Climate Change in Libya and Desertification of Jifara Plain

Using Geographical Information System and Remote Sensing Techniques

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Dedication

to

Prof. Dr. Dr. h. c. Manfred Domrös

Mrs. Gisela Domrös

as a token of admiration and respect

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1. Introduction

1.1 Background

1.1.1 Climate change

Climate is always changing and has forever been a hot topic of discussion for park-bench philosophers (ROACH, 1997). In the late 20th century, natural sciences have increasingly focused on the problems and risks of modern societies. Climate change is considered as the most serious environmental challenge that threatens developed and less developed countries. It has reached a critical magnitude with a serious impact on society, human welfare and quality of human life (DOMRÖS, 1996: 163). So, the impact on environment, human welfare, and socio-economic systems, at present time, is seriously taken into consideration by international authorities and has been receiving considerable recent attention from governments.

Climate change is every deviation from the normal, having significance according to the actual use of statistical tests. It seems to be very difficult to put apart man-induced changes from natural ones as the natural changes are not yet well understood (DONAIRE, 2000: 140). In addition to changes of climate, there are other terms for describing climate (e.g. variability, trends, oscillation, periodicity and fluctuation). Climate variability means the variability inherent in the stationary stochastic process approximating the climate on scale of a few decades (ALMABRUK, 1995: 51). Climatic variations involve changes in the magnitude of the annual or decadal values and the mean is constant, while in climatic changes, both the mean and the variance are changing with time (DONAIRE, 2000: 127). The term trend[1] denotes climate change characterized by a smooth, monotonic increase or decrease of average values over the period of record.

The number of scientific publications on varies aspects of the climate change reached 7,000 abstracts, the period 1951–1997 containing 95 % of the literature, with a steeper exponential growth rate, doubling every 11 years (STANHILL, 2001: 516). The number of conferences on climate change abstracted in Meteorological and Geostrophysical Abstracts were examined. The first appeared in 1962 and by 1997 abstracts of a total of 89 conference proceedings had been published (e.g. Berlin in March/April 1995, where, in an

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[1] The word “trend” was used in the study to designate a generally progressive change in the level of a variable.

agreement called the "Berlin Mandate", the Kyoto Protocol was adopted in Kyoto in December 1997). In Kyoto, more than 170 nations were to sign a treaty to stop human-induced climate change (HOUGHTON, et al., 2001). The estimation of global spending on climate change research presented above is similar to the sum of US$ 3 billion (STANHILL, 2001: 516).

It is clearly identified that the 20th century was the warmest century during the past 1000 years; it was also shown that warming pronouncedly occurred over two periods, 1910-1945 and 1976-2000. The 1990s were experienced as the warmest decade while 1998 was the warmest individual year during instrumental records (HOUGHTON, et al., 2001). Global mean surface temperature is projected to increase between 1.5 and 6 °C by 2100 (DESANKER, 2002). Climate changes have also occurred in other important aspects; precipitation increased by 0.5-1 % per decade in the 20th century over most mid- and high-latitudes of the Northern Hemisphere, and by 0.2-0.3 % per decade over the tropical land areas (10° N-10° S), while it decreased over much of the north hemispheric sub-tropical land areas (10° N-30° N) by about 0.3 %/decade. It has been observed that the cloud cover has increased over mid- and high-latitude land areas by 2 % (HOUGHTON, et al., 2001).

Global warming is commonly explained by the anthropogenic greenhouse effect resulting from emissions of CO_2[2]. The contribution of CO_2 emissions to global warming is more than 50 % of greenhouse gases (WELLBURN, 1997: 188), and other gases which allow sunlight to reach the earth's surface but prevent some of the infrared or heat radiation given off by the earth from escaping into space (PITTOCK, 1988: 306). During the past 100 years, as a result of burning (coal, oil, and gas) and clearing forests, the chemical composition of the atmospheric layers has greatly changed. These changes in the chemist composition have far-reaching consequences for the earth's climate and ecosystems that are sustained by climate as well as human health and economy (HARDY, 2003: 3).

The magnitude and rate of future climate change depends on the amount of greenhouse gases emitted, the sensitivity of climate to these gases and the degree to which the effects are modified by aerosol emissions (JACQUELINE, 2000). In Libya, due to 2002 estimations, energy consumption was 69.2 % from oil and 30.8 % from natural gas, the emissions of CO_2 attributed mainly to oil (71.7 %) and (28.3 %) natural gas (EIA, 2005),

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[2] CO_2 is chemically stable and lasts for many decades

which means that the energy sector which is the main source of greenhouse emissions in Libya depends mainly on fossil fuels (oil and natural gas).

The expected impacts of climate change will be acute in different aspects, such as biodiversity, food security, water resources and human health. Libya is potentially one of the countries most at risk from the effects of climate change because it has limited natural resources (water and soils); located in the arid and semi-arid lands and more than 95 % of its people live in coastal zone which is threatened by sea level rise.

1.1.2 Desertification

Among the important consequences resulting from climate change in arid and semi-arid lands, ranks desertification. It is a worldwide phenomenon affecting about one-fifth of the world population, 70 % of all dry lands (3.6 billion ha) and one-quarter of the total land area of the world. Every year an additional 200,000 km^2 of productive lands are lost by desertification to the point of yielding nothing (ABAHUSSAIN, et al., 2002: 522). The risks of desertification have increased over the last century as population in the desert margins has multiplied several times, the cultivated area has increased and stock numbers have grown with disease controlled to meet commercial demands (GROVE, 1977: 305). The term "desertification" refers not only to areas surrounding deserts, but also to major food-producing areas in semi-arid and sub-humid areas (IMAGAWA, et al., 1997). The problems of desertification are greatest in poor countries where people rely directly on what the land at the desert margins can produce (GROVE, 1977: 306).

Due to the United Nations Environment Programme (UNEP)'s definition, desertification is the diminution or destruction of the biological potential of the land that can ultimately lead to desert-like conditions. It is an aspect of widespread deterioration of ecosystems because of the adverse climate fluctuation and excessive exploitation (ODINGO, 1990: 18). Desertification differs from drought; drought is a temporary phenomenon occurring when precipitation falls below normal or when near normal precipitation is made less effective by other climate parameters such as high temperature, low humidity and strong winds.

In the context of the FAO/UNEP assessment and mapping project of desertification, it is defined as a comprehensive expression of economic and social processes as well as those of natural origin or induced ones which destroy the equilibrium of soil, vegetation, air and water in areas subject to climatic aridity. Continued deterioration leads to decrease or destruction of the biological potential of the land, deterioration of living conditions and increasing of desert landscapes (ODINGO, 1990: 24).

Many conferences have been held to investigate desertification process (e.g. United Nations Conference on Desertification (UNCOD) Nairobi 1977), The Ad-Hoc Consultative Meeting on Assessment of Global Desertification: status and methodologies, February 1990, UNEP- Nairobi and international conferences held (October 1994 and May 1997) in Tucson, Arizona, USA, in support of (UNCCD) United Nations Conventions to Combat Desertification). These conferences raised the world's awareness to the effects and causes of desertification and provided programs of action for sustainable development and combat desertification.

Jifara Plain which lies in northwestern Libya has suffered from desertification in the last half of the 20th century; soils has been degraded, vegetation cover disappeared and the ground water wells were getting dry in many areas. Actions and measures had been taken to combat desertification in Libya from the early 1960s (BEN-MAHMOUD, et al., 2000).

Climate change and desertification remain inextricably linked through feedbacks between land degradation and variabilities of precipitation. Climate change might exacerbate desertification through alteration of spatial and temporal patterns in temperature, precipitation, solar insolation, and winds. Conversely, desertification induces climate change through the release of CO_2 from cleared and dead vegetation and reduction of the carbon sequestration potential of desertified land (McCARTHY, et al., 2001).

Urgent actions are needed to mitigate climate change and to combat desertification. It is essential that communities develop the capacity to make informed decisions about their development strategies. Substantial reductions of heat-trapping gas emissions in developed countries and adaptation strategies are crucial (DESANKER, 2002).

The present study tried to discuss the spatial and temporal climate changes, its causes and its impacts in Libya and the effect of climate change on desertification process in Jifara Plain as a case study, as well as the other causes and manifestations of desertification in Jifara Plain.

1.2 Objectives

The main objectives of this study are:

- To discern the characteristics of the climate parameters in Libya.
- To analyze the climate parameters using instrumental climate data in Libya.
- To investigate recent climate changes over time and space in Libya and to compare them with the global scenario.
- To reveal the pattern of climate change which has occurred in the second half of the 20th century in two periods (1946-2000), as a long-term period, and (1976-2000), as a short-term period.
- To determine the real causes of climate change.
- To assess the impacts of climate change on life in Libya.
- To evaluate the relationship between climate change and desertification.
- To depict manifestations and degrees of desertification in Jifara Plain.
- To investigate the factors and processes that cause and affect land degradation and desertification in Jifara Plain.
- To discuss the mitigation of climate change in Libya and combating of desertification of Jifara Plain.

1.3 Assumptions

- There are clear changes of climate parameters in Libya (e.g. temperature characteristics, precipitation, relative humidity and cloud amount).
- The effect of an abnormal long series of dry years is going to give a foreseeing of what may happen in Libya following climate change.
- The change of climatic components is able to re-rank the climate classification in Libya.
- Climate change has caused changes in the flora and fauna in Libya.
- There are many problems as a result of climate change in Libya such as drought, desertification, and water scarcity.

- Jifara Plain suffers from severe and moderate desertification.
- There is a relationship between climate change and desertification of Jifara Plain.
- Climate change mitigation, combat of desertification and sustainable development issues are closely linked; each calls for policies that combine economic growth with environmental protection.

1.4 Data and methods

1.4.1 Data

Climate data were available at 15 stations in Libya over the 54 years-period 1946-2000 (Tab. 1): Zuara, Tripoli city and Tripoli airport in northwestern Libya; Misurata, Sirt and Agedabia in the north; Benina, Shahat and Derna in northeastern Libya; Gadames and Nalut in the west; Sebha and El-Kufra in the south; Jalo and Jaghboub in eastern Libya (Fig. 1).

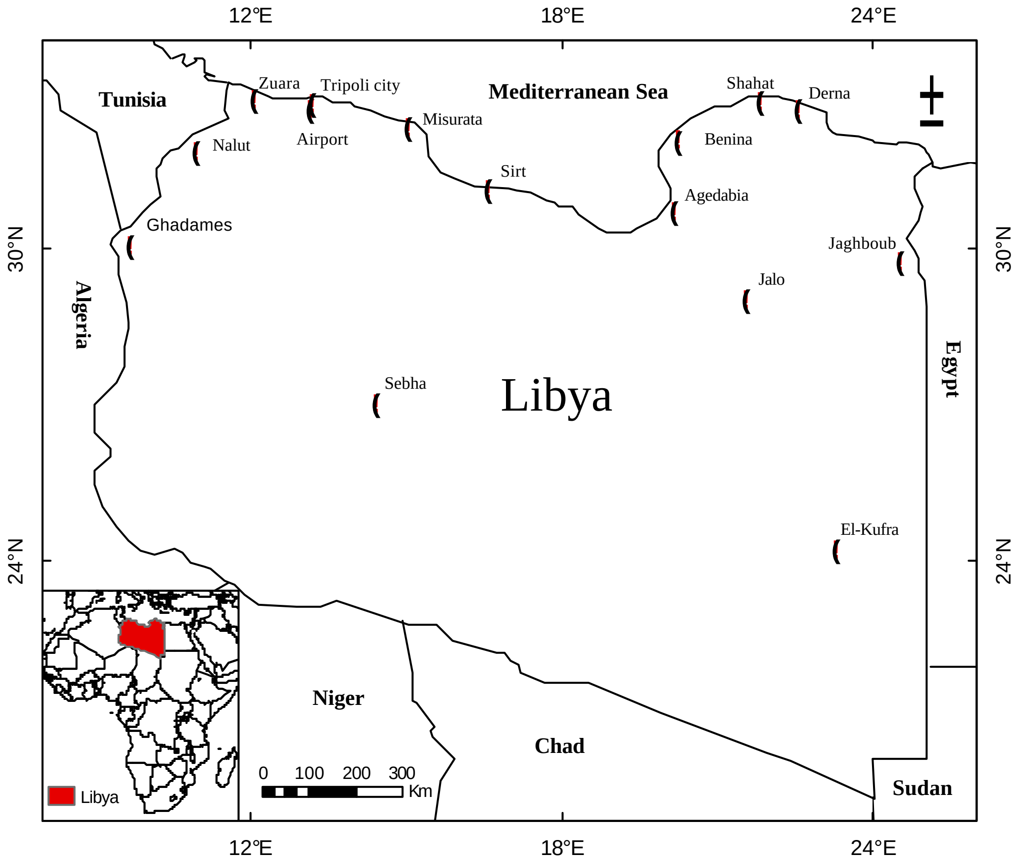
Tab. 1: Stations under study, their location, elevation and observation period

WMO Nr.	Station	Latitude (N)	Longitude (E)	Elevation (m)
62055	Agedabia	30.43	20.10	7
62053	Benina	32.05	20.16	129
62059	Derna	32.47	22.35	26
62271	El-Kufra	24.13	23.18	436
62103	Ghadames	30.08	9.30	357
62176	Jaghboub	29.45	24.32	-1
62161	Jalo	29.02	21.34	60
62016	Misurata	32.19	15.03	32
62002	Nalut	31.52	10.59	621
62124	Sebha	27.01	14.26	432
62056	Shahat	32.49	21.51	621
62019	Sirt	31.12	16.35	13
62010	Tripoli airport	32.40	13.09	81
6201007	Tripoli city	32.54	13.11	25
62007	Zuara	32.53	12.05	3

Source: Libyan Meteorological Department, Tripoli

Distribution of meteorological stations shows considerable gaps in southern Libya where stations are partially lacking in major parts of the Sahara. The names and WMO-reference numbers of all stations are given (Tab. 1), together with their coordinates and altitude above sea level.

Fig. 1: Location of climatic stations under study in Libya



Source: AMANAT EL-TAKHTIET, 1978: National Atlas of Libya, Tripoli
Libyan Metrological Department, Tripoli

All climate information used in this study is represented by original data, according to the official readings from the Libyan Meteorological Department, Climatic Section. Illustrations of the present study represent original drafts and compiled from climatic records. The reference data of the global temperature trends were taken from IPCC Third Assessment Report climate change, 2001 and from JONES et al., 1999 and 2001.

The climate data consisted of mean monthly and annual records of temperature, precipitation, relative humidity and cloud amount records for individual stations selected in Libya. Annual means are the means of all 12 months from a respective year; seasons were defined as follows: winter is the mean through December-January-February; spring through March-April-May; summer through June-July-August; and autumn through September-October-November.

Other main data used in the present study were acquired as follows:

Sunspots number data (NOAA's National Geophysical Data Center, 2004), *http://www.ngdc.noaa.gov/stp/SOLAR/ftpsunspotnumber.html#international*

North Atlantic Oscillation index (NAOI) and Southern Oscillation Index (SOI) data (JONES, 2003), *http://www.cru.uea.ac.uk/cru/data/pci.htm*

Global and Libyan annual CO_2 emissions from fossil-fuel burning, cement production, and gas flaring (MARLAND, et al., 2003), *http://cdiac.esd.ornl. gov/ndps/ndp030.html*

Annual estimates of global anthropogenic methane emissions (STERN and KAUFMANN, 1998), *http://cdiac.ornl.gov/trends/meth/ch4.htm*

For the investigation of desertification of Jifara Plain, in addition to precipitation and temperature data used, also data of water resources, population and agricultural production were analyzed acquiring from the Libyan Water Authority, National Information Authority of Libya, *http://www.nidaly.org/skan.htm* and Libyan Agricultural Research Center.

The national atlas of Libya, the first national report of environment (GENERAL ENVIRONMENTAL AUTHORITY, 2002) and National Commit to Combat Desertification reports (1999, 2002) were also used. The data used in the present study were collected during the field work in Libya carried out from 7 October to 4 November 2002.

In order to monitor desertification process of Jifara Plain, the following data were used (Tab. 2): Landsat data (MSS[3], TM[4], ETM+[5]) acquired form *ftp://ftp.glcf.umiacs.umd .edu/glcf/Landsat (*NASA Landsat Program, the Earth Science Data Interface (ESDI) at the Global Land Cover Facility (GLCF), U.S. Geological Survey). Mosaics ID zone (30-33 N), TM (mosaics 1987-1990) and ETM+ (mosaics 1999-2002) acquired from Global Land Cover Facility, *http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp*. And Shuttle Radar

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[3] The Multispectral Scanner (MSS) is a multispectral scanning radiometer that was carried on board Landsats 1 through 5. MSS image data consists of four spectral bands from within the visible green, visible red and near-infrared wavelengths. The resolution for all bands is 79 meters.

[4] Thematic Mapper (TM): The TM was flown on Landsat-4 and Landsat-5. The TM is a cross-track scanner providing seven multispectral channels (3 visible, 1 near-infrared, 2 mid-infrared, 1 thermal-infrared) at 30-meter resolution (120-meter resolution for the thermal-infrared band).

[5] Enhanced Thematic Mapper Plus (ETM+): The ETM+ instrument currently flying on Landsat-7 is similar to the earlier TM, but adds an extra 15-meter resolution panchromatic band, and improved resolution for the thermal-infrared band (60-meters).

Topography Mission (SRTM)[6] acquired from ftp://ftp.glcf.umiacs.umd.edu/glcf/SRTM (USGS reprocessing by the GLCF, 2004, University of Maryland).

Tab. 2: Satellites images used in the present study

Sensor	Image ID	Date	Platform
MSS	p203r37_2m	29.01.1976	Landsat2
TM	P188R37_4T	31.07.1990	Landsat 4
TM	P189R37_4T	29.03.1989	Landsat 4
TM	P189R38_5T	04.06.1987	Landsat 5
TM	P190R38_5T	02.01.1987	Landsat 5
ETM+	p188r037_7T	11.06.2001	Landsat 7
ETM+	p189r037_7T	25.01.2001	Landsat 7
ETM+	p189r038_7T	23.01.2000	Landsat 7
ETM+	p190r038_7T	11.11.1999	Landsat 7
SRTM	SRTM_u03	Feb-00	SRTM
SRTM	SRTM_u03	Feb-00	SRTM

1.4.2 Methods

In respect of the objectives outlined above, the following statistical approaches are used in the present study:

Homogeneity: Applying the statistical test for homogeneity after Abbe (SCHÄFER, 1996: 15), temperature data series under study at Zuara, Tripoli city, Misurata, Sirt, Derna, Gadames, Nalut, Sebha, El-Kufra, Jalo and Jaghboub were shown as homogeneous data from 1946-2000, at Agedabia, Benina and Shahat, data were homogeneous from 1946-1998, while temperature data at Tripoli airport were inhomogeneous. In contrast, precipitation data series was shown as inhomogeneous at most stations under study from 1946-2000, while in the period 1946-1975, precipitation data at eleven stations were homogeneous and in the period 1976-2000, it was homogeneous at five stations.

