
2016-17	0	0.1	3	183.6	54.1	25.7	16.5	3.5	0	0	0	0	286.5
AVER.	0.17	14.91	35.01	68.97	99.70	91.43	42.55	15.66	3.35	0.05	0.0	0.0	371.8
ST. DEV.	0.64	18.80	40.13	61.01	72.48	60.13	38.01	19.72	5.51	0.23	0.0	0.0	114.8
C. VAR.	3.81	1.26	1.15	0.88	0.73	0.66	0.89	1.26	1.65	4.69	N/A	N/A	0.31

AVER: Average Value, ST. DEV: Standard Deviation, C.VAR.: Coefficient of Variation

TABLE 3-7: MONTHLY RAINFALL DATA VALUES FOR TALLU033 RAINFALL STATION

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	ANNUAL
1969-70	1.0	30.9	61.1	56.2	184.3	74.2	173.1	32.4	4.3	0	0	0	617.5
1970-71	0.3	10.4	55.3	79.6	115.7	159.5	82.2	96.2	0.0	0	0	0	599.1
1971-72	0.0	7.4	66.6	138.7	125.4	192.0	93.0	22.8	0.9	0	0	0	646.8
1972-73	0.1	8.9	80.5	51.6	142.6	45.1	108.5	13.6	23.4	0	0	0	474.3
1973-74	0.0	19.8	112.0	51.2	271.1	108.5	66.4	24.1	1.2	0	0	0	654.3
1974-75	0	0	31.1	133.8	58.4	223	88.8	2.7	0	0	0	0	537.8
1975-76	7	0	45.7	135.6	79.4	144	138	34.9	0	0	0	0	584.6
1976-77	0	24.8	120.4	51.7	153.7	71.6	139.2	67.6	0	0	0	0	629.0
1977-78	0	60.8	2	221.5	72.2	51.5	90.4	9.5	0	0	0	0	507.9
1978-79	0	40	23.2	99.5	108.7	17.5	66.9	5.5	0	0	0	0	361.3
1979-80	0	32.2	177	266.7	120.8	160.1	154	14.5	0.8	0	0	0	926.1
1980-81	0	13.2	8.1	198.6	185.6	100.7	63.1	9.2	0	0	0	0	578.5
1981-82	0	3.7	130	19.8	93.5	136.6	96.5	4	11.3	0	0	0	495.4
1982-83	0	0.2	101.8	106	205	261.4	170.5	16.9	5	0	0	0	866.8
1983-84	0	6.5	98	24.5	185.2	68.4	169.8	57.7	0	0	0	0	610.1
1984-85	0	12.6	30	49.4	71.7	265.9	19.2	41	0.3	0	0	0	490.1
1985-86	0	13.4	55.6	51.8	94.7	157.3	48.7	27.2	59.6	0	0	0	508.3
1986-87	0	25.4	236.3	119.7	149.2	50.9	122.5	2.3	0	0	0	0	706.3
1987-88	0	46.5	15.5	183.9	111.3	249.4	104	11.4	0	0	0	0	722.0
1988-89	0	9.6	53	253.3	68.4	28	91.8	3	0	0	0	0	507.1
1989-90	0	21.5	75.5	109.6	126	92.5	56.4	29.1	0	0	0	0	510.6
1990-91	0	22.9	31.5	10.2	230.5	66.1	106.6	26.6	4.8	0	0	0	499.2
1991-92	0	3.6	151.2	414	265.8	410.4	61	4.6	36.5	0	0	0	1347.1
1992-93	0	0	54.4	366.3	141.9	84.2	76.2	2.4	9	0	0	0	734.4
1993-94	0	13.8	23.7	25.4	203.6	86.1	131	0	0	0	0	0	483.6
1994-95	0	25.3	248.8	177.3	59.5	105.6	37.2	25.2	0	0	0	0	678.9
1995-96	0	0	90.3	58.8	138.3	20.2	231	35.1	0	0	0	0	573.7
1996-97	0	40	10.6	77.9	169.8	258.9	157.2	16.8	10	0	0	0	741.2
1997-98	0	16.3	50.2	204.7	184.8	76.8	186.5	5.4	0	0	0	0	724.7
1998-99	0	0	7.5	48.7	125.6	48.6	39.3	22.5	0	0	0	0	292.2
1999-00	0	0.0	14.0	85.2	256.0	46.3	89.5	7.4	0.0	0	0	0	498.4
2000-01	0	39.9	6.6	71	56.8	99	5.5	1.5	0	0	0	0	280.3
2001-02	0	26.7	47.5	121.9	140	27	75.5	28.3	2.9	0	0	0	469.8
2002-03	0	6.5	23.4	123.2	101.6	301.8	184.7	27.0	0	0	0	0	768.2
2003-04	0	0	24.4	74.6	141.5	94.7	12.4	0	0	0	0	0	347.6
2004-05	0	0	104.7	33.5	123.2	152.5	18.7	8.9	3	0	0	0	444.5
2005-06	0	4.9	32.9	79.8	73	110.7	14	68.9	0	0	0	0	384.2
2006-07	0	0	1	60.4	101.5	98.3	98.8	0.0	0.0	0	0	0	360.0
2007-08	0	0	44.9	53.8	24.1	97.5	38.6	4.9	1.6	0	0	0	265.4

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	ANNUAL
2008-09	0	0	0.5	146.9	17.8	341.7	90.4	18.9	0	0	0	0	616.2
2009-10	7	41.7	113.7	87.5	89.8	235.1	19.5	1	6.2	0	0	0	601.5
2010-11	0	6.2	0	195.9	99.1	91	101.5	41.6	8.9	0	0	0	544.2
2011-12	0	4	132.5	41	120	193.3	99.1	0	0	0	0	0	589.9
2012-13	0	2.5	38.7	101.5	356.7	48.9	10.9	46.5	7.5	0	0	0	613.2
2013-14	0.4	8.8	4.3	204.2	2.5	8.1	96.7	0	33.4	0	0	0	358.4
2014-15	0	23.8	175.7	53.8	208.2	181.2	24.8	53.2	6.6	0	0	0	727.3
2015-16	0	40.9	46	92.3	173.1	96.5	34.6	21.9	0	0	0	0	505.3
2016-17	0	0	7	311	87.3	83.9	11.3	7.2	0	0	0	0	507.7
AVER.	0.2	13.0	61.9	119.9	134.7	131.8	80.9	18.3	5.6	0.0	0.0	0.0	572.7
ST. DEV.	1.2	14.4	63.8	96.0	73.7	97.2	58.4	18.4	12.3	0.0	0.0	0.0	197.1
C. VAR.	5.8	1.1	1.0	0.8	0.5	0.7	0.7	1.0	2.2	N/A	N/A	N/A	0.3

AVER: Average Value, ST. DEV: Standard Deviation, C.VAR.: Coefficient of Variation

Values in italics are a result of gap filling.

TABLE 3-8: MONTHLY RAINFALL DATA VALUES FOR ATTEEL2 RAINFALL STATION

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	ANNUAL
1969-70	*0.5*	*57.3*	*69.8*	*53.8*	*203.8*	*63.5*	*143.1*	*38.9*	*3.4*	*0*	*0*	*0*	634.1
1970-71	*0.1*	*11.6*	*64.0*	*80.3*	*113.3*	*147.0*	*60.2*	*128.6*	*0.0*	*0*	*0*	*0*	604.9
1971-72	*0.0*	*4.9*	*75.2*	*147.3*	*126.1*	*178.7*	*70.0*	*25.4*	*1.1*	*0*	*0*	*0*	628.7
1972-73	*0.0*	*8.2*	*88.9*	*48.6*	*148.8*	*35.0*	*84.2*	*12.5*	*16.4*	*0*	*0*	*0*	442.7
1973-74	*0.0*	*32.5*	*120.1*	*48.1*	*318.4*	*97.1*	*45.7*	*27.2*	*1.3*	*0*	*0*	*0*	690.4
1974-75	0	0	48.9	167.8	104.7	145.5	68.9	2	0	0	0	0	537.8
1975-76	3.4	5.5	48.4	118.9	89.5	146.8	87	54.4	4.8	0	0	0	558.7
1976-77	0	35.1	216.7	102.2	129.2	59.3	149.8	98.1	1	0	0	0	791.4
1977-78	0	85.8	*71.9*	267.5	125.3	45.2	1.7	6.3	0	0	0	0	603.7
1978-79	0	32.7	12.5	127.1	90.3	26.4	48.8	4.2	1.5	0	0	0	343.5
1979-80	0	47.6	98.2	310.7	85.5	172.4	66	32.1	0	0	0	0	812.5
1980-81	0	17.2	7.5	152.3	306.6	115.3	57.6	37.7	2.1	0	0	0	696.3
1981-82	0	0	71.7	26.7	70	116.6	86.3	0	17.3	0	0	0	388.6
1982-83	0	0	133.1	128.4	173.9	198.7	136.6	12	4.3	0	0	0	787.0
1983-84	0	0	82.3	33.6	121	63	103.1	33	0	0	0	0	436.0
1984-85	0	3.3	31.8	63.6	50.9	180.2	10.6	15	0	0	0	0	355.4
1985-86	0	32.2	59.2	75	147.1	92.7	22.3	14.4	64.6	0	0	0	507.5
1986-87	0	139	218.5	174	95.7	42	119.3	2.3	0	0	0	0	790.8
1987-88	0	55.4	44	253.3	106.6	201.7	67.7	5.7	0	0	0	0	734.4
1988-89	0	37	77.5	157.4	87.2	44.4	69.6	0	0	0	0	0	473.1
1989-90	0	70.3	99.5	103.5	178.5	125.3	49.2	34.5	0.2	0	0	0	661.0
1990-91	0	2.7	13.5	21.1	229.7	78.6	120.3	61.5	4	0	0	0	531.4

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	ANNUAL
1991-92	0	16	149.7	454.4	283.1	410.4	54.8	2	2.6	0	0	0	1373.0
1992-93	0	0	52.8	314.9	123.3	109.5	60.2	9.5	12	0	0	0	682.2
1993-94	0	52.3	16.1	13.5	221.6	87.5	93.1	0	0	0	0	0	484.1
1994-95	0	35.7	340	207.3	62.3	132.1	29.4	36.6	2	0	0	0	845.4
1995-96	0	1.5	73.3	52	183.3	18.8	160	21.1	0	0	0	0	510.0
1996-97	0	33.1	9.6	77.3	96.5	190.5	143.8	5.2	16.5	0	0	0	572.5
1997-98	0.7	7.9	60	149.4	164.7	50	191	0	0	0	0	0	623.7
1998-99	*0*	*0.0*	*24.4*	*62.1*	*136.4*	*52.4*	*32.8*	*21.7*	*0.0*	*0*	*0*	*0*	329.8
1999-00	*0*	*17.1*	*17.0*	*19.1*	*19.7*	*17.2*	*0.7*	*0.5*	*0.4*	*0*	*0*	*0*	91.8
2000-01	*0*	*53.2*	*23.5*	*81.8*	*72.5*	*89.0*	*5.2*	*1.9*	*0.0*	*0*	*0*	*0*	327.1
2001-02	*0*	*41.2*	*63.7*	*126.7*	*149.8*	*36.7*	*62.4*	*27.1*	*2.8*	*0*	*0*	*0*	510.5
2002-03	*0*	*23.0*	*40.0*	*127.8*	*19.7*	*17.2*	*0.7*	*0.5*	*0.0*	*0*	*0*	*0*	229.0
2003-04	*0*	*0.0*	*41.0*	*85.0*	*151.2*	*85.8*	*10.9*	*0.0*	*0.0*	*0*	*0*	*0*	373.9
2004-05	*0*	*0.0*	*119.9*	*48.7*	*134.2*	*127.7*	*16.0*	*8.9*	*2.9*	*0*	*0*	*0*	458.2
2005-06	0	26	99.5	96.3	125.5	96	4.5	86.5	0	0	0	0	534.3
2006-07	0	117.5	52.5	67.5	131.5	131	*81.4*	*0.6*	0	0	0	0	581.9
2007-08	0	0	130.2	51.8	13.9	*87.9*	*32.3*	*5.0*	*1.7*	0	0	0	322.8
2008-09	8.2	25.3	7	97.5	16	246	47	7.4	0	0	0	0	454.4
2009-10	42.5	42	127	199.5	94	100	13.5	0	1	0	0	0	619.5
2010-11	0	0.6	0	147.7	144.2	86.5	108.5	51.5	15.1	0	0	0	554.1
2011-12	13	2.5	147	39.5	249.3	111	109.5	0	0	0	0	0	671.8
2012-13	0	29	118.5	179.5	350.5	39.5	9	42.5	1.5	0	0	0	770.0
2013-14	0	2	71	313.5	20	7.5	70	0	0	0	0	0	484.0
2014-15	0	8.5	226	32	218.5	223.5	35	41.5	0	0	0	0	785.0
2015-16	0	64	54.5	30.5	164.5	76.5	42	35	0	0	0	0	467.0
2016-17	0	0	9	279	76	48	7.5	0	0	0	0	0	419.5
AVER.	1.4	26.6	79.7	125.3	135.9	105.3	64.4	21.9	3.8	0.0	0.0	0.0	564.3
ST. DEV.	6.5	31.0	67.2	95.9	78.6	74.0	48.0	27.9	10.1	0.0	0.0	0.0	203.0
C. VAR.	4.5	1.2	0.8	0.8	0.6	0.7	0.7	1.3	2.7	N/A	N/A	N/A	0.4

AVER: Average Value, ST. DEV: Standard Deviation, C.VAR.: Coefficient of Variation

Values in italics are a result of gap filling.

TABLE 3-9: MONTHLY RAINFALL DATA VALUES FOR JEN00001 RAINFALL STATION

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	ANNUAL
1969-70	0	0	50.1	57.3	144.2	51.1	150.1	28.4	3.5	0	0	0	484.7
1970-71	0	4.1	20	70.6	89.2	132.2	33.8	131.4	0	0	0	0	481.3
1971-72	0	0	36.4	142	77	109.1	92.3	12	0	0	0	0	468.8
1972-73	0	1.4	25.1	49.3	137.2	22.1	73.8	18.3	15.5	0	0	0	342.7
1973-74	0	12.5	61.8	49.2	345.1	72.1	33.2	15.9	0	0	0	0	589.8
1974-75	0	0	24.3	109.8	50.2	141.4	57.5	4.3	0	0	0	0	387.5
1975-76	0	8.3	32.9	106.4	80.8	104.3	72.2	27	2	0	0	0	433.9
1976-77	0	37.2	108	62.4	136	47.4	116.1	70.9	2	0	0	0	580.0
1977-78	0	43	0.4	140.1	63.3	30.7	62.8	9.2	0	0	0	0	349.5
1978-79	0	18.7	13.5	101.5	60.5	15.5	71.5	3	0	0	0	0	284.2
1979-80	0	21.8	102.4	233.1	98.9	113.1	102.5	20.7	0	0	0	0	692.5
1980-81	0	17.1	11.1	108.8	191	76.3	71	8	0	0	0	0	483.3
1981-82	0	0	63.6	28.4	32	121.4	53.7	0	0	0	0	0	299.1
1982-83	0	0	58.6	95.7	162.2	183.2	143.8	0	0	0	0	0	643.5
1983-84	0	0	67.7	31.8	109	47.3	78.2	39.8	0	0	0	0	373.8
1984-85	0	13	23	48.7	62.9	119.6	8	22.4	0	0	0	0	297.6
1985-86	0	31.3	55.6	41.8	94.6	96.6	14.4	21	38.8	0	0	0	394.1
1986-87	0	47.3	157.1	101.9	71.7	19.2	81.1	0.1	0	0	0	0	478.4
1987-88	0	15.3	15.3	211	181.2	223.2	91.9	0	0	0	0	0	737.9
1988-89	0	0	60	171.6	84.5	30.7	76.7	0	0	0	0	0	423.5
1989-90	0	17.8	57.5	98.1	118	90.5	46.8	20	0	0	0	0	448.7
1990-91	0	3	11.4	9.7	156	60.3	112	17.6	0	0	0	0	370.0
1991-92	0	5.1	87	254.3	216.3	367.3	38.2	0	4.9	0	0	0	973.1
1992-93	0	0	48.4	241.5	50.3	77	27.3	4	9.9	0	0	0	458.4
1993-94	0	21.9	39.7	5.6	144.9	54.3	74.7	7.2	0	0	0	0	348.3
1994-95	0	11.4	192.3	162.2	32.6	87.9	29.8	27.5	0	0	0	0	543.7
1995-96	0	0	92.1	32.9	129.7	28.3	119.8	15.5	0	0	0	0	418.3
1996-97	0	18.8	3	42.7	90.2	161	92.6	9.6	2.8	0	0	0	420.7
1997-98	0	7.5	52	137.9	143.2	57.0	122.2	1.9	0.0	0	0	0	521.7
1998-99	0	0.0	15.4	52.6	103.5	36.1	30.4	17.5	0.0	0	0	0	255.5
1999-00	0	0.0	19.6	75.3	191.0	34.3	61.8	3.7	0.0	0	0	0	385.7
2000-01	0	30.8	14.8	66.5	57.4	73.5	9.4	0.0	0.0	0	0	0	252.3
2001-02	0	22.0	41.3	98.1	113.2	20.0	53.0	22.8	1.4	0	0	0	371.8
2002-03	0	8.6	25.7	98.9	87.4	224.1	121.1	21.6	0.0	0	0	0	587.4
2003-04	0	0.0	26.3	68.7	114.2	70.3	13.7	0.0	0.0	0	0	0	293.2
2004-05	0	0.0	78.4	43.2	101.9	113.2	17.6	5.1	1.4	0	0	0	360.8
2005-06	0	7.5	30.9	69.7	68.2	82.2	14.7	59.8	0.0	0	0	0	333.0
2006-07	0	0.0	10.0	57.4	87.3	73.0	67.5	0.0	0.0	0	0	0	295.1
2007-08	0	0.0	38.8	53.2	35.4	72.4	30.0	0.0	0.0	0	0	0	229.9

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	ANNUAL
2008-09	5	15.3	17.8	69.7	28.1	214.7	48	7	0	0	0	0	405.6
2009-10	3.9	58.1	88.6	149	69.8	126.3	16.4	0.4	1	0	0	0	513.5
2010-11	0	4.5	0	124.9	93.5	107.7	92.8	37	13.6	0	0	0	474.0
2011-12	0.3	0	88.8	32.2	167.2	118	47.4	0	0	0	0	0	453.9
2012-13	0	30.6	67.6	122.8	258.7	18.1	3.8	25.7	0.4	0	0	0	527.7
2013-14	0	6.8	0.2	167.2	6.7	5.9	75.9	3.9	22.5	0	0	0	289.1
2014-15	3	16.5	142.1	20.9	139.8	185.6	14.4	57.8	0.2	0	0	0	580.3
2015-16	0	46.3	36.5	48.5	146	67.6	25.6	9	3.9	0	0	0	383.4
2016-17	0	0.1	3	183.6	54.1	25.7	16.5	0	0	0	0	0	283.0
AVER.	0.3	12.6	48.3	94.8	109.9	91.8	60.6	16.8	2.6	0.0	0.0	0.0	437.6
ST. DEV.	1.0	15.0	42.1	61.7	63.2	69.3	38.6	23.7	7.0	0.0	0.0	0.0	141.4
C. VAR.	3.9	1.2	0.9	0.7	0.6	0.8	0.6	1.4	2.7	N/A	N/A	N/A	0.3

AVER: Average Value, ST. DEV: Standard Deviation, C.VAR.: Coefficient of Variation

Values in italics are a result of gap filling.

TABLE 3-10: MONTHLY RAINFALL DATA VALUES FOR QABATYA1 RAINFALL STATION

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	ANNUAL
1969-70	0	0	*67.8*	*57.7*	142	60.7	162	30.6	0	0	0	0	520.8
1970-71	0	2	25.4	64.8	88.1	136.8	46.1	123.2	0	0	0	0	486.4
1971-72	0	0	46.4	212.1	99.7	106	87.3	13.7	0	0	0	0	565.2
1972-73	0	12	34.5	41	196	20	73	23.5	12	0	0	0	412.0
1973-74	0	23	76	47.5	280.5	63	42.5	15	0	0	0	0	547.5
1974-75	0	0	37	86.1	67.2	154	56	2	0	0	0	0	402.3
1975-76	0	3	291.7	92	61	82.5	80.5	26.5	3.5	0	0	0	640.7
1976-77	0	21.5	114.5	57.5	139.7	45	120.5	76.5	0	0	0	0	575.2
1977-78	0	37	*73.1*	164.8	82.2	36.4	68.9	15.3	0	0	0	0	477.7
1978-79	0	32	10.1	107.3	68.3	15.3	84.4	4.4	0	0	0	0	321.8
1979-80	0	23.6	96.5	250.2	79.4	125.4	110	19.2	0	0	0	0	704.3
1980-81	0	10	7.2	134.7	162.4	100.3	80.3	15.1	0	0	0	0	510.0
1981-82	0	0	72.8	37.9	69.1	123.3	63.9	5.5	0	0	0	0	372.5
1982-83	0	0	100.3	109.8	143.9	175.6	122.4	9	3.1	0	0	0	664.1
1983-84	0	0	78.3	34.9	95.9	52.3	87.6	38.2	*0.0*	0	0	0	387.2
1984-85	0	24.9	38.8	62.5	85.4	119.4	7.4	24.3	0	0	0	0	362.7
1985-86	0	54.5	58.3	36.4	95.8	117	23.7	21.4	35.1	0	0	0	442.2
1986-87	0	119.5	221.6	126.9	108.5	33.3	84.9	15.3	0	0	0	0	710.0
1987-88	0	26.3	9.9	183.6	134.8	132.8	82.9	12.7	0	0	0	0	583.0
1988-89	0	17.8	63.5	135.2	70.3	33.4	86.6	0	0	0	0	0	406.8
1989-90	0	28.1	64.6	94.1	150.9	91.4	53.5	19.5	0	0	0	0	502.1
1990-91	0	13.2	14.9	12.4	183.1	69.7	117.4	24.8	0	0	0	0	435.5
1991-92	0	2.8	117.3	300.3	228	369.3	70.9	0	9.1	0	0	0	1097.7

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	ANNUAL
1992-93	0	0	51.2	282.5	85.5	70.6	38.1	4.2	6	0	0	0	538.1
1993-94	0	6.6	21.2	10.1	183.1	66.3	72.6	10	0	0	0	0	369.9
1994-95	0	16.4	213.8	179.4	41	105.6	32.4	30.2	0	0	0	0	618.8
1995-96	0	0	80.5	43	56.5	20.7	119.8	0	0	0	0	0	320.5
1996-97	0	20.8	0.5	67	129.5	176.2	106.5	9	2.8	0	0	0	512.3
1997-98	0	10	41.1	136.9	*149.9*	*58.4*	*124.1*	*8.8*	0	0	0	0	529.2
1998-99	0	*0.0*	*29.9*	*52.5*	*106.6*	*39.2*	*41.7*	*18.9*	*0.0*	0	0	0	288.7
1999-00	0	*0.0*	*34.4*	*78.2*	*202.1*	*37.6*	*69.8*	*10.0*	*0.0*	0	0	0	432.2
2000-01	0	*35.1*	*29.2*	*68.2*	*56.2*	*73.5*	*22.8*	*6.5*	*0.0*	0	0	0	291.4
2001-02	0	*25.6*	*58.1*	*104.1*	*117.1*	*24.5*	*62.0*	*22.4*	*1.8*	0	0	0	415.5
2002-03	0	2.5	54.5	179.1	71	320	160.5	40.5	0	0	0	0	828.1
2003-04	0	*0.0*	*45.9*	*71.4*	*119.3*	*71.4*	*22.6*	*0.0*	*0.0*	0	0	0	330.6
2004-05	0	*0.0*	*99.8*	*42.5*	*106.6*	*113.7*	*26.5*	*9.6*	*1.8*	0	0	0	400.5
2005-06	0	28	57.5	79	89	49	*27.5*	0	0	0	0	0	330.0
2006-07	0	*0.0*	*25.3*	*60.7*	*88.9*	*73.0*	*0.0*	*0.0*	*0.0*	0	0	0	247.9
2007-08	0	*0.0*	*56.3*	*56.1*	*32.2*	*72.5*	*41.3*	*8.5*	*1.1*	0	0	0	267.9
2008-09	0	0	*24.9*	93.7	25.1	258.2	80.4	13.7	0	0	0	0	496.0
2009-10	0	51	123.9	168	94.3	104	31	0	13	0	0	0	585.2
2010-11	0	4	0	96	100.6	102.3	107.9	37.5	15.5	0	0	0	463.8
2011-12	0	0	125.5	41.6	186.5	99.5	133.5	0	0	0	0	0	586.6
2012-13	0	36.8	92.5	133	290.7	63	10	58.3	6	0	0	0	690.3
2013-14	0	0	*73.1*	248	6.4	11	54.5	0	17	0	0	0	410.0
2014-15	0	7.3	142	15.5	165	156.5	24.8	49.5	0	0	0	0	560.6
2015-16	0	34.3	49	19	123	71.5	33.2	35	0	0	0	0	365.0
2016-17	0	0	*73.1*	220.3	44	32.7	12	0	0	0	0	0	382.1
AVER.	0.0	15.2	69.2	104.1	114.6	94.5	68.1	18.9	2.7	0.0	0.0	0.0	487.3
ST. DEV.	0.0	21.5	57.5	73.3	61.1	72.4	40.4	22.6	6.4	0.0	0.0	0.0	157.8
C. VAR.	N/A	1.4	0.8	0.7	0.5	0.8	0.6	1.2	2.4	N/A	N/A	N/A	0.32

AVER: Average Value, ST. DEV: Standard Deviation, C.VAR.: Coefficient of Variation

Values in italics are a result of gap filling.

TABLE 3-11: MONTHLY RAINFALL DATA VALUES FOR TUBAS038 RAINFALL STATION

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	ANNUAL
1969-70	*0*	*34.9*	*39.6*	*33.1*	*138.2*	*43.4*	*99.0*	*25.0*	*2.2*	*0*	*0*	*0*	415.3
1970-71	0	0	*35.1*	*49.3*	68.6	64.6	40.3	109.3	0	0	0	0	367.2
1971-72	0	0	64.5	155.2	81.3	100.3	91	0	0	0	0	0	492.3
1972-73	0	0	24.1	32.7	137.3	8	66	6.7	6.5	0	0	0	281.3
1973-74	0	0	80.5	43.5	282.8	71.6	27	18	0	0	0	0	523.4
1974-75	0	0	15.5	84	30.1	139.5	54.7	0	0	0	0	0	323.8
1975-76	0	2.5	24.2	60	42.8	76.8	83.7	24	7	0	0	0	321.0
1976-77	0	23.2	80	44.3	113.7	24	63	37	0	0	0	0	385.2
1977-78	0	135	1	122.5	25	43	67	9	0	0	0	0	402.5
1978-79	0	16	15	69	58.5	15.5	48	0	0	0	0	0	222.0
1979-80	0	32.5	142	170.9	132	112	100	6	0	0	0	0	695.4
1980-81	0	0	0	136	132.4	37	31	68.5	3.5	0	0	0	408.4
1981-82	0	0	64	14.5	69.5	87	45.1	0	0	0	0	0	280.1
1982-83	0	0	79	60	135	137	102	0	5	0	0	0	518.0
1983-84	0	0	36	16.5	105	37	86.5	24	0	0	0	0	305.0
1984-85	0	22	11	37	50	157	13	28	0	0	0	0	318.0
1985-86	0	10	27	36	69	91.5	20.5	49	34	0	0	0	337.0
1986-87	0	25	179	105	96	34	94	1.5	0	0	0	0	534.5
1987-88	0	27	8	121	93	200	15	0	0	0	0	0	464.0
1988-89	0	19	45	94	*52.6*	*35.3*	*66.7*	0	0	0	0	0	312.6
1989-90	0	15	76	94	108	*73.8*	*50.9*	0	0	0	0	0	417.7
1990-91	0	8.5	12	4.5	133	81	77	10.5	0	0	0	0	326.5
1991-92	0	0	114.5	291	190	262	46.5	0	18.5	0	0	0	922.5
1992-93	0	0	41	234	69	69	38	2	3.5	0	0	0	456.5
1993-94	0	8.5	17.7	7.5	132.5	64.5	95	3	0	0	0	0	328.7
1994-95	0	16.5	167	150	23.5	48	30	14	0	0	0	0	449.0
1995-96	0	0	63.5	22	140.5	15.5	122	8.5	0	0	0	0	372.0
1996-97	0	29.5	5	53	126	181.5	109	9.5	0	0	0	0	513.5
1997-98	0	34.5	22.5	121	*127.6*	*49.6*	*110.8*	*3.0*	0	0	0	0	469.0
1998-99	0	*0.0*	*7.1*	*32.6*	*91.5*	*33.7*	*25.8*	*16.1*	*0.0*	0	0	0	206.8
1999-00	0	*0.0*	*11.6*	*54.8*	*171.0*	*32.4*	*54.8*	*4.5*	*0.0*	0	0	0	329.1
2000-01	0	*43.7*	*6.4*	*46.2*	*49.6*	*62.1*	*6.3*	*0.1*	*0.0*	0	0	0	214.3
2001-02	0	*29.7*	*35.0*	*77.0*	*100.3*	*21.6*	*46.7*	*20.5*	*1.8*	0	0	0	332.6
2002-03	0	*8.2*	*18.2*	*77.8*	*76.9*	*176.1*	*109.7*	*19.5*	*0.0*	0	0	0	486.4
2003-04	0	*0.0*	*18.9*	*48.3*	*101.2*	*59.7*	*10.3*	*0.0*	*0.0*	0	0	0	238.3
2004-05	0	*0.0*	*74.9*	*23.4*	*90.1*	*92.2*	*13.9*	*5.7*	*1.9*	0	0	0	302.0
2005-06	0	5	46	82	88.2	98	10	115	0	0	0	0	444.2
2006-07	0	58.5	18	50	50.5	83	*60.1*	0	0	0	0	0	320.1
2007-08	0	0	62	42	20.7	*61.2*	*25.4*	0	0	0	0	0	211.4

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	ANNUAL
2008-09	7	24	12	93	32	175	46	4	0	0	0	0	393.0
2009-10	19	72	83	88.1	153	19	*14.4*	0	6	0	0	0	454.5
2010-11	0	3.5	0	74	106.5	69.3	117	26	5.5	0	0	0	401.8
2011-12	0	0	103.5	37.8	107.6	109.5	61	0	0	0	0	0	419.4
2012-13	0	11	52	47	218	20	1	20.5	5	0	0	0	374.5
2013-14	0	3.5	*4.8*	135	1	5	61	0	33	0	0	0	243.3
2014-15	0	32.5	123.5	40	150.6	137.5	16	28.5	3.5	0	0	0	532.1
2015-16	0	12	19.5	9	123.5	53.5	20.5	15.5	0	0	0	0	253.5
2016-17	0	0	3.5	188.5	51.5	40.5	10	0	0	0	0	0	294.0
AVER.	0.5	15.5	45.7	78.2	98.1	78.0	53.3	15.1	2.9	0.0	0.0	0.0	387.8
ST. DEV.	2.9	24.3	44.7	59.9	54.3	56.6	34.7	25.2	7.3	0.0	0.0	0.0	130.2
C. VAR.	5.4	1.6	1.0	0.8	0.6	0.7	0.7	1.7	2.5	N/A	N/A	N/A	0.3

AVER: Average Value, ST. DEV: Standard Deviation, C.VAR.: Coefficient of Variation

Values in italics are a result of gap filling.