A simple linear regression analysis, namely the least square method or linear regression (THOM, 1966) was used to detect climatic trends over time series at all fifteen stations under investigation, as the trend is the basic tool for describing and analysing the changes of climate parameters (HOUGHTON, et al., 2001). The least-square method (SCHÄFER, 1996 and SCHÖNWIESE, 1992) (y) is a linear function of (x) - $y = mx + b$ -

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[6] SRTM obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA).

where the slope of the line is given by “m” (? x over ? y or the rise over the run) and the intercept of the y axis is given as “b”. For “N” data pairs, the equations used to find the slope “m” and intercept “b” are:

$$b = (\sum y \sum x^2 - \sum x \sum xy)/(N \sum x^2 - (\sum x)^2)$$

$$m = (N \sum xy - \sum y \sum x)/(N \sum x^2 - (\sum x)^2)$$

Low-pass filtering for the annual temperature, precipitation data was investigated over the two different study periods (1946-2000) and (1976-2000). A trend test based on a trend-to-noise ratio (total trend/standard deviation) was applied for detecting linear or non-linear trends (a T/N ratio >1.96), which means two times of its standard deviation, can be regarded as a significant trend at a 95 % level of confidence. Lower ratios express a less significant level of confidence (DOMRÖS, 1996: 167). The values of the T/N ratio are expressed as (SCHÖNWIESE, 1992: 212):

T/N ratio	3.90	3.291	2.576	1.960	1.645	1.282
Level of confidence %	99.99	99.90	99	95	90	80

The non-parametric Mann-Kendall test for trend was also computed to detect the behavior of trends over the periods under study and their significance levels. This test is widely used in environmental science, because it is simple, robust and can cope with missing values and values below a detection limit. Since the first proposals of the test by MANN 1945 and KENDALL 1975, covariance between Mann-Kendall statistics were proposed by DIETZ and KILEEN 1981 (LIBISELLER, 2002). If the number of data values less than 10, the Mann-Kendall test statistic *S* is calculated using the formula:

$$S = \sum_{k=1}^{n-1} \sum_{i=k+1}^{n} \operatorname{sgn}(X_j - X_k)$$

where *xj* and *xk* are the annual values in years *j* and *k*, *j* > *k*, respectively, and

$$\operatorname{sgn}(x_j - x_k) = \begin{pmatrix} 1 & if\ x_j - x_k > 0 \\ 0 & if\ x_j - x_k = 0 \\ -1 & if\ x_j - x_k < 0 \end{pmatrix}$$

If the number of data values (n) is at least 10, the variance of *S* is computed by the following equation:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5) \right]$$

Here q is the number of tied groups and tp is the number of data values in the p^{th} group. The values of S and $VAR(S)$ are used to compute the test statistic Z as follows:

$$Z = \begin{pmatrix} \dfrac{s-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{s-1}{\sqrt{VAR(S)}} & if\ S < 0 \end{pmatrix}$$

A positive (negative) Z value indicates an upward (downward) trend. Levels of significant range between (0,001) level of significance which means that the existence of a monotonic trend is very probable and null hypothesis of no trend should be rejected, and (0.1) level which means there is a 10 % probability that we make a mistake when rejecting H_0 of no trend. If the cell is blank, the significance level is >0.1 (SALMI, et al., 2002).

Trends of temperature and precipitation over Libya were computed for the available data, from 1946-2000, as a "long-term trend", from 1946-1975 and from 1976-2000, as "short-term trend". The short-term periods are corresponding with the IPCC Third Assessment Report 2001 about climate change which has divided the 20th century in three periods according to the behavior of temperature trends; 1910-1945, 1946-1975 and 1976-2000. The trends of mean annual relative humidity and annual cloud amount were elaborated as a long-term period from 1946-1975 and a short-term period from 1976-2000 at all meteorological stations under study.

Principle Component Analysis was used to construct the All-Libya climatic parameters trends[7] for the mean annual and seasonal data. 15 stations were taken to build the data matrix for two periods (1951-2000 and 1976-2000). Trend computations of temperature are based on means of annual, maximum and minimum as well as seasonal temperatures. Trends of precipitation were based on the means of annual and seasonal precipitation, and annual precipitation intensity. Computations of relative humidity trends and annual total cloud amount trends are based on the mean annual values.

Humidity and aridity shown after Walter-Lieth was applying the correlation **n=2t** (DOMRÖS and GONGBING, 1988: 258) for computing humid respectively arid months at all stations under study in Libya and to compile the corresponding diagrams.

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[7] Trends of parameters were typified by a regular and monotonous increase or decrease of the mean values during the observation periods.

Geographical Information System (GIS) techniques were applied to clarify the illustrations of the present study (e.g. locations of meteorological stations, distribution of population, isotherms maps, isohyets maps, annual relative humidity and annual cloud amount distribution, climatic regions).

Correlation coefficient, after Pearson, was used to detect the tele-connection between CO_2 and methane emissions, North Atlantic Oscillation Index (NAOI), Southern Oscillation Index (SOI), sun spot numbers from one hand, and global warming and climate change in Libya from other hand.

De Martonne's aridity index which is given by **AI = P/ (T+10)** where, P = mean annual precipitation (mm), t = mean annual temperature (°C) was applied to classify the climatic regions in Libya, as well as to elaborate the trends of aridity index in Jifara Plain.

Remote sensing techniques were applied to investigate desertification in Jifara Plain using the available satellite images through the following digital imaging processing:

- Geometric correction: all images have been referenced as UTM projection, Zone number: 33-30 North. Datum: WGS84, ellipsoid: WGS84 and output map: geographical latitude and longitude.

- Spectral enhancement (indices) was applied in vegetation analysis to bring out the differences between various vegetation classes and sand dunes encroachments. Such indices infrared/red (IR/R), Vegetation Index = (IR-R*)*, Iron Oxide = TM 3/1 (LEICA GEOSYSTEMS, 2003: 182).

- Subpixel classification method was also applied to detect the changes of vegetation cover and settlement areas between TM and ETM+ images and relief profiles in Jifara plain were compiled from SRTM (189/37 and 190/38) using digital elevation model.

1.5 Fieldwork study in Libya

The present study is based not only on raw climate data and satellite images but also on field investigations on Jifara Plain in northwestern Libya. Field work was carried out from 7 October to 4 November 2002.

All reference data were collected from Libyan authorities: Libyan Meteorological Department (Climatic Section); General Environmental Authority; General Water Resources

Authority; Agricultural Research Centre; ACSAD (the Arab Centre for the Studies of Arid zones and Dry lands) in Tripoli, and the libraries of El-Fateh University, Tripoli and El-Sabeà Men April University, El-Zawia, Libya

An excursion, arranged by Mr. H. Ageli (Secretary of popular committee, desalination and water treatment research center, was carried out in Jifara Plain on 4 November 2002; in El-Ajilat, El-Zawia, Surman and the road which connects south of the Plain (Jebal Naffusah[8]) and Tripoli city[9]. Some photos were taken to clarify some of desertification manifestations on the plain.

1.6 Computer programs used

Illustrations and data analyses contained in this study were achieved using different programs: SPSS 11, Origin 6.0, Excel 2003, Surfer 7, Arc GIS 9, and Erdas Imagine 7, in addition to the general cartography skills. The full text of the thesis is typed using word processing (Word 2003) system. Klimagramm was used to investigate humid and arid months after Walter-Lieth and an Excel template MAKESENS (SALMI, 2002) was also used to depict Mann-Kendall test for trend of the annual values of climate parameters.

1.7 Organization of the thesis

The thesis was arranged to manifest its objectives through preceding it with an introduction, six chapters followed by the main results and recommendations as follows:

In the second part, after introduction and before attempting to analyze climate data, particular attention was paid to detect the physical setting of the study area, together with an attempt to show the climatic characteristics in Libya.

Climate data were analyzed in the third chapter in order to investigate observed climate change in Libya through the trends of temperature, precipitation, relative humidity and cloud amount in the study periods (1946-2000), (1946-1975), and (1976-2000), as well as to compare the results with global scales.

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[8] A plateau with elevations of up to 800 m, locates in the south of Jifara Plain.

[9] Excursion was arranged by Secretary of Popular Committee, Desalination and Water Treatment Research Center, National Association of Scientific Research, Tripoli, Libya.

The forth part of the study investigated the natural and human causes of climate change concentrating on the greenhouse effect.

The potential impacts of climate change on Libya were examined in the fifth chapter.

Case study: desertification of Jifara Plain in northwestern Libya, its manifestations, its causes and its effects were studied in the sixth part of the study.

In the last chapter, projections and mitigations of climate change and desertification were discussed.

Ultimately, the main results and recommendations of the study were summarized.

1.8 Previous studies

Although a large amount of global climate change studies were carried out, studies about climate change in Libya are sparse. The present study is considered as one of the primary studies that are concerned with climate change in Libya. There are many environmental and climatic studies about Libya, among them:

Abufayed, A. and El-Ghuel, M. (2001): Desalination process applications in Libya, Presented at the *European Conference on Desalination and the Environment*: Water Shortage. Lemesos, Cyprus, 28–31 May 2001. Desalination 138: 47–53.

Al-Adyoush, R. (2000): Environmental deterioration in northwestern Jifara Plain in Libya, unpublished M. Sc., El-Fateh University, Tripoli, Libya. (in Arabic)

Almabruk, A. (1995): Reflections on climate variability within selected monthly mean time series in Libya and neighboring countries, *Geographia Polonica* 65: 51-62.

Almabruk, A. (1997): Estimation of evapotranspiration in Libya under the impact of plausible global climate change, *Geographia Polonica* 70: 25-42.

Ben-Mahmoud, R., Mansur, S. and Al-Gomati, A. (2000): Land degradation and desertification in Libya, Land Degradation and Desertification Research Unit, Libyan Center for Remote Sensing and Space Science, Tripoli, Libya.

El-Tantawi, A. (1998): Water resources in Libya (applied study), published M. Sc., Institute of African Researches and Studies, Cairo University, Egypt. (in Arabic)

El-Tantawi, A. (1998): Water balance in Libya, *presented in the first Arabic conference on water and desertification*, Academy of Scientific Research, Cairo. (in Arabic)

Kredegh, A. M. (2002): Sand storm and its effect on man and environment in north western Libya (1965-1997), unpublished M. Sc., Elsabeà Men April University, El-Zawia, Libya. (in Arabic)

Mgely, M. (1994): Drought and desertification in arid and semi-arid lands: Northwest Libya, *Journal of Faculty of Education*, El-Fateh University, Tripoli. (in Arabic)

2. Physical setting of the study area

2.1 Location and population of Libya[10]

Libya occupies a part of northern Africa from 20 to 34° N and 10 to 25° E (Fig. 1). It is bounded in the east by Egypt (1150 km), in the west by Tunisia (459 km), and Algeria (982 km), Mediterranean Sea in the north, and by Sudan (383 km), Chad (1055 km), and Niger (354 km), in the south (CIA, 2004). It has an important physical asset by its strategic location at the midpoint of Africa's northern rim. Total area of Libya is about 1.76 Million km^2; it ranks forth in area among all countries of Africa and fifteenth among all countries on earth (McMORRIS, 1979: 62). More than 95 % of Libya is desert which is a part of Sahara[11] that is the most extensive area of severe aridity. Aridity of the central and eastern Sahara is due to its domination by continental tropical air (cT) all-year which is continually descending from the upper levels of the atmosphere where, in these latitudes, anticyclone conditions are permanent.

The cultivable areas are estimated at 3.8 mill. ha or slightly over 2 % of the total area, while the irrigation areas in all Libya were estimated at 400,000 ha (BEN-MAHMOUD, et al. 2000: 2). The fertile lands of Jifara Plain in the northwest, Jebal Al-Akhdar in the northeast and the coastal plain east of Sirt receive sufficient precipitation to support agriculture. As a result, more than 90 % of Libyan population resides there. Between the productive lowland agriculture zones lies the Gulf of Sirt that stretches 500 km along the coast, from where deserts extend northward to the sea. Libya's total population was at 5.3 million in 2001 including more than 500,000 non-nationals; in 2004, population estimate was at 5.9 million with a growth rate of 2.37 %, birth rate of 27.17/1,000/year and death rate of 3.48/1,000/year (National Information Authority of Libya, 2002). Almost 95 % of the population lives in the coastal region in the north, and the rest in widely scattered oases in mid- and southern Libya.

According to the population distribution in Libya based on 2001 estimation, people concentrate on two centers (Fig. 2): the first, in the northwest (Jifara Plain) where about 60 % of all Libyans live, including Tripoli city - the capital of Libya - where more than one

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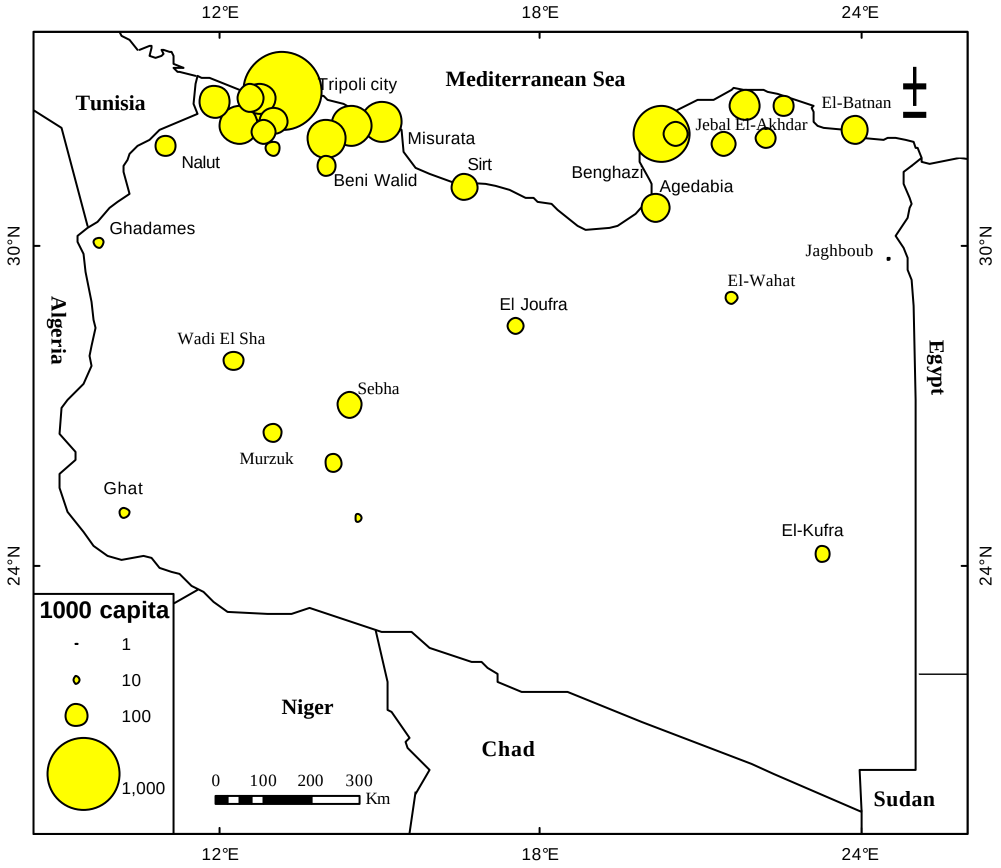
[10] Official name: The Great Socialist People's Libyan Arab Jamahiriya
(Al-Jamahiriya Al-Arabiya Al-Libiya Ash-Shabiya Al-Ishtirakiya Al-Uzma)

[11] The name of Sahara is derived from an Arabic word meaning wilderness (GRIFFITHS and SOLIMAN, 1972).

million people live, and the second center in northeastern Libya (Ben-Ghazi Plain). The main reasons for this concentration are fertile soils and seasonable, moderate climatic conditions.

Fig. 2: Spatial distribution of population in Libya, 2001



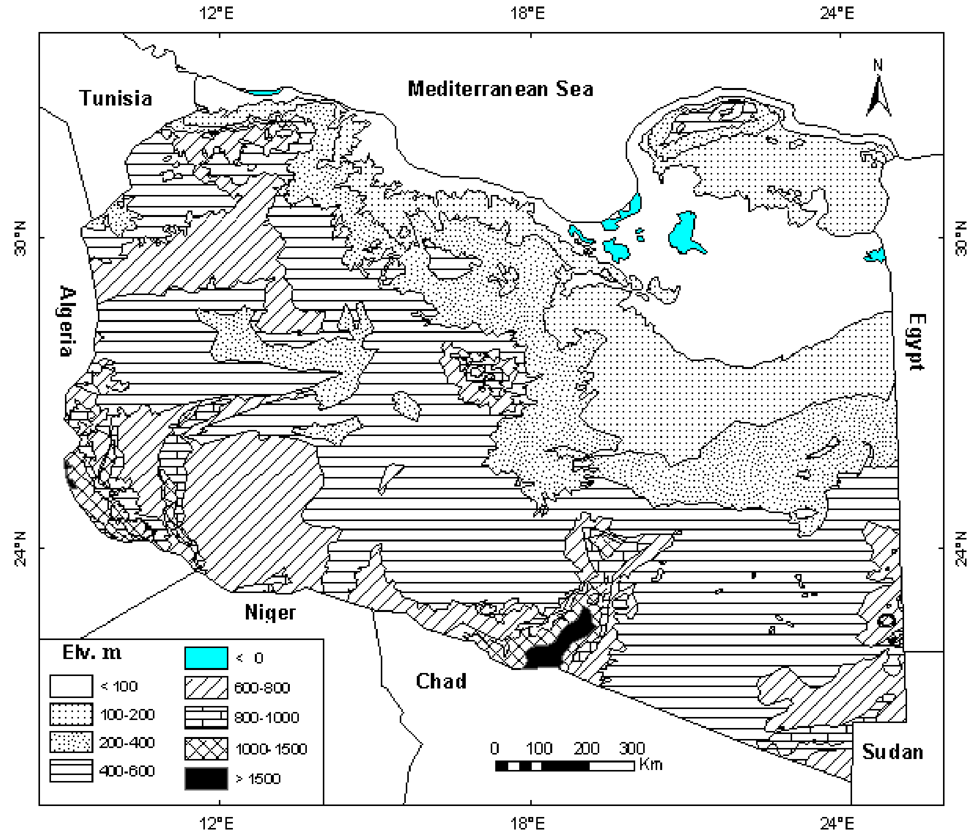
Data source: National Information Authority of Libya, 2002

2.2 Landforms

Landforms of Libya generally consist of barren plains in the north against plateaus and depressions in the south; the Mediterranean coast lands and the Sahara desert are the most prominent natural features. Though there are several highlands, no true mountain ranges exist except in southern desert near the Chad border where the Tibesti Massif rises to over 3,000 m (Fig. 3). Elsewhere a barren waste land of rocky plateaus and sand occur which only allow minimal human habitation and agriculture possible in a few scattered oases (McMORRIS, 1979: 63). The dominant features of the northern coastal zone are the low-lying areas. The lowest point is Sebkhat Ghuzayil (47 m below sea-level), the highest one

Bikku Bitti (2,267 m) above sea-level (CIA, 2004). The Mediterranean coastal zone of Libya which stretches from west to east , from the Tunisian border to the Egyptian border, over about 1,900 km ranging between 15 and 100 km in width (BEN-MAHMOUD, et al, 2000: 2). The main contrast is between narrow enclaves of fertile lowlands along the Mediterranean coast and the vast expanse of arid rocky plains and sand seas to the south (NELSON, 1979).

Fig. 3: Relief map of Libya



Source: AMANAT EL-TAKHTIET, 1978: National Atlas of Libya: 43

The main landforms of Libya can be identified as follow (Fig. 4):

In northern Libya, coastal plain includes coastal lowlands (Jifara Plain, Sirt Plain and Ben-Ghazi Plain) as well as Sebkhas[12], lagoons, salty marshes, swamps and coastal sand dunes. Coastal lowlands are separated from each other by pre-desert zone and backed by plateaus with steep, north-facing scarps. In the west, along the coast of Tripoli, more than 300 km coastal oases alternate with sandy areas and lagoons. Inland, the Jifara Plain is a quaternary erosion surface developed on the northern flank of the regional dome of Jebal

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[12] Sebkha: the arab term sebkha refers to the broad, salt-encrusted, supra-tidal surfaces or coastal flats bordering lagoonal or inner shelf regions (WHITTEN AND BROOKS, 1972: 397)

Naffusah and on Miocene marine sediments, which are deposited over a distance of about 30 km south of the present coastline, raised beaches, sand dunes and the quaternary alluvial sediments (PESCE, 1968: 32). In the east, there are fewer coastal oases and the Marj Plain extends inland at a maximum of 50 km along the coast, the cliffs of an arid plateau reach to the Mediterranean Sea in northeastern Libya. Behind the Marj Plain the terrain rises abruptly to form Jebal El-Akhdar (Green Mountain[13]; McMORRIS, 1979: 63).

Fig. 4: Main landforms in Libya

Source: ESRI Media Kit, (2001): World Sat Color Satellite Image

The highlands run in the vicinity of the coastal plain including Jebal Naffusah (960 m) in northwestern Libya which is hilly limestone massif prior to Upper Cretaceous and Jebal El-Akhdar (875 m) in northeastern Libya composed of Paleogene limestone. Both mountain ranges are divided by a line of fractures and tilt towards the north, such as Jifara Plain which rises slowly from sea level along the coast to 200 m at the foot slops of Jebal Naffusah (PALLAS, 1980: 566). Jebal Naffusah grades southwards to an extensive plateau with stone deserts (El-Hamada El-Hamraa) which persist at heights of about 500 m. The

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[13] Jebal El-Akhdar because of its leafy cover of pine, juniper, cypress, and wild olive

same elevation is gained further to the east by shallow gradation of the Sirt gulf hinterland. The low table-shaped elevations surround the gravel areas (Serir desert) in the east, sizable in places and in parts covered by extensive basalt slabs towards the south. The volcanoes rise to 800 m above sea level in the El-Sawda Mountain and up to 1,200 m in the Haruj es Sawda (KANTER, 1967: 76).

Jebal El-Akhdar is economically the most important highland, and some forest remnants are found. Otherwise, vegetation - where existing - consists mainly of shrubs, scrub and palms (GRIFFITHS, 1972: 38). From Jebal El-Akhdar, a barren grazing belt gives way to the Sahara desert and extends southward where elevation is generally below 200 m. Here the extensive gravel areas of the Serir desert and the sands of the Libyan deserts advance close to 300 km from the coast (KANTER, 1967: 77).

In southern Libya, the prominent and very rugged slopes Tadrart Mountain dip gently north and north eastward, the board valley extends northward from the oases of Ghat and the great sand seas of Murzuq and Ubari which are separated from the Serir Tibesti by the Nubian-Post-Tassilian outcrops of Jebal Ben-Ghnema and Jebal El-Gussa (PESCE, 1968: 24). Only on arrival in the vicinity of El-Kufra, low hill ranges rise to some 700 m, small oases, and near the southern border; Jebal Uwainat attains 1,934 m (KANTER, 1967: 77).

2.3 Climate

2.3.1 Controlling factors

Climate of Libya is largely determined by the interaction of the following factors:

1 - Location: Libya due to its location between 20° to 34° N experiences a sub-tropical climate. Libya climate is determined by contrasting Mediterranean and Sahara climates, so air masses of either continental or maritime origin affect climate. A costal belt follows the coast receiving more efficient precipitation against the dry, vast area occupied by the Sahara desert. As from a global perspective, the sun's mean angle is highest, on average at the equator and then becomes progressively lower polewards, mean temperatures gradually decrease with increasing latitude in Libya.

2 - Landforms: Mountains act as strong barriers which block the further passage of air masses associated with a different pattern of precipitation on the windward and leeward sides either (DOMRÖS, and GONGBING, 1988: 26). In Libya, there are no mountain

ranges extending either from west to east or from north to south, so the Saharan influence extends northwards to the Mediterranean coast (Sirt gulf). Jebal Naffusah and Jebal El-Akhdar in northern Libya have local effects on climate (precipitation and temperature). Different elevation can cause the locations at similar latitudes vary greatly in temperature that decreases an average of about 0.64 °C/100 m. Therefore, high mountains and plateau stations (Shahat (621 m), 16.5 °C) are colder than low-elevation stations (Zuara (3 m), 19.8 °C) at approximately the same latitude. Aerological influence is the air lifting effect of mountain peaks and ranges on winds that pass over them. As air approaches a mountain barrier, it rises, typically producing clouds and precipitation on the windward (upwind) side of the mountains. After it crosses the crest, it descends downwind side of the mountains (SCOTT, 2001).

3 - Distribution of land and sea: Libya has no interior lakes or rivers, all its area is land, and only Mediterranean Sea plays an important role in modifying the climatic parameters in the coastal zone. It affects temperature and moisture conditions. The relatively warm Mediterranean Sea area attracts cool masses of maritime polar air sometimes, maritime Arctic air from the Atlantic and continental air from Europe. These air masses are rapidly transformed, especially from November to January, when the Sea is warmer than the land. The influence of Mediterranean Sea on land areas decreases generally southward. Climate in Libya is mainly considered the interaction between the Mediterranean Sea and Sahara desert.

4 - Air pressure and wind belts: The air pressure distribution which is responsible of the wind patterns affects the annual temperature and precipitation. Wind is produced by the differences in the air pressure and the weather systems, such as weather fronts and storms controlled by wind patterns. Globally, the subtropical high-pressure belts centered near 30 degrees north and south latitude is responsible for many of the world's deserts. The regions between the ITCZ and the sub-tropical highs are dominated by the trade winds. The mid-latitudes are mostly situated between the subtropical highs and the sub-polar lows and are within the westerly wind belt. In the equatorial zone there is a permanent belt of low pressure due to heating and strong convection currents. North and south of this belt, subtropical highs are formed in belts of descending air masses, going farther polewards (MARTYN, 1992: 14).

In winter, six important features of pressure built can be identified, each of which can play a significant role in the weather over the northern desert; 1- The Sahara High, an extension of the Azores anticyclone; 2- The Arabian High, another part of the sub-tropical high pressure built. 3- The Balkan High in conjunction with the great anticyclone over central Asia, 4- A low pressure area over the central and eastern Mediterranean. 5- The equatorial trough over central Africa. 6- The ITCZ[14] (GRIFFITHS and SOLIMAN, 1972: 76). At the beginning of winter the belt of the horse latitude with high pressure gradually move south and origination from the Azores south of the atlas mountain and on the plateau of shots, they form a zone of high pressure with a small area of high pressure over the Ahaggar extending before it. The pressure gradient reaches from them both to the tropical belt, i.e. the north-east trade which below from the Mediterranean into the country during summer is being moved farther south into the Sahara. It is now replaced by winter depressions which advance from the Northwest to the North African coast moving a long the polar front to the east and bringing humid Atlantic air towards the east (KANTER, 1967: 97).

In summer, an approximate inverse of the winter situation is experienced. The main features are; 1 - a depression over the Arabian Peninsula, 2 – a depression over the southern Sahara; 3 - a high pressure ridge over central Africa; 4 - the ITCZ (GRIFFITHS and SOLIMAN, 1972: 77). When the Azores High intensifies, a period of calm sunny weather predominates. The belt of high pressure from the horse latitude gradually shifts to the north and a Saharan depression forms south of the tropics and the north east trade succeeds, bringing with it the fine summer days. But soon the hot southerly wind (Gibli) starts here and there to blow from the desert to the steppe (KANTER, 1967: 98).

This zone continuous in spring to be affected by depressions related to the air mass movements over Europe. This is a windy time around the coast line but because of the small temperature deferential between land and sea, there is relatively little rain and cloud (GRIFFITHS, 1972: 39).

In autumn, a hot, close wind from the south usually blows and thunderstorms with precipitation occur repeatedly, possibly together with varying Southerlies and Northwesterlies to Northeasterlies for several days. Winds that entrain and transport the dust from

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[14] Intertropical Convergence Zone is a belt of low pressure girdling the globe at the equator. It is formed by the convergence of warm, moist air from the latitudes above and below the equator. This region is also known as Intertropical Front or the Equatorial Convergence Zone (Wikipedia encyclopedia, 2005).

Sahara are regular features of local climates and have a large number of local names (gibli) in Libya. The Saharan source strength for dust transport to Europe was estimated at 80–120 million tones/ year (GOUDIE and MIDDLETON, 2001: 186).

2.3.2 Climatic elements

Temperature

The spatial pattern of annual, winter, and summer temperatures over Libya mainly depend on latitude and elevation (Tab. 3).

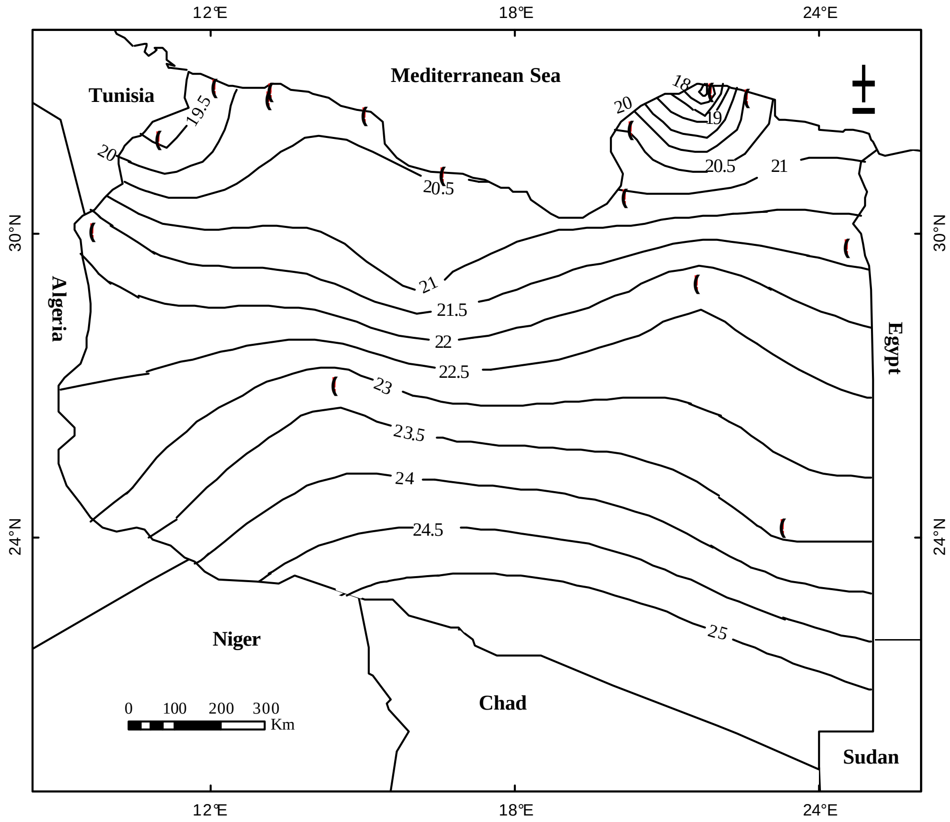
Tab. 3: Latitude and elevations of stations under study in Libya and their annual, winter and summer temperatures, 1946-2000

Station	Latitude N.	Elevation (m)	Annual (°C)	Winter (Dec.-Feb.)	Summer (Jun.-Aug.)
El-Kufra	24.13	436	23.3	14.2	30.8
Sebha	27.01	432	23.4	12.8	30.6
Jalo	29.02	60	22.4	14.1	29.8
Jaghboub	29.45	-1	21.3	12.9	28.8
Ghadames	30.08	357	21.9	11.8	31.4
Agedabia	30.43	7	20.5	13.5	26.5
Sirt	31.12	13	20.5	13.4	25.5
Nalut	31.52	621	19.1	10.5	27.2
Benina	32.05	129	20.1	13.4	26.1
Misurata	32.19	32	20.4	14.1	26.2
Tripoli airport	32.40	81	20.4	12.8	27.6
Derna	32.47	26	20.0	14.8	25.1
Shahat	32.49	621	16.5	10.1	22.8
Zuara	32.53	3	19.8	13.3	25.8
Tripoli city	32.54	25	20.2	14.0	26.4

Data source: Libyan Meteorological Department, Tripoli.
Jaghboub and Jalo, 1950-2000

Distribution of mean *annual* temperature in Libya was investigated, the different thermal conditions have been observed due to latitude and altitude. Most significant temperatures vary over space and produce a rather confusing picture of temperature distribution. Fig. 5 shows a remarkable distribution towards south-north direction which indicates lower temperatures towards the Mediterranean Sea in the north and higher temperature inland southwards (e.g. annual temperature in southern Libya reaches 23.4 °C at Sebha and 23.4 °C at El-Kufra, in mid-Libya at Jalo (22.4 °C) and at Ghadames (21.9 °C), while in northern Libya temperatures range between 16.5 °C at Shahat on the Jebal El-Akhdar, 19.8 °C at Zura) in the west of the coast and 20.5 °C at Sirt and Agedabia on the gulf of Sirt). The implications of elevation can also be observed through the temperature at Shahat 16.5 °C, Zuara 19.8 °C, Jaghboub 21.3 °C and Ghadames 21.9 °C (Tab. 3).

Fig. 5: Mean annual isotherms (°C) in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

Isotherms of mean *winter* temperatures show a different distribution (Fig. 6); because of Mediterranean Sea effects on the coastal parts, temperature generally declines northwards but it increases in the coastal area (e.g. in the eastern Libya, 14.2 °C at El-Kufra in the south, 12.9 °C at Jaghboub in the middle, and 14.8 °C at Derna in the north, as well as in the west of Libya, temperatures reach 12.8 °C at Sebha in the south, 10.5 °C at Nalut, and 14.0 °C at Tripoli city). It reaches 10.1 °C at Shahat on mountain (Tab. 3). Temperatures are normally pleasantly cool at night in the Sahara desert. In some parts in Libya temperatures below freezing occur often in winter, for example, in January 1962 temperature recorded (-6 °C) east of Ghadames (GRIFFITHS and SOLIMAN, 1972: 95).