TABLE 3-12: MONTHLY RAINFALL DATA VALUES FOR YABAD1 RAINFALL STATION

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	ANNUAL
1969-70	0	0	*63.1*	*87.2*	256	63.9	208	36.7	0	0	0	0	714.9
1970-71	0	12.5	42.3	103.9	110.9	177.8	35	168.5	0	0	0	0	650.9
1971-72	0	0	52.1	202.8	119.6	142.2	89.6	15.5	0	0	0	0	621.8
1972-73	0	6.2	59	69.7	201.2	52.8	100.3	23.2	28	0	0	0	540.4
1973-74	0	0	93.6	63	399.1	84	82.2	33	0	0	0	0	754.9
1974-75	0	0	34	211.4	99.3	194	73.9	0	7	0	0	0	619.6
1975-76	0	21.8	34.1	178.7	109.9	132	107.5	44.5	6	0	0	0	634.5
1976-77	0	66.5	160	96	162.2	68	184.7	106.3	2	0	0	0	845.7
1977-78	0	80.5	*69.8*	234.5	137	48.8	84	3.8	0	0	0	0	658.4
1978-79	0	30.2	16.2	136.1	88.9	21.1	73.4	8.5	0	0	0	0	374.4
1979-80	0	24	108.6	355	116.1	157.1	125.4	39.4	0	0	0	0	925.6
1980-81	0	16.6	2.7	166	327.9	142.9	74.8	19	0	0	0	0	749.9
1981-82	0	0	90.4	39.4	84	134.7	67.8	0	0	0	0	0	416.3
1982-83	0	0	102.8	145.3	212	237	175.1	0	0	0	0	0	872.2
1983-84	0	0	91.6	36.3	104	66.8	101.1	56.2	0	0	0	0	456.0
1984-85	0	27.9	38.4	71.9	125.6	192.6	10.1	62.1	0	0	0	0	528.6
1985-86	0	64.5	49.7	77.9	146.9	127.2	15.2	16.7	66.4	0	0	0	564.5
1986-87	0	60.5	206	137.1	82.8	39.2	116.9	4.7	0	0	0	0	647.2
1987-88	0	26.1	11.6	204.8	102.9	*200.9*	*88.6*	0	0	0	0	0	634.9
1988-89	0	22	57	162.5	63.5	*35.0*	*79.4*	0	0	0	0	0	419.4
1989-90	0	38.5	79.2	86.3	172.4	90.4	60.2	0	0	0	0	0	527.0
1990-91	0	8.7	12.7	12	216.5	98.6	110.6	22.5	0	0	0	0	481.6
1991-92	0	6.3	182.6	260	240.3	352.3	64.4	0	2.2	0	0	0	1108.1

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	ANNUAL
1992-93	0	0	58.1	231.6	78.6	91.2	46.3	5.8	6.5	0	0	0	518.1
1993-94	0	15.4	20.7	11.6	205.6	71.6	78.1	20	0	0	0	0	423.0
1994-95	0	16.4	216.3	182.5	44.2	84	34.6	44.5	0	0	0	0	622.5
1995-96	0	0	86.5	49	150.4	20.5	147.6	13.8	0	0	0	0	467.8
1996-97	0	37.1	4.3	78.9	145.5	189.7	118.3	6.5	0	0	0	0	580.3
1997-98	0	5.4	64.9	175.8	*174.3*	*71.5*	*150.6*	*4.6*	*0.0*	0	0	0	647.2
1998-99	0	*0.0*	*17.4*	*82.5*	*129.2*	*50.4*	*40.0*	*25.0*	*0.0*	0	0	0	344.6
1999-00	0	*0.0*	*22.9*	*105.3*	*228.6*	*48.6*	*77.7*	*7.0*	*0.0*	0	0	0	490.2
2000-01	0	*47.3*	*16.7*	*96.4*	*76.8*	*88.2*	*14.6*	*0.0*	*0.0*	0	0	0	340.0
2001-02	0	*34.2*	*51.5*	*128.1*	*140.2*	*34.2*	*67.2*	*32.0*	*1.5*	0	0	0	488.9
2002-03	0	0	29.8	249	84.6	314.5	260.8	23.9	0	0	0	0	962.6
2003-04	0	*0.0*	*31.8*	*98.7*	*141.3*	*84.9*	*19.8*	*0.0*	*0.0*	0	0	0	376.5
2004-05	0	*0.0*	*100.2*	*73.1*	*127.4*	*128.3*	*24.5*	*8.8*	*1.6*	0	0	0	463.9
2005-06	0	29.1	20.5	89	144.4	45.9	18.2	85.9	0	0	0	0	433.0
2006-07	0	0	0	216	51.6	126.4	*88.0*	0	0	0	0	0	482.0
2007-08	0	0	104.4	88.4	32.6	*82.9*	*30.4*	*2.3*	0	0	0	0	341.1
2008-09	5.7	42.1	15	94.3	31.7	274	42.9	2.2	0	0	0	0	507.9
2009-10	0	86.2	91.2	167.2	83.1	95.6	36.3	0	6.3	0	0	0	565.9
2010-11	0	6.3	0	141	105.1	111.7	118.9	45.2	12	0	0	0	540.2
2011-12	0	0	147.6	40.4	229.1	108.9	112.9	0	0	0	0	0	638.9
2012-13	0	46.4	122.4	163.7	266.1	54.8	2.9	68.3	0	0	0	0	724.6
2013-14	0	12.9	*66.2*	150.9	9.4	5.6	92.5	0	19.4	0	0	0	356.9
2014-15	0	4	167.2	19	149.4	192.7	22.7	57.4	0	0	0	0	612.4
2015-16	2	56.2	40.2	32.2	196.4	82.3	35.8	25	0	0	0	0	470.1
2016-17	0	0	7.9	216.2	45.6	28.4	20	0	0	0	0	0	318.1
AVER.	0.2	19.8	65.9	127.5	140.6	111.4	79.8	23.7	3.3	0.0	0.0	0.0	572.2
ST. DEV.	0.9	23.8	55.1	75.0	78.1	76.5	54.8	32.9	10.7	0.0	0.0	0.0	173.2
C.. VAR.	5.4	1.2	0.8	0.6	0.6	0.7	0.7	1.4	3.2	N/A	N/A	N/A	0.3

AVER: Average Value, ST. DEV: Standard Deviation, C.VAR.: Coefficient of Variation

Values in italics are a result of gap filling.

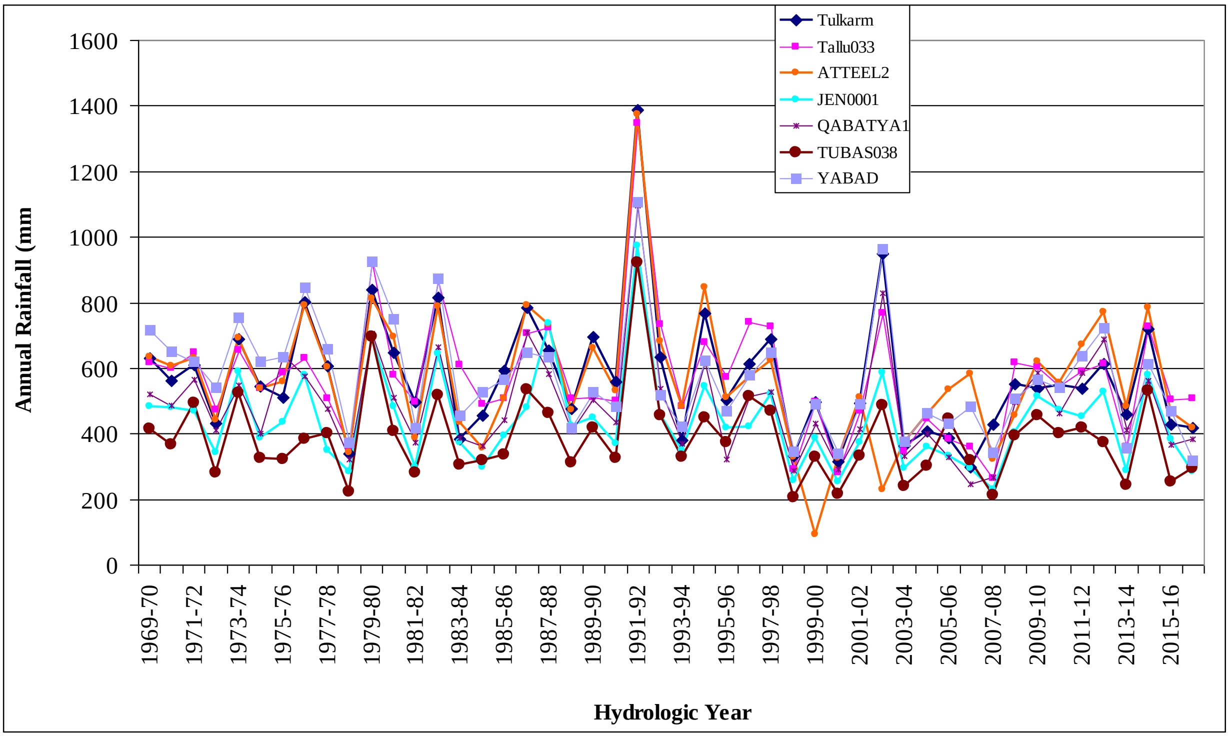


FIGURE 3-5: DIAGRAM OF ANNUAL RAINFALL DEPTHS FOR ALL SEVEN STATIONS

3.2 POTENTIAL EVAPOTRANSPIRATION

Potential Evapotranspiration (ET) is computed throughout the methodological context using the Penman - Monteith (P-M) method. It was developed by Howard Penman in 1948 (later modified by John Monteith et al. to yield the Penman–Monteith model). It is well established and a basis for further theoretical development in the field of evaporation research. Basically, it is a combination of turbulent transfer and energy-balance approaches (3 equations)

$$\lambda ET_o = \frac{\Delta\,(R_n - G) + \dfrac{86{,}400\,\rho_a C_P \left(e_s^{\,o} - e_a\right)}{r_{av}}}{\Delta + \gamma\left(1 + \dfrac{r_s}{r_{av}}\right)}$$

ET_o	=	Reference Evapotranspiration
R_n	=	Net radiation flux in MJ m^{-2} d^{-1},
G	=	Sensible heat flux into the soil in MJ m^{-2} d^{-1}
p_a	=	Air density in kg m^{-3}
C_p	=	Specific heat of dry air [~1.013 x 10^{-3}MJ kg^{-1} $ºC^{-1}$]
e_a	=	Saturation vapor pressure at mean air temperature in kPa
e_s	=	Saturation vapor pressure at dew point in kPa

r_s = Canopy surface resistance in s m^{-1}.

r_a = Bulk surface aerodynamic resistance for water vapor in s m^{-1}

λ = Latent heat of vaporization in MJ kg-1

γ = Psychrometric constant in kPa $^oC^{-1}$

Δ = Slope of the saturated vapor pressure curve.

As already stated, Penman-Moneith method needs the following data, (a) Temperature (mean monthly or mean monthly maximum and minimum) (^{o}C), (b) Relative humidity (%), (c) Wind Speed (m/s at 2 m height of the sensor), and (d) sunshine duration (h). These types of data are not available even in technologically developed countries, so a fair approximation of P-M method, is the Hargreaves method.

Hargreaves method was originally developed in 1975 and uses solar radiation and temperature data inputs.

It was updated in 1982 and 1985 to accommodate grass reference ET (ETo) estimates. The Hargreaves equation is the following:

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

where,

Ra = Extraterrestrial solar radiation (MJ/m2/day),

Hargreaves method can be used to compute daily PET. It is a simple and easy to use method with Minimal data requirements—maximum and minimum air temperature, has better predictive accuracy in arid climates than other empirical methods (such as modified Blaney-Criddle), it needs only the max-min temperature difference and the extra-terrestrial radiation.

3.2.1 Temperature Data

Temperature data are provided only for 2 stations. Average temperatures are calculated as the average values of the minimum and maximum monthly temperatures.

TABLE 3-13: TEMPERATURE DATA FOR THE JENIN & TULKARM GOVERNORATES

Station	Data Period (with gaps)	Type of Data	Maximum Temperature (^{o}C)	Minimum Temperature (^{o}C)	Average Temperature (^{o}C)
Khadouri Institute Tulkarem	1969-2017 (16 years gap)	Average, Maximum and Minimum Monthly Temperatures	25.1	17.44	20.7
Jenin	1997-2015 (2 years gap)	Average, Maximum and Minimum Monthly Temperatures	26.3	16.32	20.9

3.2.2 Relative Humidity Data

Relative humidity data are provided only for 2 stations.

TABLE 3-14: RELATIVE HUMIDITY DATA FOR THE FOR THE JENIN & TULKARM GOVERNORATES

Station	Data Period (with gaps)	Type of Data	Average Relative Humidity (%)
Khadouri Institute Tulkarem	1997-2015 (4 years gap)	Relative Humidity	61.3
Jenin	1997-2015 (4 years gap)	Relative Humidity	64.8

3.2.3 Sunshine Duration Data

Sunshine duration data are provided only for 2 stations..

TABLE 3-15: SUNSHINE DURATION DATA FOR THE FOR THE JENIN & TULKARM GOVERNORATES

Station	Data Period (with gaps)	Type of Data	Average Daily Sunshine Duration (h)
Khadouri Institute Tulkarem	2008 – 2015 (no gaps)	Average Sunshine Duration	8.29
Jenin	2008 – 2015 (no gaps)	Average Sunshine Duration	8.29

3.2.4 Wind Speed Data

Wind Speed data are provided for 2 meteorological stations and are measured in m/s.

TABLE 3-16: WIND SPEED DATA FOR THE FOR THE JENIN & TULKARM GOVERNORATES

Station	Data Period (with gaps)	Type of Data	Average Wind Speed (m/s)
Khadouri Institute Tulkarem	2003 – 2015 (no gaps)	Average Wind Speed	4.7
Jenin	2003 – 2015 (no gaps)	Average Wind Speed	5.7

3.2.5 PET Computations

Values of PET are computed both with PM and HG methods and the results are summarized in the following Table. Generally, it is not possible to directly compare PM to HG because common periods with PET estimates are not generally available, but we can see that for Jenin station, PM and HG methodologies provide quite similar results but the difference is huge of Tulkarm station. Monthly PET values are listed in Table 3-18 for Jenin and Table 3-19 for Tulkarm.

TABLE 3-17: PET ESTIMATES WITH PM AND HG METHODS

Station	Data Period (with gaps)	PET Penman Monteith (mm/y)	PET Hargreaves (mm/y)
Khadouri Institute Tulkarem	1966 – 2016 (significant gaps)	1250.1	1093.3
Jenin	1997 – 2015 (2 years gap)	1234.8	1315.7

TABLE 3-18: POTENTIAL EVAPOTRANSPIRATION (IN MM) ACCORDING TO PENMAN-MONTEITH METHOD FOR JENIN

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1997	33.4	45.4	78.7	110.7	149.7	170.2	186.8	164.5	122.5	87.9	48.2	32.9	1231.0
1998	33.1	45.7	80.8	116.8	164.0	180.8	203.5	191.0	146.4	100.2	59.3	46.7	1368.3
1999	31.8	49.1	82.4	111.6	161.5	180.1	198.9	184.2	122.6	92.5	56.8	40.8	1312.1
2000	40.3	47.3	75.1	117.4	151.3	182.4	210.4	179.8	134.3	93.9	50.0	31.9	1314.0
2001	34.9	50.3	94.1	124.9	164.0	193.4	198.9	183.5	149.4	113.2	50.2	32.8	1389.4
2002	45.3	65.9	78.7	110.7	147.6	166.4	184.7	173.7	128.6	89.1	47.7	32.8	1271.2
2003	33.4	45.4	78.7	110.7	147.6	166.4	170.5	173.7	117.4	89.1	40.6	27.8	1201.4
2004	28.0	38.7	71.5	102.3	135.4	153.9	177.2	158.1	127.8	88.3	47.2	32.8	1161.1
2005	28.4	37.5	70.7	101.7	132.0	152.0	169.1	158.9	117.9	74.6	34.5	26.1	1103.6
2006	32.6	45.1	86.1	114.3	155.8	136.5	166.3	173.7	128.6	89.1	47.7	32.8	1208.6
2007	39.7	46.1	76.4	92.5	150.4	157.9	196.2	173.4	128.6	89.1	47.7	32.8	1230.8
2008	37.2	48.7	92.7	131.4	148.6	172.3	183.6	173.3	128.0	86.6	75.8	39.0	1317.1
2009	39.5	50.1	79.6	111.0	148.6	178.2	189.3	172.6	127.6	94.2	46.5	37.7	1274.8
2010	38.9	48.7	82.7	118.2	155.6	182.2	187.7	186.3	140.3	99.0	51.4	29.5	1320.5
2011	32.9	42.9	74.3	104.8	137.1	171.1	193.6	186.1	134.7	93.2	41.1	31.5	1243.3
2012	26.6	37.0	65.1	103.2	125.6	144.3	167.3	151.7	109.4	72.3	38.6	27.4	1068.6
2013	25.8	40.7	76.9	99.2	141.9	156.1	174.0	166.5	122.7	75.1	41.9	23.9	1144.7
2014	26.6	40.7	71.2	108.7	140.0	160.7	174.1	165.9	120.5	79.1	37.3	37.1	1161.8
2015	24.9	39.1	73.7	100.3	140.8	154.5	173.8	167.7	120.3	80.9	41.5	20.6	1138.1
AVER	33.3	45.5	78.4	110.0	147.2	166.3	184.5	172.9	127.8	88.8	47.6	32.5	1234.8
ST. DEV	5.7	6.5	7.2	9.4	10.6	14.8	13.2	10.6	10.0	9.8	9.3	6.1	90.1
C. VAR.	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1

TABLE 3-19: POTENTIAL EVAPOTRANSPIRATION (IN MM) ACCORDING TO PENMAN-MONTEITH METHOD FOR TULKARM

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1997	33.4	38.2	63.1	95.3	126.0	147.5	165.0	147.4	110.5	79.2	46.9	31.4	1084.0
1998	31.7	41.8	66.6	122.1	133.1	151.7	168.0	160.9	117.1	82.2	49.7	37.4	1162.2
1999	32.3	38.6	68.6	96.1	146.3	153.2	168.1	161.5	122.3	86.5	51.0	36.5	1161.0
2000	30.6	40.0	65.1	105.1	132.1	156.8	174.3	166.4	118.3	80.4	48.1	35.8	1153.0
2001	35.7	44.5	81.0	116.9	147.6	160.5	165.1	151.1	116.4	89.3	47.4	38.0	1193.5
2002	40.6	48.1	79.0	112.8	145.8	162.5	178.5	167.0	125.2	92.1	56.9	39.1	1247.5
2003	43.7	45.9	78.2	107.8	156.7	163.3	179.0	166.7	122.2	90.3	49.7	38.2	1241.8
2004	36.8	45.4	80.2	109.8	142.8	161.9	185.7	164.5	118.6	87.6	54.2	31.0	1218.4
2005	37.0	42.9	78.3	114.8	142.9	163.0	180.5	168.2	127.6	81.7	58.0	46.8	1241.7
2006	30.1	47.9	79.0	113.7	145.5	170.9	178.5	167.0	125.2	92.1	56.9	39.1	1245.8
2007	47.5	53.1	83.7	127.1	159.0	176.0	193.0	173.6	129.2	102.1	59.9	46.4	1350.7
2008	51.6	52.6	102.6	137.4	155.5	177.1	187.2	176.0	133.1	88.4	62.7	43.1	1367.1
2009	65.8	77.2	88.0	124.3	171.4	193.1	205.5	191.0	165.2	139.4	112.7	49.7	1583.2
2010	52.2	61.0	92.7	114.8	147.1	170.0	178.9	173.2	135.2	104.5	61.4	37.0	1327.9
2011	50.4	56.5	88.0	119.5	153.8	162.5	197.5	184.1	122.3	109.6	59.0	34.1	1337.2
2012	41.0	47.6	79.5	114.0	135.6	148.5	165.6	152.2	115.3	84.8	56.7	42.4	1183.3
2013	40.8	48.4	79.7	109.6	147.9	159.5	180.9	171.2	130.3	95.0	56.8	39.9	1259.8
2014	40.1	49.1	77.1	116.4	149.4	165.2	180.2	170.5	128.0	94.2	56.9	38.7	1265.9
2015	40.9	44.8	75.7	97.4	135.1	147.8	164.4	159.4	114.7	79.0	46.4	22.8	1128.3
AVER	41.2	48.6	79.3	113.4	146.0	162.7	178.7	166.9	125.1	92.5	57.4	38.3	1250.1
ST. DEV	9.1	9.1	9.6	10.6	10.8	11.4	11.6	10.7	11.8	14.2	14.3	6.1	111.8
C. VAR.	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1

The direct comparison between PM and HG methods is only possible for the Jenin station (Figure 3-6). It can be seen that HG estimates are higher than PM because HG overestimates of PET during winter months.

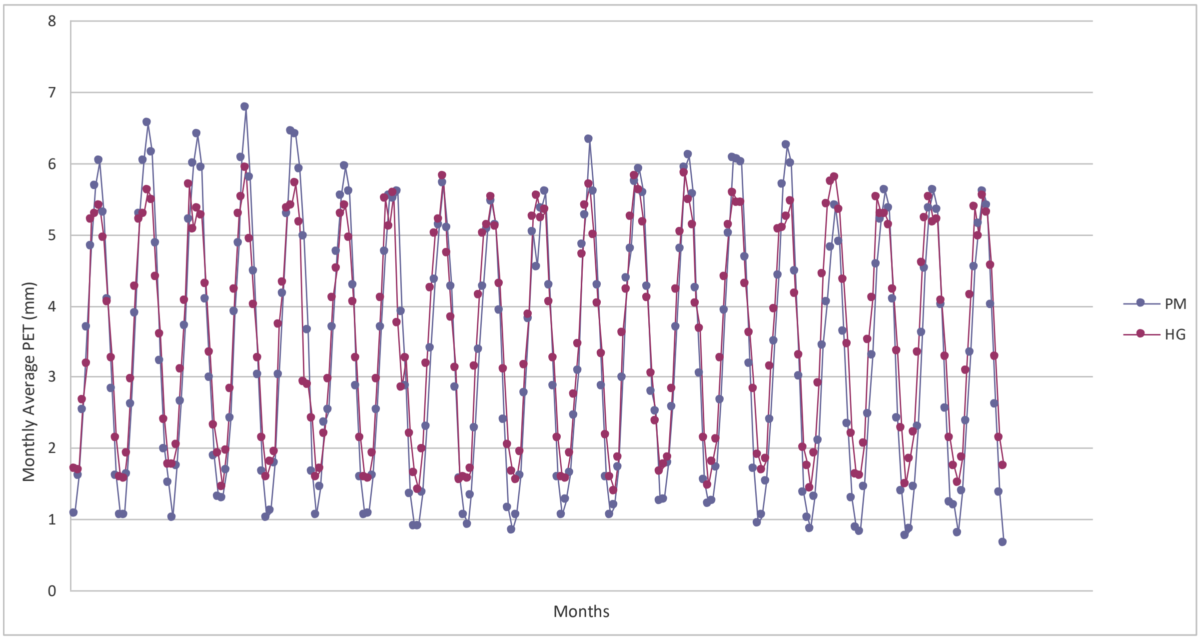


FIGURE 3-6: DIRECT COMPARISON BETWEEN PM AND HG METHODS FOR THE PET ESTIMATION

4 DROUGHT HAZARD

4.1 INTRODUCTION

Yevjevich (1967) proposed the theory for identifying drought parameters and investigating their statistical properties: (a) duration, (b) severity, and (c) intensity. The most basic element for deriving these parameters is the truncation or threshold level, which may be a constant or a function of time. A run is defined as a portion of time series of drought variable Xt, in which all values are either below or above the selected truncation level of X0; accordingly, it is called either a negative run or a positive run. Fig. 1 represents a plot of a drought variable denoted by Xt, which is intersected at many places by the truncation level X0, which can be a deterministic variable, a stochastic variable, or a combination thereof. Various statistical parameters concerning drought duration, severity and intensity at different truncation levels are much useful for drought characterization.

A drought event has the following major components (Dracup et al., 1980) as derived from Figure 4-1 which include: (a) Drought initiation time (t_i): it is the starting of the water shortage period, which indicates the beginning of a drought. (b) Drought termination time (t_e): it is the time when the water shortage becomes sufficiently small so that drought conditions no longer persist. (c) Drought duration (D_d): it is expressed in years/months/weeks, etc., during which a drought parameter is continuously below the critical level. In other words, it is the time period between the initiation and termination of a drought. (d) Drought severity (S_d): it indicates a cumulative deficiency of a drought parameter below the critical level. (e) Drought intensity

(I_d): it is the average value of a drought parameter below the critical level. It is measured as the drought severity divided by the duration.

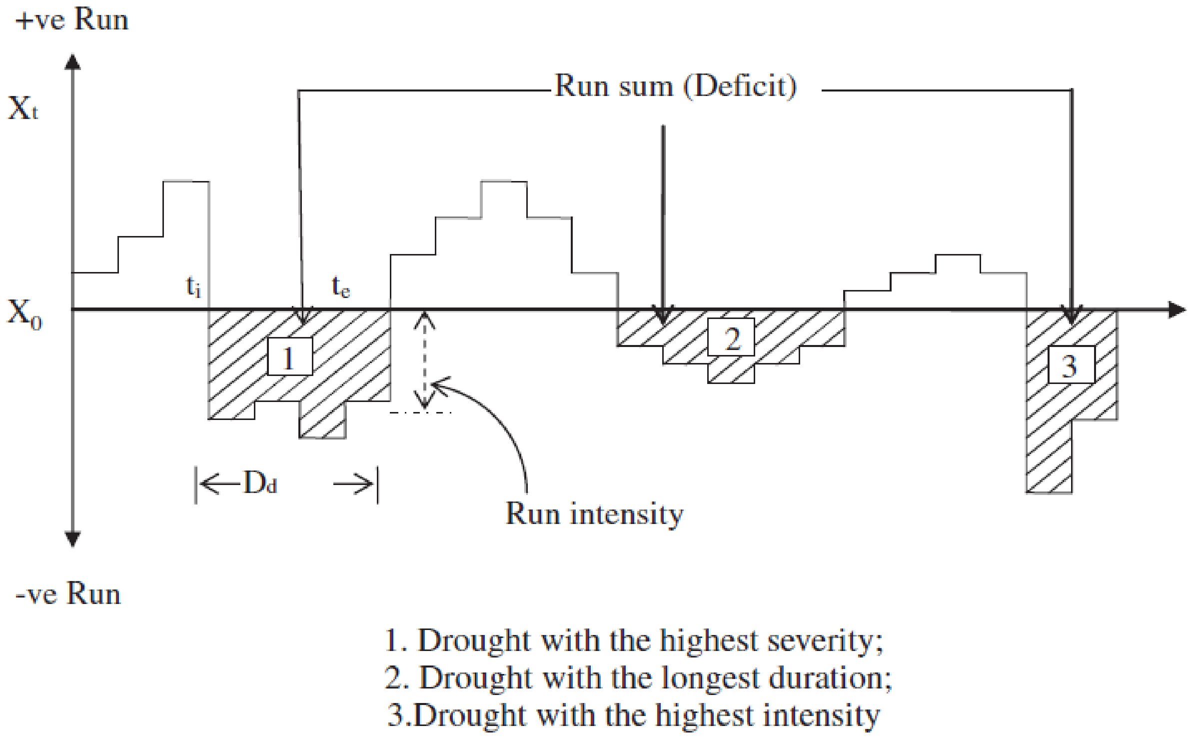


FIGURE 4-1: DEFINITION OF DROUGHT SEVERITY, INTENSITY AND DURATION

4.2 THE DECILE INDEX

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.

4.3 THE STANDARDIZED PRECIPITATION INDEX (SPI)

4.3.1 Introduction- theoretical background

The SPI was designed to quantify the precipitation deficit for multiple timescales. These timescales reflect the impact of drought on the availability of the different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short scale. Groundwater, streamflow and reservoir storage reflect the longer-term precipitation anomalies. For these reasons, McKee and others (1993) originally calculated the SPI for 3-, 6-,12-, 24- and 48-month timescales.

The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record 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 (Edwards and McKee, 1997). Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation. Because the SPI is normalized, wetter and drier climates can be represented in the same way; thus, wet periods can also be monitored using the SPI.

McKee et al. (1993, 1995) fitted a gamma distribution to the precipitation histogram for calculating SPI. Using an equiprobable transformation, the cumulative density function (CDF) of the gamma distribution was then transformed to the CDF of the standard normal distribution. The transformed standard deviate is the SPI for the given precipitation total (Kim et al. 2006). The SPI is computed by dividing the difference between the normalised seasonal precipitation and its long-term seasonal mean by the standard deviation (Bhuiyan et al. 2006):

$$SPI=(X_{i,j}-X_{i,m})/\sigma$$

where, X_{ij} is the seasonal precipitation at the i_{th} raingauge station and jth observation, X_{im} the long-term seasonal mean and σ is its standard deviation. Since the SPI is equal to the z-value of the normal distribution, McKee et al. (1993, 1995) proposed a seven-category classification for the SPI: extremely wet (z>2.0), very wet (1.5 to 1.99), moderately wet (1.0 to 1.49), near normal (−0.99 to 0.99), moderately dry (−1.49 to 1.0), severely dry (−1.99 to 1.5), and extremely dry (<−2.0) (Table 1). The expected time in each drought category was based on an analysis of a large number of rainfall stations across Colorado, USA.

McKee and others (1993) used the classification system shown in the SPI value table below (Table 1) to define drought intensities resulting from the SPI. They also defined the criteria for a drought event for any of the timescales. A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive.

TABLE 4-1: DROUGHT CHARACTERIZATION ACCORDING TO SPI

SPI>2.0	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 and less	Extremely Dry

Based on an analysis of stations across Colorado in the United States, McKee determined that the SPI indicates mild drought 24% of the time, moderate drought 9.2% of the time, severe drought 4.4% of the time and extreme drought 2.3% of the time (McKee et al.,1993). Because the SPI is standardized, these percentages are expected from a normal distribution of the SPI. The 2.3% of SPI values within the “extreme drought” category is a percentage that is typically expected for an “extreme” event. In contrast, the Palmer Drought Severity Index reaches its “extreme” category more than 10% of the time across portions of the central Great Plains in the United States. This standardization allows the SPI to determine the rarity of a current drought, as well as the probability of the precipitation necessary to end it (McKee et al., 1993). It also allows the user to confidently compare historical and current droughts between different climatic and geographic locations when assessing how rare, or frequent, a given drought event is.

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.

The standardized precipitation index (SPI) for any location is calculated, based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed to a normal distribution so that the mean SPI for the location and desired period is zero (McKee et al., 1993; Edwards and McKee, 1997). The fundamental strength of SPI is that it can be calculated for a variety of time scales. This versatility allows SPI to monitor short-term water supplies, such as soil moisture which is important for agricultural production, and long-term water resources, such as groundwater supplies, streamflow, and lake and reservoir levels. Soil moisture conditions respond to precipitation anomalies on a relatively short scale. Groundwater, streamflow, and reservoir storage reflect the longterm precipitation anomalies.

The length of precipitation record and nature of probability distribution play an important role for calculating SPI and the following section discusses limitations of SPI. The length of a precipitation record has a significant impact on the SPI values. Similar and consistent results are observed when the SPI values, computed from different lengths of record, have similar gamma distributions over different time periods. However, the SPI values are significantly discrepant when the distributions are different. It is recommended that the SPI user should be aware of the numerical differences in the SPI values if different lengths of record are used in interpreting and making decisions based on the SPI values. For example, Wu et al. (2005) investigated the effect of the length of record on the SPI calculation by examining correlation coefficients, the index of agreement, and the consistency of dry/wet event categories between the SPI values derived from different precipitation record lengths. The reason for discrepancy in the SPI value is due to changes in the shape and scale parameters of the gamma distribution when different lengths of record are involved.

The use of different probability distributions affect the SPI values as the SPI is based on the fitting of a distribution to precipitation series. Some of the commonly applied distributions include: gamma distribution (McKee et al., 1993; Edwards and McKee, 1997; Mishra and Singh, 2009); and Pearson Type III distribution (Guttman, 1999); and lognormal, extreme value, and exponential distributions have been widely applied to simulations of precipitation distributions (Lloyd-Hughes and Saunders, 2002; Madsen et al., 1998; Todorovic and Woolhiser, 1976; Wu et al., 2007).

Two types of problems arise: (i) When SPIs are calculated for long time scales (longer than 24 months) fitting a distribution might be biased due to the limitation in data length and it is true that when finer resolutions of spatial analysis need to be investigated, long data sets are not available in many catchments around the world. Lloyd-Hughes and Saunders (2002) and Sonmez et al. (2005) reported biased SPI values. (ii) For dry climates where precipitation is seasonal in nature and zero values are common, there will be too many zero precipitation values in a particular season. In these climatic zones, the calculated SPI values at short time scales may not be normally distributed because of the highly skewed underlying precipitation distribution and because of the limitation of the fitted gamma distribution. This may be prone to large errors while simulating precipitation distributions in dry climates from small data samples.

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.

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.

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 in 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

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.

4.3.2 Drought Analysis in the Jenin & Tulkarem Governorates

In Palestine, due to the absence of rainfall from June to September, SPI-3 is only informative for the first of the year (from October to December SPI-3 computed in January each 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 and it is important to compare the SPI3 with longer timescales such as SPI-6 and SPI-12 (see Figure 4-2 where SPI3 is frequently higher than SPI12).

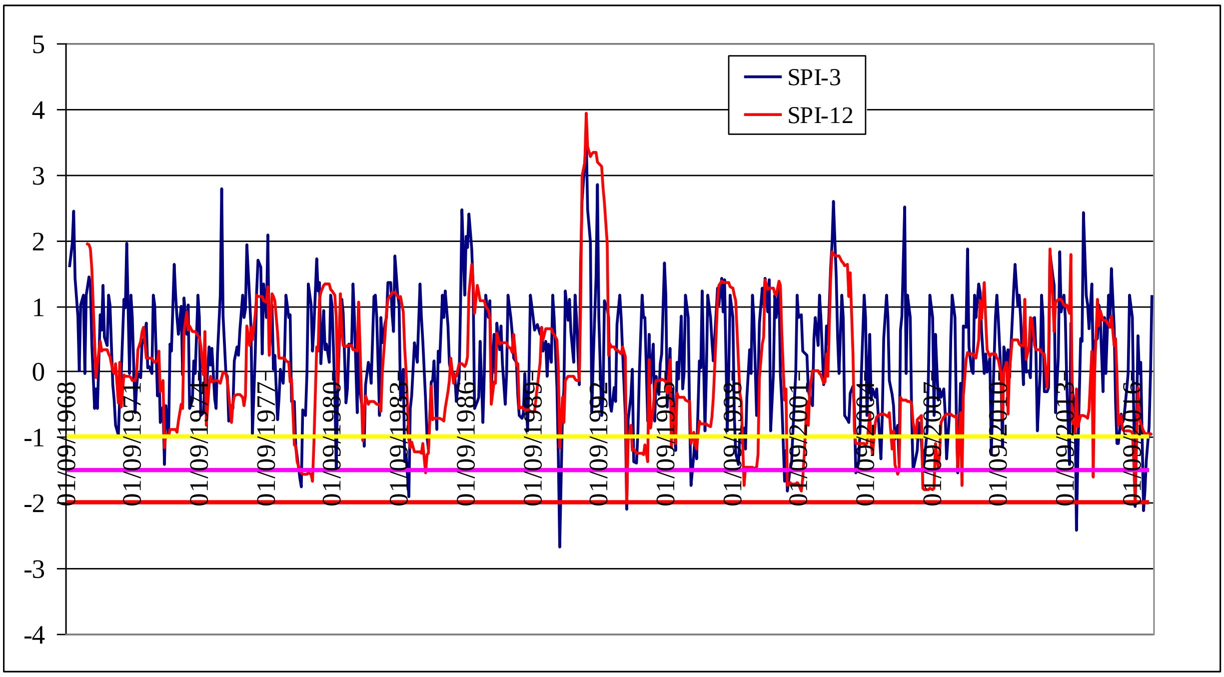


FIGURE 4-2: COMPARISON BETWEEN SPI-3 AND SPI-12 FOR THE TULKARM RAIN

For each of the six rainfall stations the SPI-12 is computed by using the computer program developed by the World Meterological Organisation (WMO). In the following pages, we will present SPI-12 results from all six stations, providing the number of drought events, the duration for each event in months, the intensity (i.e. the minimum number of SPI-12 of the drought event under consideration) and the drought severity/magnitude.

A. Khadouri Institute Tulkarem Rainfall Station

There were recorded 7 drought events with total duration 201 months, which is 34.9% of all data set duration) with maximum duration 65 months for the drought event between 11/2003 and 03/2009 with associated maximum drought magnitude equal to 71.2. Maximum drought intensity is recorded during the ongoing drought event starting from 12/2015 that hits a maximum of -1.87 (severe drought) until 08/2017 which is the last year provided from the available rainfall dataset. Note that the rainfall data sets end at 08/2017, therefore "ongoing" means after 08/2017. Drought analyses results presented in Table 4-2 and Figure 4-3.

TABLE 4-2: DROUGHT EVENTS FOR THE KHADOURI INSTITUTE TULKARM STATION

Drought Event	Month/Year Start	Month/Year End	Duration (Months)	Intensity (min SPI-12)	Drought Magnitude
1	09/1978	11/1979	14	-1.59	15.47
2	12/1983	11/1985	24	-1.42	17.66
3	11/1993	10/1994	12	-1.65	11.87
4	10/1998	11/2002	50	-1.75	44.64

5	11/2003	03/2009	65	-1.82	71.18
6	10/2013	12/2014	15	-1.32	7.34
7	12/2015	08/2017 (Cont.)	21	-1.87	15.16
TOTAL MONTHS			**201**	**PERCENTAGE DURATION**	**34.9%**

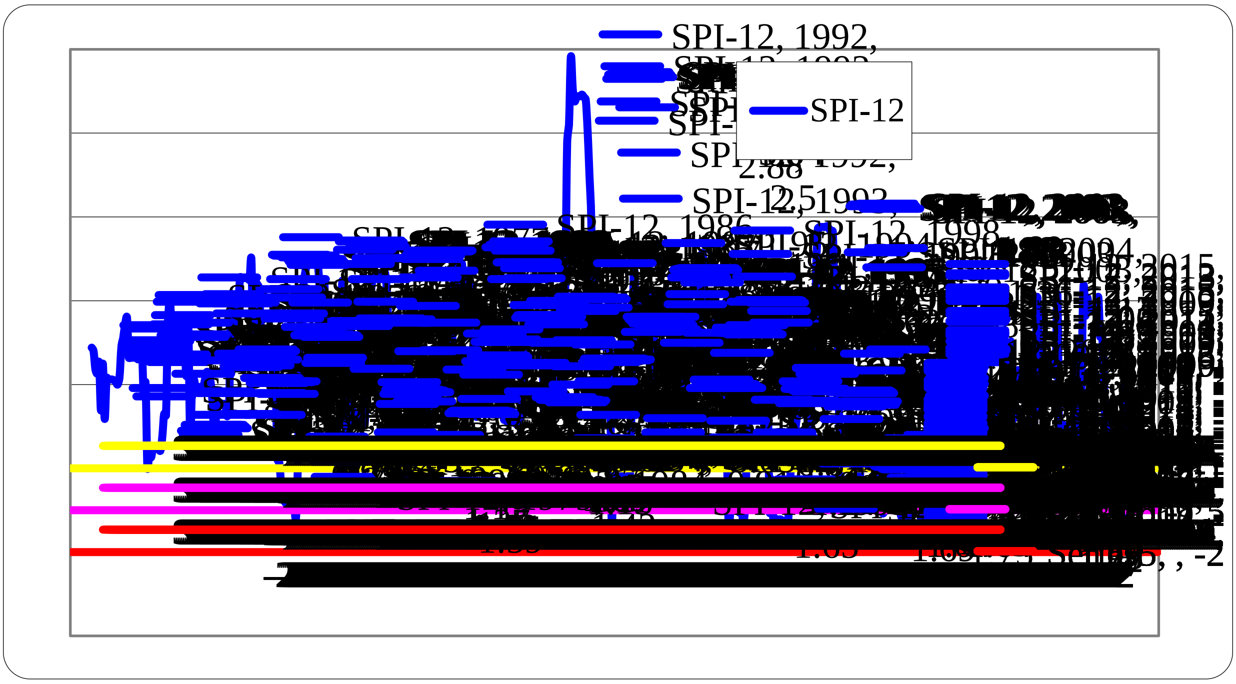


FIGURE 4-3: SPI-12 VARIATION FOR THE KHADOURI INSTITUTE TULKAREM STATION

B. Tallu033 Rainfall Station

There were recorded 7 drought events with total duration 206 months, which is 35.8% of all data set duration) with maximum duration 65 months for the drought event between 10/2003 and 02/2009 with associated maximum drought magnitude equal to 78.8. Maximum drought intensity is also recorded during same event that hits a maximum of -2.71 (extreme drought). Results presented in Table 4-3 and Figure 4-4.

TABLE 4-3: DROUGHT EVENTS FOR THE TALLU033 STATION

Drought Event	Month/Year Start	Month/Year End	Duration (Months)	Intensity (min SPI-12)	Drought Magnitude
1	01/1978	11/1979	23	-1.34	15.94
2	01/1989	10/1991	34	-1.26	12.28
3	11/1993	10/1994	12	-1.21	5.95

4	10/1995	02/1996	5	-1.24	3.46
5	10/1998	01/2003	52	-2.08	55.06
6	10/2003	02/2009	65	-2.71	78.8
7	10/2013	12/2014	15	-1.86	15.0
TOTAL MONTHS			**206**	**PERCENTAGE DURATION**	**35.8%**

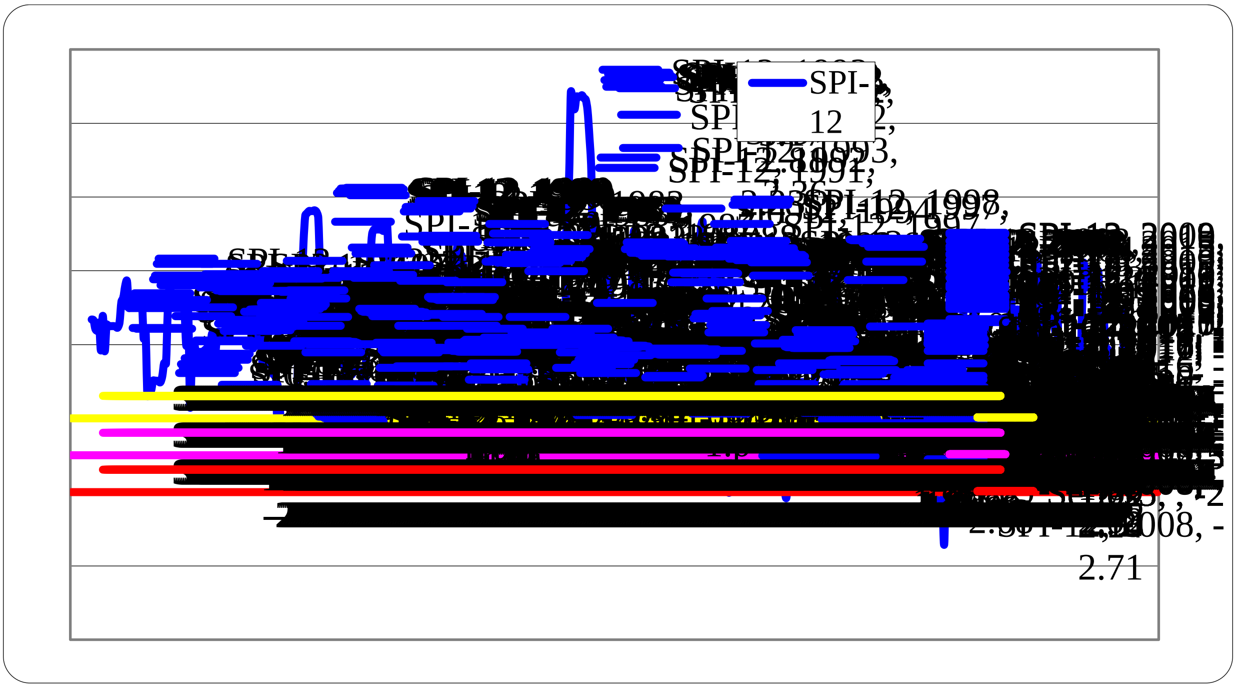


FIGURE 4-4: SPI-12 (Y-AXIS) VARIATION FOR THE TALLU033 STATION

C. Atteel2 Rainfall Station

There were recorded 6 drought events with total duration 199 months, which is 34.5% of all data set duration) with maximum duration 96 months for the drought event between 10/1998 and 09/2006 with associated maximum drought magnitude equal to 111.3, which is the maximum drought magnitude for all rainfall stations. Maximum drought intensity is also recorded during same event that hits a maximum of -3.65 (extreme drought). Results presented in Table 4-4 and Figure 4-5.

TABLE 4-4: DROUGHT EVENTS FOR THE ATTEEL2 STATION

Drought Event	Month/Year Start	Month/Year End	Duration (Months)	Intensity (min SPI-12)	Drought Magnitude
1	11/1978	11/1979	13	-1.48	13.5
2	10/1983	09/1986	36	-1.15	19.72
3	10/1998	09/2006	96	-3.65	111.32

4	10/2007	10/2009	25	-2.12	20.53
5	09/2010	03/2011	7	-1.04	3.65
6	11/2015	08/2017 (Cont.)	22	-1.10	8.35
TOTAL MONTHS			**199**	**PERCENTAGE DURATION**	**34.5%**

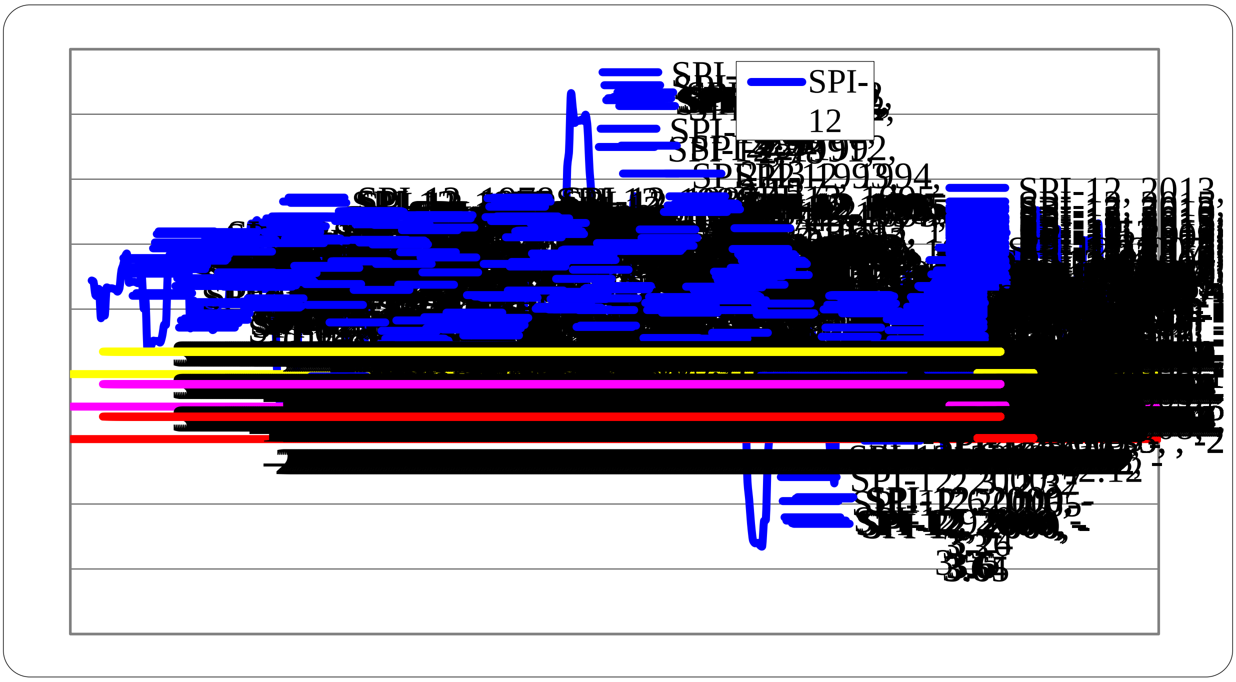


FIGURE 4-5: SPI-12 (Y-AXIS) VARIATION FOR THE ATTEEL2 STATION

D. Jennin0001 Rainfall Station

There were recorded 11 drought events with total duration 290 months, which is 50.4% of all data set duration) with maximum duration 72 months for the drought event between 10/2003 and 09/2009 with associated maximum drought magnitude equal to 65.7. Maximum drought intensity is also recorded during same event that hits a maximum of -2.04 (severe drought). Results presented in Table 4-5 and Figure 4-6.

TABLE 4-5: DROUGHT EVENTS FOR THE JENIN0001 STATION

Drought Event	Month/Year Start	Month/Year End	Duration (Months)	Intensity (min SPI-12)	Drought Magnitude
1	10/1974	03/1976	18	-1.03	4.47
2	11/1977	11/1979	25	-1.25	18.89
3	10/1981	12/1982	15	-1.28	12.55

Drought Event	Month/Year Start	Month/Year End	Duration (Months)	Intensity (min SPI-12)	Drought Magnitude
4	12/1983	10/1986	35	-1.14	19.57
5	10/1990	10/1991	13	-1.10	6.69
6	12/1993	10/1994	11	-1.78	8.51
7	10/1995	01/1997	16	-1.07	4.26
8	10/1998	11/2002	50	-1.76	46.03
9	10/2003	09/2009	72	-2.04	65.68
10	10/2013	12/2014	15	-1.96	14.24
11	01/2016	08/2017 (Cont.)	20	-1.24	12.54
TOTAL MONTHS			**290**	**PERCENTAGE DURATION**	**50.4%**

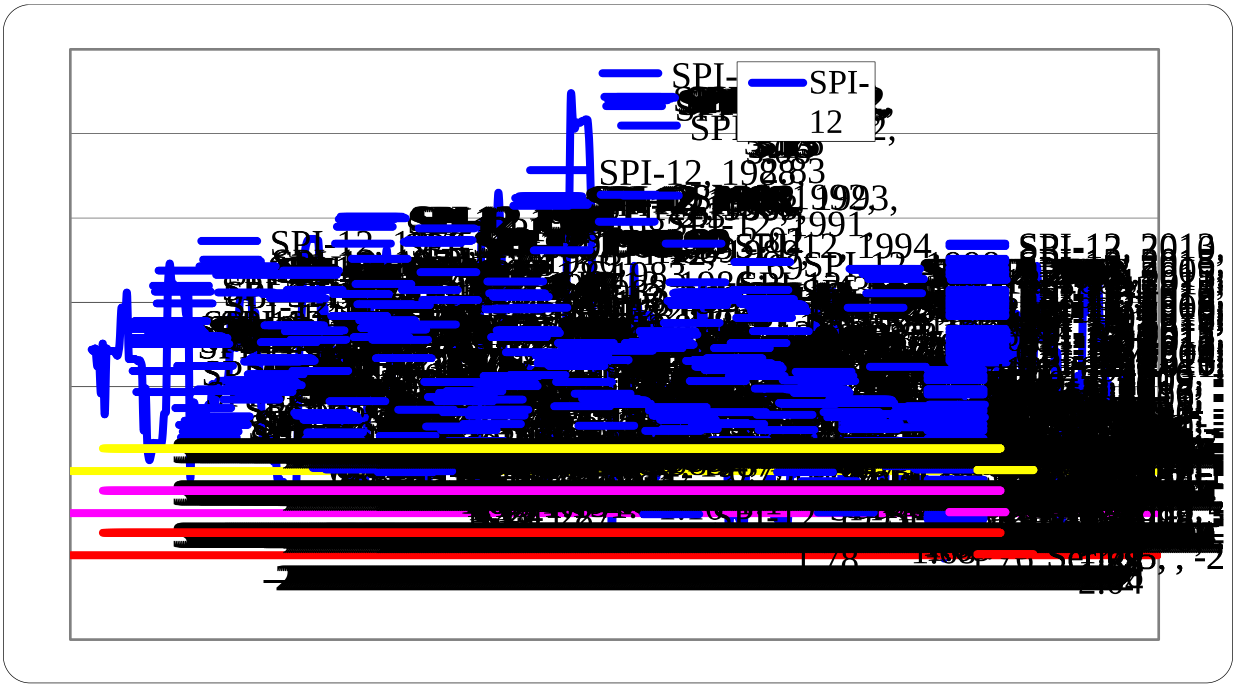


FIGURE 4-6: SPI-12 (Y-AXIS) VARIATION FOR THE JENIN0001 STATION

E. Tubas038 Rainfall Station

There were recorded 10 drought events with total duration 203 months, which is 35.3% of all data set duration) with maximum duration 52 months for the drought event between 10/1998 and 01/2003 with associated maximum drought magnitude equal to 49.1. Maximum drought intensity is also recorded during same event that hits a maximum of -2.21 (severe drought). Results presented in Table 4-6 and Figure 4-7.

TABLE 4-6: DROUGHT EVENTS FOR THE TUBAS038 STATION

Drought Event	Month/Year Start	Month/Year End	Duration (Months)	Intensity (min SPI-12)	Drought Magnitude
1	10/1978	11/1979	14	-1.56	17.08
2	01/1989	12/1089	12	-1.06	6.33
3	10/1990	10/1991	13	-1.16	6.65
3	11/1993	10/1994	12	-1.65	6.43
4	10/1995	02/1996	5	-1.84	3.64
5	10/1998	01/2003	52	-1.90	49.10
6	10/2003	03/2006	30	-1.38	22.34
7	01/2007	02/2009	26	-2.21	25.41
8	10/2010	02/2011	5	-1.51	4.56
9	11/2013	10/2014	12	-2.05	14.22
10	11/2015	08/2017 (Cont.)	22	-1.69	16.68
TOTAL MONTHS			**203**	**PERCENTAGE DURATION**	**35.3%**

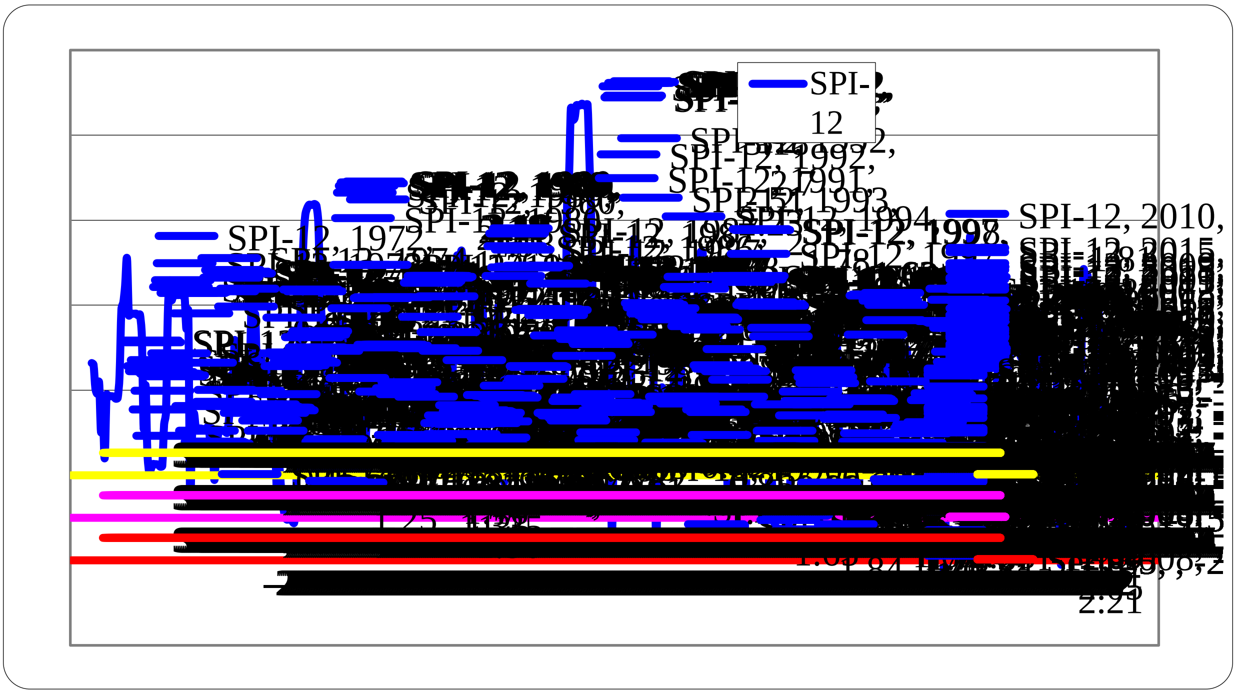


FIGURE 4-7: SPI-12 (Y-AXIS) VARIATION FOR THE TUBAS038 STATION

E. Yabad1 Rainfall Station

There were recorded 9 drought events with total duration 172 months, which is 29.9% of all data set duration) with maximum duration 71 months for the drought event between 12/2003 and 10/2009 with associated maximum drought magnitude equal to 58.7. Maximum drought intensity is also recorded during same event that hits a maximum of -2.04 (severe drought). Results presented in Table 4-7 and Figure 4-8.

TABLE 4-7: DROUGHT EVENTS FOR THE YABAD1 STATION

Drought Event	Month/Year Start	Month/Year End	Duration (Months)	Intensity (min SPI-12)	Drought Magnitude
1	11/1978	11/1979	13	-1.40	14.00
2	01/1989	10/1991	34	-1.38	16.58
3	01/1993	10/1994	22	-2.06	13.97
4	10/1995	01/1997	16	-1.48	10.47
5	10/1998	01/2003	52	-1.75	46.05
6	12/2003	10/2009	71	-2.04	58.70
7	10/2010	10/2011	13	-1.29	6.43
8	01/2014	01/2015	13	-1.79	17.57
9	11/2015	08/2017 (Cont.)	22	-1.76	19.12

Drought Event	Month/Year Start	Month/Year End	Duration (Months)	Intensity (min SPI-12)	Drought Magnitude
TOTAL MONTHS			**257**	**PERCENTAGE DURATION**	**44.6%**

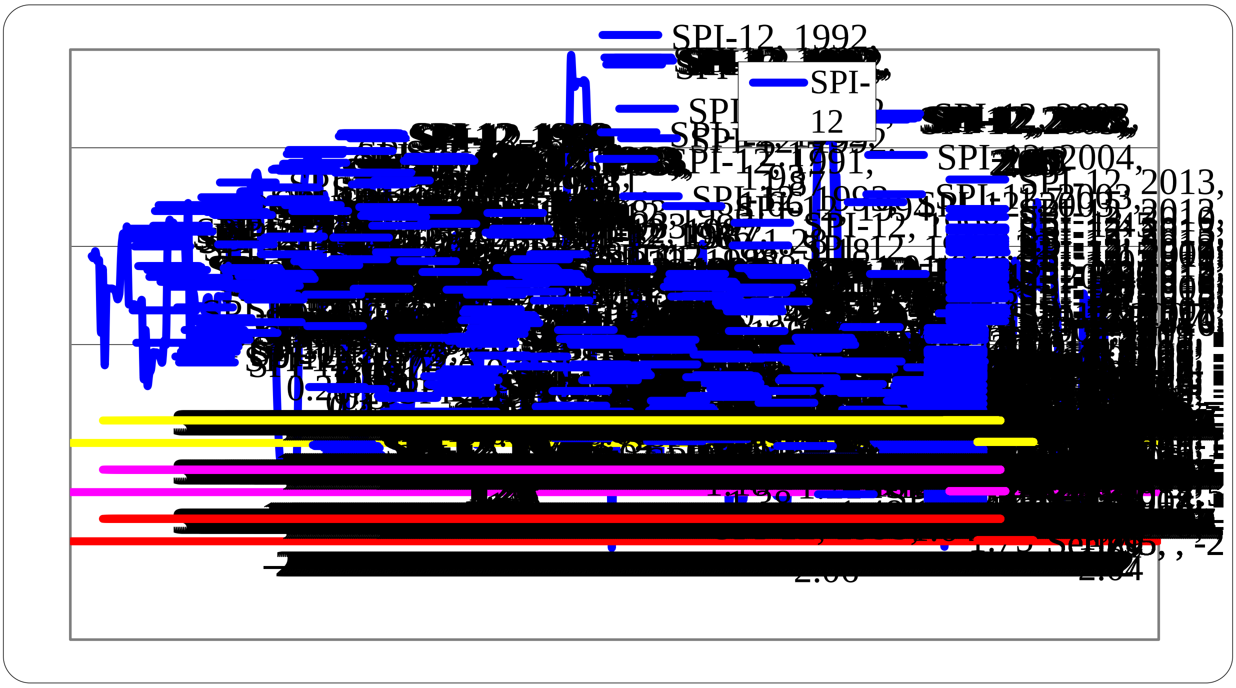


FIGURE 4-8: SPI-12 (Y-AXIS) VARIATION FOR THE YABAD1 STATION

F. Qabataya1 Rainfall Station

There were recorded 7 drought events with total duration 192 months, which is 33.3% of all data set duration) with maximum duration 61 months for the drought event between 02/2004 and 02/2009 with associated maximum drought magnitude equal to 65.4. Maximum drought intensity is also recorded during same event that hits a maximum of -2.22 (severe drought). Results presented in Table 4-8 and Figure 4-9.