In summer, the northeast trade blows across the Libyan Desert area with alternative Easterlies at times, particularly in the southeastern parts. Their influence maintains the fine

Fig. 6: Mean winter isotherms (°C) in Libya, 1946-2000

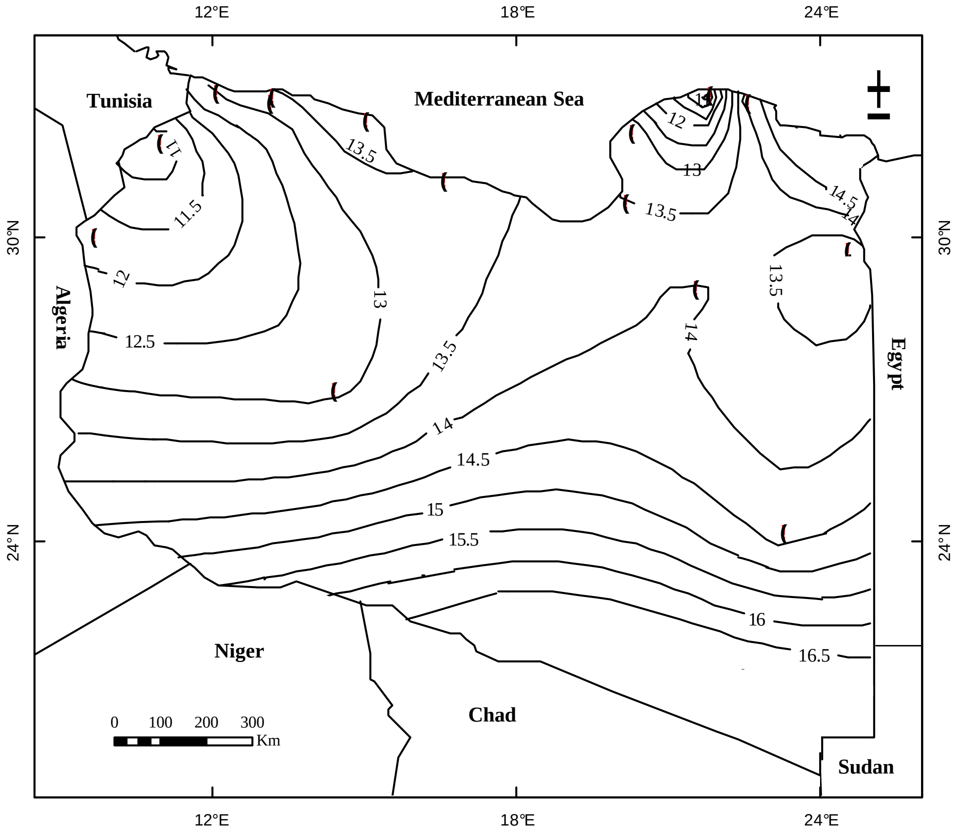
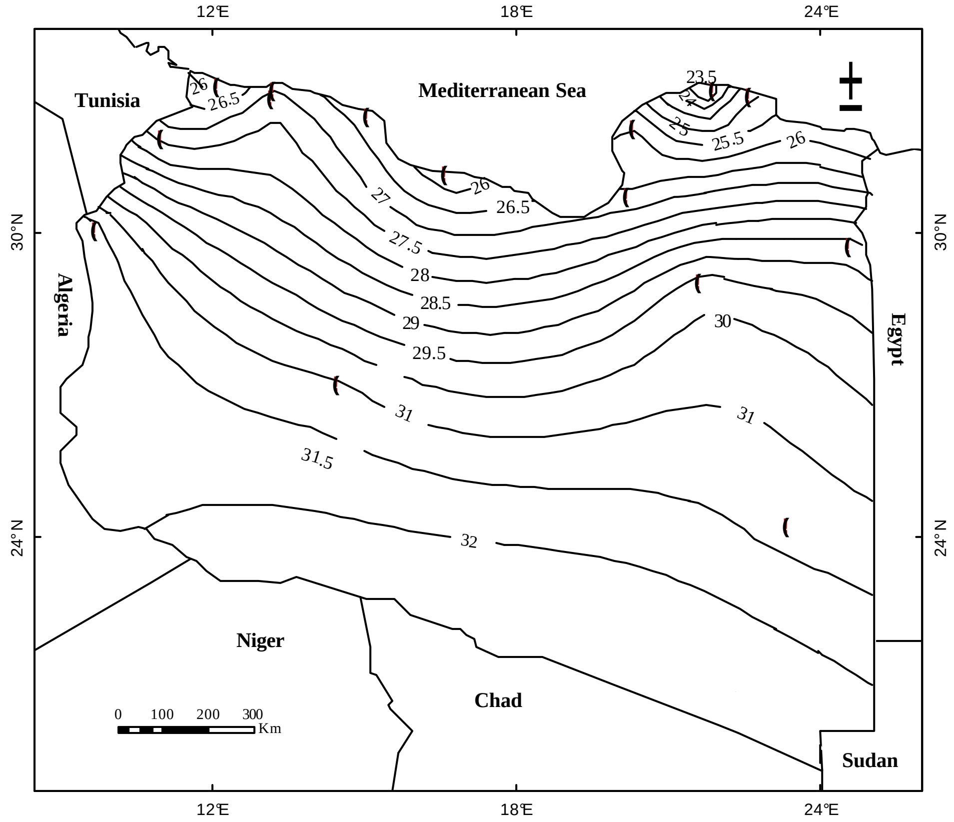


Fig. 7: Mean summer isotherms (°C) in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

weather with predominantly cloudless skies and temperatures are 30.8 °C at El-Kufra in southeastern Libya, 30.6 °C at Sebha in the southwest, while in the north, temperature ranges between 27.6 °C at Tripoli airport in the west of coastal area, 25.5 °C at Sirt in the middle and 22.8 °C at Shahat in eastern Libya on Jebal El-Akhdar (Fig. 7). Temperatures generally increase southwards and decrease northwards. But with the onset of the gibli wind which blows from Sahara, temperature rises to an uncomfortable 30 °C, bellowing dust are evident and an innervating sultriness occur (GRIFFITHS and SOLIMAN, 1972: 95). The highest temperature ever recorded on the earth was experienced in Libya 57.8 °C at Al-Azizia near Tripoli on 13 September 1922 (MARTYN, 1992: 31).

It can be observed that annual, winter and summer temperatures over Libya increase gradually from north to south; additionally, the specific location of the stations must be taken into account. The highest month in the coastal zone is August, while July is the heist month in the desert and the coldest one in Libya is January.

The mean of annual temperature ranges were computed at study stations (Tab. 4) showing the lowest values in the north and the highest in the south explained by the Mediterranean Sea and Sahara effects (e.g. minimum range of 4.9 °C at Tripoli city and 6.8 °C at Derna in the coastal area, with southward the values of the mean annual temperature ranges rise to a maximum value of 14.7 °C at Sebha and 15 °C at El-Kufra in southern Libya).

Tab. 4: Mean annual temperature ranges in Libya, 1946-2000

Station	range °C	Station	range °C	Station	range °C
Agedabia	12.4	Jaghboub	15.4	Shahat	8.5
Benina	10.3	Jalo	14.4	Sirt	9.0
Derna	6.8	Misurata	9.4	Tri. airport	13.0
El-Kufra	15.0	Nalut	10.7	Tripoli city	4.9
Ghadames	15.0	Sebha	14.7	Zuara	9.3

Data source: Libyan Meteorological Department, Tripoli

Precipitation

Rainfall is the main feature of precipitation in Libya, but snow can fall along the Mediterranean coast (e.g. in Feb. 1949, a 1-m-thick layer of snow persisted for three days at Jebal El-Akhdar; MARTYN, 1992: 222). Fig. 8 expresses annual isohyets in Libya based on the period 1946-2000 showing parallel to the coastal configuration except where high plateaus on Jebal El-Akhdar in the northeast and on Jebal Naffusah in northwestern Libya. It can also be observed that mean annual precipitation varies from 0 mm in the south of Libya to 600 mm on the coast, isohyets roughly run in a south-to-north direction. It increases northwards to over 300 mm in the northwest (335.9 mm at Tripoli city) and over 550 mm (559.3 mm at Shahat) on Jebal El-Akhdar in the northeastern Libya (Tab. 5).

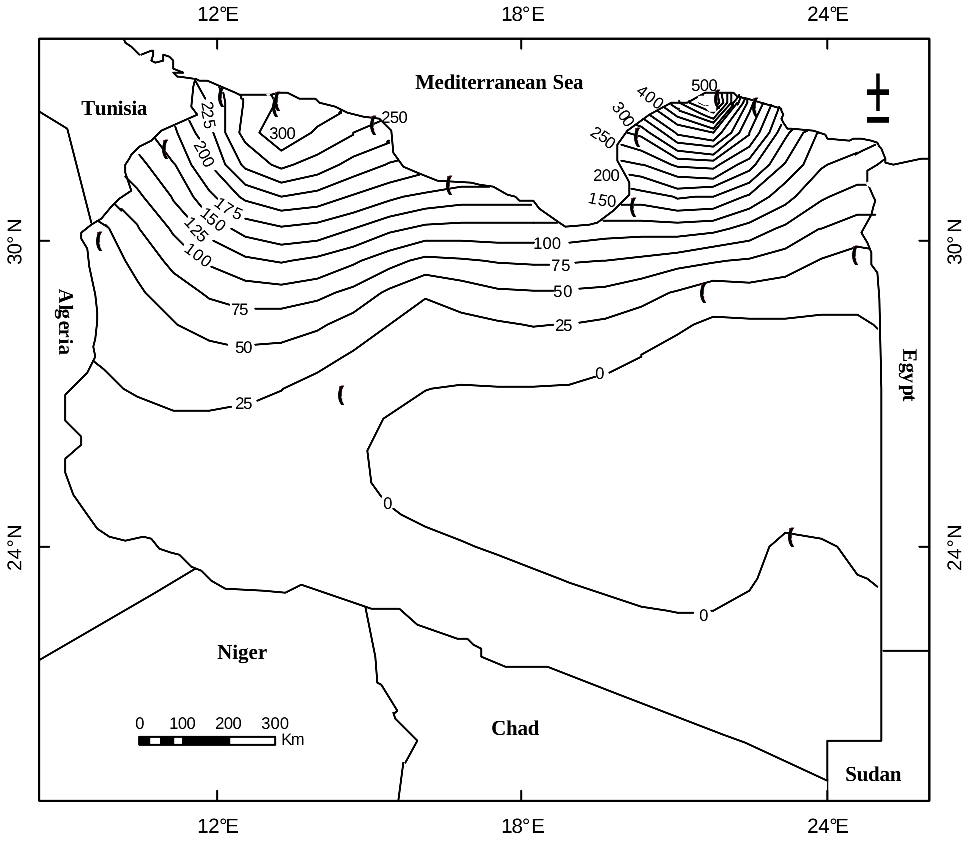
Tab. 5: Spatial variations of mean annual precipitation in Libya, 1946-2000

Station	mm	Station	Mm	Station	mm
Agedabia	145.4	Jaghboub	15.8	Shahat	559.3
Benina	268.5	Jalo	9.3	Sirt	187.3
Derna	268.5	Misurata	274.3	Tripoli Airport	277.2
El-Kufra	2.1	Nalut	148.5	Tripoli city	335.9
Ghadames	31.9	Sebha	9.0	Zuara	238.6

Data source: Libyan Meteorological Department, Tripoli

Note: Different observation periods at: Ghadames (1958-2000), Jaghboub and Jalo (1950-2000), and Sebha (1962-2000)

Fig. 8: Distribution of mean annual precipitation (mm) in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

On the whole, the 50 mm-isohyet can be regarded as the borderline of total desert, from Mediterranean coast (Tripoli city 335.9 mm) towards Jebal Naffusah in the south

(Tripoli airport 277.2 mm) as well as towards the Tunisian border (Zuara 238.6 mm). Precipitation decreases ever farther and increases again on Jebal Naffusah (322 mm) at Gharian. Southern Jebal shows a decreasing precipitation, total mean annual at Nalut is only 149 mm. In the Sirt region towards the east, precipitation decreases (Sirt 187.3 mm, Agedabia 145.4 mm) but increases in the plain west of Jebal El-Akhder (Benina 268.5 mm), on the mountain Jebal El-Akhdar, annual precipitation rises to 559 mm at Shahat, towards the east, the amount of precipitation decreases (Derna 269 mm), while on the southern slope of Jebal Naffusah and Jebal El-Akhdar, the amount of precipitation decreases because it is situated in the rain shadow.

South of 30° N, Libya is almost entirely occupied by desert (see the annual precipitation total for El-Kufra, Sebha and Jalo); only some higher mountains, like Haruj and Jebal El-Sawda, receive some precipitation. High-mountain steppe, however, is only developed outside Libya in the Tibesti in the south (KANTER, 1967: 97). The rare and isolated rain showers which are known in parts of the Sahara are caused chiefly by incursions of unstable maritime polar air (mP) from the northwest or the occasional penetration of moist equatorial air from the south. In the southern areas precipitation can stem from small depressions moving from the north respectively northwest and northeast and, if ITCZ takes place, heavy precipitation over El-Hamada south of Jebal Naffusah can occur (e.g. October 1937), producing large lakes of precipitation water (GRIFFITHS and SOLIMAN, 1972: 94).

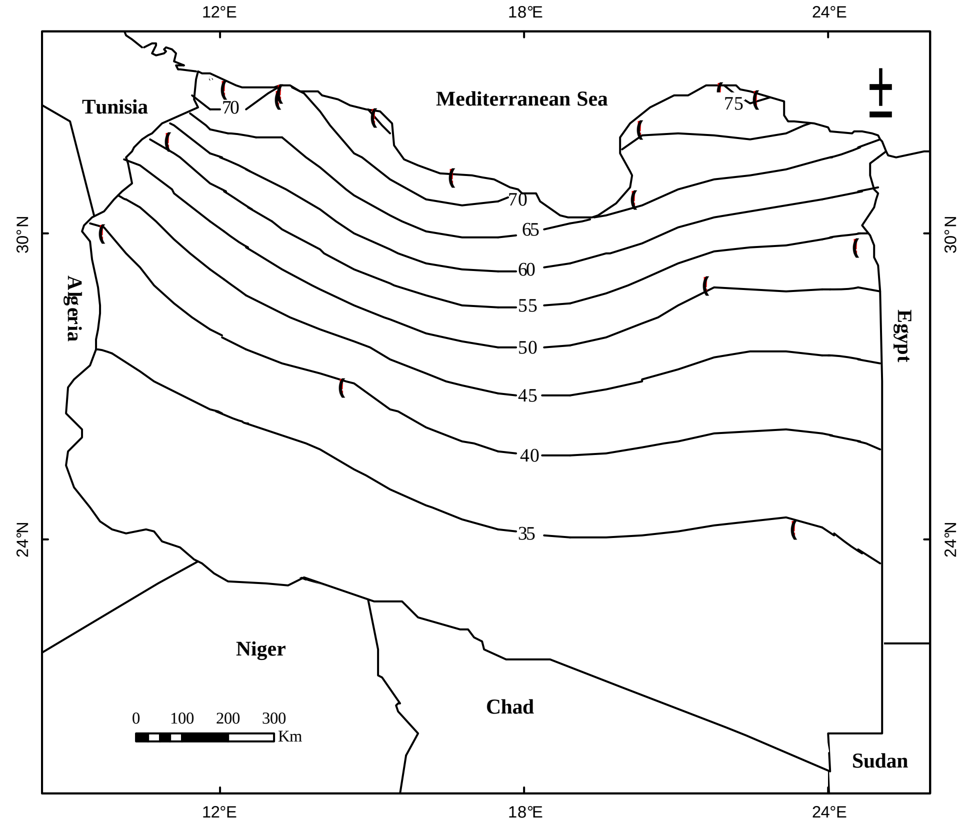
Relative humidity

Relative humidity is generally low throughout the year owing to minimal evaporation and paucity of water vapour. Mean annual relative humidity falls from 65-75 % in the coastal region to less than 35 % in the desert (Fig. 9).

Highest water vapour only occurs in coastal region by Mediterranean Sea effects. In winter, relative humidity decreases southwards, it ranges between 76 % at Shahat, 73.3 % at Benina in the coastal zone and 41.6 % at El-Kufra. It can be observed that relative humidity varies between winter and summer. On the coast, summer values are at most stations higher than winter values, while in the desert, winter values are mostly higher (Tab. 6). Relative humidity also varies over the day. In the early morning hours it falls from 80-90 % on coasts to 40 % and less in January and to 20-30 % and less in July inland. In

January and July alike, the air in the afternoon hours is very dry in the Sahara and humidity then may even drop to 5-30 % (MARTYN, 1992: 220).

Fig. 9: Mean annual relative humidity (%) in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

Tab. 6: Mean annual and seasonal relative humidity in Libya (%), 1946-2000

Station	Annual	Summer (Jun.-Aug.)	Winter (Dec.-Feb.)	Location
Agedabia	61.8	59.5	69.1	Coast
Benina	65.3	61.6	73.3	Coast
Derna	72.0	74.9	71.0	Coast
El-Kufra	29.3	21.7	41.6	Desert
Ghadames	33.8	22.2	48.7	Desert
Jaghboub	48.2	40.2	59.9	Desert
Jalo	45.2	37.7	56.2	Desert
Misurata	70.8	72.0	70.6	Coast
Nalut	50.7	42.5	59.9	Desert
Sebha	33.9	25.0	46.7	Desert
Shahat	68.9	63.8	76.1	Coast
Sirt	70.4	74.7	68.3	Coast
Tripoli airport	61.8	55.5	69.0	Coast
Tripoli city	64.8	63.5	62.5	Coast
Zuara	73.1	76.2	70.7	Coast

Data source: Libyan Meteorological Department, Tripoli

Note: Observation periods at El-Kufra (1949-2000), Jaghboub and Jalo (1951-2000)

Cloud amount

Cloudiness is highest in the coastal region decreasing to the south and from east to west (Fig. 10); correspondingly, cloudiness increases with elevation: Shahat (46.5 Oktas) on Jebal El-Akhdar records among all stations under study the highest values (Tab. 7).

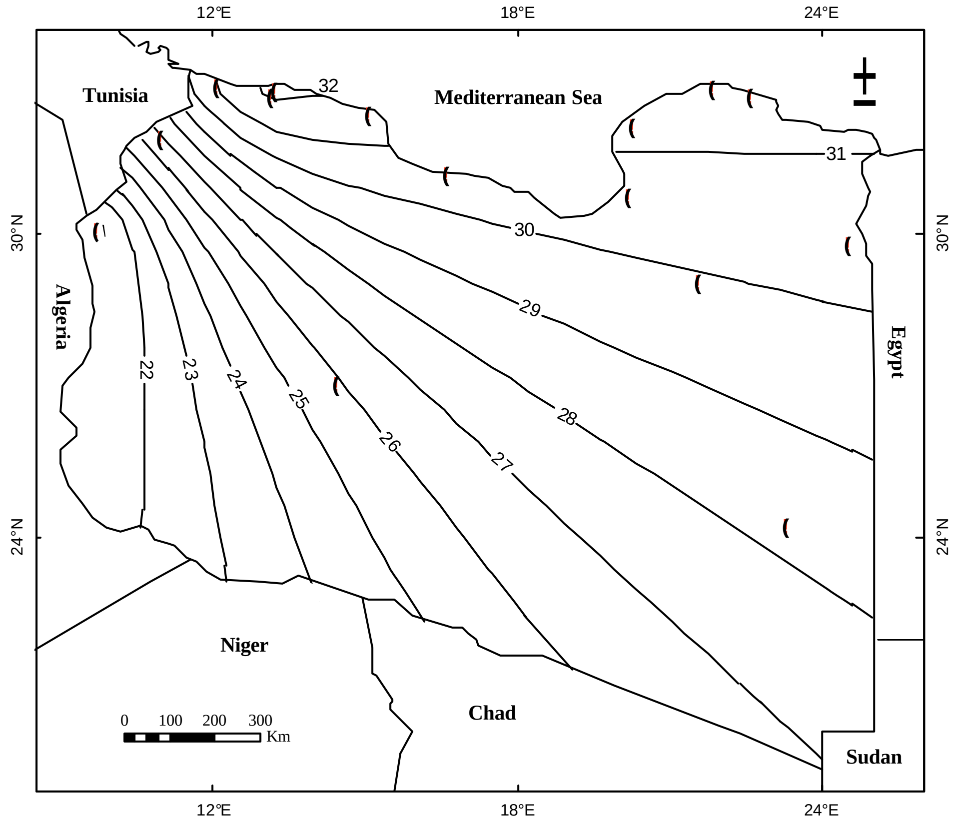
Tab. 7: Mean annual total cloud amount (Oktas) in Libya, 1946-2000

Coastal stations	Annual total	Desert stations	Annual total
Agedabia	24.5	El-Kufra	20.0
Benina	35.1	Ghadames	18.4
Derna	11.1	Jaghboub	15.6
Misurata	35.6	Jalo	33.7
Shahat	17.1	Nalut	38.4
Sirt	46.5	Sebha	26.0
Tripoli airport	33.3		
Tripoli city	32.2		
Zuara	31.3		

Data source: Libyan Meteorological Department, Tripoli

Note: Observation periods at Ghadames and Sebha (1962-2000), Jaghboub and Jalo (1950-2000)

Fig. 10: Mean annual total cloud amount (Oktas) in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

The increased cloudiness of the Mediterranean region during winter is of cyclonic origin. In January, cloudiness is higher by 40-50 %, in the transition seasons, by 40 % in the western Atlas and by 30 % in the eastern atlas. Summer is a fair weather period with less than 10-20 % cloudiness. The finest part of North Africa is the driest belt of the Sahara as here conditions are not conducive to cloud formation (MARTYN, 1992: 221).