TABLE 4-8: DROUGHT EVENTS FOR THE QABATAYA1 STATION

Drought Event	Month/Year Start	Month/Year End	Duration (Months)	Intensity (min SPI-12)	Drought Magnitude
1	10/1974	10/1975	13	-1.21	5.69
2	09/1978	11/1979	15	-1.29	13.65
3	11/1993	10/1994	12	-1.76	9.76
4	10/1995	01/1997	16	-1.84	16.56
5	09/1998	01/2003	53	-1.59	41.65

6	02/2004	02/2009	61	-2.22	65.40
7	11/2015	08/2017 (Cont.)	22	-1.12	11.87
TOTAL MONTHS			**192**	**PERCENTAGE DURATION**	**33.3%**

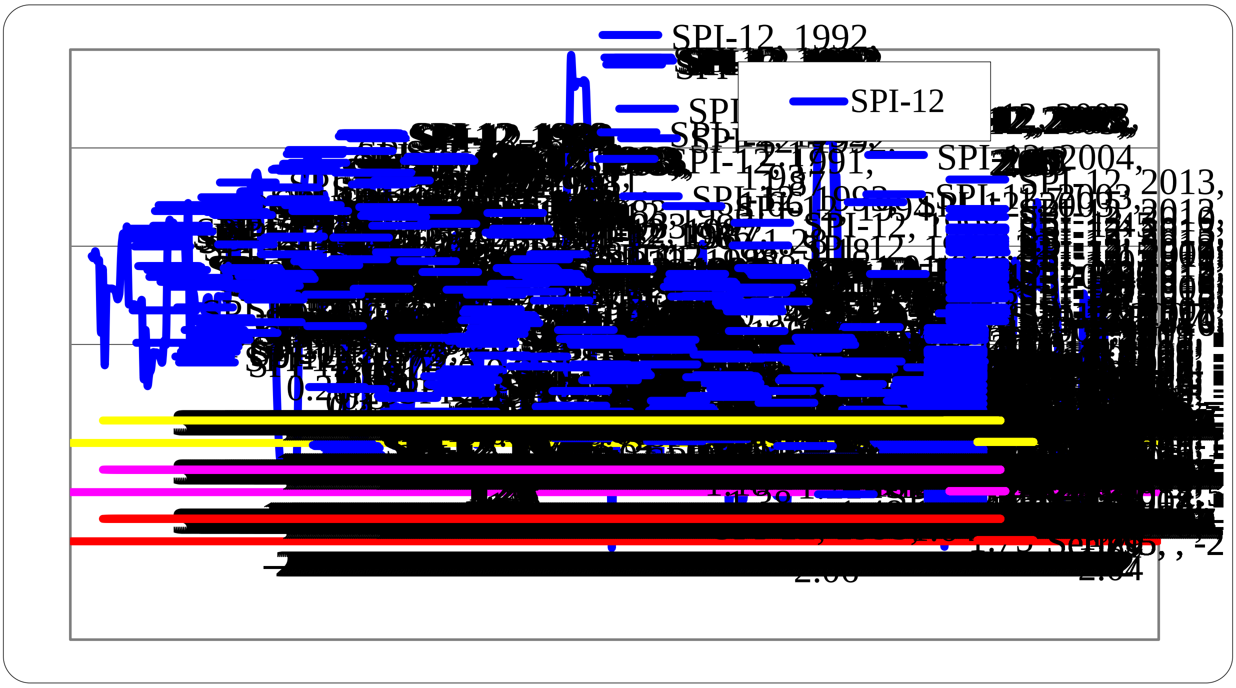


FIGURE 4-9: SPI-12 (Y-AXIS) VARIATION FOR THE QABATAYA1STATION

Table 4-9 presents the drought analysis results for all stations for Jenin and Tulkarm Governorates. In terms of drought duration, it seems that JENIN0001 suffers most while Tubas032 the least. Drought magnitude acquires the maximum value for ATTEEL2 station and also the highest drought intensity. It seems that, although drought intensities are not too high, due to long durations, drought magnitudes acquire high values.

TABLE 4-9: ENSEMBLE RESULTS FOR ALL 7 RAINFALL STATIONS

Rainfall Station	Governorate	Number of Drought Events	Total Duration (Months) and Percentage	Maximum Intensity	Maximum Drought Magnitude
KHADOURI INSTITUTE TULKARM	Tulkarm	7	201 (34.9%)	-1.87	71.2

TALLU033	Nablus	7	206 (35.8%)	-2.71	78.8
ATTEEL2	Tulkarm	6	199 (34.5%)	-3.65	111.32
JEN00001	Jenin	11	290 (50.4%)	-2.04	65.68
TUBAS038	Tubas	10	203 (35.3%)	-2.21	49.10
YABAD1	Jenin	9	257 (44.6%)	-2.04	58.7
QABATIYA1	Jenin	7	192 (33.3%)	-2.22	65.40

4.4 THE STANDARDIZED PRECIPITATION–EVAPORATION INDEX (SPEI)

The Standardized Precipitation Evapotranspiration Index (SPEI) is an extension of the widely used Standardized Precipitation Index (SPI). The SPEI is designed to take into account both precipitation and potential evapotranspiration (PET) in determining drought. Thus, unlike the SPI, the SPEI captures the main impact of increased temperatures on water demand. Like the SPI, the SPEI can be calculated on a range of timescales from 1-48 months. If only limited data are available, say temperature and precipitation, PET can be estimated with the simple Thornthwaite method. In this simplified approach, variables that can affect PET such as wind speed, surface humidity and solar radiation are not accounted for. In cases where more data are available, a more sophisticated method to calculate PET is often preferred in order to make a more complete accounting of drought variability. However, these additional variables can have large uncertainties.

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 Palmer Drought Severity Index (PDSI) to changes in evaporation demand (caused by temperature fluctuations and trends) with the multitemporal nature of the SPI.

The SPEI has great promise as a drought index because it captures a broader measure of the available water (climatic water balance) and avoids issues inherent in the SPI, such as fitting periods with zero precipitation. However, as a newer index, it requires more rigorous testing with respect to its methodology and assumptions before it can gain widespread acceptance within the drought community. The Index sensitivity to PET calculation method has already been addressed but to date there has been little testing of the univariate distributions used to normalize the SPEI.

The procedure for calculating the SPEI is similar to that for the SPI. However, the SPEI uses “climatic water balance”, the difference between precipitation and reference evapotranspiration ($P–ET_o$), rather than precipitation (P) as the input. The climatic water balance compares the available water (P) with the atmospheric evaporative demand (ET_o), and therefore provides a more reliable measure of drought severity than only considering precipitation. The climatic water balance is calculated at various time scales (i.e. over one month, two months, three months, etc.), and the resulting values are fit to a loglogistic probability distribution to transform the original values to standardized units that are comparable in space and time and at different SPEI time scales.

The presence of negative values in the P-ET terms can impose errors in the statistical manipulations. Therefore, we use the Reconnaissance Drought Index (RDI) instead, which uses uses the P and ETo ratio instead of the difference between P and ETo.

4.5 THE RECONNAISSANCE DROUGHT INDEX (RDI)

Introduction - Theoretical Background

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. 2007). It is based both on cumulative precipitation (P) and potential evapotranspiration (PET), of which one is measured (P) and one is calculated (PET) determinant.

It should be emphasized that the RDI is based both on precipitation and on potential evapotranspiration. The mean initial index (α_k) represents the normal climatic conditions of the area and is equal to the Aridity Index as was proposed by the FAO. Among others, some of the advantages of the RDI are as follows:

1. It is physically sound, since it calculates the aggregated deficit between precipitation and the evaporative demand of the atmosphere.
2. It can be calculated for any period of time (e.g., 1 month, 2 months etc).
3. The calculation always leads to a meaningful figure.
4. It can be effectively associated with agricultural drought.
5. It is directly linked to the climatic conditions of the region, since for the yearly value it can be compared with the FAO Aridity Index.
6. It can be used under “climate instability” conditions, for examining the significance of various changes of climatic factors related to water scarcity. From the above advantages, it can be concluded that the RDI is an ideal index for the reconnaissance assessment of drought severity for general use giving comparable results within a large geographical area, such as the Mediterranean.

The initial value (α_k) of RDI is calculated **<u>for the i-th year</u>** in a **<u>time basis of k (months)</u>** as follows:

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

in which P_{ij} and PET_{ij} 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.

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 the standardized RDI (RDI_{st}):

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

in which y(i) is the ln(α_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.

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.

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

It should be mentioned that usually droughts in the Mediterranean are accompanied by high temperatures, which lead to higher evapotranspiration rates. Evidence for this has been produced from simultaneous monthly data of precipitation and evapotranspiration in many Greek watersheds. From the cases analyzed it seems that about 90% of them comply with the previous statement (Tsakiris and Vangelis2005). Therefore, the RDI is expected to be more sensitive index than those related only to precipitation, such as the SPI. The RDI can be calculated for any period of time from 1 month to the entire year, even starting from a month different than October, which is customary for the Mediterranean. Very significant results can be derived if the period of analysis coincides with the growing season of the maincrops of the area under study or other periods related to sensitive stages of crop growth. Then, the RDI can be associated successfully with the expected loss in rainfed crop production, which in turn is linked to the anticipated hazard in the agricultural sector due to drought occurrence. As it was shown from previous studies, precipitation (and therefore the SPI) was not successfully correlated to agricultural production (Tsakiris and Vangelis, 2005). However, the inclusion of potential evapotranspiration (PET) in the calculation of the RDI enhances its validity in studies aiming at risk assessment in agriculture caused by drought occurrence. Likewise, PET may be a representative quantity of the consumption in various sectors apart from agriculture. Water demand is increasing in general in case of higher temperatures. Therefore, the RDI could be modified to be used in the future as an indicator for the drought risk assessment related to the various sectors of water use.

Figure 4-10 and Figure 4-11 illusterates the comparison between RDI-12 and SPI-12 for Jenin and Khadouri Institute Tulkarm, where it seems that RDI values show more severe drought intensities during droughts, but SPI values are higher during normal conditions.

The operational use of RDI is still not recommended for Palestine since there are a lot of uncertainties regarding data collection and processing for meteorological variables for the PET calculation.

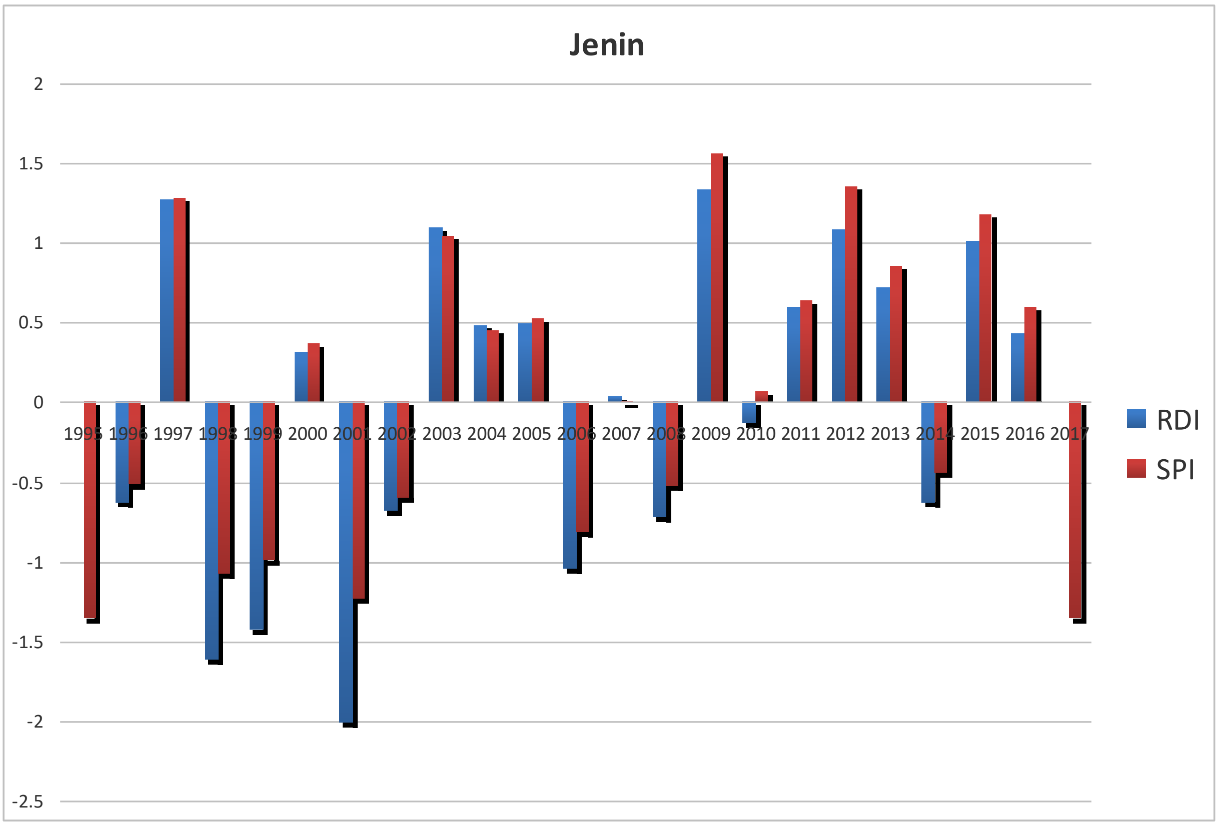


FIGURE 4-10: COMPARISON BETWEEN RDI-12 AND SPI-12 FOR JENIN METEOROLOGIC STATION.

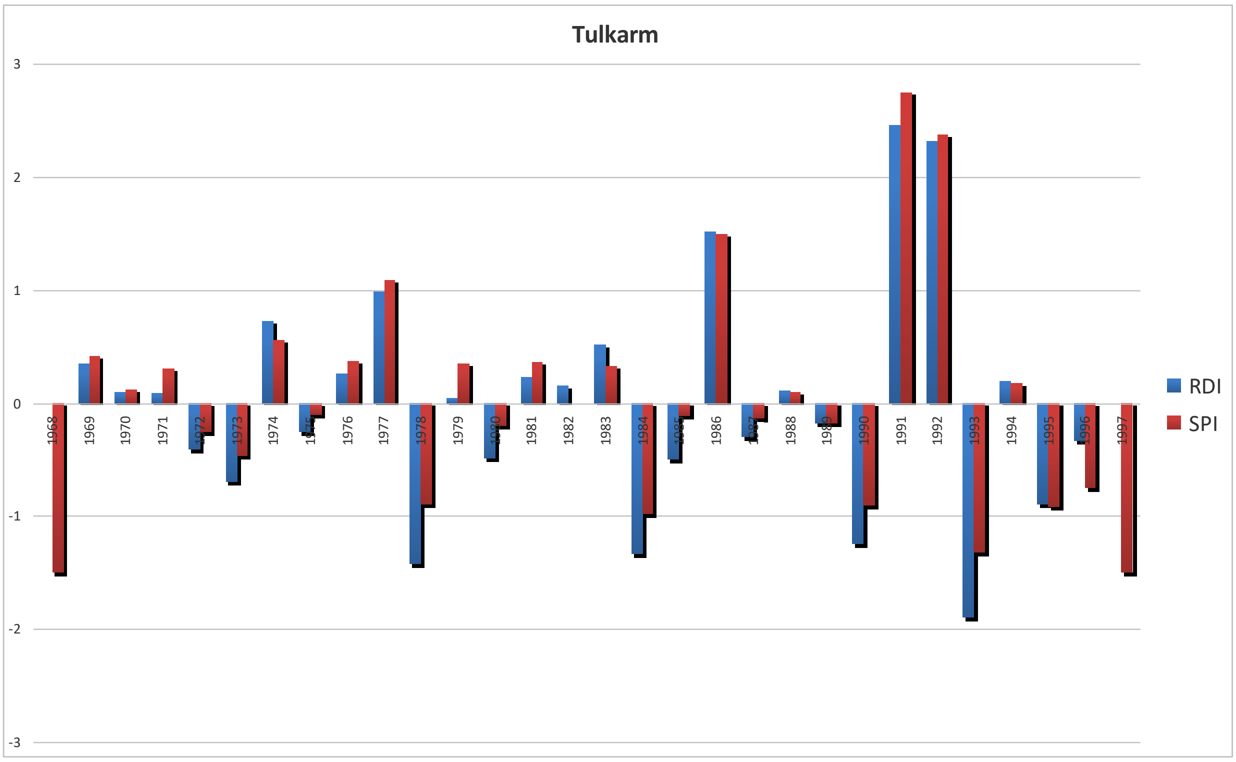


FIGURE 4-11: COMPARISON BETWEEN RDI-12 AND SPI-12 FOR KHADOURI INSTITUTE TULKARM METEOROLOGIC STATION.

4.6 THE STREAMFLOW DROUGHT INDEX (SDI)

Streamflow commonly shows a greater spatial variability than climatic variables that are used to derive drought indicators. This is because of the influence of a number of factors, including topography, lithology, vegetation, and human management; it is also a consequence of the spatial aggregation of the flows, which changes the statistical properties of the series downstream. Based on the SPI developing concepts, the SDI was developed by Nalbantis and Tsakiris (2009) for characterizing hydrological drought. To compute SDI, it is assumed that a time series of monthly streamflow volumes $\boldsymbol{Q}_{i,j}$ is available where *i* denotes the hydrological year and *j* the month within that hydrological year (j01 for September and j012 for August). Based on this series, cumulative streamflow volume is computed as follows according to Nalbantis (2008),

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

in which $\boldsymbol{V}_{i,k}$ 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 $\mathbf{V}_{i,k}$, the Streamflow Drought Index (SDI) is defined for each reference period k of the i-th hydrological year as follows:

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

in which $\mathbf{V_k}$ and $\mathbf{S_k}$ 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 as follows:

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	$\mathrm{SDI} < -2.0$

This index cannot be applied to Tulkarm and Jenin Governorates because there are no natural runoff series without distortion from unknown abstractions.

4.7 PALMER'S DROUGHT SEVERITY INDEX (PDSI)

In 1965, W. Palmer published his model for a drought index that incorporated antecedent precipitation, moisture supply, and moisture demand (based on the pioneering evapotranspiration work by Thornthwaite) into a hydrologic accounting system (Palmer 1965). He used a two-layered model for soil moisture computations and made certain assumptions concerning field capacity and transfer of moisture to and from the layers. These assumptions include the following: the top soil layer ("plough layer") has a field capacity of 1 inch (2.54 cm), moisture is not transferred to the bottom layer ("root zone") until the top layer is saturated, runoff does not occur until both soil layers are saturated, and all of the precipitation occurring in a month is utilized during that month to meet evapotranspiration and soil moisture demand or be lost as runoff. Palmer applied what he called Climatologically Appropriate for Existing Conditions (CAFEC) quantities to normalize his computations so he could compare the dimensionless index across space and time. This procedure enables the index to measure abnormal wetness (positive values) as well as dryness (negative values), with persistently normal precipitation and temperature theoretically resulting in an index of zero in all seasons in all climates. The term "Palmer Index" refers collectively to three indices that have come to be known as the PDSI, PHDI, and the Z Index.

The computation of Palmer's indices consists of the following steps:

1) Carry out a monthly hydrologic accounting for a long series of years using five parameters: precipitation, evapotranspiration, soil moisture loss and recharge, and runoff. Potential and actual values are computed

for the last four. Palmer used monthly averages, but other timescales (such as weeks or days) can be used as well. Means of the potential and actual values for these parameters are computed over a calibration period that is usually, but not necessarily, the data period of the records.

2) Summarize the results to obtain coefficients (of evapotranspiration, recharge, runoff, and loss) that are dependent on the climate of the location being analyzed. These coefficients are computed by dividing the mean actual quantity by the mean potential quantity.

3) Reanalyze the series using the derived coefficients to determine the amount of moisture required for "normal" weather during each month. These normal, or CAFEC, quantities are computed for each of the parameters listed in step 1).

4) Compute the precipitation departure (precipitation minus CAFEC precipitation) for each month, then convert the departures to indices of moisture anomaly. This moisture anomaly index has come to be known as the Palmer Z Index and reflects the departure of the weather of a particular month from the average moisture climate for that month, regardless of what has occurred in prior or sub-sequent months. 5) Analyze the index series to determine the beginning, ending, and severity of the drought periods. In Palmer's computations, the drought severity for a month depends on the moisture anomaly for that month and on the drought severity for the previous and subsequent months (see Table 4-10).

The Palmer Index was a landmark in the development of drought indices. However, it is not without limitations. The index was specifically designed to treat the drought problem in semiarid and dry subhumid climates where local precipitation is the sole or primary source of moisture (Doesken et al. 1991). Palmer himself cautioned that extrapolation beyond these conditions may lead to unrealistic results (Palmer 1965; Guttman 1991). During the last 30 years, several scientists have evaluated the model as applied under different climate regimes and have expressed concerns with some of the model's assumptions.

These concerns fall into two broad categories: the use of water balance models in general, and Palmer's model in particular. Alley (1984) expressed concerns regarding how water balance models treat potential evapotranspiration, soil moisture, runoff, distribution of precipitation, and evapotranspiration within a month or week, and how they fail to consider seasonal or annual changes in vegetation cover and root development.

TABLE 4-10: DROUGHT CHARACTERIZATION ACCORDING TO PALMER'S INDEX

Moisture category	PDSI
Extremely wet	≥ 4.00
Very wet	3.00 to 3.99
Moderately wet	2.00 to 2.99
Slightly wet	1.00 to 1.99
Incipient wet spell	0.50 to 0.99
Near normal	0.49 to −0.49
Incipient drought	−0.50 to −0.99
Mild drought	−1.00 to −1.99
Moderate drought	−2.00 to −2.99
Severe drought	−3.00 to −3.99
Extreme drought	≤−4.00

4.8 SOIL MOISTURE DEFICIT INDEX (SMDI)

The Soil Moisture Deficit Index (SMDI) was originally developed from research at the Texas Agricultural Experiment Station, United States. To evaluate soil moisture variations in the dry and wet periods, a Soil Water Deficit Index (SWDI), was developed based on SMI values with 8-day time steps as:

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

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

whereby:

SDij = the soil water deficit (%)

SWij = the mean weekly soil water available in the soil profile (mm),

MSWj = the long-term median available soil water in the soil profile (mm)

maxSWj = he long-term maximum available soil water in the soil profile (mm)

minSWj = he long-term minimum available soil water in the soil profile (mm)

The median was chosen over the mean as a measure of ‘‘normal’’ available soil water because median is more stable and is not influenced by few outliers. By using the above equations, the seasonality inherent in soil water was removed. Hence, the deficit values can be compared across seasons. The SD values during a week range from

100 to +100 indicating very dry to very wet conditions. As the SD values for all the sub-basins were scaled between 100 and +100 they are also spatially comparable across different climatic zones (humid or arid). The SD value during any week gives the dryness (wetness) during that week when compared to long-term historical data. Drought occurs only when the dryness continues for a prolonged period of time that can affect crop growth.

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

A transformation is being made in order to be compatible with the PDSI scale (-4 to +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 SD1/50.

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

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

We will use the next index in Paragraph 4.9, the Soil Moisture Index.

4.9 SOIL MOISTURE INDEX (SMI)

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 θ is the average volumetric water content of the soil over a layer of soil and Δd 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 (θ) at field capacity and −5.0 representing θ at wilting point.

The available water content (FAW) in the soil is computed by the equation:

$FAW = (\theta - \theta W_P)/(\theta F_C - \theta W_P)$

where θ is the measured volumetric soil water content; θW_P is the volumetric soil water content at the wilting point; and θF_C is the volumetric soil water content at field capacity. Note that FAW 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 FAW changed from 0 to 1.

This allows SMI to be written as follows:

$SMI = -5 + 10\ FAW$

$SMI = -5 + 10(\theta - \theta W_P)/(\theta F_C - \theta W_P)$

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).

4.10 HYDROLOGIC MODELLING WITH HEC-HMS

The HEC-HMS model is designed to simulate the precipitation - runoff processes of dendritic watershed systems and with soil moisture accounting (SMA) algorithm, it accounts for watershed's soil moisture balance over a long-term period and is suitable for simulating daily, monthly, and seasonal stream flow. The SMA algorithm takes explicit account of all runoff components including direct runoff (surface flow) and indirect runoff (interflow and groundwater flow) (Ponce, 1989). The model requires inputs of daily rainfall, soil condition and other hydro meteorological data. The HMS SMA algorithm represents the watershed with five storage layers viz., canopy - interception, surface-depression, soil profile, groundwater storages (1 and 2) as shown in the Figure 4-12 involving twelve parameters viz., canopy interception storage, surface depression storage, maximum infiltration rate, soil storage, tension zone storage and soil zone percolation rate and groundwater 1 and 2 storage depths, storage coefficients and percolation rates. Rates of inflow to, outflow from and capacities of the layers control the volume of water lost from or gained by each of these storage layers. Current storage contents are calculated during the simulation and vary continuously both during and between storms. Besides precipitation, the only other input to the SMA algorithm is the potential evapotranspiration rate (HEC 2000).

Two HEC-HMS models have been formulated, **in a lumped way, both for Jenin and Tulkarm Governorates,** incorporating daily rainfall, monthly PET expressed in mm/day, information on soils, topography and percentage of impervious (urban) surfaces. The most crucial issue regarding the Soil Moisture Accounting (SMA) procedure is to accurately introduce the values regarding the soil capacity to retain water and to lose it according to gravity (to groundwater) and potential evapotranspiration (to evapotranspiration). As said, we introduced both models lumped (that means one catchment for the whole Governorate for both Governorates) and one rainfall and PET value. This has the meaning of a first approximation on groundwater recharge, which is the most important water budget parameter, for groundwater dependent countries.

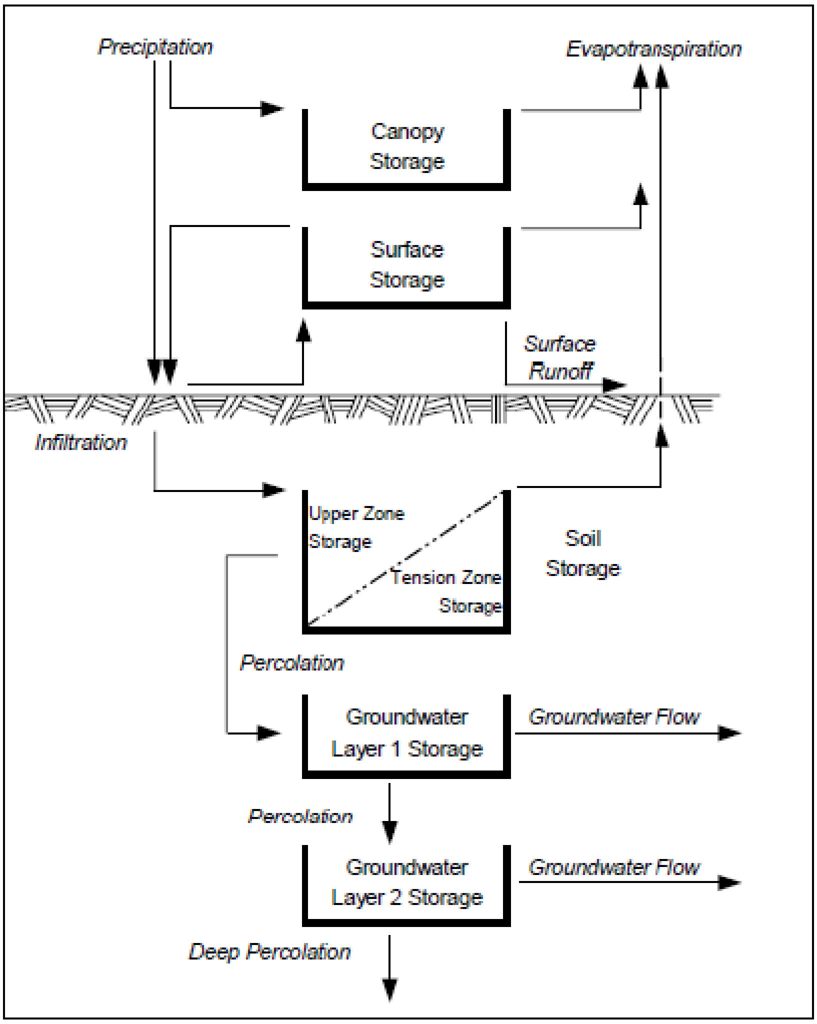


FIGURE 4-12: HEC-HMS SMA MODEL FLOW DIAGRAM

Figure 4-13 presents the model screen for the parameters input for the SMA model. The model uses the following parameters for soil moisture accounting (Table 4-11).

TABLE 4-11: INPUT PARAMETERS FOR THE SMA MODEL

Parameter	Tulkarm Governorate	Jenin Governorate
Maximum Infiltration (mm/h)	7	25
Impervious (%)	20	4
Soil Storage (mm)	310	200
Tension Storage (mm)	110	50
Soil Percolation (mm/h)	12	15

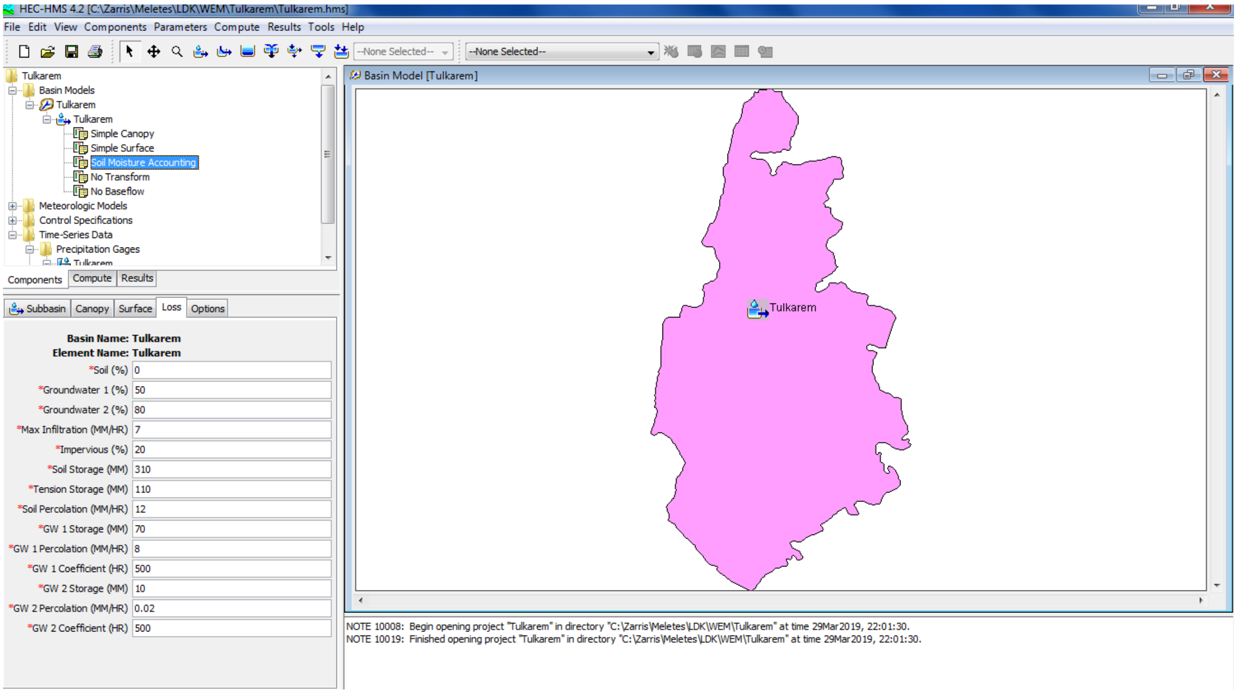


FIGURE 4-13: HEC-HMS SMA SCREEN FOR TULKAREM GOVERNORATE

In the following tables the calculated results regarding GW recharge are presented, that are in general agreement with other references regarding recharge of the western and northeaster aquifers. Groundwater recharge, especially in Tulkarm, is significant nominating groundwater as a vital water resource for Palestine.

Table 4-12. STATISTICAL RESULTS OF HEC-HMS SIMULATIONS FOR GROUNDWATER RECHARGE.

Governorate	Variable	Annual Amounts (mm)		
		Minimum	Average	Maximum
Tulkarm	Rainfall	210	607	1320
	GW Recharge	45.2	254.8	575.9
Jenin	Rainfall	172	388	580
	GW Recharge	0	119.5	262.7

TABLE 4-13: TULKAREM PERCOLATION (WESTERN BASIN) (IN MM)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annual
1969-70	0.0	0.0	0.0	117.4	18.5	119.5	0.0	0.0	0.0	0.0	0.0	0.0	255.5
1970-71	0.0	0.0	0.0	45.5	99.6	0.4	45.5	0.0	0.0	0.0	0.0	0.0	191.1
1971-72	0.0	0.0	39.2	101.8	139.9	18.7	0.0	0.0	0.0	0.0	0.0	0.0	299.6
1972-73	0.0	0.0	0.0	66.9	18.9	33.1	0.0	0.0	0.0	0.0	0.0	0.0	119.0
1973-74	0.0	5.1	24.8	167.9	125.7	47.0	0.0	0.0	0.0	0.0	0.0	0.0	370.5
1974-75	0.0	0.0	44.9	92.4	123.2	6.1	0.0	0.0	0.0	0.0	0.0	0.0	266.6
1975-76	0.0	0.0	21.8	39.6	57.8	48.1	0.0	0.0	0.0	0.0	0.0	0.0	167.3
1976-77	0.0	92.4	58.8	84.8	49.3	105.4	0.0	0.0	0.0	0.0	0.0	0.0	390.8
1977-78	0.0	0.0	122.5	56.2	34.9	27.1	0.0	0.0	0.0	0.0	0.0	0.0	240.7
1978-79	0.0	0.0	0.0	52.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	52.3
1979-80	0.0	0.0	172.7	131.9	119.0	58.2	0.0	0.0	0.0	0.0	0.0	0.0	481.9
1980-81	0.0	0.0	36.8	187.0	121.8	23.1	0.0	0.0	0.0	0.0	0.0	0.0	368.8
1981-82	0.0	0.0	0.5	70.9	79.9	25.0	0.0	0.0	0.0	0.0	0.0	0.0	176.3
1982-83	0.0	0.0	103.8	134.5	120.3	113.5	0.0	0.0	0.0	0.0	0.0	0.0	472.0
1983-84	0.0	0.0	0.0	8.3	25.8	11.1	0.0	0.0	0.0	0.0	0.0	0.0	45.2
1984-85	0.0	0.0	0.0	71.3	93.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	165.0
1985-86	0.0	0.0	15.7	149.7	75.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	240.8
1986-87	0.0	127.8	134.4	83.3	4.6	63.9	0.0	0.0	0.0	0.0	0.0	0.0	413.9
1987-88	0.0	0.0	93.2	106.9	98.6	25.3	0.0	0.0	0.0	0.0	0.0	0.0	324.0
1988-89	0.0	0.0	43.0	71.5	25.3	25.1	0.0	0.0	0.0	0.0	0.0	0.0	164.9
1989-90	0.0	0.0	120.7	106.8	117.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	344.7
1990-91	0.0	0.0	0.0	88.0	73.9	98.7	0.0	0.0	0.0	0.0	0.0	0.0	260.5
1991-92	0.0	42.8	162.6	131.9	121.8	116.8	0.0	0.0	0.0	0.0	0.0	0.0	575.9
1992-93	0.0	0.0	156.1	106.2	44.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	306.3
1993-94	0.0	0.0	0.0	15.1	43.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	58.1
1994-95	0.0	0.0	74.3	41.6	58.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	174.6
1995-96	0.0	0.0	0.0	57.5	0.0	38.0	0.0	0.0	0.0	0.0	0.0	0.0	95.5
1996-97	0.0	0.0	0.0	24.3	0.0	87.2	0.0	0.0	0.0	0.0	0.0		111.5
AVER.	0.0	9.6	50.9	86.1	67.5	39.0	1.6	0.0	0.0	0.0	0.0	0.0	254.8
ST.DEV.	0.0	29.9	58.4	45.0	46.0	40.8	8.6	0.0	0.0	0.0	0.0	0.0	138.6
C. VAR.	N/A!	3.1	1.1	0.5	0.7	1.0	5.3	N/A	N/A	N/A	N/A	N/A	0.5

TABLE 4-14: JENIN PERCOLATION (NORTHEASTERN BASIN) (IN MM)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Annual
1996-97	0.0	0.0	0.0	0.0	9.9	104.0	0.0	0.0	0.0	0.0	0.0	0.0	113.9
1997-98	0.0	0.0	0.0	80.4	32.1	26.9	0.0	0.0	0.0	0.0	0.0	0.0	139.4
1998-99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1999-00	0.0	0.0	0.0	0.0	159.8	9.2	0.0	0.0	0.0	0.0	0.0	0.0	169.0
2000-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2001-02	0.0	0.0	0.0	0.0	41.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.1
2002-03	0.0	0.0	0.0	0.0	0.0	93.0	27.9	0.0	0.0	0.0	0.0	0.0	120.9
2003-04	0.0	0.0	0.0	15.9	111.0	26.8	0.0	0.0	0.0	0.0	0.0	0.0	153.7
2004-05	0.0	0.0	18.1	3.5	57.7	92.8	0.0	0.0	0.0	0.0	0.0	0.0	172.2
2005-06	0.0	0.0	0.0	22.3	22.9	21.2	0.0	0.0	0.0	0.0	0.0	0.0	66.4
2006-07	0.0	0.0	0.0	0.0	0.0	25.9	0.0	0.0	0.0	0.0	0.0	0.0	25.9
2007-08	0.0	0.0	13.7	13.4	32.1	18.6	0.0	0.0	0.0	0.0	0.0	0.0	77.8
2008-09	0.0	0.0	0.0	0.0	0.0	95.6	16.7	0.0	0.0	0.0	0.0	0.0	112.3
2009-10	0.0	0.0	69.4	73.4	4.0	52.7	0.0	0.0	0.0	0.0	0.0	0.0	199.5
2010-11	0.0	0.0	0.0	94.6	28.1	12.9	7.5	0.0	0.0	0.0	0.0	0.0	143.1
2011-12	0.0	0.0	7.3	0.0	72.1	76.0	0.0	0.0	0.0	0.0	0.0	0.0	155.4
2012-13	0.0	0.0	9.6	79.4	143.5	30.2	0.0	0.0	0.0	0.0	0.0	0.0	262.7
2013-14	0.0	0.0	0.0	91.3	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	93.4
2014-15	0.0	0.0	58.7	0.0	79.9	106.4	0.0	0.0	0.0	0.0	0.0	0.0	245.0
2015-16	0.0	0.0	0.0	5.9	76.2	15.7	0.0	0.0	0.0	0.0	0.0	0.0	97.8
AVER.	0.0	0.0	8.4	24.0	41.4	38.5	2.6	0.0	0.0	0.0	0.0	0.0	119.5
ST. DEV.	0.0	0.0	19.3	36.2	49.1	38.9	7.0	0.0	0.0	0.0	0.0	0.0	72.7
C. VAR.	N/A	N/A!	2.3	1.5	1.2	1.0	2.7	N/A	N/A!	N/A	N/A	N/A	0.6

HEC-HMS SMA model is also capable of calculating water storage in the soil zone (in mm). We can, then, proceed with calculations for the Soil Drought Index (SDI) for both Governorates and the results are shown in Figure 4-14 and Figure 4-15. In the first figure, we assume that water stress (SDI=0) is when soil storage is in the middle between Filed Capacity (FC) and Permanent Wilting Point (PWP), and in the next Figure we assume as water-stress-free only when soil moisture is just above the PWP.

In both cases we can realize, that SDI has no practical meaning, since soil becomes dry very fast and remains dry for a considerable time of the year and every year. Therefore, in semi-arid climates, drought indices regarding soil moisture cannot give helpful results.

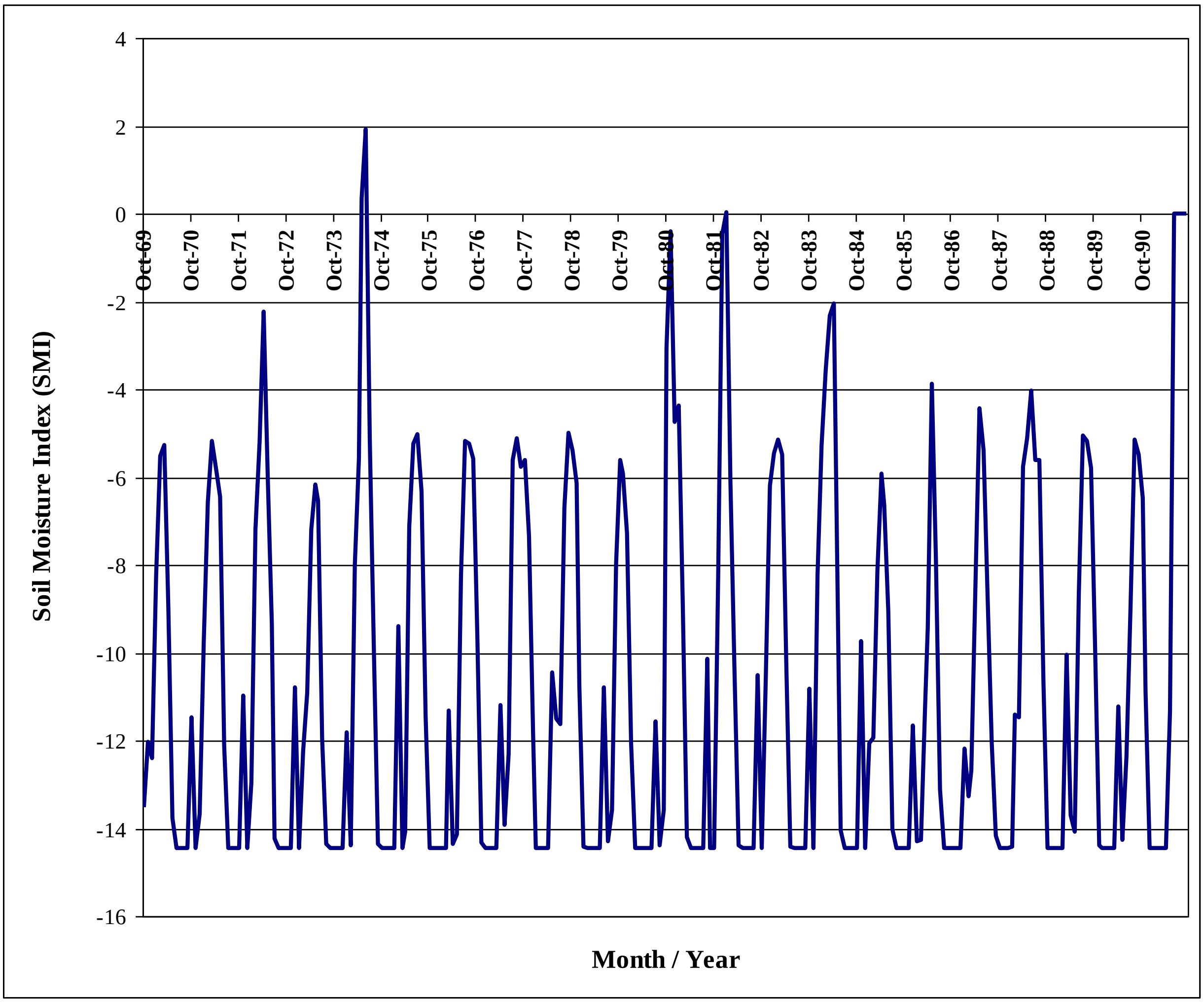


FIGURE 4-14: SOIL MOISTURE INDEX (SMI) FOR TULKAREM GOVERNOARTE ASSUMING WATER STRESS IN THE MIDDLE BETWEEN FC AND PWP

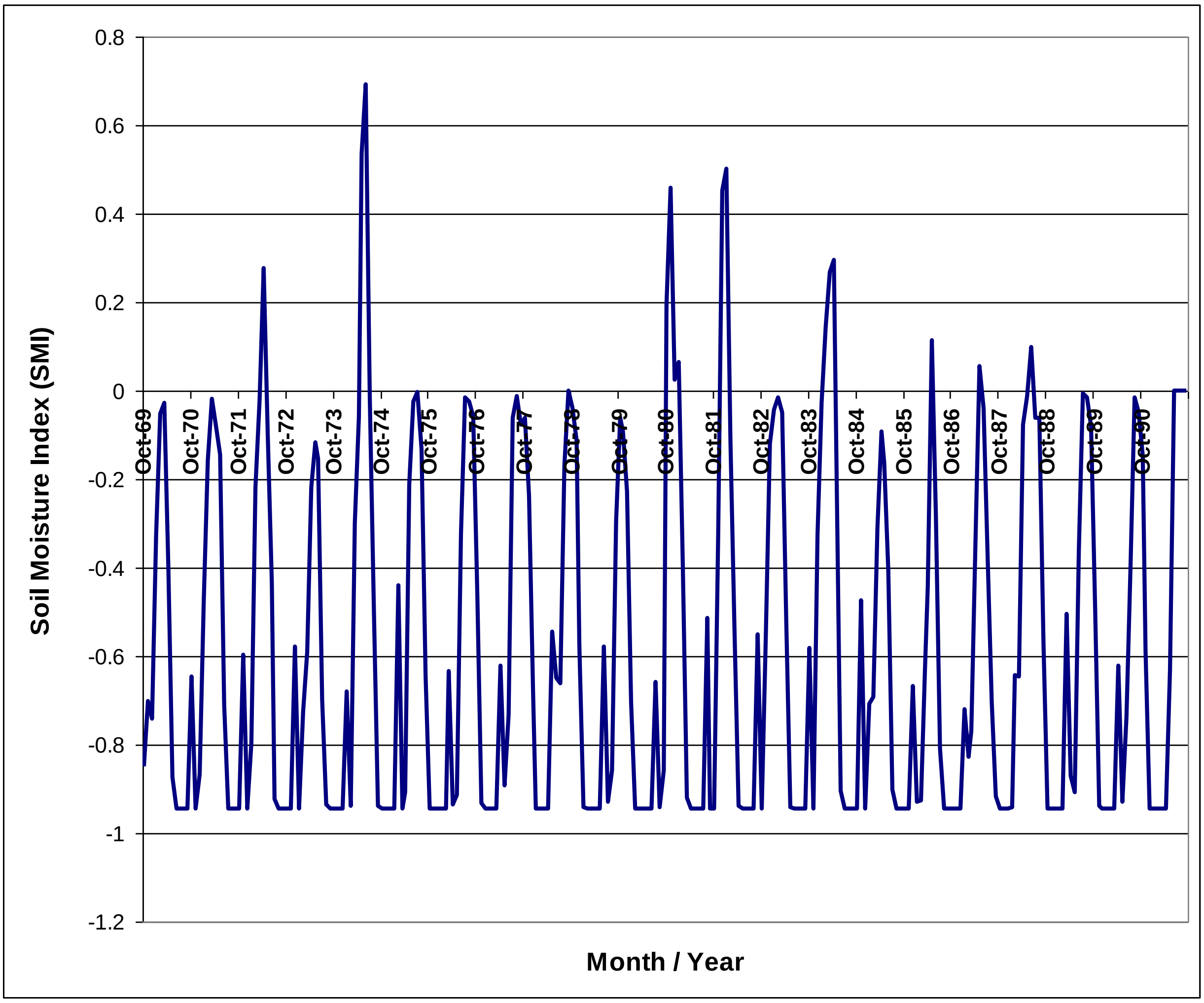


FIGURE 4-15: SOIL MOISTURE INDEX (SMI) FOR TULKAREM GOVERNOARTE ASSUMING WATER FREE STRESS JUST ABOVE PWP.

On the contrary, if we assume groundwater recharge as a water budget parameter, like rainfall, we can calculate SPI-12 values, not for rainfall this time, but for groundwater recharge. Figure 4-16 presents both SPI-12 for rainfall and groundwater recharge for Tulkarm Governorate as an example. It is evident that SPI for GWR have more negative values in drought periods than simple rainfall SPI. This is in accordance with similar findings between SPI and RDI, where RDI (which incorporates PET) has more negative values than SPI during drought periods. This finding is significant for the importance of the estimation of actual evapotranspiration in determining drought indices. In any case, it seems that RDI and SPI for GWR calculates more severe droughts than rainfall SPI itself.

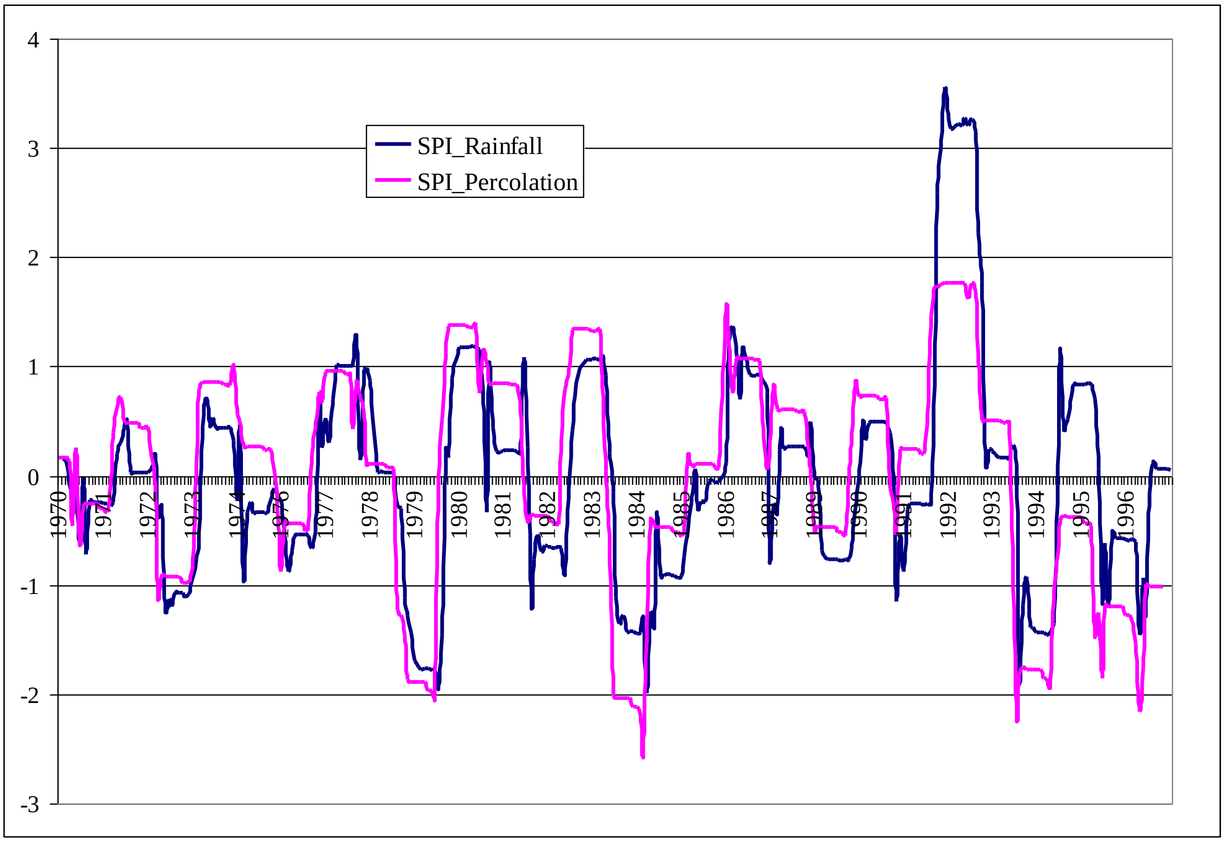


FIGURE 4-16: PLOT BETWEEN SPI FOR RAINFALL AND GWR FOR TULKARM.

5 DROUGHT HAZARD INDEX (DHI)

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.

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 continues to increase (higher negative values) 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).

The second step involved the post-processing of the SPI-12 results to derive four new sub-indicators that can reflect the 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.

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 sub-indicator is used as metrics of "severity".

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

TABLE 5-1: ATTRIBUTES OF DHI PARAMETERS FOR THE SEVEN RAINFALL STATIONS FOR JENIN & TULKARM GOVERNORATES.

a/a	Rainfall Station	Number of Drought Events (FRQ)	Number of Drought Events with Duration more than 24 months (FRQ24)	Maximum Magnitude (Drmax)	Maximum Duration (dmax)
1	Khadouri Institute Tulkarm	7	3	71.2	65
2	Tallu033	7	3	78.8	64
3	Atteel2	6	3	111.3	96
4	Jenin0001	11	4	65.7	72
5	Tubas038	11	4	49.1	53
6	Yabad1	9	3	58.7	71
7	Qabataya1	7	2	65.4	61

We attempted to make a comparison between DM and actual stress in the water system. The only way to do that is to compare the reduction of flow series in runoff springs (provided that springs are remote and free from upstream abstractions). We did this by comparing natural response of the hydrologic system during such drought events.

For instance, Figure 5-1 presents groundwater level for the Fadel Well in Tulkarm Governorate. It is evident that major level drawdown has taken place between 1994 to 2013 but only partially can be attributed to the 1998-2006 drought by comparing drought magnitude values for the nearby rainfall stations. Unfortunately, there is no strong relation between a severe drought event with a major stress of the hydrologic system in order to attribute drought magnitudes, drought frequencies, drought concurrencies to a specified level of severity.

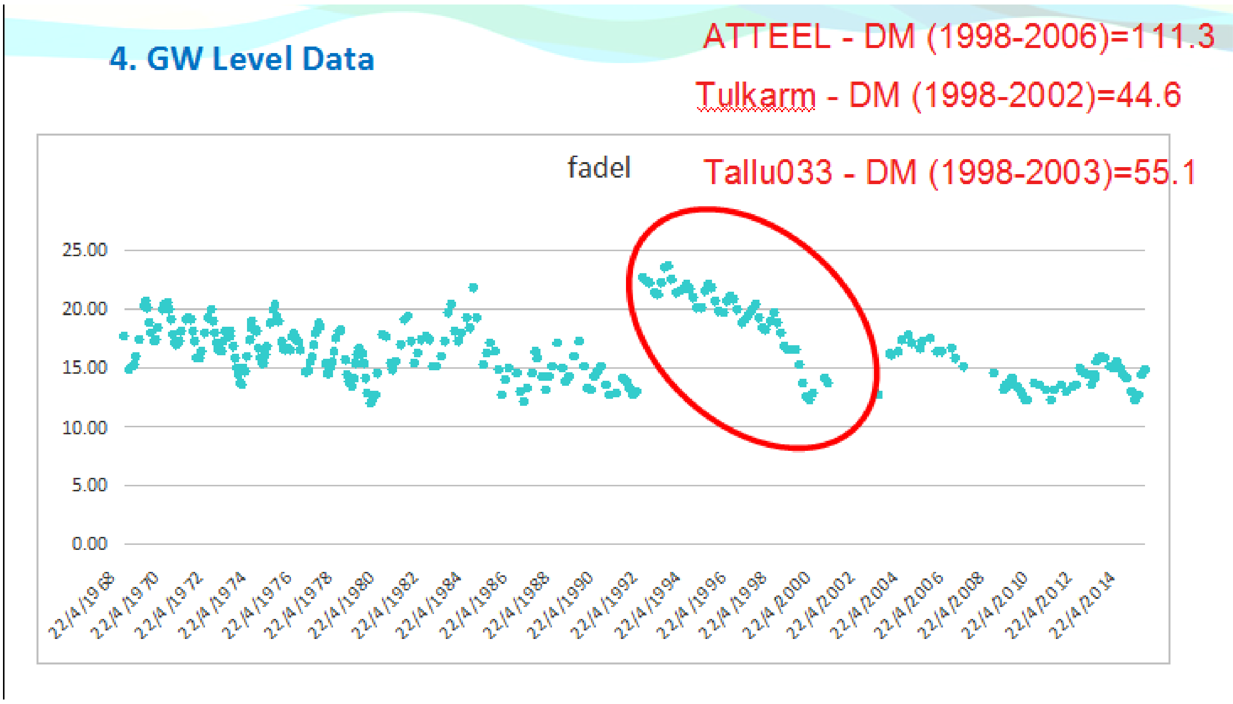


FIGURE 5-1: GROUNDWATER LEVEL DRAWDOWN (IN METERS) DURING THE NOTORIOUS DROUGHT EVENT BETWEEN 1998-2006 IN FADEL WELL (TULKARM GOVERNORATE).

Therefore, we are using thresholds from international literature. For instance, presents the classification thresholds for each sub-indicator as it was deducted from international literature (Kossida, 2015) in areas with similar climatic characteristics. It is important to understand the first sub-indicator (FRQ) that is linked to a percentage of drought events according to the whole duration of our data series. The more the data, the most accurate the prediction. That is the reason why we put so much effort on the rainfall gap filling. We have now 49 years of data, then we can define threshold levels on percentages of drought concurrencies, setting thresholds up to 5% of the time (2 events, for low hazard), up to 10% (5 events - for medium hazard), up to 20% (10 events - for severe hazard) and more than 10 events for extreme hazard.

TABLE 5-2: CLASSIFICATION THRESHOLDS FOR EACH SUB-INDICATOR

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

It has been decided that equal weights for all of four sub-indicators (i.e. frequency of drought events is not that critical since most of them have low magnitudes) are considered. 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 θi are the equal weights of the sub-indicators (θ1=θ2=θ3=θ4=0.25)

TABLE 5-3: CLASSIFICATION OF THE DROUGHT HAZARD INDEX

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

Correspondingly, each DHI value class is related to a certain level of Score / Class as described in Table 5-4.

TABLE 5-4: DROUGHT HAZARD INDEX (DHI) ATTRIBUTE TO EACH ONE OF THE 7 RAINFALL STATIONS FOR JENIN & TULKARM GOVERNORATES

a/a	Rainfall Station	Number of Drought Events (FRQ)	Number of Drought Events with Duration more than 24 months (FRQ24)	Maximum Magnitude (Drmax)	Maximum Duration (dmax)	DHI Final Score
1	Khadouri Institute Tulkarm	3.	3	4	4	3.50
2	Tallu033	3	3	4	4	3.50
3	Atteel2	3	3	4	4	3.50
4	Jenin0001	4	4	3	4	3.75
5	Tubas038	4	4	2	3	3.25
6	Yabad1	3	3	3	4	3.25
7	Qabataya1	3	2	3	4	3.00

Table 5-4 presents the drought hazard index score and classification for all rainfall stations. It is evident that for all stations under consideration, drought hazard index classification is defined as "Extreme". (Table 5- 5-5).

TABLE 5- 5-5: DROUGHT HAZARD CLASS FOR JENIN & TULKARM GOVERNORATES.

a/a	Rainfall Station	Governorate	DHI Final Score	Drought Hazard Class
1	Khadouri Institute Tulkarm	Tulkarem	3.50	Extreme
2	Tallu033	Nablus	3.50	Extreme
3	Atteel2	Tulkarem	3.50	Extreme
4	Jenin0001	Jenin	3.75	Extreme
5	Tubas038	Tubas	3.25	Extreme
6	Yabad1	Jenin	3.25	Extreme
7	Qabataya1	Jenin	3.00	Extreme

Therefore, Drought Hazard in Jenin and Tulkarm Governorates is characterized as EXTREME.

6 CONCLUSIONS

Drought Hazard for Jenin and Tulkarm Governorates was investigated using actually two indices that are appropriate for the particular case, i.e. the SPI and the RDI, where the latter incorporates PET in addition to rainfall. However, it is evident that SPI-12 is the only appropriate index in areas with zero rainfall during summer period and with groundwater level series that are distorted from abstractions or when the natural system is not identifiable.

We have also attempted to describe a modification of SPI-12 by using groundwater recharge monthly rates as produced by the HEC-HMS modelling. The results showed that drought intensity by using groundwater recharge gives more severe indicators during drought periods. This finding is in accordance with the observation that RDI (rainfall divided by potential evapotranspiration) gives higher (more negative) values than SPI during drought periods.