2.3.3 Climatic characteristics of Libya

Climate is by nature a rather complex theme, because of the manifold earth-atmosphere interaction which considerably varies over space and time and finally creates a specific type of climate at a particular location (DOMRÖS and GONGBING, 1988: 1). Most descriptions of climate deal with temperature and precipitation characteristics because these two major climatic elements usually exert more impacts on environmental conditions and human activities than other elements do, such as wind, humidity, and cloud cover. Mean monthly precipitation and temperature data were used to investigate the main characteristics.

Concerning the inter-annual variabilities of temperature and precipitation for all reference stations, it can be observed that the warmest period of the year can occur in June to August in southern and middle parts of Libya (El-Kufra, Sebha, Jalo, Ghadames, and Jaghboub), and in August on Mediterranean Sea coast (Zuara, Tripoli city, Tripoli airport, Misurata, Sirt, Benina, Shahat, and Derna). In the desert, climate is continental with very hot summer and extreme daily temperature ranges (Fig. 11).

It must be underlined that Libya is an arid country with only trace precipitation from the southern border to just south of Jebal Naffusah in northwestern Libya and Jebal El-Akhdar in northeastern Libya. There is no precipitation at El-Kufra, Jalo, Jaghboub, Sebha, and Ghadames, while up to 250 mm of annual precipitation is experienced at Tripoli, Zuara, Misurata, Derna, Benina and Shahat which are along the Mediterranean coast. Less than 2 % of Libya’s territory receives enough precipitation for settled agriculture.

As far as precipitation is concerned, winter is prevailing followed by autumn and spring, while no or negligible precipitation occurs sometimes in summer, in the latter of thunderstorms are experienced in summer.

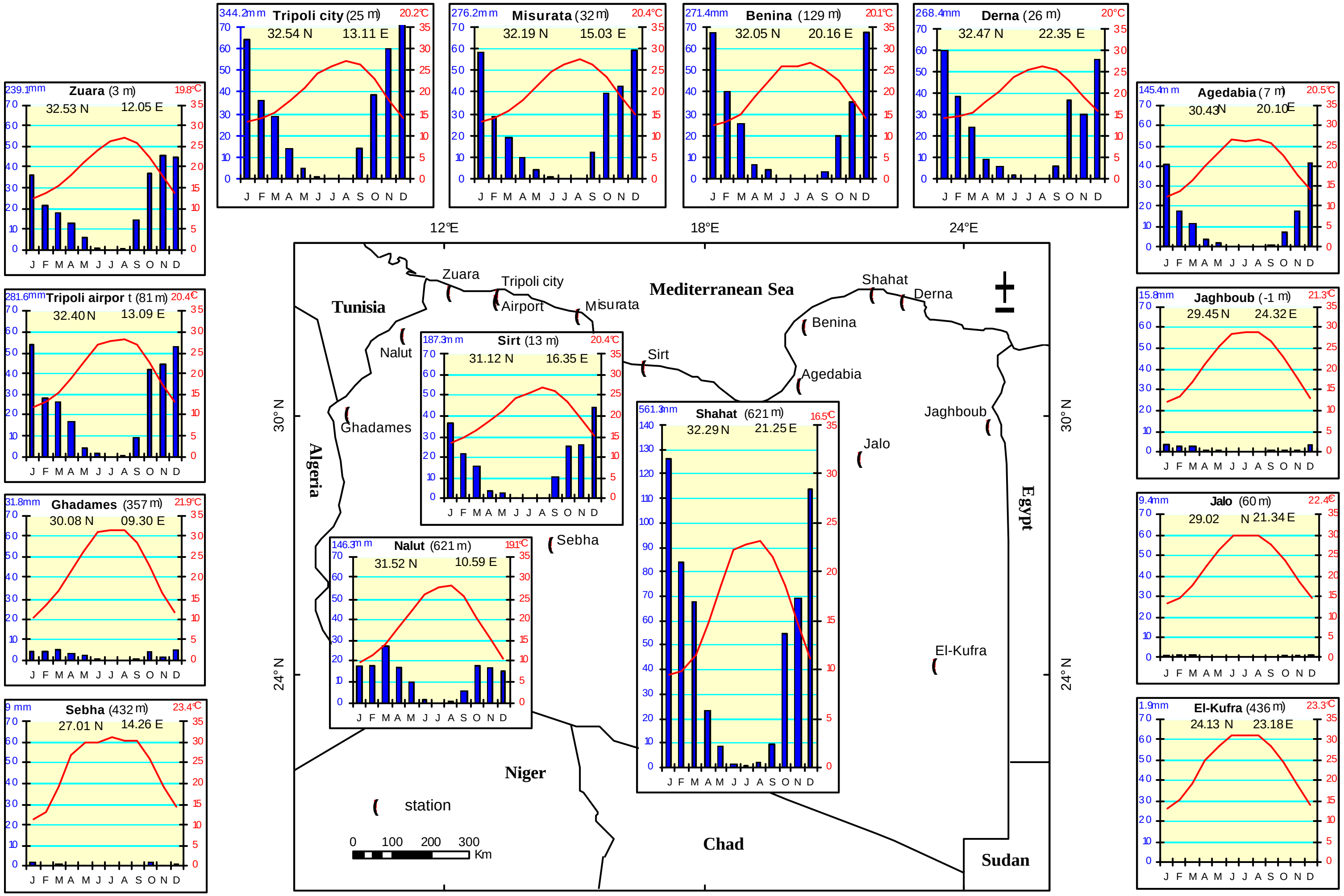


Fig. 11 Inter-anuual variabilities of temperature and precipitation in Libya, 1946-2000

Seasonal precipitation was studied at all study stations (Tab. 8). Winter totals of precipitation decrease moving toward the south due to the decreasing Mediterranean climate effect. About 50-70 % of the annual precipitation total falls during winter.

Tab. 8: Seasonal percentages of precipitation in Libya, 1946-2000

Station	Annual total precipitation (mm)	Winter (%) (Dec.-Feb.)	Autumn (%) (Sep.-Nov.)	Spring (%) (Mar.-May)	Summer (%) (Jun-Aug.)
Agedabia	145	68.9	18.7	12.4	0.0
Benina	269	64.5	21.7	13.6	0.2
Derna	269	57.3	27.3	14.4	1.0
El-Kufra	10	37.7	14.2	38.6	9.5
Ghadames	32	43.6	18.8	34.8	2.8
Jaghboub	16	61.3	10.7	27.4	0.6
Jalo	9	47.9	22.3	29.8	0.0
Misurata	274	53.1	34.1	12.2	0.6
Nalut	149	34.4	26.9	37.1	1.6
Sebha	9	40.9	29.8	25.3	4.0
Shahat	559	57.9	23.8	17.6	0.7
Sirt	187	54.8	32.9	11.9	0.4
Tri.airport	277	49.8	31.9	17.7	0.6
Tripoli city	336	51.4	33.9	14.2	0.5
Zuara	239	43.3	40.8	15.4	0.5

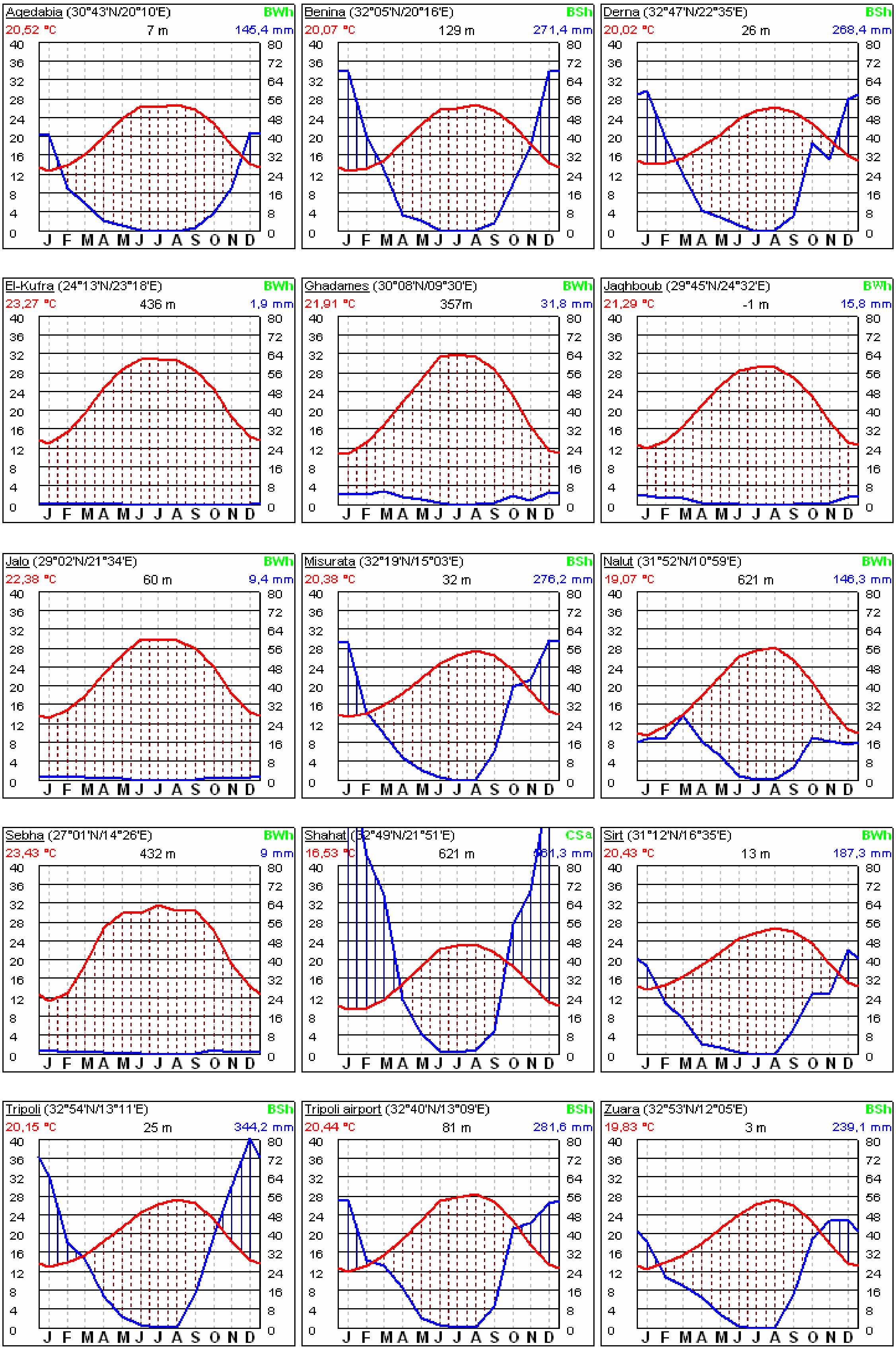
Data source: Libyan Meteorological Department, Tripoli

Heaviest precipitation occurs on Jebal El-Akhdar in northeastern Libya where the mean annual total amounts to 559 mm at Shahat. Over the Sahara desert 50 mm or less precipitation per year occur. Precipitation is often erratic, and a pronounced drought (precipitation less than annual average) may even extend over two years (e.g. epic flood in 1945 occurred at Tripoli, but two years later an unprecedented severe drought caused the loss of thousands of head of cattle (McMORRIS, 1979: 66).

Humid and arid months

Underlining the pronounced seasonality of precipitation and temperature in Libya, the annual variation of humid and arid months can be considered as a major climatic characteristic (DOMRÖS and GONGBING, 1988: 160). Humid and arid represent relative rather than absolute terms, hence climatic diagrams developed by Walter-Lieth method make an easy definition of arid and humid months; diagrams are based on the equation:

Fig. 12: Annual variation of precipitation and temperature according to humid and arid month's distribution (Data source: Libyan Meteorological Department)



N (mm) = 2T (°C)
n = mean monthly precipitation (mm)
t = mean monthly temperature (°C)

The diagrams compiled show the variation of the mean temperature and mean precipitation from 1946 to 2000 (Fig. 12). When the curve of precipitation falls under the temperature curve, arid months occur shown by dots. Vice-versa when the temperature curve falls under the precipitation curve, humid months occurs shown by vertical lines.

Tab. 9: Number of humid and arid months in Libya

Station	Humid months	Humid months	Arid months
Agedabia	2	January, December	10
Benina	3	January, February, December	9
Derna	3	January, February, December	9
Ghadames	0	--------------------	12
Jaghboub	0	--------------------	12
Jalo	0	--------------------	12
Misurata	3	January, November, December	9
Nalut	0	--------------------	12
Shahat	6	Jan., Feb., March, Oct., Nov., December	6
Sirt	2	January, December	10
Tripoli airport	4	January, February, November, December	8
Tripoli city	4	January, February, November, December	8
Zuara	3	January, November, December	9

Data source: Libyan Meteorological Department, Tripoli

The number of humid months varies between a maximum of six months at Shahat on Jebal El-Akhdar in the coastal region and a minimum of nil months in the inner parts of Libya. The majority of stations in the coastal regions records three or four humid months in Libya (Tab. 9). Hence, the number of arid months is prevailing all over Libya.

2.3.4 Climatic regions in Libya

Due to Köppen's climatic classification (MÜHR, 2004), Libya is mostly occupied by a hot desert climate type (BWh) which covers a large percentage of the mid- and southern Libya where the mean temperature is above 18 °C all year. The annual precipitation total (cm) in this type is lower than the mean annual temperature (°C); followed by a hot steppe climate type (BSh) in northern parts, in this type, the annual precipitation total (cm) is higher than the mean annual temperature (°C); Mediterranean zone (CSa) in northeastern Libya on Jebal El-Akhdar, the hottest month in this climate type is more than 22 °C and annual precipitation total is more than two times mean annual temperature (Fig. 13).

Libya was also classified into climatic regions according to the De Martonne climate classification based on the duration of the aridity period over the year. The aridity index is defined by

$A = [P/ (T+10)]$

P = annual precipitation total (mm)

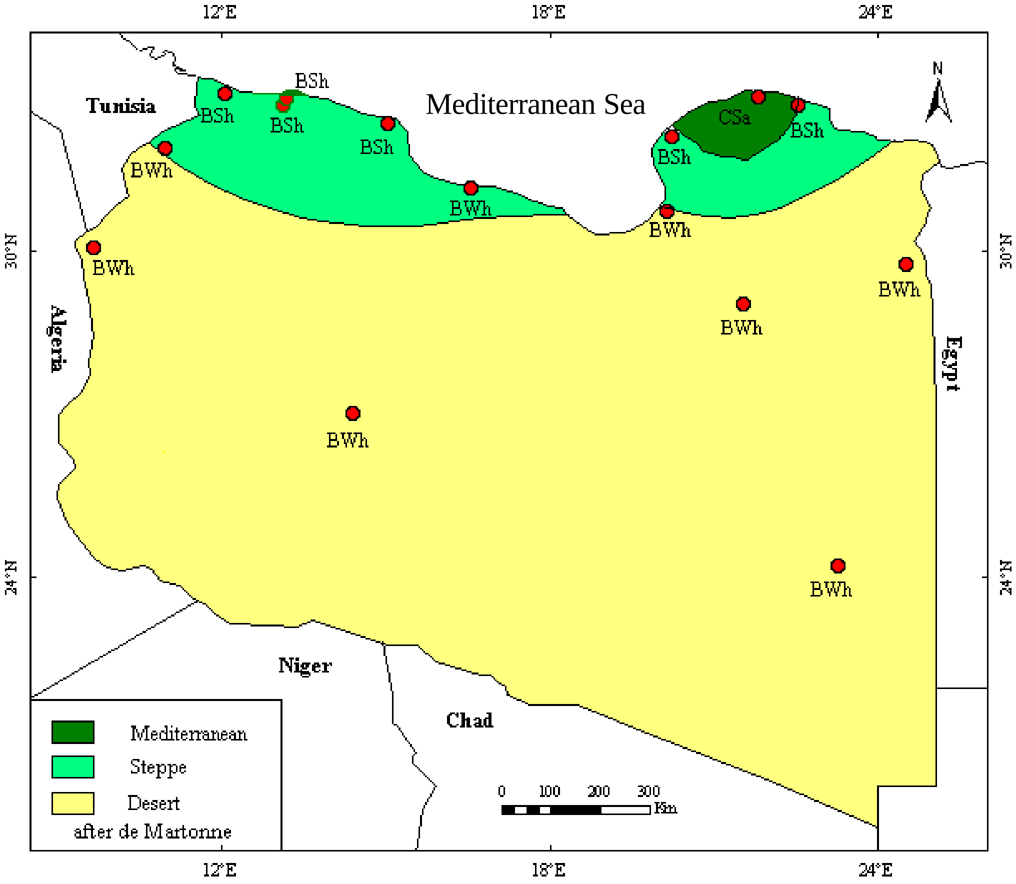
T = mean annual temperature (°C)

Due to the De Martonne aridity index, climate can be identified by the following types as: desert (0-5); steppe (5-12); Mediterranean (15-20); sub-humid (20-30); humid (30-60) very humid (>60). Based on precipitation and temperature data (1946-2000), arid indices were computed at all stations under study in Libya to produce the regions shown (Fig. 13).