Drought hazard index and its classification are also proposed where the whole of Jenin and Tulkarm Governorates are classified as "Extreme Drought Hazard".

7 WATER DEMAND AND WATER SUPPLY

Water scarcity is the lack of fresh water resources to meet water demand. Water scarcity can mean scarcity in availability due to physical shortage, or scarcity in access due to the failure of institutions to ensure a regular supply or due to a lack of adequate infrastructure. This chapter focusses on the physical aspects: the comparison between water available and water demand. Although the volume of water available is restricted by infrastructure and political aspects.

Water scarcity hazard indicators result from comparison between water demand, water abstraction and the annual recharge rates. Water resources are sources of water that are potentially useful for agriculture, industry, household, recreation and nature. This chapter considers the aspects of agricultural and domestic use.

7.1 WATER DEMAND

7.1.1 Domestic water demand

Methodology

The domestic water demand is linked to the population size and the per capita daily consumption. The WHO defines a standard of 100 L of drinking water per person per day to ensure that most basic needs are met, and few health concerns arise (WHO, 2015). Multiplying population size with the WHO standard provides the water demand from the tap. More production of water is needed because a portion of the water that has been produced is lost in the pipe system before it reaches the customer. This percentage of Non Revenue Water (NRW) is taking into account. Data on the population and the quantities of water supplied and water losses were derived from the Palestinian Central Bureau of Statistics.

Results

The total domestic water supply and demand is presented in Table 7-1.

TABLE 7-1: DOMESTIC WATER SUPPLY AND DEMAND IN JENIN AND TULKARM (2016)

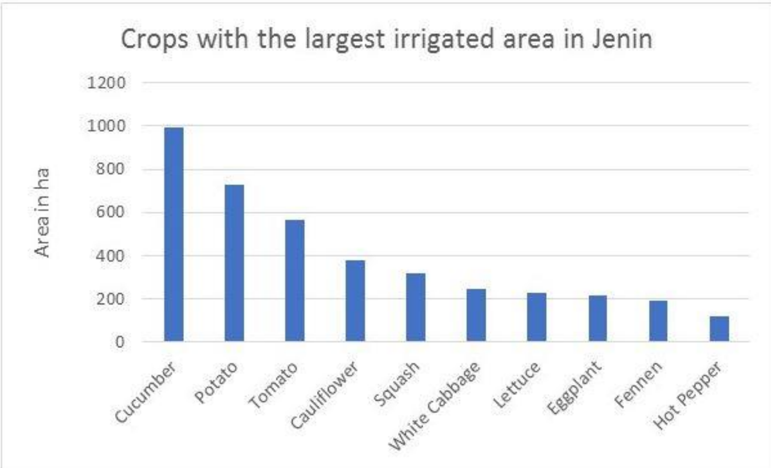
Governorate	Total population (in 2016)	Total volume water supplied in 2016 (Mm3/yr)	Total water loss NRW		Domestic water demand (without NRW) (M m3/yr)	Domestic water demand (with NRW) (M m3/yr)
			(M m^3/yr)	%		
Jenin	318957	7.8	2.6	33 %	11.6	17.5
Tulkarm	185314	10.8	4.1	38 %	6.8	10.9

The balance in domestic water supply and demand varies significantly between the governorates of Jenin and Tulkarm. Although Jenin has a larger population, the total volume of domestic water supplied is lower than in Tulkarm.

7.1.2 Irrigation demand for agriculture

Methodology

Detailed information about the area and production of crops is available for Jenin and Tulkarm. This allows for a relatively accurate assessment of the total irrigation demand. The ten mentioned crops in Figure 7-1 are the dominant crops in the irrigated areas in Jenin and Tulkarm. We assumed that no water is available in the soil in summer time and crops completely rely on irrigation. This is an overestimation. Per crop type, the water consumption was calculated taking into account the water need per growing stage.



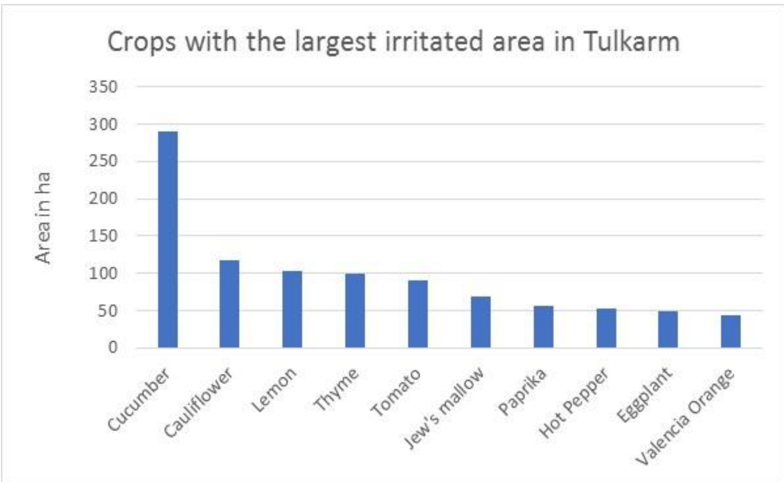


FIGURE 7-1 THE 10 CROPS WITH THE LARGEST IRRIGATED AREA IN JENIN AND TULKARM.

The total irrigated area in Jenin covers an area more than three times larger than in Tulkarm (see Table 7-2. In both governorates cucumber is the most irrigated crop. Olive trees cover by far the largest agricultural area. Only the young trees are irrigated in the first three years of life cycle. There is no detailed information available about these volumes because it was assumed that irrigation of the young olive trees makes part of the category “irrigated land” covering different intensive cultivated crops.

The water demand of each individual crop was calculated based on the reference evapotranspiration per month (derived from data provided by the Palestinian Meteorological Service) and crop values and growth cycle of each crop. The crop values differ per crop and per growing stage and are used to transfer reference evapotranspiration into crop specific evapotranspiration. In this way, a good estimation of the agricultural water demand could be made. The climate data and reference evapotranspiration that were used can be found in Figure 7-2.

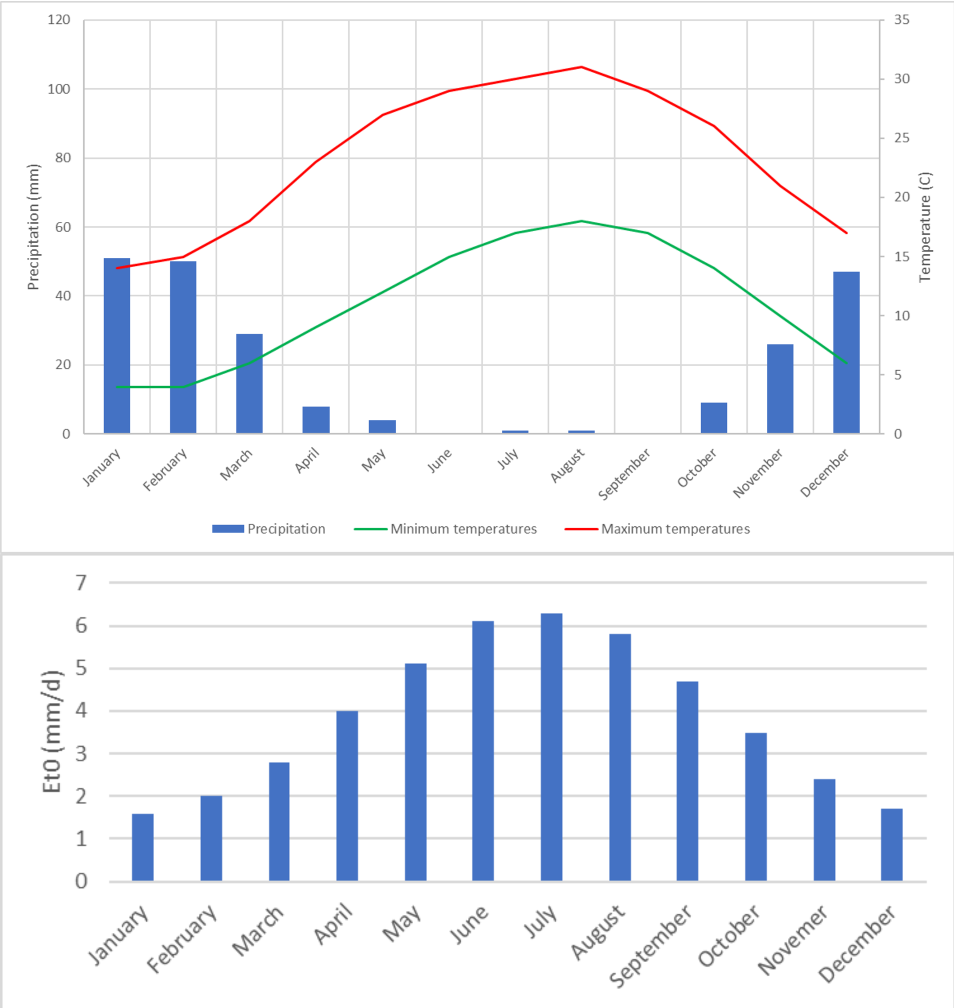


FIGURE 7-2: AVERAGE CLIMATE DATA FOR THE WEST BANK (ABOVE) AND REFERENCE EVAPOTRANSPIRATION OF THE WEST BANK (METEOBLUE, 2018, PALESTINIAN METOROLOGIC SERVICE)

Results

Calculated crop water demands are presented in Table 7-2. To translate these numbers into actual irrigation requirements, the irrigation efficiency was included. In Jenin 52% of the irrigated crops are cultivated using drip irrigation or greenhouses. In Tulkarm this percentage is 27%. According to FAO statistics, drip irrigation systems have an average field application efficiency of 90% (FAO, 1989). For the remaining irrigated areas, a field application efficiency of 60% was assumed. No data about the type of irrigation canals and application method was available. Therefore, the irrigation efficiency should be regarded as a indicative value.

TABLE 7-2: TOTAL IRRIGATION DEMAND (MM^3/Y) FOR JENIN AND TULKARM

Governorate	Irrigated area (ha)	Assumed irrigation efficiency (%)	Water crop demand (Mm^3/y)	Irrigation water demand (Mm^3/y)
Jenin	7538	77	26,3	34,1
Tulkarm	2219	66	15,7	23,7

7.1.3 Livestock demand

The water demand per animal per day was based on international literature providing climate specific standards per type of livestock (FAO, 1986). FAO Poultry water demand data was not available. The total water demand for poultry will be very limited and was estimated.

Results

Livestock water demand in Jenin and Tulkarm are presented in Table 7-3 and Table 7-4

The total livestock water demand is very small related to the irrigation demand. Jenin has more agriculture than Tulkarm, with a significant larger irrigated area and a larger number of livestock.

TABLE 7-3: LIVESTOCK WATER DEMAND IN JENIN IN 2016

Livestock type	Number of animals (in 2016)	Water demand per animal (L/d)			Total water demand (m^3/yr)
		Cold season	Warm season	Average	
Cattle	9,626	20	27	24.7	87
Goats	29,722	4	5	4.7	51
Sheep	83,420	4	5	4.7	142
Poultry	123,000	0.2	0.25	0.23	10
Total					**290**

Table 7-4: Livestock water demand in Tulkarm

Livestock type	Number of animals (in 2016)	Water demand per animal (L/d)			Total water demand (m^3/yr)
		Cold season	**Warm season**	**Average**	
Cattle	2,011	20	27	24,67	18.1
Goats	2,435	4	5	4,67	4.1
Sheep	22,313	4	5	4,67	38.0
Poultry	244,000	0,2	0,25	0,23	20.8
Total					**81.0**

The total water demand for livestock is 371 m^3 per year.

7.2 WATER SUPPLY FROM GROUNDWATER ABSTRACTIONS

Groundwater is the main source for domestic and agricultural water use. Surface water or reclaimed water are not used in Jenin and Tulkarm. This paragraph focusses on groundwater abstractions. Locations of abstractions (domestic and irrigation use) and abstraction rates from pumping wells and springs per year were provided by the PWA.

7.2.1 Domestic water use

Methodology

The volume of water available is based on the data provided about historical groundwater abstractions per domestic well by the Palestinian Water Authority.

Results

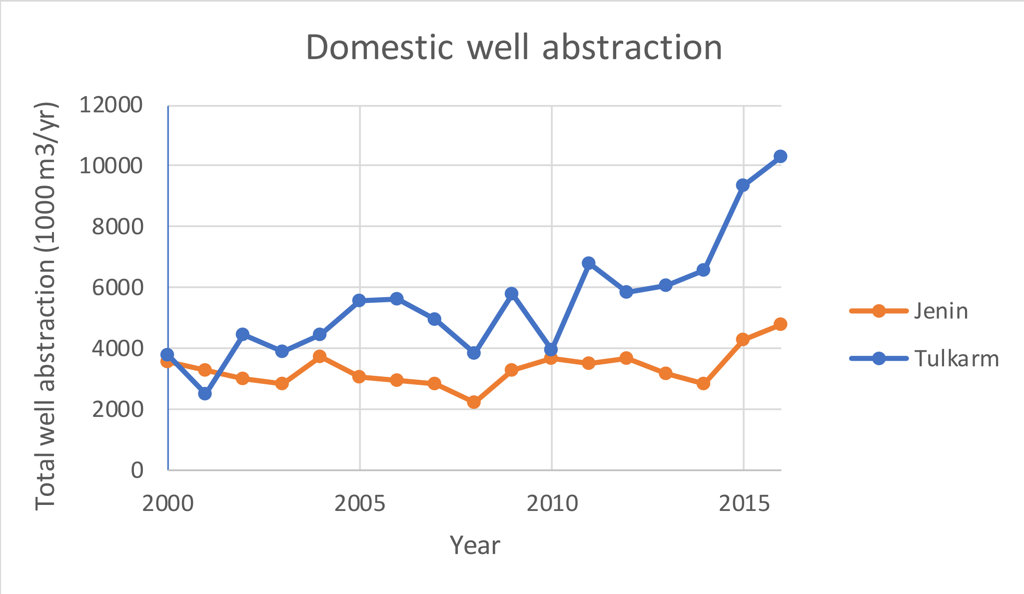


FIGURE 7-3: ABSTRACTION VOLUME PER YEAR FROM GROUNDWATER FOR DOMESTIC USE IN JENIN AN TULKARM (SOURCE: PWA. DATA PROVIDED 2018-01-17)

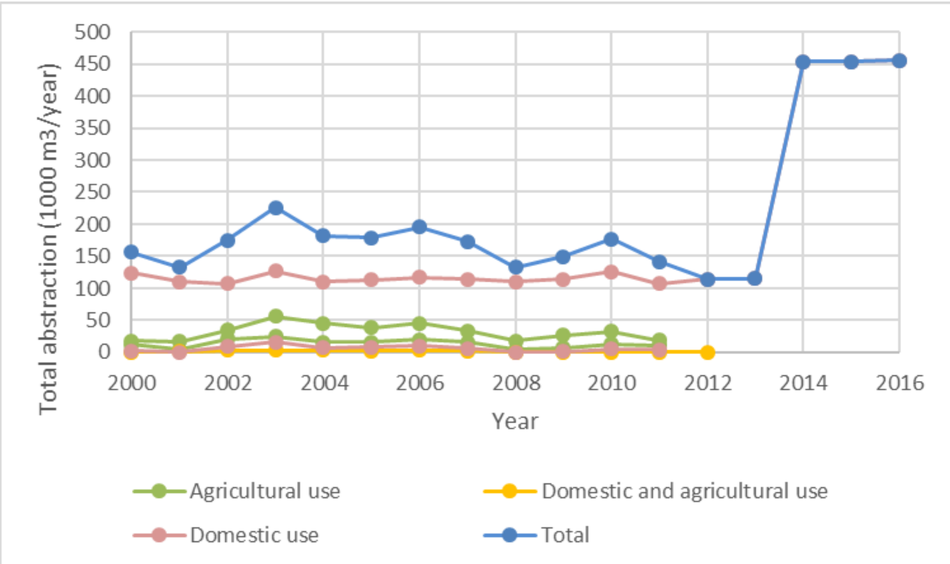


FIGURE 7-4: ABSTRACTION VOLUME PER YEAR FROM SPRINGS FOR DOMESTIC AND AGRICULTURAL USE IN JENIN AN TULKARM (SOURCE: PWA. DATA PROVIDED 2018-01-17)

There are five springs, all located in Jenin. Data availability for four springs after 2011/2012 is limited. It is not known if these springs are still in use. Based on the data of one spring the water use is increasing. It was noted that the water abstraction from springs is very small compared to the abstraction volume of wells.

7.2.2 Total domestic water use

For Tulkarm the total domestic groundwater abstraction adds up to 10.3 Mm^3, close to the volume of 10,8 Mm^3 reported by the Palestinian Central Bureau of Statistics. A volume of 0,5 Mm^3 purchased water from the Israeli water company in 2016 results in 10,8 Mm^3 exactly.

For Jenin the total domestic abstraction from wells and springs add up to 5,2 Mm^3. This is significantly less than the 7,8 Mm^3 reported by the Palestinian Central Bureau of Statistics. Jenin reported purchase of 3 Mm^3 from the Israeli water company, adding up to 8,2 Mm^3. This difference might be explained by the fact that the water purchased from the Israeli water company includes "*pumped water from the wells which are located in the territories of the State of Palestine and controlled by Israeli Water Company*". This may result in double counting of water abstractions.

7.2.3 Agricultural use (irrigation and livestock)

Methodology

The volume of water available for irrigation and livestock was based on the reported abstraction rates from agricultural wells. It was assumed all water abstracted is lost by evaporation and plant growth. No irrigation water remains for recharge the groundwater.

Results

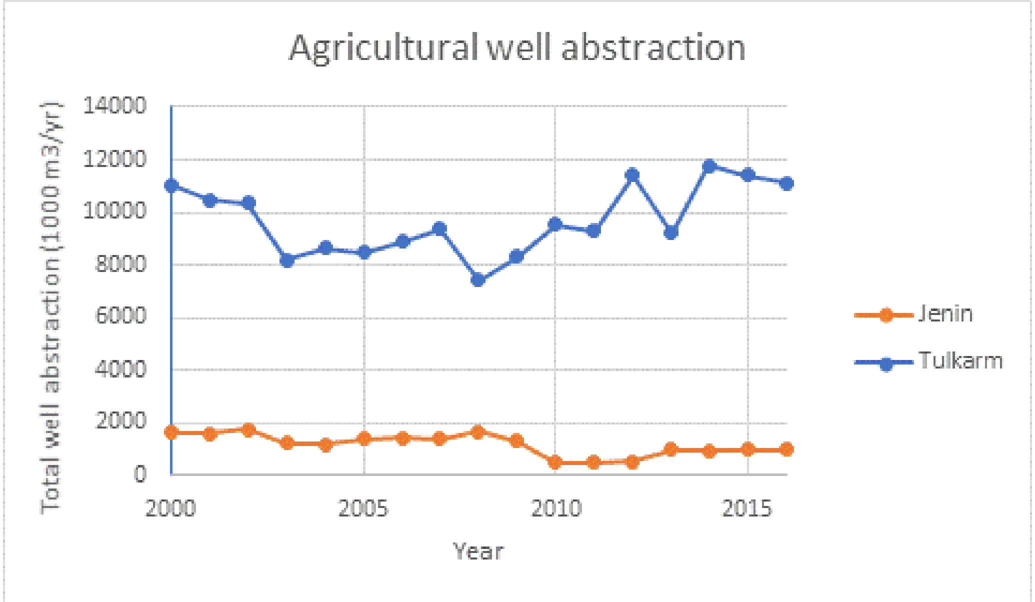


FIGURE 7-5: THE TOTAL WELL ABSTRACTION FOR AGRICULTURAL USE IN JENIN AN TULKARM (SOURCE: PWA. DATA PROVIDED 2018-01-17)

The volume of abstracted groundwater for agriculture in Tulkarm is higher than in Jenin, although the irrigated area in Jenin is three times larger. Figure 6 shows a denser network of larger groundwater wells in Tulkarm.

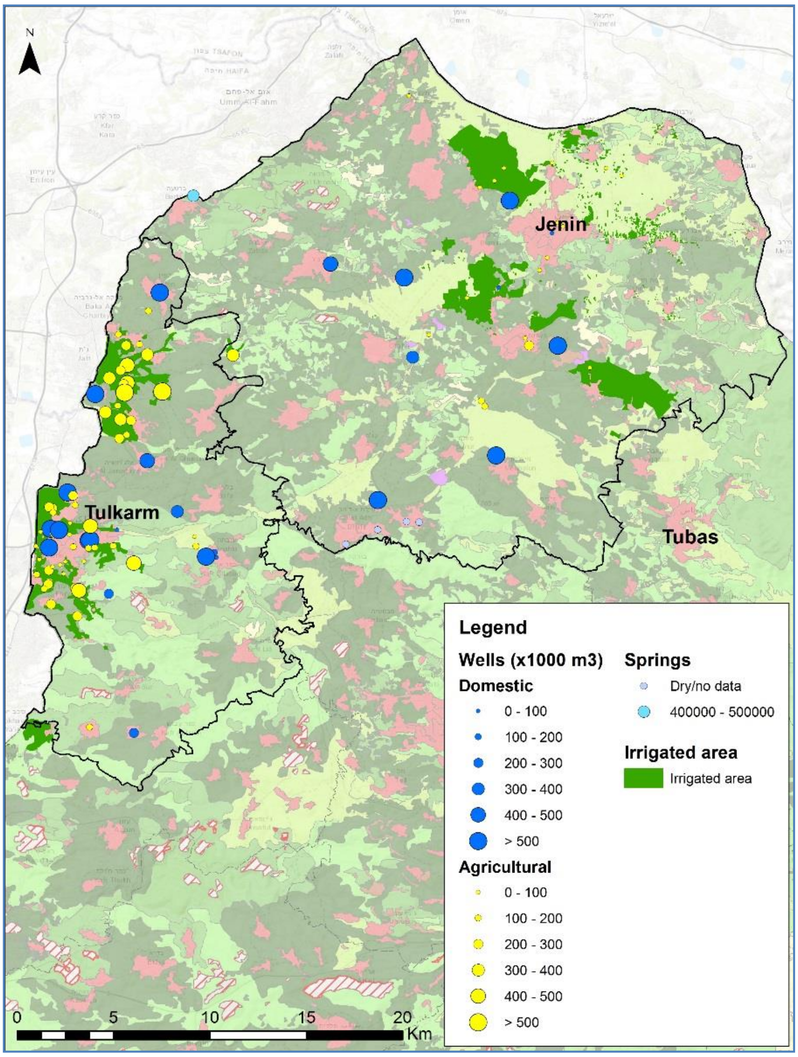


FIGURE 7-6: LOCATION AND AVERAGE ABSTRACTION VOLUME PER YEAR OF DOMESTIC AND AGRICULTURAL WELLS AND SPRINGS RELATED TO URBAN AREAS AND IRRIGATED AREAS (DATA SOURCE: PWA, PROVIDED 2018-03-04)

Total groundwater abstraction increased since 2010, mainly due to an increase in abstraction for domestic use in Tulkarm (Figure 7-7).

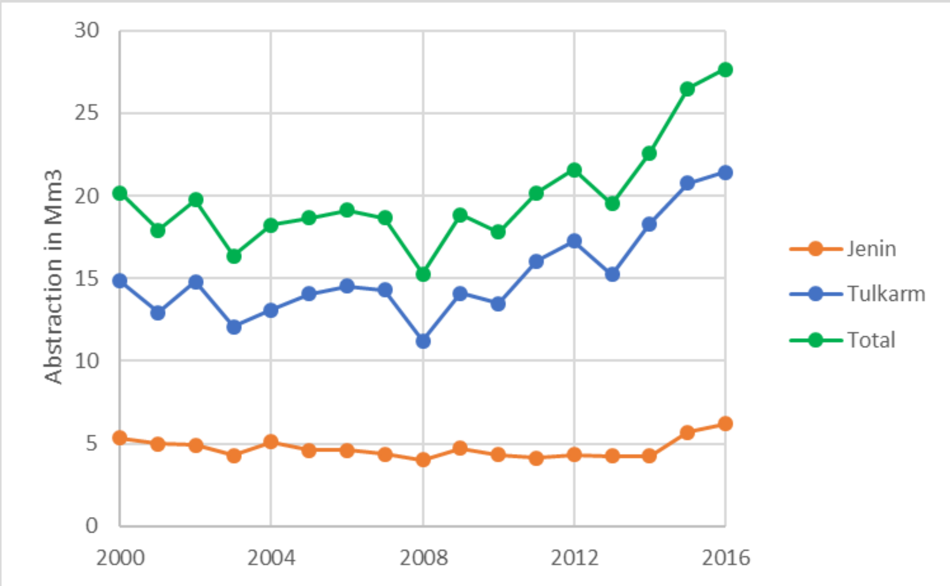


FIGURE 7-7: TOTAL GROUNDWATER ABSTRACTION (BOTH DOMESTIC AND AGRICULTURAL) FOR JENIN AND TULKARM

7.3 OTHER SOURCES OF WATER SUPPLY

Deep groundwater is the main source for water supply for domestic and agricultural use. According to information from the Palestine Water Authority, there are the following other sources for water:

- Deep groundwater wells managed by Israel. There is no information available about their location nor their discharge rates;
- Rain water harvesting especially in Jenin. Water is collected in tanks at individual houses. There is no administration available;
- Shallow groundwater wells in the upper aquifer of Jenin. No permit is needed for these type of abstractions and administration lacks;
- The water company Mekorot from Israel provides water to small communities not connected to the public water system. This volume is limited to 10.000 m3 per year.

8 WATER SCARCITY

This chapter is started with a description of existing water scarcity indicators (paragraph 8.1). In the following paragraphs, recharge and groundwater storage is evaluated using measurements of groundwater levels and modelled recharge (paragraph 8.2 - paragraph 8.4). Next the balance between abstraction and demand (paragraph 8.5) and the balance between water supply and demand (paragraph 8.6), the unmet demand, was calculated.

8.1 AVAILABLE WATER SCARCITY INDICATORS

In the literature different water scarcity indicators are mentioned. This paragraph highlights three indicators: The Water Exploitation Index, Relevant Water Stress Indicator (RWSI) and the Percentage of Unmet Demand.

8.1.1 The Water Exploitation Index (WEI)

The Water Exploitation Index (WEI) is an indicator of the level of pressure that human activity exerts on the natural water resources of a territory, helping to identify those prone to suffer problems of water stress. Traditionally the WEI has been defined as the annual total water abstraction as a percentage of available long-term freshwater resources. It has been calculated so far mainly on a national basis. A review and upgrade of the index (WEI+) has been developed by the Expert Group on Water Scarcity & Droughts of the European Union with the purpose of better capturing the balance between Renewable Water Resources (RWR) and water consumption, to assess the prevailing water stress conditions in a river basin. The WEI+ aims mainly at redefining the actual water exploitation, since it incorporates returns from water uses and effective management, tackling issues of temporal and spatial scaling as well.

WEI+ is formulated in these terms:

WEI+ = (Abstractions – Returns) / Renewable Water Resources (RWR)

RWR can be calculated either by the relationship

Option 1. RWR = ExIn + P – Eta – ΔSnat

Or;

Option 2. RWR = Outflow + (Abstraction – Return) – ΔSart

Where:

- ExIn: actual external Inflow,
- P: precipitation,
- Eta: actual evapotranspiration,
- Δsnat: changes in the amount of water stored from natural processes,
- Δsart: changes in storage from artificial processes (regulated lakes or artificial reservoirs),
- Outflow: Actual outflow of rivers and groundwater into the sea or neighbouring territories (within or outside a country).

Groundwater is not connected with surface water in Jenin and Tulkarm. Assuming there is no external inflow and looking at the long-term, option 1 can be formulated as RWR = P – Eta.

8.1.2 Relevant Water Stress Indicator (RWSI)

The Relevant Water Stress Indicator (RWSI) equals the percentage of Total Freshwater Abstracted (ABS) over the total Renewable Water Availability (RWA). RWA could be difficult to assess, especially when it must take into account water exchanges between neighbouring groundwater catchments (contribution included in External Inflow). Moreover, RWSI equals ABS / RWA.

8.1.3 Percentage of Unmet Demand

Percentage of unmet demand relative to total demand per sector can be annually or per season (e.g. summer) aggregated. Comparison of the total demand to the annually renewable water resources will be carried out. If existing abstractions are overexploiting annual renewable water resources, total demand will be proposed to be reduced by demand control measures.

8.2 CHANGES IN GROUNDWATER LEVELS AND GROUNDWATER STORAGE

Methodology

Long term changes in groundwater levels are indicators of a mismatch between groundwater recharge and total groundwater abstraction. Measurements of groundwater depth were provided by the PWA. Trends in groundwater level were used as an indicator for changes in groundwater storage. Most simple approach of a trend analysis would be a linear trend analysis. Gaps in data impede a proper linear trend analysis. To overcome this, the rise and fall in groundwater level per summer and winter season was derived and summarized into a total value (Figure 8-1).

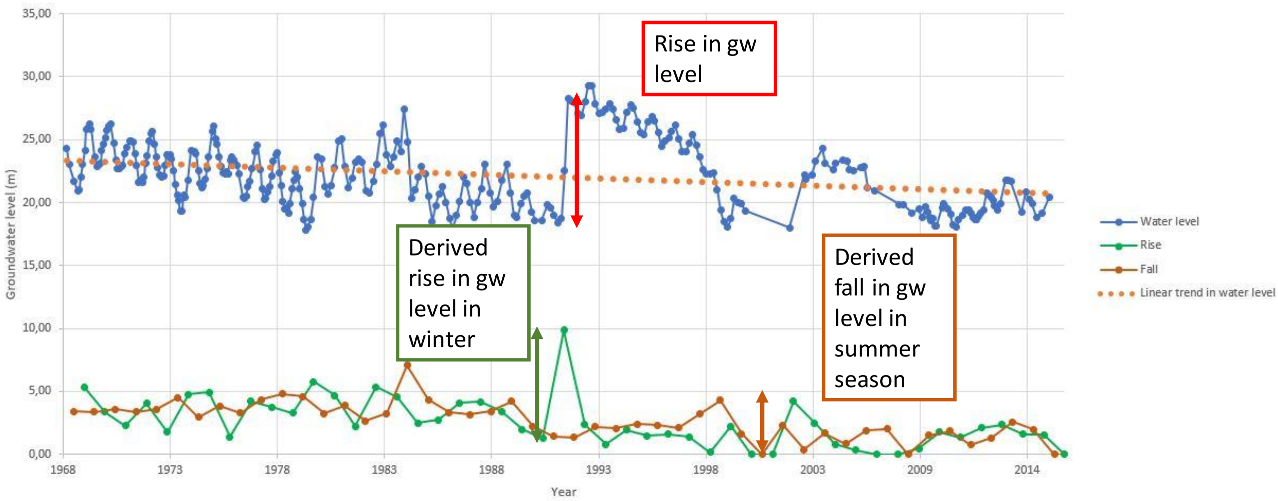


FIGURE 8-1 METHOD OF TREND ANALYSIS OF GROUNDWATER LEVELS BASED ON ANNUAL RISE AND FALL IN GROUNDWATER LEVEL

Results

The trend in measured groundwater level for 11 wells is presented in Figure 8-2. All wells show a similar seasonal pattern and long-term trend:

- The long term trend in the time frame 1968 – 2015 is an average annual decrease of 7 cm;
- Within this time frame there are extreme wet and dry years. These years have a large and long-term effect on groundwater levels. Especially the wet year 1991-1992 resulted in a large increase of groundwater levels. This impact was evident for almost ten years
- The seasonal pattern (winter/summer) in the 1970's and 1980's shows much more variation compared with the years after 2000;
- Less data was available after 2001 with large data gaps in the time frames 2001-2003 and 2007-2009. There are some data errors with sudden jumps in readings. These readings are ignored in the trend analysis.