Arid desert climate type: It occupies most of Libya stretching from the south border to the Mediterranean Sea along the Gulf of Sirt. Deserts are characterized by low precipitation that is highly variable both intra- and inter-annually. Desert air is very dry, large daily temperature fluctuations occur and the potential evapotranspiration is high (NOBLE and GITAY, 1995:162). The desert climate type in Libya is distinguished by high mean annual temperature, El-Kufra (23.3 °C), Sebha (23.4 °C), and by erratic annual rainfall, El-Kufra (2.1 mm), Sebha (9.0 mm), and a very high mean annual temperature range, El-Kufra (15 °C), Sebha (14.7 °C). Summer temperatures are extremely hot, mean summer temperature are30.8 and 30.6 °C at El-Kufra and Sebha, respectively. The dry air enables rapid relative cooling during winter, when temperatures reach at El-Kufra (14.2 °C) and at Sebha (12.8 °C). Annual precipitation totals under the desert climate type are generally less than 50 mm; it sometimes falls violent after thunderstorms. The rare and isolated rain showers are caused chiefly by incursions of unstable maritime polar air (mP) from the northwest or the occasional penetration of moist equatorial air from the south.

In the desert, the hot summer (Jun.-Aug.) is almost rainless. In November 1937, an exceptionally heavy thunderstorm raged during the night in the area from Edri to Brak in western Libya included the southern sand desert collapsing most houses in Akar north of Sebha. In autumn (Sep. - Nov.) 1963, rainstorms filled west of Hiruj EsSawda in the middle of Libya resulting large basins of water fold to about 2 meters. Deeps and Wadis carried water for up to four months (KANTER, 1967: 99). Mean annual relative humidity in this type is low, El-Kufra (29.3 %) and Sebha (33.9 %) with decreasing values of 21.7 % and 25 % in summer and increasing values of 41.6 %, 46.7 % in winter, respectively.

Fig. 13: Climatic types in Libya, after the Köppen and De Martonne climate classification schemes



Data source: Libyan Meteorological Department, Tripoli

Steppe climate type: It is found mostly on the northern margins of the arid climate with decreasing mean annual temperatures northwards (Misurata 20.4 °C, Zuara 19.8 °C). A few higher mountain ranges rise from the desert fringe, showing slight deviations in the increase of precipitation and temperature (Jebal Naffusah in northwestern Libya and Jebal El-Akhdar in northeastern Libya). Annual precipitation usually ranges from 100 to 350 mm (Tripoli airport 277 mm, Misurata 274, Derna 269 mm), most of it occurring during winter due to the penetration of cyclonic storms associated with the equatorward shift of the westerly wind belt. Mean annual temperatures are high exceeding 18 °C at all stations (Zuara 19.8 °C, Benina 20.1 °C). The moderating influence of the Mediterranean Sea helps to keep temperature relatively low during summer (GRIFFITHS, 1968: 40). Mean annual relative humidity is higher than for the desert climate type (Zuara 73 %, Misurata 70.8 %).

Sub-humid Mediterranean climate type: This type is caused by the seasonal shift in latitude of the Subtropical High and the Westerlies. During summer, the Subtropical high shifts poleward into the Mediterranean region, blanketing them with dry, warm and stable air. As winter approaches, this pressure center retreats equatorward, allowing the Westerlies, with their eastward-traveling weather fronts and cyclonic storms, to overspread this region (SCOTT, 2001). It is characterized by a distinctive pattern of dry summers and moderately wet winters; annual precipitation is above 325 mm.

This region occupies El-Jebal El-Akhdar region in northeastern Libya and a tiny area around Tripoli city in northwestern Libya. In altitudinal respects, there is a cooler and wet altitudinal climate which resembles that of the Mediterranean (at Shahat on Jebal El-Akhdar (621 m), the mean annual temperature is (16.5 °C) and the annual precipitation is (559 mm). Most precipitation is in the form of rain and snow is rare. In most instances, precipitation is associated with Northerlies or Westerlies so that obviously wind exposed northern and western slopes are wetter than the sheltered southern and eastern slopes.

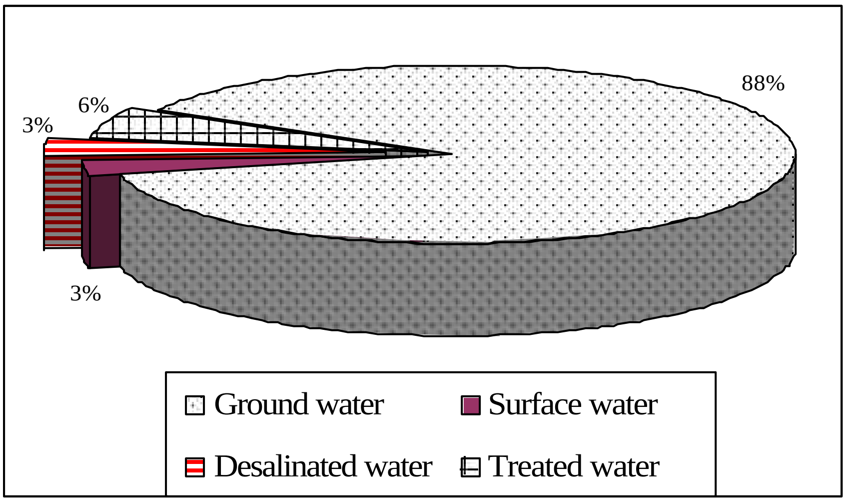
Concerning livelihoods systems, in general, light pastoral use is possible in arid areas, in semi-arid areas, grazing is satisfactory, agricultural areas are irregular and rainfed agriculture prevails, while irrigated agriculture prevails in Mediterranean climate.

2.4 Water resources

Based on Libyan General Water Authority and General Environmental Authority reports, water resources in Libya were compiled (Fig. 14):

Groundwater is the main source of water supply with 88 % of the water needs. It is found in five basins, three of them in northern Libya: Jifara Plain, El Jebal El-Akhdar, El-Hamada El-Hamra, two in southern Libya: Murzuq and El-Kufra-Serir. The basins in the north suffer from severe deterioration; their recharges have not been precisely determined, it is estimated about 500 mill. m^3 per year only from precipitation. Water storage of the basins in the south is not renewable, but the basins contain huge storage of water. These storages are transferred to the northern areas by the Great Man-made River Project (EL-TANTAWI, 1998a).

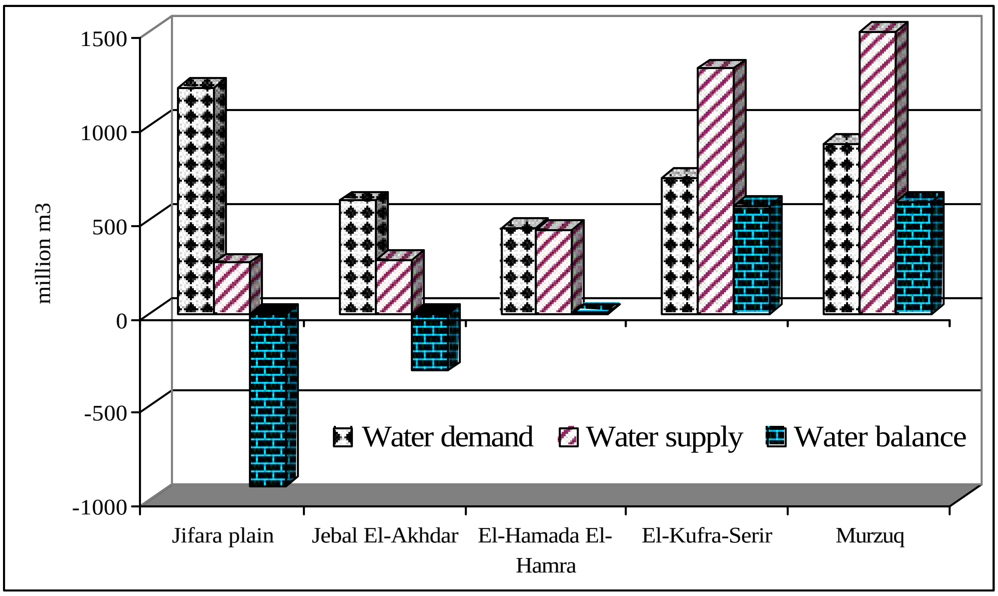
Fig. 14: Water resources in Libya, 2000



Data source: GENERAL ENVIRONMENTAL AUTHORITY, 2002: 67

According to water balance of the groundwater basins in Libya, a severe deficit in water supply occurs in the Jifara Plain basin and moderate deficit in Jebal El-Akhdar basin explained by concentration of population in northwestern and northeastern Libya. While there is no deficit water in the southern basins (El-Kufra-Serir and Murzuq), this water is not renewable (Fig. 15). Groundwater in southern Libya is from last pluvial period to Ca. 8000 years. UN research groups estimate the amount of groundwater in El-Kufra basin with 200 billion m^3 and in sarir 15 billion m^3 (SCHLIEPHAKE, 2004: 210).

Fig. 15: Water balance in the groundwater basins in Libya, 1995



Data source: BEN-MAHMOUD, et al., 2000

Surface water is controlled by precipitation reflecting its deficiency in an absence of permanent streams. It supplies about 3 % of the total water consumption (Fig. 14). Libya has established 16 dams on the wadis with a total storage capacity of 385 million m^3 and an average annual capacity of 60.6 million m^3 per year; this water appears in winter season only (General Environmental Authority, 2001: 50). These dams serve both as water reservoirs and for flood and erosion control. The wadis are heavily settled because soil in their bottoms is often suitable for agriculture. And often a high water table in their vicinity makes them logical locations for well digging (McMORRIS, 1979: 67).

Many springs are found in mountainous areas. A big number of reservoirs in the coastal parts derive from roman origin; these reservoirs are considered as one of the early storage systems of runoff water. Additional dams are planned to achieve a total storage capacity of 686 million m^3/year of precipitation water (EL-TANTAWI, 1998a).

Unconventional water (desalinated and treated water): A number of desalination plants have been built near large municipal centers and industrial complexes. The total desalinated water was 120 million m^3 in 2000 (General Environmental Authority, 2002, 67). A number of sewage-treated water plants are already in operation or planned for the near future, for example, El-Hadaba El-Khadra plant was established in 1970 in the south of Tripoli city. The treated water was estimated with 91 million in 1990 and increased to 200 million m^3 in 2000 (UNEP, et al., 1996: 271).

The Great Man-made River Project described as the ‘eighth wonder of the world’ is a massive project with four-meters-diameter pipes and a length of about 4000 km aiming to divert part of the groundwater from the southern basins to the coastal areas where about 90 % of Libya’s population has settled. The project consists of three phases (THE GREAT MAN-MADE RIVER WATER UTILIZATION AUTHORITY, GENERAL WATER AUTHORITY OF LIBYA, UNEP, ET AL., 1996, TARBUSH, 1988, and EL-TANTAWI, 1998a):

The first and largest phase, water is produced by two well fields (Serir and Tazirbu) in southeastern Libya to carry 2 mill. m^3/day of water to the coastal areas extending from Ben-Ghazi to Sirt. This phase was completed in September 1991.

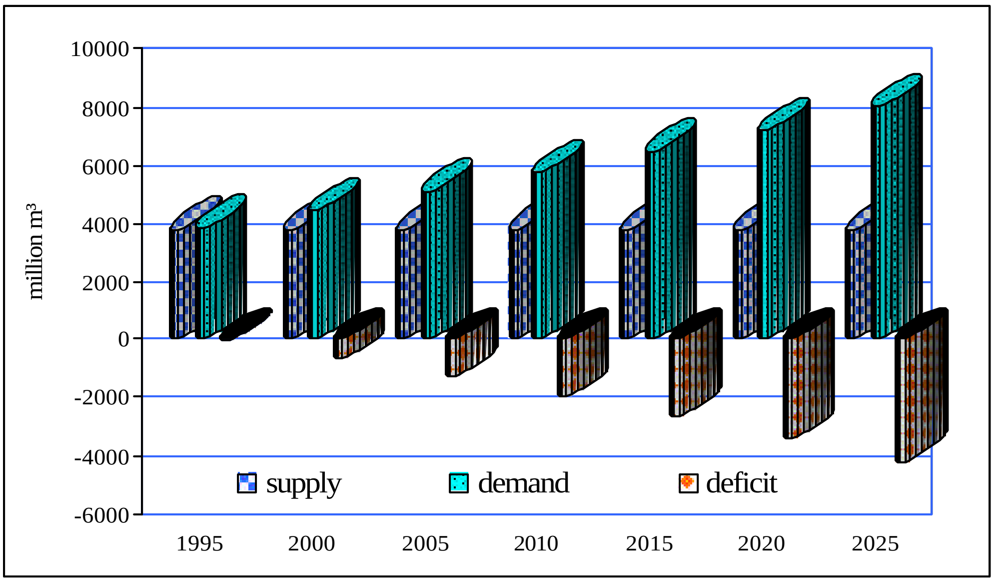
The second phase delivers 1 mill. m^3/day of water to the fertile Jifara Plain in north-western Libya from more than 500 wells distributed in several fields of the Murzuq Basin in southwestern Libya. This phase was completed in September 1996.

The third phase consists of three parts; the first one conveys 1.68 mill. m^3/day of water to the first phase from an additional well field within El-Kufra-Serir Basin. The second and the third one do not involve any additional water productions. Instead, conveyance lines of the first phase (Agedabia reservoir) will be extended farther to the east to reach Tobruq in the east of coastal area, and farther to the west to link (Sirt Reservoir) with the second phase pipelines. The third phase is carried out due to the financial possibilities and the needs of water; the first part will be operated in 2010, while the first and the second phases were linked in 2000, all phases will be completed in 2015 (SCHLIEPHAKE, 2004: 212).

The Great Man-made River Project will carry 5.68 mill. m^3 of water a day from the southern basins to the heavily populated areas in the north: 3.68 million m^3 in the eastern conveyance system and 2 mill. m^3 in the western system, with 80 % of its water being used for irrigation. The scheme is expected to cost around $ 25 Billion, including the provision of associated agriculture and utilities infrastructure (TARBUSH, 1988: 6).

Libya has been exploiting its non-renewable fossil water to relieve the immediate pressure of water stress in northern parts. Non-renewable fossil water supplies are accessible, the ratio of withdrawal to water resources is high and the potential for additional water supply is either marginal or nil (mean annual precipitation in southern Libya ranges from 0-25 mm).

Fig. 16: Water deficit in Libya, 1995-2025



Data source: EL-TANTAWI, 1998b, after General Water Authority of Libya

It is noted that in Libya the amount of water withdrawal is over eight times its renewable water resources. The gap is filled largely by the pumping of fossil groundwater (FAO, 2001). Water needs of Libya are growing rapidly and water deficit will be more than 4 billion m^3/year in 2025 (Fig. 16).

Total annual renewable water resources in Libya in 2000 was about 0.70 billion m^3, and renewable water resources were 538 m^3/capita/year in 1960, (154 m^3) in 1990 (154 m^3), projected to 55 m^3 in 2025 (HIRJI and IBREKK, 2001). With the intensification of water resources stress and the limited potential for additional water supply, increasing emphasis has been given to the improvement of water use efficiency in recent years. In the agricultural sector, it has been concretized as ‘more crop and higher value per drop’ (YANG and ZEHNDER, 2001: 1315).

3. Observed climate changes

Climate of the past 1000 years has undergone a warm period during the middle ages (1150-1350 A.D.) followed by a cold period known as the 'little ice age' (1500-1850 A.D) and a warming trend was set from 1880 until the late 1930s and early 1940s (MGELY, 1984: 1). Recent climate analyses for the last 1000 years over the northern hemisphere indicate that the magnitude of 20th century warming is likely to have been the largest of any century during this period. In addition, the 1990s were experienced as the warmest decade of the millennium. The regional patterns of warming that occurred in the early part of the 20th century were different from those occurred in the latter part, as well as for three periods according to IPCC division (1910-1945), (1946-1975) and (1976-2000) in the Third Assessment Report about Climate Change, 2001. The more recent period of warming (1976-2000) has been almost global. The overall picture does also suggest an increase in the frequency of extreme events (JACQUELINE, 2000). Climatic parameters trends (temperature, precipitation, relative humidity and cloud amount) and the trend-noise ratio over three different periods (1946-2000) as a long-term period, (1946-1975) and (1976-2000) as short-term periods were elaborated at all reference stations in order to estimate the observations of climate changes in Libya and to compare them with global climate change. These methods require the determination of the statistical significance of the trend, for which the non-parametric Mann-Kendall test for trend was applied.

3.1 Global climate change

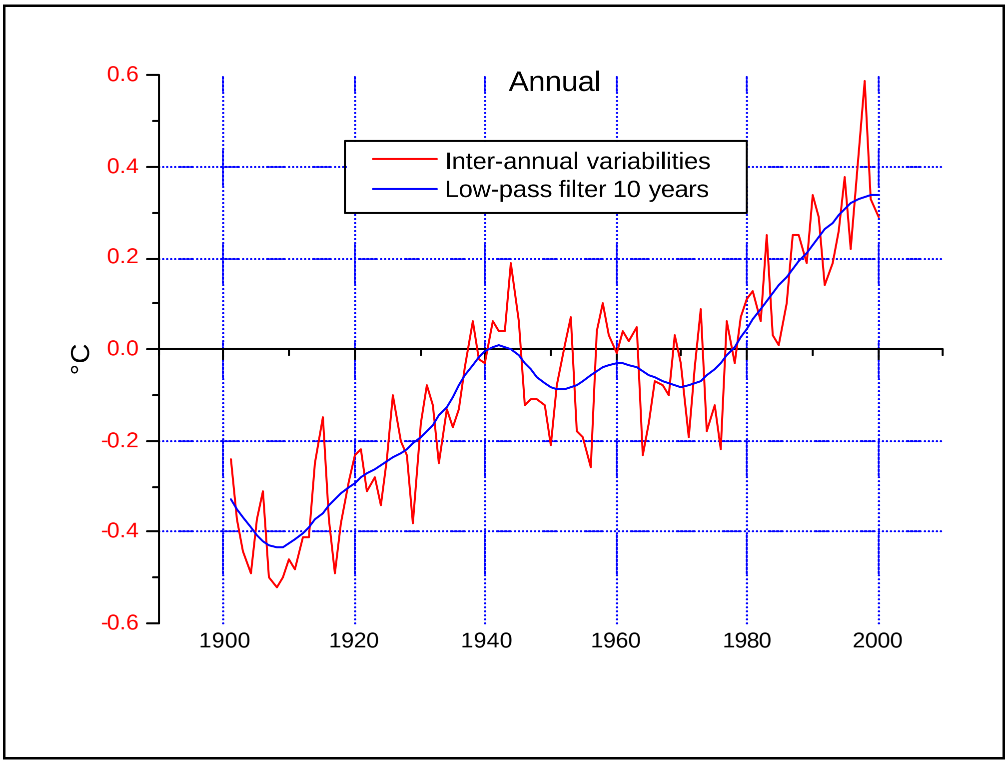
3.1.1 Observed changes in temperature

Global surface air temperature has clearly risen over the last 150 years, it is virtually agreed that a generally increasing trend in global surface air temperature has occurred over the 20th century; annual global air surface temperatures warmed by 0.62 °C over 1901-1997 (JONES, et al., 1999: 196). IPCC Third Assessment Report, 2001 and several studies objectively identified the worldwide behavior of temperature changes in the three periods; 1910-1945 (first warming period), 1946-1975 (period of little temperature changes), and 1976-2000 (the warmest period).

According to IPCC 2001, average global air surface temperature has increased by 0.6 °C (limits of close to 0.4 and 0.8 °C) during the past 100 years, with 95 % confidence. The largest recent warming occurred in winter over the extra-tropical Northern Hemisphere. The warming rate in the more recent period 1976-2000 (0.17 °C/decade) has been slightly larger than the rate of warming during 1910 to 1945 (0.14 °C/decade), although the total increase in temperature is larger for the period 1910 to 1945.

The most recent warming period has also a faster rate of warming over land compared with the oceans. The warmest years under record occur in the 1990s. The warmest year, in descending order, is 1998, 0.57 °C above the 1961-1990 average, (JONES, et al., 1999: 196). The warmest global year (1998) is associated with the 1997/98 El Niño event. Since 1861, the 1990s was the warmest decade and 1998 was the warmest year during instrumental record (HOUGHTON, et al., 2001). This increasing of temperature in the last century takes into account various adjustments, including urban heat island effects.

Fig. 17: Global inter-annual and inter-decadal tempeterature variabilities in the 20th century



Data source: JONES, et al., 2001

From the trend of the global mean annual temperature, year by year and decade by decade, according to temperature data (JONES, et al., 2001), two warming periods were seen; 1910-1945 and 1976-2000, while no significant trend of temperatures (0.01 °C/decade) from 1946-1975 was observed (Fig. 17).

Global temperatures show equivalent linear trends (Tab. 10), all trends are given in (°C/decade), it can be seen that the global annual temperature trend in the 20th century was at 0.07 °C/decade; in absolute terms, the global temperature increased at 0.7 °C from 1901-2000. The trend was linear according to the trend-noise ratio value >1.96 and very highly significant at level 0.001 according to non-parametric Mann-Kendall test for trend.

Tab. 10: Global annual and seasonal temperature trends, 1901-2000

	Trend/decade	T/noise	Test Z	Sig.
Annual temperature	**0.07**	2.87	9.72	***
Winter (December-February)	**0.07**	2.57	8.11	***
Spring (March-May)	**0.07**	2.81	9.47	***
Summer (June-August)	**0.06**	2.75	9.32	***
Autumn (September-November)	**0.06**	2.79	9.38	***

Data source: JONES, et al., 2001

T/decade = trend of temperature per decade, °C

T/N = trend-to-noise-ratio; values >1.96 indicate a linear trend

Z value = A positive (negative) value indicates an upward (downward) trend

Sig. = the tested significance levels are 0.001, 0.01, 0.05 and 0.1 as:

*** = 0.001 level of significance - ** = 0.01 level of significance

* = 0.05 level of significance - + = 0.1 level of significance

If the cell is blank, the significance level is > 0.1

Concerning global seasonal temperature trends in the 20th century, positive trends prevailed in all seasons. In *winter*, the trend was at 0.07 °C/decade (1901-2000); it was linear trend (Fig. 18) and very highly significant (Tab.10). The trend of *spring* temperature was positive at 0.07 °C/decade (1901-2000), linear and very highly significant. Due to IPCC Third Assessment Report, 2001 and JONES, et al., 1999, the bulk of global warming occurred in winter and spring. In *autumn* and *summer*, the trends were in both cases at 0.06 °C/decade, they were linear and very highly significant. It can be seen (Fig. 19) that the trend of global summer temperature was linear in the 20th century and the behavior of the trend is positive from 1910-1945, negative from 1946-1975 and strongly positive in the period 1976-2000.

1910-1945: The rate of warming for global annual temperatures (Tab. 11) shows an increase at 0.15 °C/decade, the trend was linear and very highly significant. Seasonally, all temperature trends were positive from 1910-1945 with higher values in summer and autumn.

Fig. 18: Global winter temperature trends in the 20th century

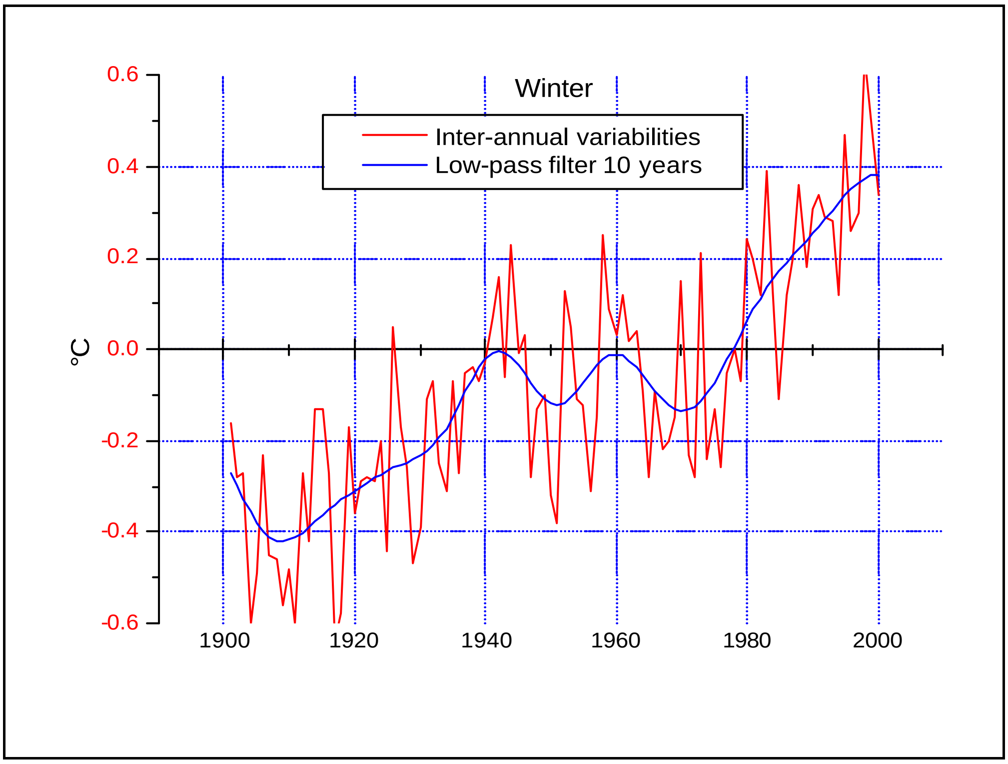
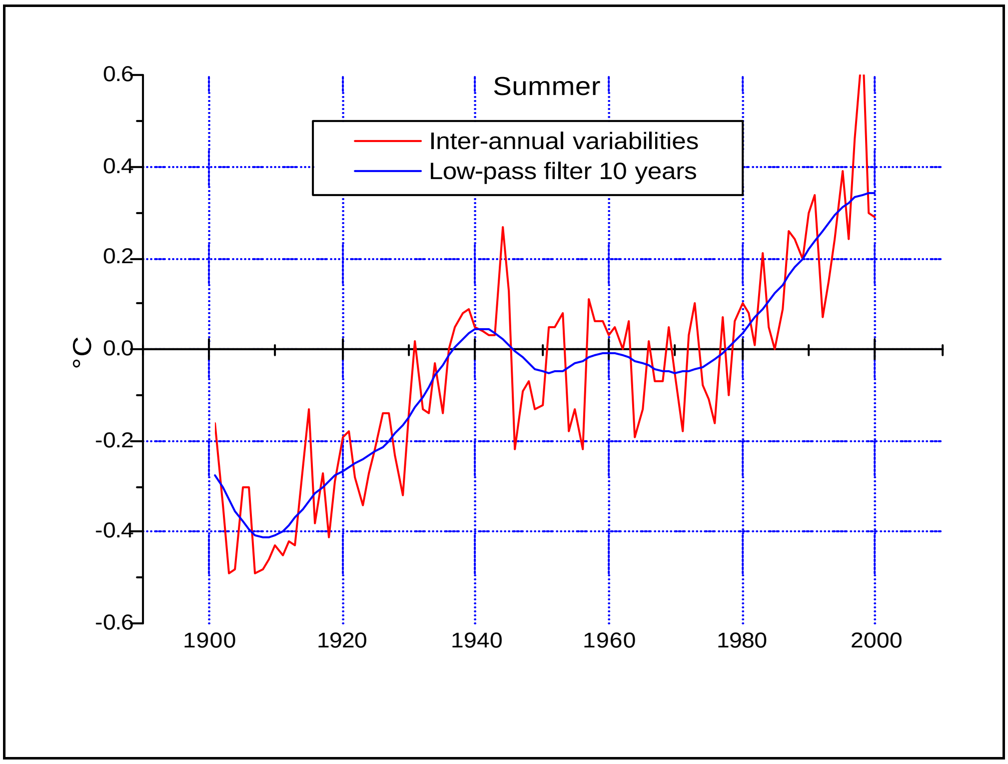


Fig. 19: Global summer temperature trends in the 20th century



Data source: JONES , et al., 2001

Tab. 11: Global annual and seasonal temperature trends, 1910-1945

	Trend/decade	T/noise	Test Z	Sig.
Annual	**0.15**	2.91	6.03	***
Winter (December-February)	**0.14**	2.30	4.53	***
Spring (March-May)	**0.14**	2.54	5.07	***
Summer (June-August)	**0.16**	2.98	6.14	***
Autumn (September-November)	**0.15**	2.93	6.26	***

Data source: JONES, et al., 2001. Explanation: see Tab. 10

1946-1975: Although positive temperature trends prevailed in annual and seasonal respects, such trends were very weakly positive (Tab. 12). This period had no significant changes of temperature and all trends were not linear.

Tab. 12: Rate of global warming for annual and seasonal temperatures, 1946-1975

	Trend/decade	T/noise	Test Z	Sig.
Annual	**0.01**	0.34	0.45	
Winter (December-February)	**0.02**	0.24	0.06	
Spring (March-May)	**0.02**	0.46	0.55	
Summer (June-August)	**0.02**	0.48	0.37	
Autumn (September-November)	**0.01**	0.26	0.23	

Data source: JONES, et al., 2001. Explanation: see Tab. 10

1976-2000: Warming during this period was globally largely synchronous, especially during winter and spring, and was faster (but inter-annually more variable) than from 1910-1945 warming. Mean annual temperature increased at 0.18 °C/decade, in absolute terms it increased at 0.45 °C. Trends of temperature in this period were very highly significant (Tab. 13), all trends were linear (due to trend-noise ratio >1.96). It can also be observed that the bulk of global warming occurred in winter and spring, in contrast to the warming period 1910-1945.

Tab. 13: Rate of global warming for annual and seasonal temperatures, 1976-2000

	Trend/decade	T/noise	Test Z	Sig.
Annual	**0.18**	2.62	4.38	***
Winter (December-February)	**0.21**	2.42	3.60	***
Spring (March-May)	**0.20**	2.60	4.63	***
Summer (June-August)	**0.19**	2.57	4.30	***
Autumn (September-November)	**0.15**	2.25	3.50	***

Data source: JONES, et al., 2001. Explanation: see Tab. 10

Concerning changes of minimum and maximum temperatures, analyses of mean daily maximum and minimum temperatures continue to support a reduction in the diurnal temperature range in many parts of the world. Globally, minimum temperatures increased at nearly twice the rate of maximum temperatures from 1950-1993. The rate of temperature increase during this time has been 0.1 and 0.2 °C/decade for the maximum and minimum temperature respectively. A reduction in the frequency of extreme low temperatures has been observed, without an equivalent increase in the frequency of extreme high over the last twenty-five years temperatures (HOUGHTON, et al., 2001).

Concerning the trends of annual temperature in global respects as well as for the Northern and Southern Hemisphere and Africa computed after JONES and FOLLAND for the periods: 1901-2000; 1910-1945; 1946-1975; 1976-2000 (Tab. 14). It can be seen that globally, for Africa and both hemispheres two periods of warming are clearly exhibited: 1910-1945 and 1976-2000. From 1946-1975, temperature trends were negative for global and northern hemisphere, no trend was observed for Africa, and slightly positive trends for southern hemisphere. It can also be observed that warming over the last century was at 0.06 °C/decade over the globe and Africa, while it was higher over the northern hemisphere and lower over the southern hemisphere after JONES, 2001. The greatest rate of warming at 0.31 °C/decade occurred over the northern hemisphere from 1976-2000, while the lowest rates of temperature warming occurred from 1946-1975. The recent great increase of mean temperature results from stronger warming in night time compared with day time (JONES, et al., 1999: 197).

Tab. 14: Decadal temperature trends over globe, northern and southern hemispheres and Africa during the 20th century

	1901-2000	1910-1945	1946-1975	1976-2000
Globe	0.06 (0.06)	0.11 (0.14)	-0.01 (-0.01)	0.22 (0.17)
Northern Hemisphere	0.07 (0.06)	0.14 (0.17)	-0.04 (-0.05)	0.31 (0.24)
Southern Hemisphere	0.05 (0.05)	0.08 (0.09)	0.02 (0.03)	0.13 (0.11)
Africa	0.06	0.14	0	0.23

Sources: 0 after JONES, et al., 2001 in IPCC, 2001
(0) after FOLLAND, et al., 2001 in IPCC, 2001
For Africa: http://co2science.org/cgi-bin/jones.pl Jones

3.1.2 Observed changes in precipitation

Historic changes in global-scale precipitation are considerably more difficult reliably to estimate from measurements than changes in surface air temperature. For example, prior to the 1970s recordings existed only for about 30 % of the total Earth's surface (HULME, 1995). Overall global land precipitation has increased by about 2 % since the beginning of the 20th century. Though the increase is statistically significant, it is neither spatially nor temporally uniform (FOLLAND, et al., 2001). The IPCC Third Assessment Report 2001, climate change: the scientific basis, pointed out that annual land precipitation has continued to increase at about 0.5-1 %/decade in the mid- and high latitudes of the northern hemisphere except over Eastern Asia. Over the northern subtropics (10-30° N), land-surface precipitation has decreased on average at about 0.3 %/decade, although this has shown signs of recovery in recent years.

DAI, A., FUNG, I. Y. and DEL GENIO, A. D. (1997) have analyzed global stations data and created a grid dataset of monthly precipitation from 1900-1988. The mode suggests that, during winters with high North Atlantic Oscillation Index (NAOI), precipitation is above normal in northern Europe, eastern United States, northern Africa and the Mediterranean, while below-normal precipitation occurs in southern Europe, eastern Canada and western Greenland. Overall, global land precipitation has increased by about 2 % since the beginning of the 20th century. The increase is statistically significant but has been neither spatially nor temporally uniform (HOUGHTON, et al., 2001).

Increasing precipitation over the tropics is not evident during the past few decades. Precipitation of Africa also exhibits high inter-decadal variabilities; there has been throughout North Africa, south of the Sahara, a pattern of continuous aridity since the late 1960s, this pattern is most persistent over the western parts, the driest period was in the 1980s with some recovery occurring during the 1990s (FOLLAND, et al., 2001). The decade 1950-1959 was characterized by above-normal precipitation over most parts of Africa, although precipitation deficiencies prevailed over the near-equatorial region. During 1960-1969, the precipitation anomaly pattern dramatically reversed with precipitation deficits observed for most of Africa while the equatorial region experienced widespread abundance of precipitation (McCARTHY, et al. 2001).

In general, global precipitation was relatively stable, or slightly increased from 1900 to the early 1940s. It then increased sharply from the mid-1940s to the mid-1950s and has remained relatively high since then over most of the land areas except the tropics, where precipitation decreased to below the 1900–1988 average in the 1970s and 1980s (DAI, et al, 1997). There is also a generally decreasing trend in precipitation since the late 1970s over all latitudes south of 60 °N. Under the most rapid global warming scenario, growing areas of Africa experience changes in summer or winter precipitation. Over large parts of eastern Africa, increasing winter precipitation of 50-100 % was experienced while decreasing precipitation in summer occurred over parts of the Horn of Africa (McCARTHY, et al. 2001).

The temporal change of global precipitation is directly attributed to the changes of temperatures and its effect on the global air pressure systems and air masses movements (RITTER, 2003). The existence of such precipitation time series, nevertheless, enables a comparison to be made between terrestrial-mean precipitation and global-mean temperature during the 20th century. While there have been considerable decadal variabilities in the relationship between temperature and precipitation; periods of global warming have actually seen no change or slight decreases in terrestrial precipitation, while periods of increasing precipitation have occurred during times with little global warming; over the duration of the observed record the "terrestrial" surface has got wetter by about 1.6 %, while the world has warmed by about 0.5 °C (HULME, 1995).

3.1.3 Observed changes in total cloud amount

Clouds are an internal component of the climate system. The presence and variations of cloud sky coverage and cloud radiative effects are closely related to atmospheric humidity (SUN, et al., 2000: 4341). Over northern hemisphere mid- and high-latitude continental regions indicate an increase in cloud cover of about 2 % since the beginning of the 20th century, this increase is positively correlated with decreases in the diurnal temperature range, similar changes have been shown over Australia, the only parts of southern hemisphere, while changes in total cloud amount are uncertain both over subtropical and tropical land areas, as well as over the oceans (HOUGHTON, et al. 2001).