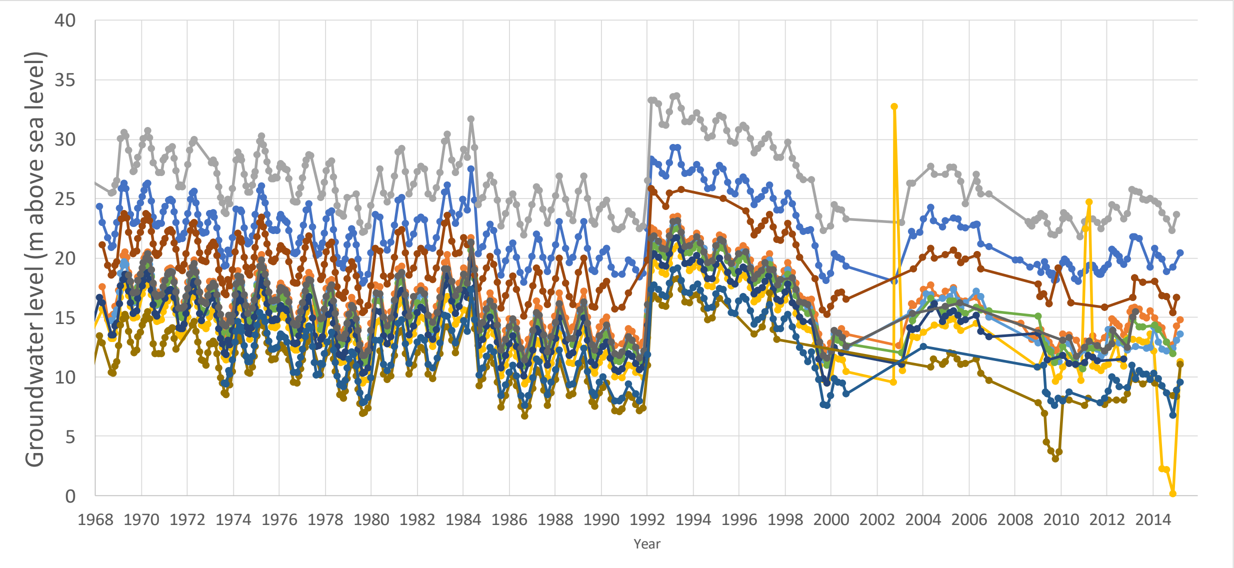


FIGURE 8-2: MEASURED GROUNDWATER LEVEL (METER ABOVE SEA LEVEL) FOR 11 WELLS IN TULKARM IN THE TIME FRAME 1968 – 2015

The conclusion is groundwater levels are gradually declining. This is an indication for a mismatch between recharge and total groundwater abstraction. The last 14 years groundwater levels are stabilizing. The conclusions above apply for Tulkarm. **No data for Jenin were available**.

8.3 GROUNDWATER RECHARGE

Methodology

Calculation of groundwater recharge in arid and semi-arid areas is complex because precipitation varies in time and evaporation depends on the spatial variability in soil characteristics, topography, vegetation and land cover (Anderson and Woessner, 1992). In arid climates the recharge is relatively small and variable (Maruo, 2003). Recharge was calculated using the model HEC-HMS with data provided about rainfall, potential evaporation, vegetation and soil types. The program includes procedures necessary for continuous simulation of evapotranspiration, event infiltration and soil moisture accounting.

Results

Recharge was calculated as an average value for Jenin and Tulkarm (Table 8-1). Calculated recharge showed a high difference in recharge per year with average annual values of 264 mm/yr for Tulkarm and 120 mm/yr in Jenin. The differences can primarily be explained by decreasing rainfall in eastern and southern direction. That is why there is less recharge in Jenin than in Tulkarm.

TABLE 8-1 CALCULATED RECHARGE (WITH HEC HMS) IN JENIN AND TULKARM FOR THE HYDROLOGICAL YEARS 1969 - 1991

Governorate	Surface area (km^2)	Recharge (mm/y)	Recharge (Mm^3/y)
Jenin	583	120	69,7
Tulkarm	239	264	63,1

8.4 GROUNDWATER STORAGE CHANGE

Methodology

Annual groundwater recharge was estimated from the average jump in measured groundwater level per winter season. The jump is defined as the difference between the lowest and highest measurement at the beginning and end of winter. Combining the climb in groundwater level with a porosity provides the recharge value. The porosity value was calibrated by comparing the calculated recharge values from measurements with the modelled recharge values with the HEC HMS model.

Results

The 11 wells presented in Figure 8-2 are listed in Table 8-2, were divided in three time frames:

- 1969 – 1991 with sufficient data for all monitoring wells. Groundwater levels are decreasing per well on average between 7 and 25 centimetres per year. The average decrease equals 16 cm.
- 1991 – 1999 with sufficient data for 10 wells. This time frame includes the wet winter of 1991-1992. Two wells even showed an increase in groundwater level. The average decrease in groundwater level was 6 cm;
- 1999 – 2013 with limited data available. The six wells with sufficient data show very different trends, both increasing and decreasing. The average increase is 7 centimetres per year.

TABLE 8-2 AVERAGE CHANGE IN GROUNDWATER LEVEL (IN METERS) IN THE PERIODS 1968-1991, 1991-1999 AND 1999-2013 (IF AVAILABLE).

Number See Figure 8-3	Location	1969 - 1991	1991 - 1999	1999 - 2013
1	Muhammad Al Taher & Partners	-0.19	0.03	-0.14
2	Fadel Kittanah & Partners	-0.09	-0.04	0.00
3	Iqab Fraij & Partners	-0.13	-0.02	0.17
4	Wasfi Abed Al Kareem	-0.14	-0.05	
5	Muhammad Omar Safareeni	-0.14	-0.01	0.23
6	Muhammad Ahmad Abu Shanab	-0.23	-0.04	0.09
7	Shaker Samarah	-0.13	-0.14	
8	Abed Al Majeed Qasem	-0.22	-0.39	
9	Ismaeel Itair	-0.25	-0.01	
10	Omar Al Karmi	-0.14		
11	Al Khaduri Agricultural School	-0.08	0.05	
	Average	-0.16	-0.06	0.07

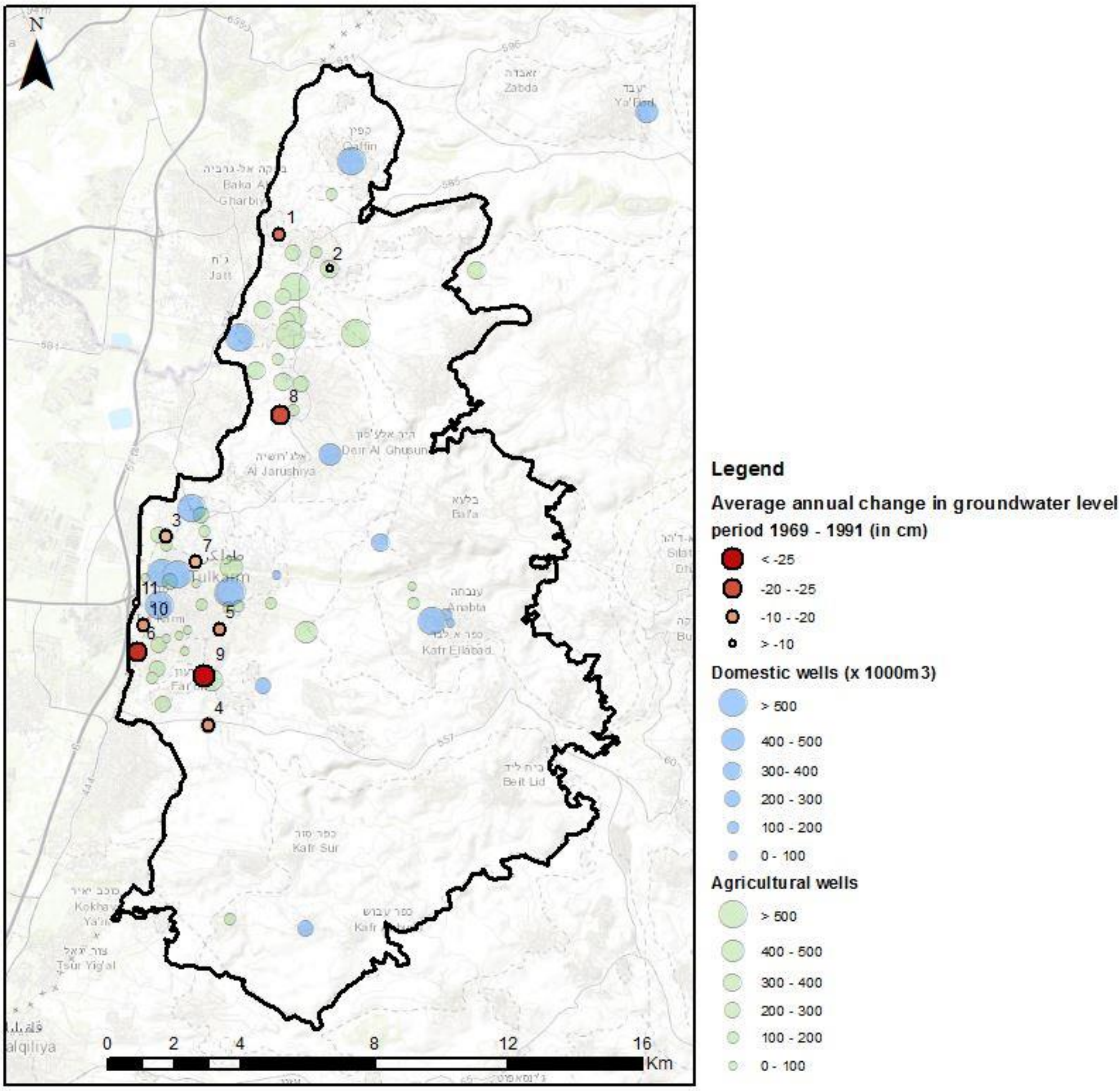


FIGURE 8-3: THE AVERAGE ANNUAL CHANGE IN WATER LEVEL FOR THE PERIOD 1969 - 1991 FOR TULKARM (IN CM)

Figure 8-3 illustrates the location of the 11 wells with the measured annual trend in groundwater level over the period 1969 – 1991. This period was selected for presentation because most data was available for this period. The spatial pattern in groundwater level change was compared with soil type, land use and location of domestic and agricultural wells (reflecting the situation 2016). The small variations in groundwater level changes per well could not be related to the spatial distribution of the soil, land use and location of abstraction wells.

Recharge was derived from measurements using the jump in groundwater level in the wet season. A porosity of 8% provided the best fit between measured and modelled recharge. In general, most measured and modelled values are in close range. But some years show large differences, especially the extreme dry and wet years. This may be caused by errors in rainfall measurements.

TABLE 8-3 MODELLED AND MEASURED RECHARGE PER HYDROLOGICAL YEAR (1969 – 1991) IN TULKARM.

Year	Measured average climb in groundwater level in wet season (mm)	Modelled recharge (mm)	Recharge measured (mm)*	Difference measured and modelled recharge (mm)
1969-1970	3356	255	269	13
1970-1971	2264	191	181	-10
1971-1972	3820	300	306	6
1972-1973	1680	119	134	15
1973-1974	5131	371	411	40
1974-1975	4645	267	372	105
1975-1976	1262	167	101	-66
1976-1977	3946	391	316	-75
1977-1978	3209	241	257	16
1978-1979	2876	52	230	178
1979-1980	5404	482	433	-49
1980-1981	4812	369	385	16
1981-1982	2202	176	176	0
1982-1983	4916	472	393	-79
1983-1984	3769	45	302	257
1984-1985	2391	165	191	26
1985-1986	2605	241	209	-32
1986-1987	3974	414	318	-96
1987-1988	3746	324	300	-24
1988-1989	3251	165	260	95
1989-1990	1922	345	154	-191

Year	Measured average climb in groundwater level in wet season (mm)	Modelled recharge (mm)	Recharge measured (mm)*	Difference measured and modelled recharge (mm)
1990-1991	1422	261	114	-147
Average	**3300**	**264**	**264**	**0**

* Assuming a porosity of 8,0 %

8.5 CALCULATED BALANCE BETWEEN RECHARGE AND ABSTRACTION

Methodology

More abstraction than recharge does not result automatically in the ongoing lowering of groundwater levels. Due to changes in surface water drainage and groundwater flow, the effect on groundwater level can be muted. Although in Jenin and Tulkarm effects of surface water are limited. Therefore the average annual recharge (modelled) and abstraction (measured) were compared. The average calculated recharge (1969-1991) in Jenin and Tulkarm was derived from the HEC HMS model and was multiplied by the surface area of the governate. Measured abstraction in 2016 comprise registered abstraction in domestic and agricultural wells (see paragraph 1.2); being the main users of water. Comparison of both values gives an indication about the sustainability of the groundwater management in the long term.

Results

Recharge in Jenin and Tulkarm is larger than total abstraction registered (Table 8-4), in both governates. This may indicate a sustainable situation, although probably some abstractions are missing in the balance, for example abstractions from the shallow aquifer in Jenin and abstractions not under jurisdiction of the Palestine government.

TABLE 8-4: RECHARGE RELATED TO ABSTRACTION AND TOTAL WATER DEMAND IN JENIN AND TULKARM

Governorate	Recharge (Mm^3/y)	Registered abstraction (Mm^3/y)	Difference between recharge and abstraction (Mm^3/y)
Jenin	69 .7	6 .2	51 .9
Tulkarm	63 .1	21 .4	34 .7

8.6 PERCENTAGE OF UNMET DEMAND

Methodology

The volume of water supplied was compared with the ideal situation for households and agriculture. The volume of water supplied was based on the registration of groundwater abstractions (see paragraph 1.2). The ideal situation was based on key figures for domestic water use (100 L/person/day) and irrigation water needed for optimum use per crop in time (see paragraph 1.2.3).

Domestic water use

The balance between water supplied and water demand is presented in Table 8-5 and Table 8-6 using the following rules:

- Water supplied = Registration of abstracted water from domestic wells in 2016
- Domestic water demand = Population * 100 l/day
- Total water demand = Water demand + NRW
- Deficit domestic supply = Total water supplied - Total water demand (including NRW)

The total volume of domestic water supplied in Tulkarm is almost sufficient to meet the WHO standard of 100 L per person per day (Table 8-5). Reduction of the NRW from 38% to 37% will be sufficient for an average water supply of 100 l per person.

Jenin has a larger population and less domestic water supplied. This results in 45 L water available per person per day (Table 8-5). Decreasing the NRW percentage will not result in a sufficient water availability. New water sources are needed to reach the desired situation of 100L per person per day.

TABLE 8-5: DOMESTIC WATER SUPPLY IN JENIN AND TULKARM IN 2016

Governorate	Total population (in 2016)	Total water supplied (M m^3 /yr)	Water loss		Per person daily consumption (L/person/day)
Jenin	318.957	7.8	2.6	33	44,7
Tulkarm	185.314	10.8	4.1	38	99,1

TABLE 8-6: DEFICIT IN DOMESTIC WATER SUPPLY FOR JENIN AND TULKARM BASED ON 100 L PER PERSON PER DAY

Governorate	Recommended water consumption (L/person/day)	Domestic water demand (without NRW) (M m^3 /yr)	Total water demand (including NRW) (M m^3 /yr)	Deficit domestic supply (Mm^3/yr)

Jenin	100	11.6	17.5	9,7
Tulkarm	100	6.8	10.9	0.1

Agricultural water use

Comparison between the agricultural water demand and water volume abstracted shows a deficit of 3 M m^3/year for Tulkarm (Table 8-7). Jenin faces a large deficit between the small irrigation volume available (1 M m3/yr) and the large water demand (34,1 M m^3/yr).

TABLE 8-7: TOTAL AGRICULTURAL WATER DEMAND AND SUPPLY FOR JENIN AND TULKARM

Governorate	Total irrigation demand (Mm^3/y)	Total livestock demand (Mm^3/y)	Total agricultural water demand (Mm^3/y)	Total agricultural abstraction (Mm^3/y)	Deficit between demand and abstraction (Mm^3/y)
Jenin	34 .1	0 .3	34.4	1 .0	33 .4
Tulkarm	23 .7	0 .1	23.8	11 .1	12.7

The large deficit between water availability and water demand for agricultural use was discussed during the training session in Ramallah in November 2018. The following remarks were made about Jenin:

- there is extra water supply using rain water harvesting;
- there is extra water supply from wells located in the shallow aquifer;
- water reuse in Jenin city (1 M m^3/year)
- local water supply from random wells for agricultural use (7 M m^3/year)
- farmers are more adopted to water scarcity and have optimized water management and agricultural practice.

9 DROUGHT AND WATER SCARCITY VULNERABILITY

9.1 METHODOLOGY

Drought vulnerability is presented geographically on maps, using geographical (GIS) data.

Sensitivity to drought is considered separately for agricultural and urban areas. Combining the physical properties to drought with the availability of water results in drought vulnerability. Physical sensitivity to drought comprise soil properties, crop yield sensitivity, irrigated land, presence of springs recharge flux conditional to monthly spring discharge time series. The socio-economic drivers are population density and connection to (public) water supply and irrigation.

The combination of the analysis for agricultural and urban area leads to drought vulnerability (Figure 9-1). Combining the results of the various indicators will make a draft drought vulnerability map.

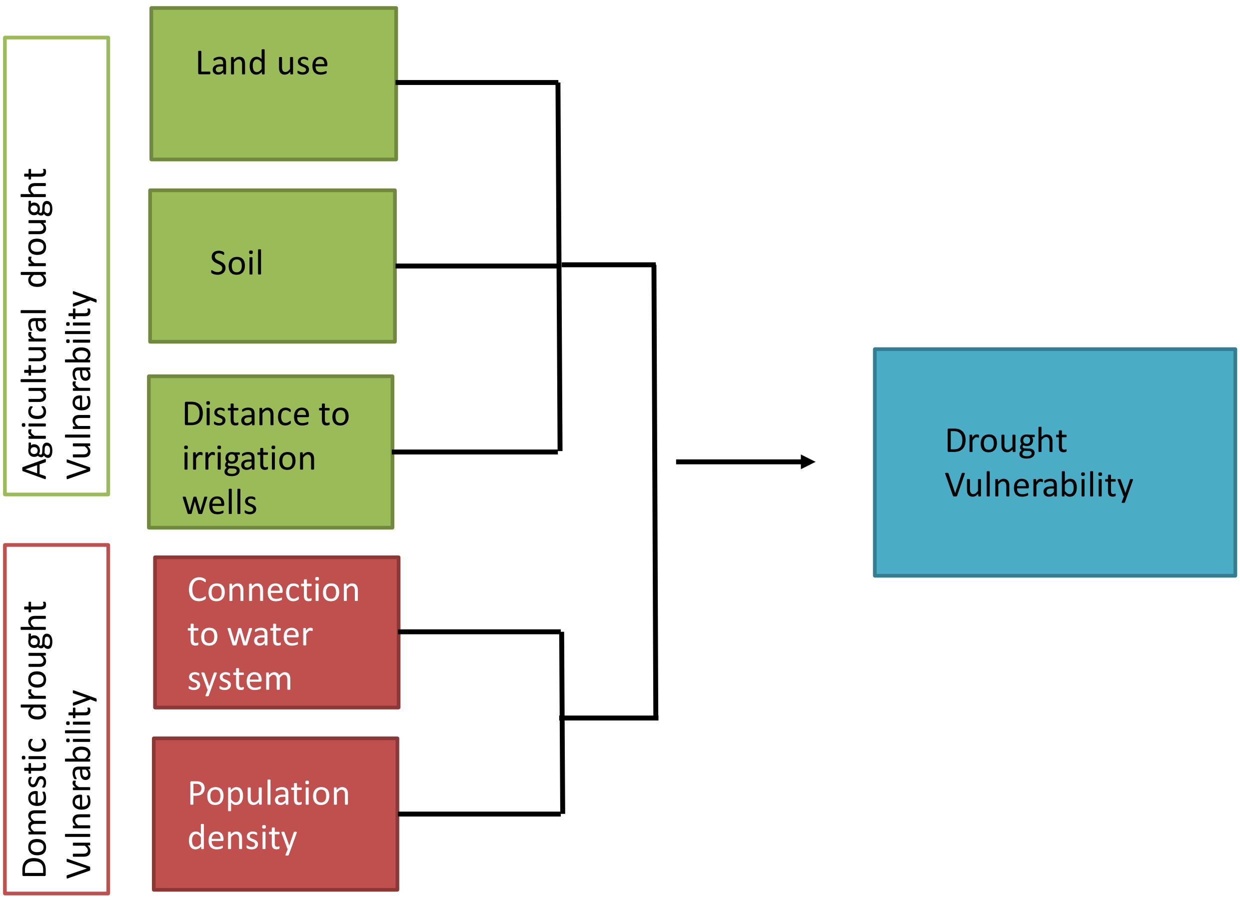


FIGURE 9-1 PROCESS OF DROUGHT VULNERABILITY INDICATORS

Table 9-1 shows how data is transferred into drought vulnerability indicators. Geographical data on a point scale (climate data, spring location) or spatial scale (soil, crops, urban areas) is transferred into new spatial data. For soil and crop yield sensitivity to drought, existing international literature values (like FAO reports) is used.

TABLE 9-1 METHODOLOGY FOR DROUGHT VULNERABILITY INDICATORS

Type of indicator	Input data	Indicator	Result
Agricultural drought	Soil map	Soil drought sensitivity	Low to high sensitivity
	Land / crop use Sensitivity per crop	Crop yield sensitivity	Low to high sensitivity
	Location of irrigation (map)	Irrigated land versus rain fed land	Irrigated or non-irrigated
	Spring locations and spring discharge	Distance to spring in relation to spring discharge	Low, medium or high distance to irrigation
Domestic drought	Map with urban areas	Population density per area	Low to high unmet water demand
	Location domestic wells (map)	Distance to well	Low, medium or high distance to wells
	Connection to water system (list of communities)	Connected or not	Connected or not

Using different weighting factors, different options of the map can be made. This process can be seen as a sensitivity analysis.

9.2 AGRICULTURAL DROUGHT VULNERABILITY

Soil type

The starting point of the physical drought vulnerability assessment is the soil type and land use. The dominant soil types are rendzinas and grumusols (Figure 9-2), both with a clay or clay loam texture. This does not result in significant spatial variation in drought vulnerability, because both soil types have a similar sensitivity to drought. The soil type is therefore not used as an indicator in the physical drought vulnerability assessment.

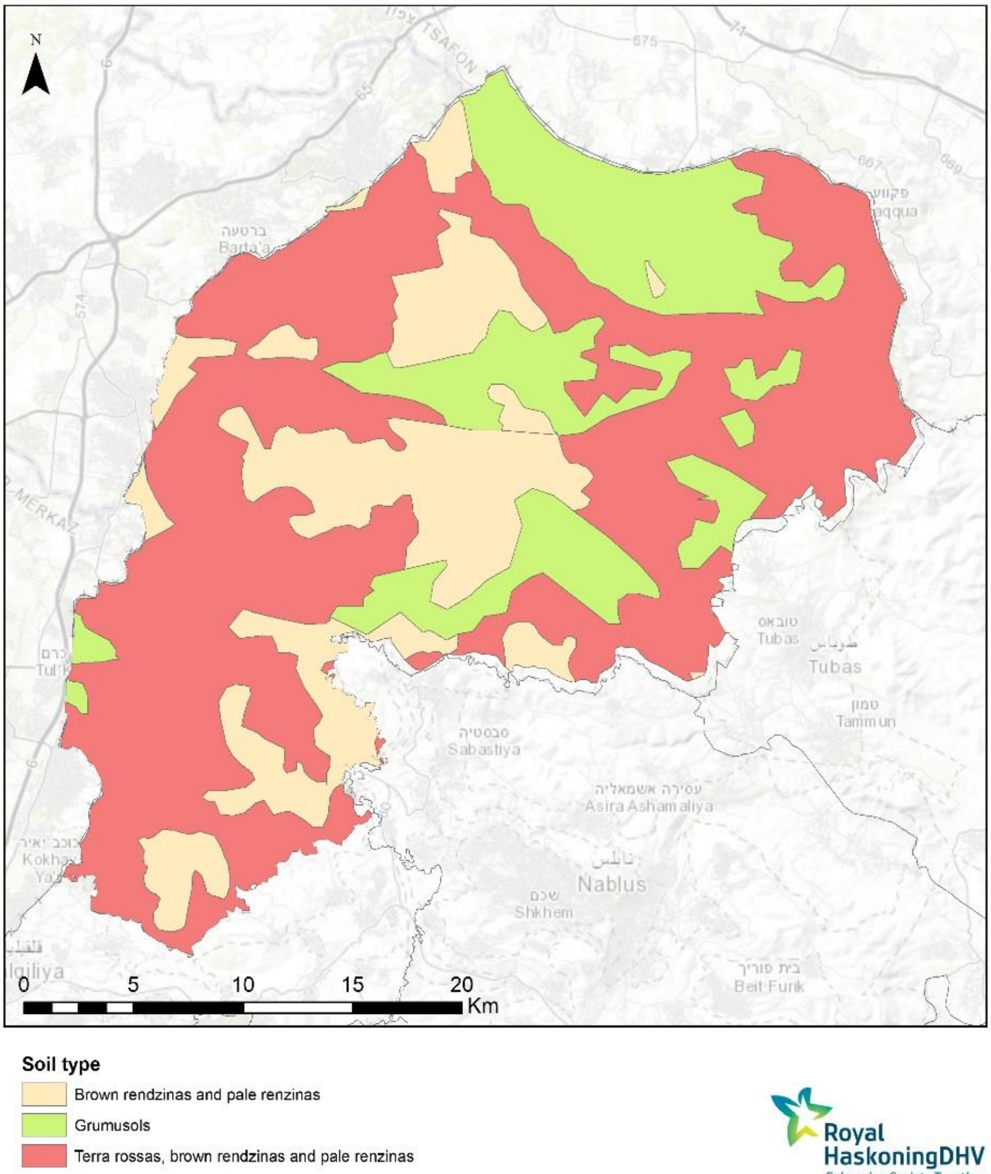


FIGURE 9-2: SOIL TYPES OF JENIN AND TULKARM

Land use

Olive groves are by far the most extensive land use class, followed by non-irrigated agriculture, irrigated agriculture and urban areas. There is sufficient spatial variation in land use (Figure 9-3).

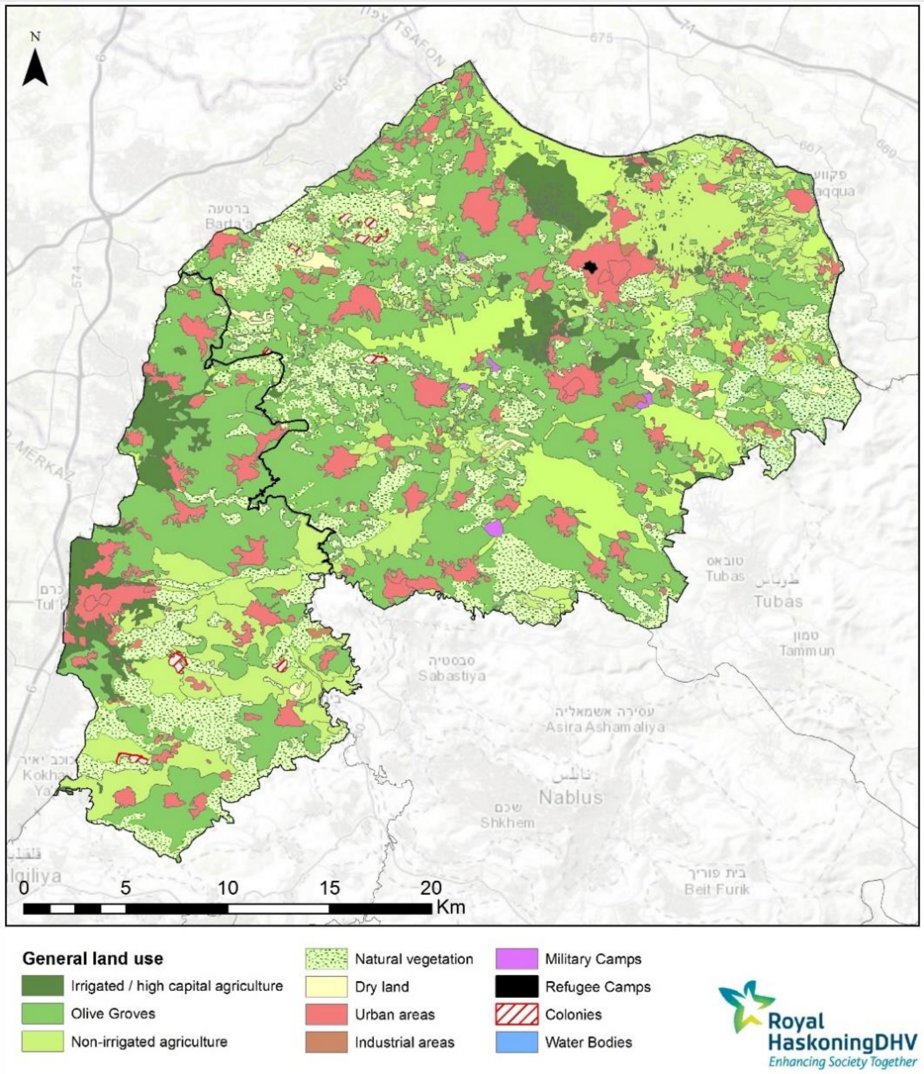


FIGURE 9-3: THE GENERAL LAND USE CLASSES IN JENIN AND TULKARM

The spatial distribution of land use is comparable for Jenin and Tulkarm, with irrigated agriculture in the close vicinity of major communities, and non-irrigated agriculture and natural vegetation in the more rural areas. Each land use type is linked to a specific sensitivity to droughts, based on expert opinion (Table 9-2). Built-up and industrial areas were omitted as non-agricultural areas. These areas are included in the domestic water vulnerability analysis.

TABLE 9-2: SENSITIVITY TO AGRICULTURAL DROUGHT PER LAND USE TYPE BASED ON EXPERT OPINION

High sensitivity	Medium sensitivity	Low sensitivity	Not relevant
Irrigated Complex Cultivation Practices	Olive Groves	Sparsely Vegetated Area	Refugee Camps
Non-Irrigated Complex Cultivation	Agricultural Land with Natural Vegetation	Bare Rock	Military Camps
Citrus Plantations	Non-Irrigated Arable Land	Salt Marshes	Mineral Extraction Sites
Drip Irrigated Arable	Palm Groves	Halophytes	Construction Sites
Vineyards		Water Bodies	Industrial or Commercial Unit
Riparian vegetation		Salinas	Colonies
Sport & Leisure Facilities		Beaches & Sand dunes	Continuous Urban Fabric
Green Houses		Forest	Sea and Ocean
Green Urban Areas		Natural Grass Land	Dump Site
Fruit Trees		Transitional Wood Land	Discontinuous Urban Fabric
		Sclerophylous vegetation	

Applying the different classes of sensitivity to droughts on the land use map, results in a drought sensitivity map as shown in Figure 9-4.

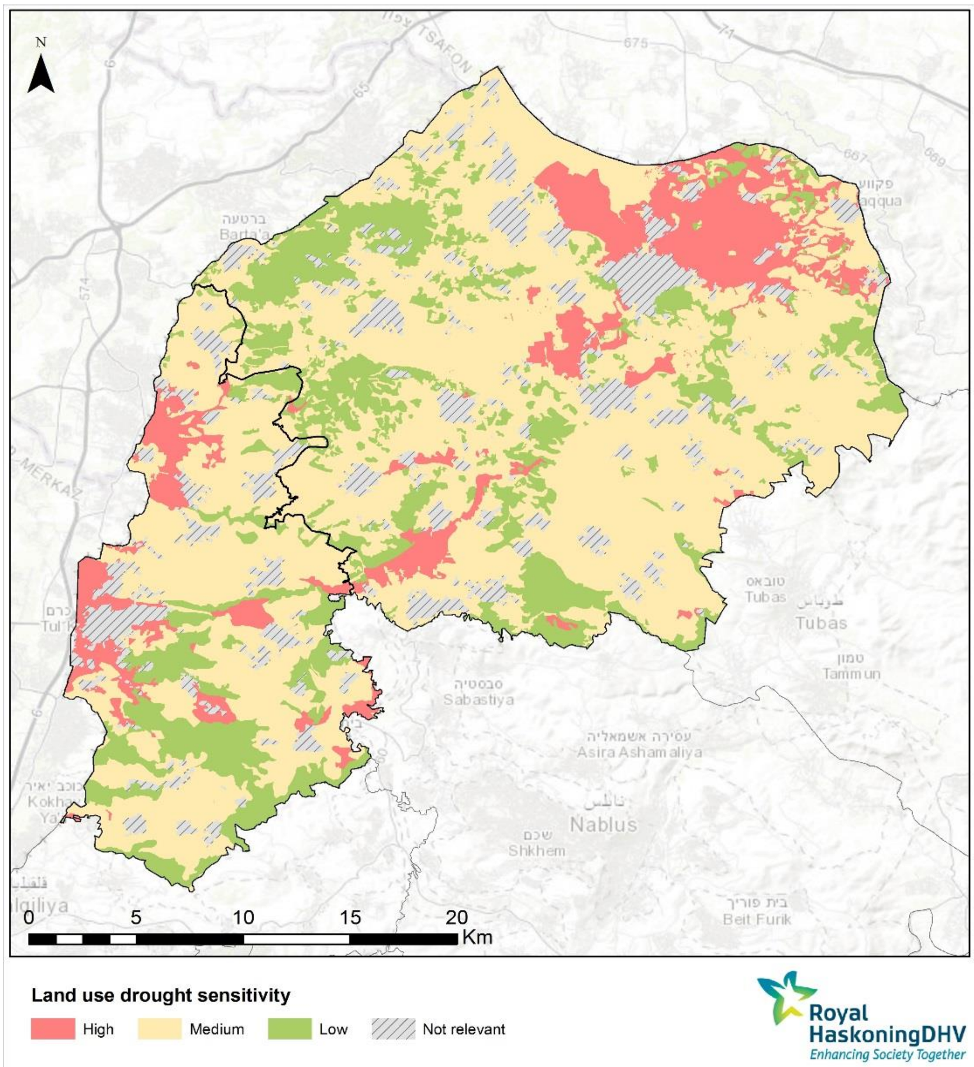


FIGURE 9-4: DROUGHT SENSITIVITY OF THE LAND USE IN JENIN AND TULKARM.

The more intensive cultivated areas clearly stand out in the drought sensitivity map, with highly sensitive areas in west Tulkarm, and northeast of the city of Jenin.

9.3 SPATIAL WATER AVAILABILITY FOR AGRICULTURE

The combination of drought sensitivity and spatial water availability results in the drought vulnerability.

Based on the location and discharge of all known agricultural wells in Jenin and Tulkarm, the relative water availability was calculated (Figure 9-5). The volume of available irrigation water was combined with the inverse distance (to the source of water) function in GIS to derive the spatial agricultural water availability as presented in figure 9-5. Irrigation water is in practice not distributed with the same ease to all directions, as is assumed in Figure 9-5.

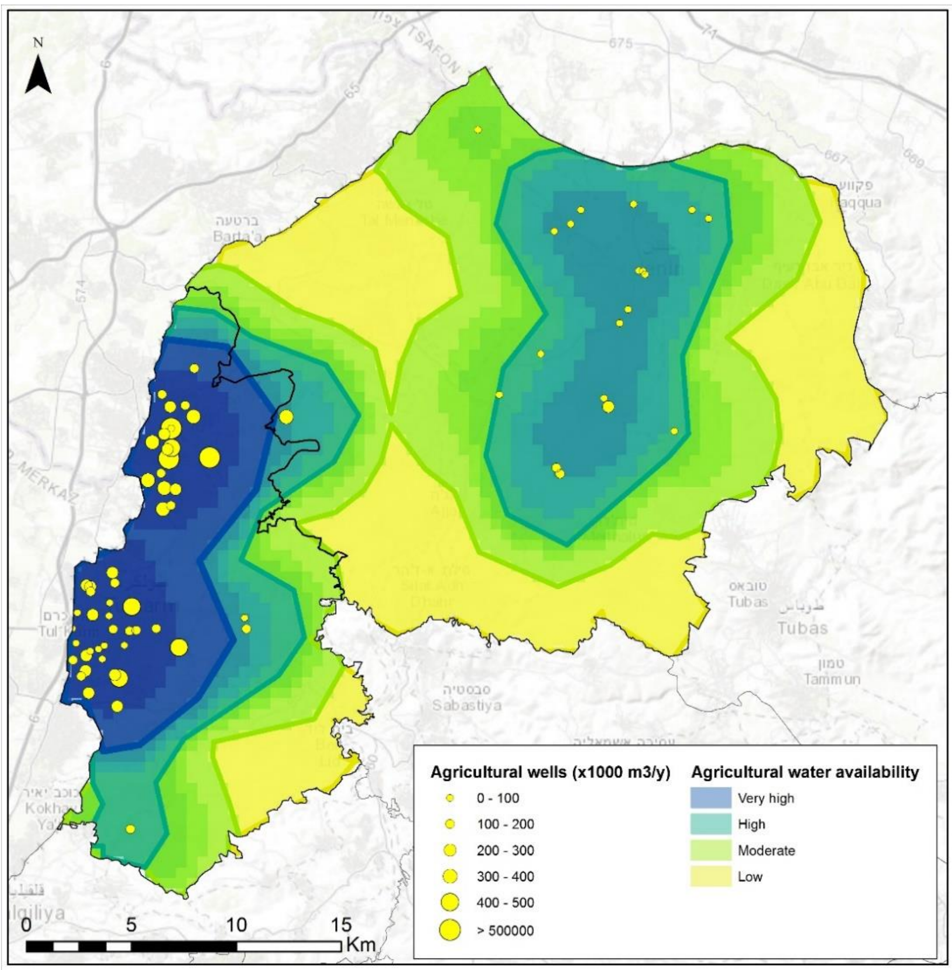


FIGURE 9-5: AGRICULTURAL WATER AVAILABILITY, BASED ON DENSITY AND DISCHARGE OF AGRICULTURAL WELLS

There is more water from springs available in Tulkarm. Thus, the category 'very high water availability' is only present in Tulkarm (Figure 9-5).

9.4 AGRICULTURAL DROUGHT VULNERABILITY

Land use sensitivity to drought and water availability are combined using weight factors (Table 9-3). Low water availability and low sensitivity have a low score; high water availability and high sensitivity score high. Both scores are combined into a total score. The colours green, yellow, orange and red indicate the drought vulnerability score in four classes (Low moderate, high and very high agricultural drought vulnerability). The spatial drought vulnerability is plotted with the same colours in a map (Figure 9-6).

TABLE 9-3: WEIGHTING SYSTEM TO CALCULATE THE AGRICULTURAL DROUGHT VULNERABILITY FROM DROUGHT SENSITIVITY AND WATER AVAILABILITY

			Agricultural water availability			
			Very high	High	Moderate	Low
			1	2	3	4
Land use sensitivity to drought	Low	1	**1**	**2**	**3**	**4**
	Medium	2	**2**	**4**	**6**	**8**
	High	3	**3**	**6**	**9**	**12**

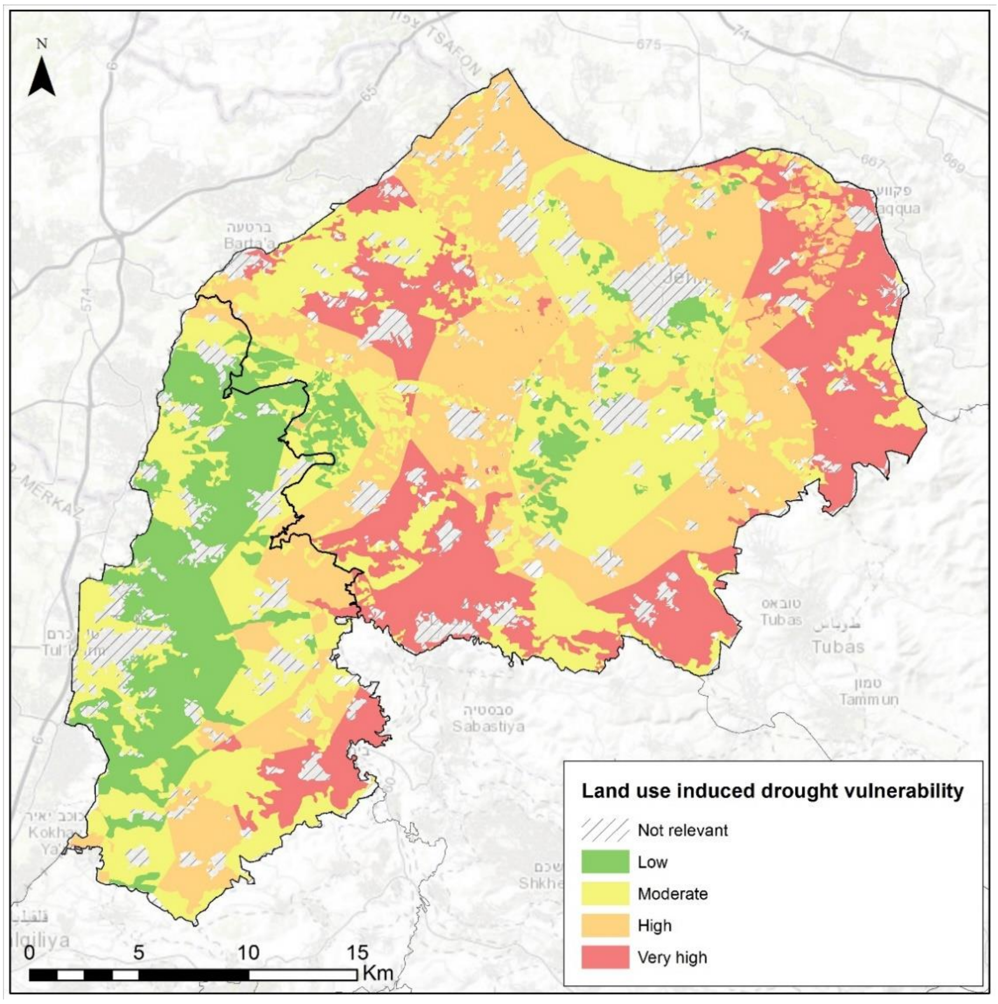


FIGURE 9-6: LAND USE INDUCED AGRICULTURAL DROUGHT VULNERABILITY

Jenin and Tulkarm differ in drought vulnerability. Lower water availability from agricultural springs in Jenin results in a relatively high drought vulnerability, especially in the more rural areas with less springs.

9.5 DOMESTIC WATER AVAILABILITY

Domestic water is distributed over Palestine by different service providers (Water sector regulatory council, 2018). However, not every household or community has access to a water network.

Communities that do not have access to a water network rely on one or more of the following water sources: collection of rainfall, collection of water from springs, and purchase of water from water tankers (B'Tselem, 2001). This makes them significantly more vulnerable to droughts. To derive domestic drought vulnerability, the known domestic water sources, and the communities with- and without a water network were mapped, based on data from 2015, provided by the PWA. It was assumed that the connected communities have sufficient water supply.

TABLE 9-4 NUMBER OF PEOPLE WITH WATER DELIVERED BY SERVICE PROVIDERS IN JENIN AND TULKARM.

Jenin	Served population[1]	Tulkarm	Served population[1]
Arraba municipality	13.000	Anabta municipality	9.027
Jenin municipality	54.000	Attil municipality	11.000
Kafr Ra'l municipality	10.000	Deir al Ghusun municipality	11.000
Mythaloun municipality	21.068	Illar municipality	7.846
North west Jenin service council	62.000	Tulkarm municipality	85.000
Qabatiya municipality	27.000		
Ya'bad municipality	17.000		
Total population served	204.068	Total population served	123.873
Reported 13 communities without a water connection[2]	39.000	Reported 10 communities without a water connection[2]	4.000
Total population with data	243.068	Total population with data	127.873
Total population Jenin	318.957	Total population Jenin	185.314
Total population without data[3]	75.889	Total population without data[3]	57.441

[1] Source: Water Sector Regulatory Council, 2017

[2] Source: B 'Tselem, Not even a drop – The Water Crisis in Palesinian Villages Without a Water Network 2001

[3] The West Bank Water Department (WBWD), the bulk water service provider, did not provide recent numbers about their performance indicators. This can explain the large data gaps.

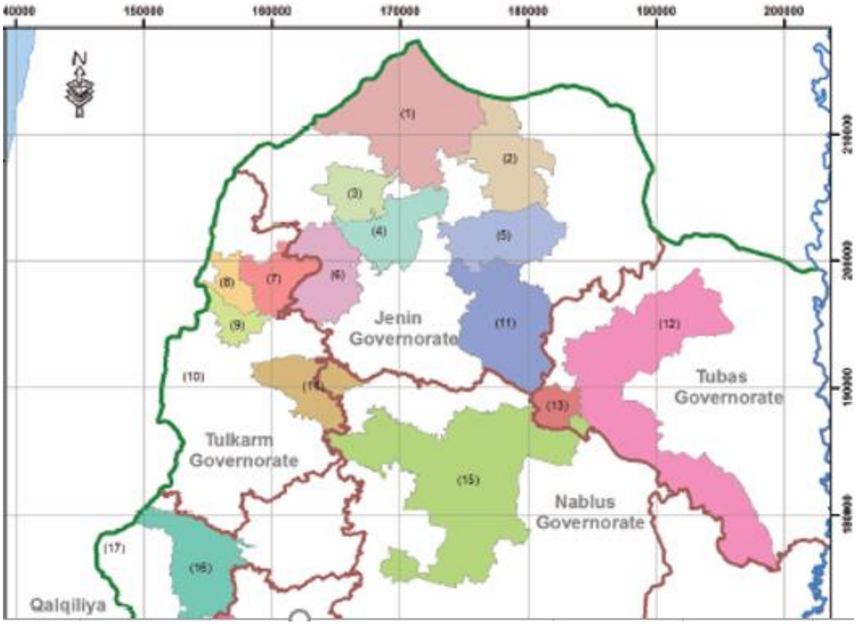


FIGURE 9-7: SERVICE PROVIDERS WITH AVAILABLE DATA ON THEIR SERVED POPULATION (PERFORMANCE MONITORING REPORT, 2016)

Performance Monitoring in 2016 does not provide a full coverage of all communities in Jenin and Tulkarm served with public water supply (Figure 9-7).

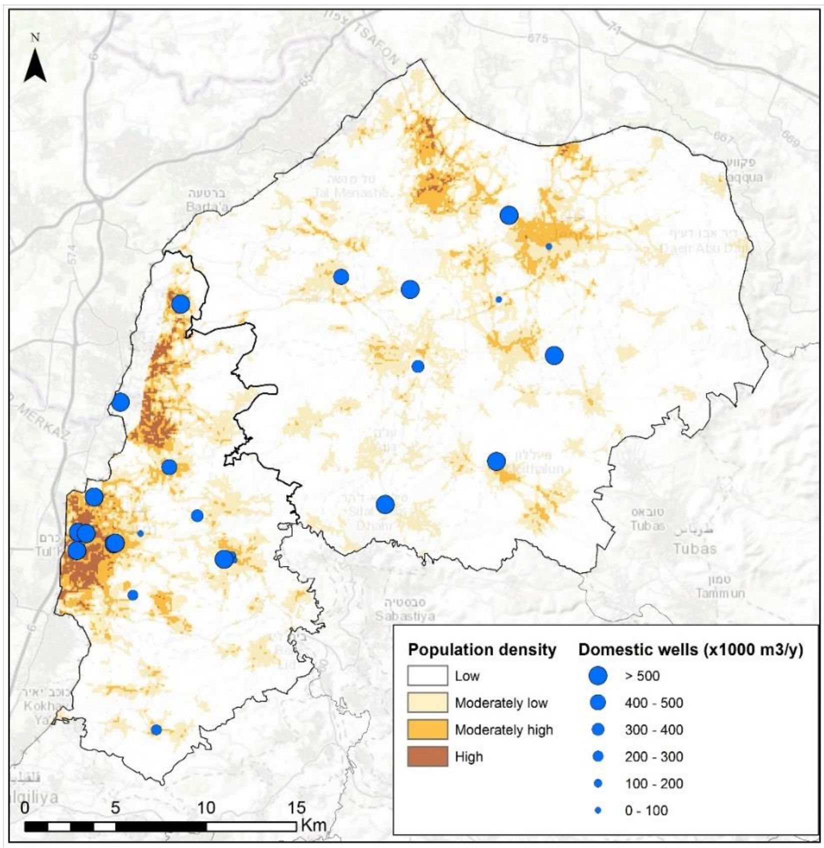


FIGURE 9-8: RELATIVE POPULATION DENSITY AND KNOWN DOMESTIC WELLS (DISCHARGE IN 1000 M3/Y)

Figure 9-8 shows the relative population density and the location of domestic wells in Jenin and Tulkarm. The communities which lack access to public water networks in 2015 (Figure 9-9) are located in the sparsely populated and rural areas in the east of Jenin. This accounts for almost 11.000 inhabitants (Table 9-5).

TABLE 9-5 COMMUNITIES NOT CONNECTED TO PUBLIC WATER SUPPLY

Community	Population
Al 'Asa'asa	Unknown
Deir Abu Da'if, Al Jameelat	8000
Beit Qad, Barghasha, Umm Qabub	1500
'Arabbuna	1200
Khirbet Sab'ein	67
Total	**10.767**

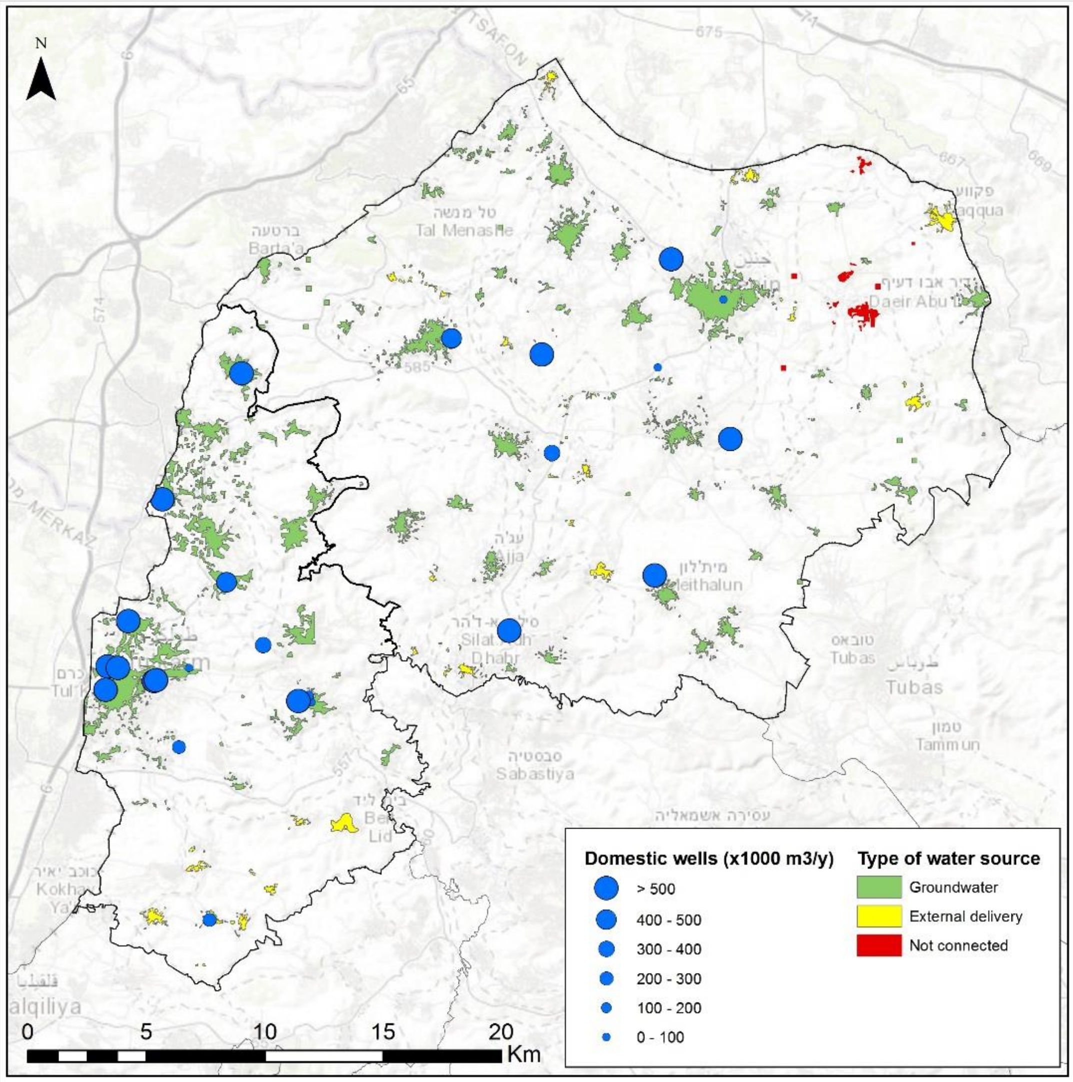


FIGURE 9-9: COMMUNITIES WITHOUT A CONNECTION TO A WATER NETWORK (B 'TSELEM, 2001). NOT ALL COMMUNITIES LISTED BY B 'TSELEM COULD BE LOCATED, ESPECIALLY THE SMALLER ONES (UNDER 200 INHABITANTS) MAY NOT APPEAR IN THE MAP.

9.6 DROUGHT DOMESTIC VULNERABILITY

Based on the location and discharge of all known domestic wells in Jenin and Tulkarm, the relative domestic water availability was derived (Figure 9-10) by calculating the inverse distance weighting (IDW) in ArcMap. This takes into account the distance to a water source and the well capacity. More wells in close vicinity, or higher well capacities lead to a higher relative water availability.Information about the infrastructure to transport the water is not used.

The location of the non-connected communities match well with the distance to domestic wells. Exceptions are the city of Meithalun, and the north of Jenin.

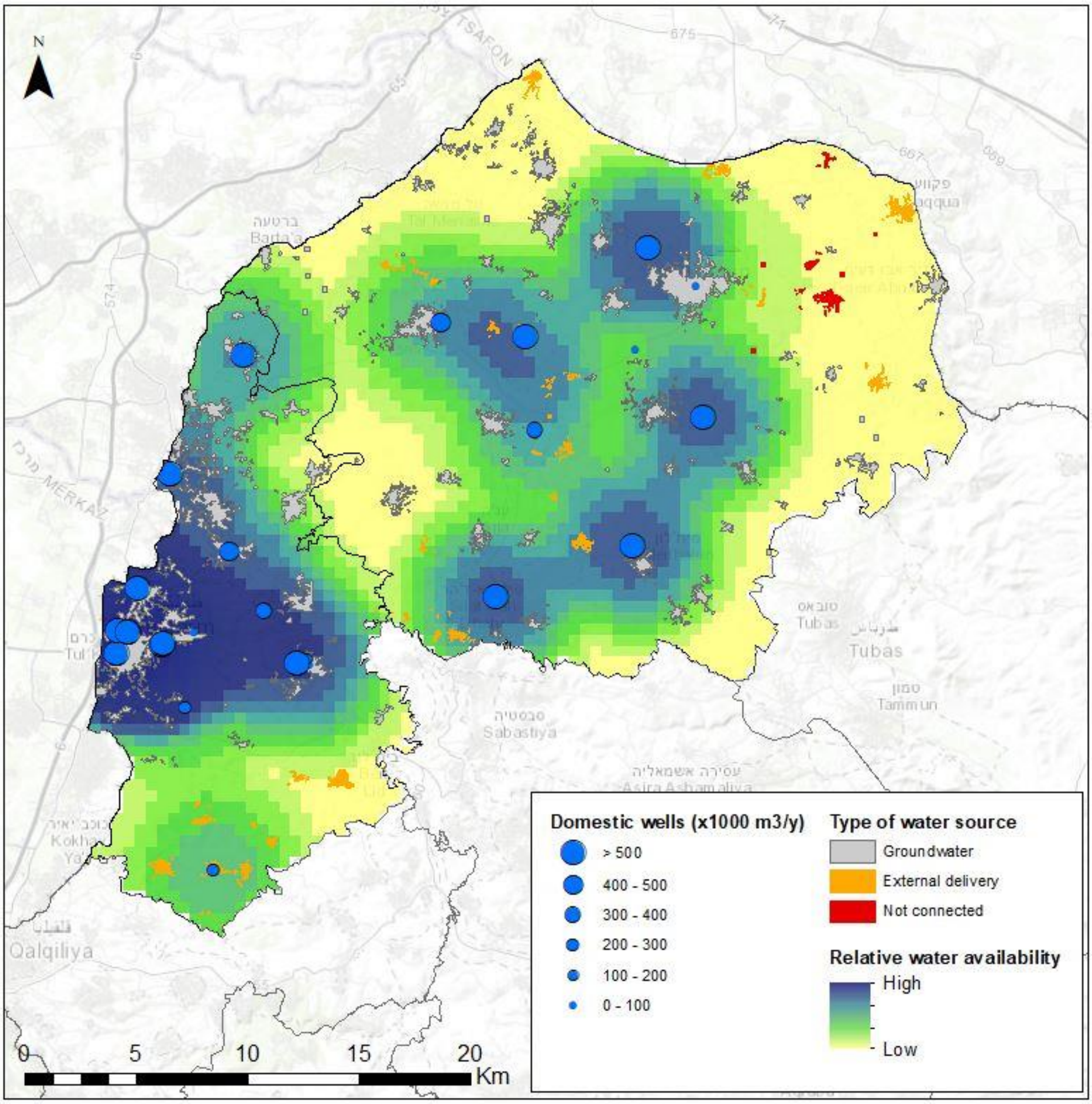


FIGURE 9-10: THE DOMESTIC DROUGHT VULNERABILITY

10 PROFILING DROUGHT RISK

Risks of drought disaster occurrence depend on the combination of exposure to natural hazard events and the social, economic and environmental vulnerability (or resilience) to these challenges in the affected communities. Profiling of drought risk thus involves 1) gathering of climate/hazard data and 2) subsequent analysis of vulnerability/resilience factors, using various tools and indicators.

Collectively, drought risk is a diverse concept. It cuts across sectoral spheres, e.g., agriculture, livestock and water, and is constantly evolving and changing over time and geographic areas. Hence, risk assessment is a multidisciplinary task that requires inputs from various sectoral practitioners, scientific experts and policymakers as well as the communities directly affected by hazards. Defining drought risk may at times inevitably entail various trade-offs. In a context where the drought risk is attributed to numerous hazard/vulnerability factors, for example, identification of the most pressing factors and prioritization of corresponding risk management measures will be necessary. The drought risk profile will be a synthesis of the drought hazard mapping and drought vulnerability analysis.

As stated before, Drought Risk is the multiplication of Hazard and Vulnerability. For instance, areas with high WEI+ values (water scarce areas) and high vulnerability will experience a higher drought risk level in a drought situation and the level of risk depends on the drought severity. Therefore, drought risk is the superposition of (a) drought hazard, (b) water scarcity hazard, and (c) drought & water scarcity vulnerability.

The drought risk indicator will be built using a factorial system such that a non-dimensional factor (on a 1-5 scale) will be attributed to each hazard and vulnerability class. The multiplication of the factors will result in new classes of drought risk characterization. Drought risk profile identification and characterization could be carried out on a GIS platform.

It was illustrated comprehensively in chapter 5 that Drought Hazard is characterized as "EXTREME" in Jenin and Tulkarm Governorates. Therefore the critical issue for overall Drought Risk is the Drought Vulnerability. The Vulnerability is the critical factor for at least these two Governorates and any Drought Risk Management approach mush first address reducing vulnerability and increasing the adaptive capacity.

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