3.1.4 Observed climate changes and extreme climate events

In the northern hemisphere, statistically significant increases have occurred in the annual precipitation total derived from heavy and extreme precipitation events. There has been a 2 to 4 % increase in the frequency of heavy precipitation events over the latter half of the 20th century. At the same time, relatively small increases of land areas experiencing severe drought or severe wetness have been observed. The frequency and intensity of droughts have been increased in recent decades in some regions, such as parts of middle Asia and Africa north of Sahara. In many regions, these changes are dominated by inter-annual and inter-decadal climate variabilities, such as the shift in El-Nino Southern Oscillation (ENSO) and its effect on the global warming (HOUGHTON, et al., 2001).

Extreme variabilities of precipitation are very dangerous (droughts, floods) especially in arid and semi-arid lands. In trying to define a wet season or a season of reliable precipitation, it is necessary to consider not only the amount of precipitation but also its variability (LOCKWOOD, 1974: 118). Droughts and floods are two extremes of precipitation variability. Such extreme precipitation events are usually associated with large anomalies in the atmospheric circulation (in terms of both spatial scales and magnitude), and the resulting anomalous surface conditions may amplify and prolong the perturbations (DAI, et al., 1997: 2956)

3.2 Observed climate changes in Libya

3.2.1 Observed changes of temperatures

3.2.1.1 Temporal temperature trends

Trends of temperature have been computed in the present study for a long-term period (1946-2000) and for two short-term periods (1946-1975) (1976-2000) referring to the mean of annual, minimum and maximum as well as seasonal temperatures.

Trends of mean annual temperature

Long-term trends 1946-2000

According to the least-square method and the Mann-Kendall test for trend (Tab. 15), positive trends of the mean annual temperature were observed at all study stations except at Misurata (-0.05 °C/decade). The trends ranged between 0.05 and 0.31 °C/decade at Jagboub and Tripoli city, respectively. Trends at Derna, Jaghboub, Jalo and Sirt were weakly positive (Fig. 21).

Except the trends of mean annual temperature at Agedabia and Tripoli city which were linear, expressed by a trend-to-noise-ratio >1.96, most trends were, however, not linear due to the high inter-annual temperature variabilities (Fig. 20).

For significance of trends, according to Mann-Kendall test for trend, the trends at seven stations (Agedabia, El-Kufra, Ghadames, Nalut, Sebha, Tripoli city and Zuara) were very high significant at 0.001 level; high significance trends were observed at Benina, Shahat and Tripoli airport, significant trend and weakly significant trend were computed at Sirt and Jalo, respectively, while the trends of mean annual temperature were not significant in this period at Derna, Jaghboub and Misurata.

Tab. 15: Annual temperature trends (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

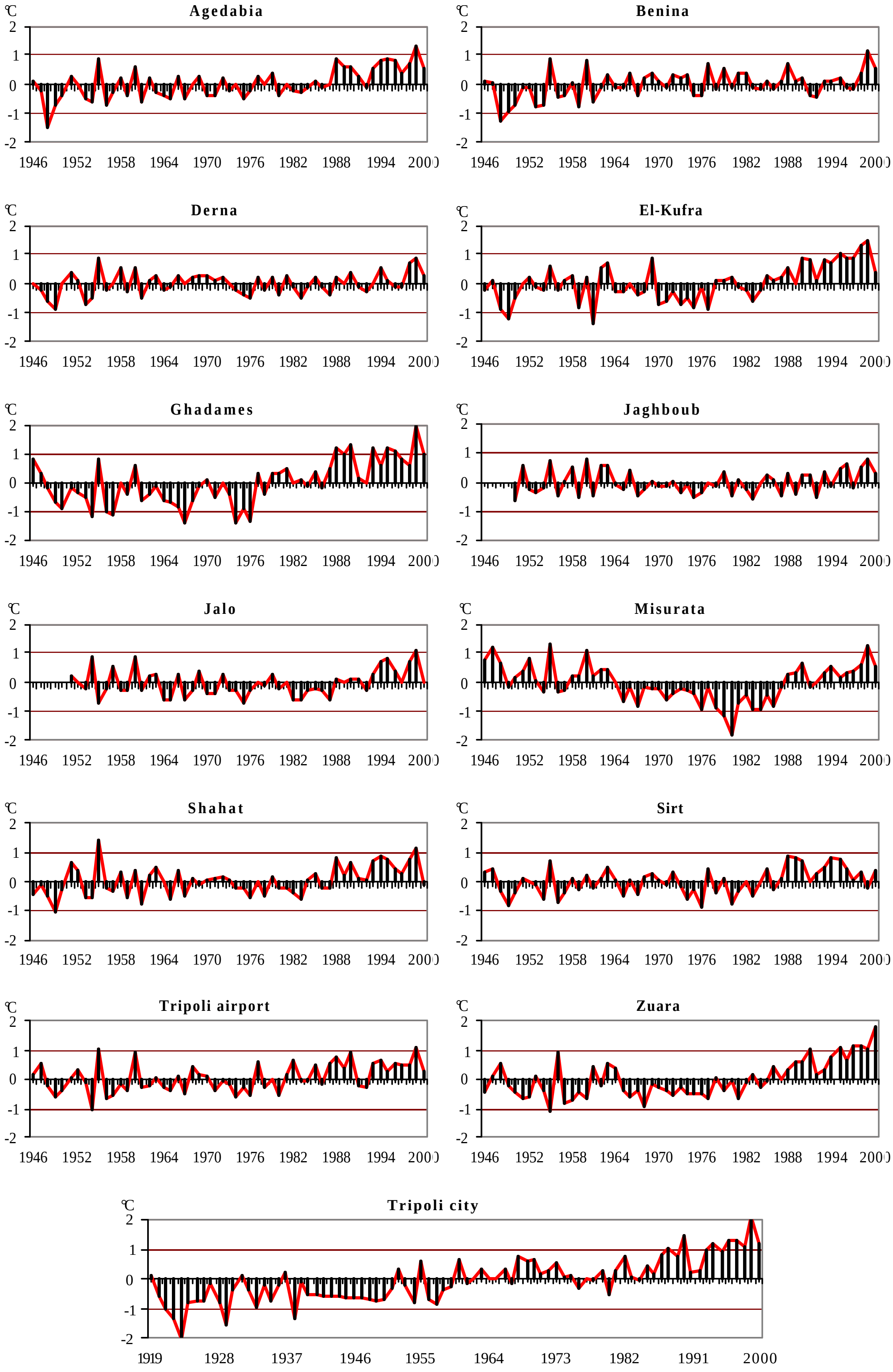
Station	Mean annual	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	20.5	**0.19**	1.97	4.46	***
Benina	20.1	**0.12**	1.36	2.66	**
Derna	20.0	**0.06**	0.86	1.39	
El-Kufra	23.2	**0.20**	1.73	3.87	***
Ghadames	21.9	**0.25**	1.75	4.41	***
Jaghboub	21.3	**0.05**	0.61	1.51	
Jalo	22.4	**0.07**	0.76	1.70	+
Misurata	20.4	**-0.05**	-0.42	-0.58	
Nalut	19.1	**0.20**	1.67	3.73	***
Sebha	22.8	**0.19**	1.67	3.99	***
Shahat	16.5	**0.12**	1.28	2.96	**
Sirt	20.4	**0.09**	1.12	2.31	*
Tripoli airport	20.5	**0.13**	1.45	3.04	**
Tripoli city	20.4	**0.31**	2.53	6.02	***
Zuara	19.8	**0.24**	1.95	4.66	***

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Short-term trends 1946-1975

The trends of temperature and the Mann-Kendall test for trend in the short-term period 1946-1976 (30 years) were computed for all study stations (Tab. 16) in order to investigate the behavior of trends and their significances.

Fig. 20: Anomalies of mean annual temperatures in Libya, 1946-2000



Decreasing trends prevailed at nine stations, while increasing trends were observed at the remaining six stations in this period (Agedabia, Benina, Derna, Shahat, Sirt and Tripoli city). Decreasing trends ranged between -0.35 and -0.01 °C/decade at Misurata and Nalut, while increasing trends ranged between 0.01 and 0.38 °C/decade at Sirt and Tripoli city, respectively.

All trends, except at Tripoli city which was linear and high significant, were not linear, expressed by a trend-to-noise-ratio value >1.96, resulting from high inter-annual temperature variabilities at all stations (Fig. 21).

It has also been noticed that most trends in this period were not significant due to Mann-Kendall test for trend.

Tab. 16: Trends of annual temperature (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-1975

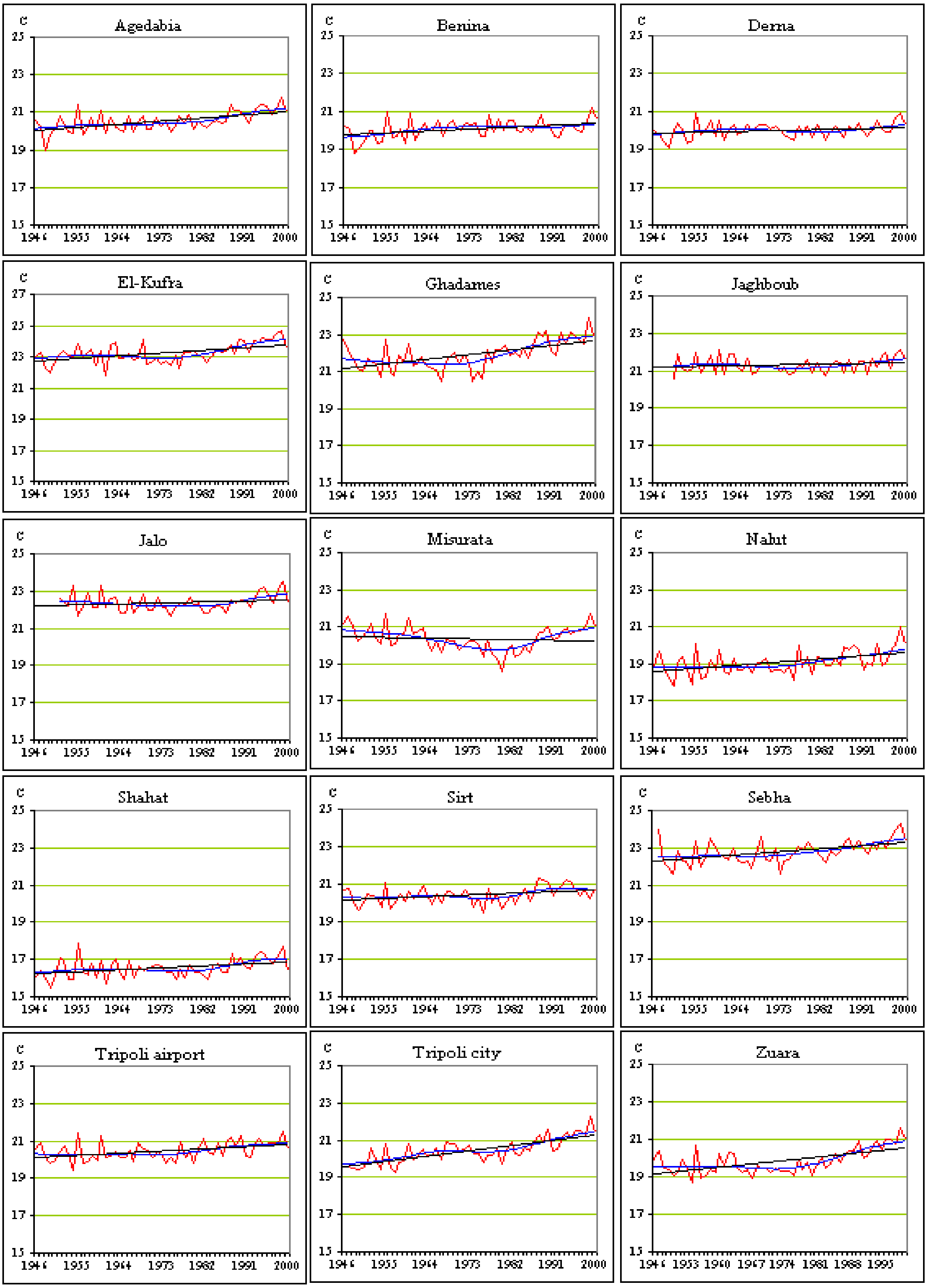
Station	Mean annual	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	20.3	**0.08**	0.49	0.63	
Benina	20.0	**0.23**	1.30	2.28	*
Derna	20.0	**0.09**	0.66	1.01	
El-Kufra	23.0	**-0.05**	-0.27	-0.98	
Ghadames	21.5	**-0.18**	-0.90	-1.29	
Jaghboub	21.3	**-0.08**	-0.46	-0.42	
Jalo	22.3	**-0.18**	-0.93	-1.16	
Misurata	20.5	**-0.35**	-1.83	-3.18	**
Nalut	18.8	**-0.01**	-0.06	-0.31	
Sebha	22.5	**-0.06**	-0.30	-0.17	
Shahat	16.4	**0.07**	0.41	0.82	
Sirt	20.3	**0.01**	0.08	0.11	
Tripoli airport	20.3	**-0.03**	-0.2	-0.13	
Tripoli city	20.1	**0.38**	2.18	3.49	***
Zuara	19.5	**-0.10**	-0.62	-0.72	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Short-term trends 1976-2000

According to IPCC Third Assessment Report 2001, most of global warming occurred in this period. Tab. 17 expresses the trends of annual temperatures and Mann-Kendall test for trend (Z value) from 1976-2000 (25 years) at all stations in Libya. Drastically increasing mean annual temperatures were seen in Libya in this period (Fig. 21). Trends ranged between 0.82 and 0.08 °C/decade at Misurata and Benina, respectively.

Fig. 21: Inter-annual variabilities and trends of annual temperature in Libya, 1946-2000, 1946-1975 and 1976-2000



Agedabia

Benina

Derna

El-Kufra

Ghadames

Jaghboub

Jalo

Misurata

Nalut

Shahat

Sirt

Sebha

Tripoli airport

Tripoli city

Zuara

Data source: Libyan Meteorological Department, Tripoli

Tab. 17: Trends of annual temperature (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1976-2000

Station	Mean annual	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	20.8	**0.42**	2.25	3.33	***
Benina	20.2	**0.08**	0.49	0.64	
Derna	20.0	**0.23**	1.56	2.17	*
El-Kufra	23.5	**0.62**	2.58	4.22	***
Ghadames	22.4	**0.65**	2.29	3.30	***
Jaghboub	21.4	**0.28**	1.72	2.58	**
Jalo	22.4	**0.35**	1.90	2.83	**
Misurata	20.2	**0.82**	2.70	4.80	***
Nalut	19.4	**0.44**	1.61	1.95	+
Sebha	23.1	**0.37**	1.91	2.86	**
Shahat	16.7	**0.46**	2.22	3.38	***
Sirt	20.5	**0.33**	1.64	2.16	*
Tripoli airport	20.7	**0.30**	1.57	1.96	+
Tripoli city	20.8	**0.70**	2.66	4.45	***
Zuara	20.2	**0.78**	2.89	5.08	***

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

It can also be noticed that the trends at Agedabia, El-Kufra, Ghadames, Misurata, Shahat, Tripoli city and Zuara were linear and very high significant. The trends at Jaghboub, Jalo and Sebha were not linear but were high significant. Significant trends at Sirt and Derna was observed, weakly significant at Nalut and Tripoli airport, while the trend at Benina was not significant. Strongly positive trends of mean annual temperature in the period 1976-2000 at all stations in Libya are corresponding with the global warming trend.

Trends of mean minimum temperature

Long-term trends 1946-2000

Positive trends of mean minimum temperatures have been computed at all reference stations (Tab. 18). The trends ranged between 0.03 and 0.55 °C/decade at Jaghboub and El-Kufra, respectively. Linear and very high significant trends were shown at Benina, Derna, El-Kufra, Ghadames, Tripoli city and Zuara (Fig. 22). Although not linear trends - due to the trend/noise ratio values >1.96 - have been observed at the remaining stations, the trends at Jalo, Nalut, Sebha, Shahat and Tripoli airport were very high significant at level 0.001, high significant at Agedabia and significant trend at Sirt, while the trends were not significant at Jaghboub and at Misurata.

Tab. 18: Trends of annual mean minimum temperature (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

Station	Mean	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	14.3	**0.18**	1.46	3.28	**
Benina	14.9	**0.36**	2.63	6.39	***
Derna	16.6	**0.18**	2.03	4.51	***
El-Kufra	15.7	**0.55**	2.78	6.25	***
Ghadames	14.1	**0.42**	2.13	4.55	***
Jaghboub	13.6	**0.03**	0.32	0.69	
Jalo	15.2	**0.24**	1.88	3.70	***
Misurata	15.6	**0.09**	0.65	1.14	
Nalut	13.7	**0.26**	1.92	4.17	***
Sebha	15.4	**0.27**	1.69	4.24	***
Shahat	12.2	**0.25**	1.79	3.33	***
Sirt	15.9	**0.11**	1.07	2.14	*
Tripoli airport	13.9	**0.18**	1.66	3.48	***
Tripoli city	15.5	**0.52**	2.99	7.83	***
Zuara	15.1	**0.39**	2.48	5.93	***

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Short-term trends 1946-1975

Tab. 19: Trends of annual mean minimum temperature (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-1975

Station	Mean	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	14.1	**-0.09**	-0.43	-0.34	
Benina	14.5	**0.43**	2.00	3.33	***
Derna	16.4	**0.10**	0.79	1.15	
El-Kufra	15.0	**0.04**	0.26	0.02	
Ghadames	13.5	**-0.32**	-1.47	-2.20	*
Jaghboub	13.6	**-0.15**	-0.81	-1.53	
Jalo	14.9	**-0.04**	-0.18	-0.50	
Misurata	15.6	**-0.17**	-1.23	-1.89	+
Nalut	13.3	**0.00**	-0.01	0.22	
Sebha	15.0	**-0.23**	-1.01	-1.24	
Shahat	12.0	**-0.07**	-0.42	-0.86	
Sirt	15.7	**-0.08**	-0.49	-0.47	
Tripoli airport	13.7	**0.10**	0.70	1.13	
Tripoli city	14.9	**0.49**	2.53	4.37	***
Zuara	14.6	**0.03**	0.14	0.18	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Trends of annual mean minimum temperatures (Tab. 19) showed negative values at eight stations, while weakly positive or no trends prevailed at the remaining seven stations. At most reference stations trends of mean minimum temperature were not linear and not significance. Trends at Benina and Tripoli city in northern Libya were linear and very highly significant, significant trend at Ghadames in the west and weakly significant trend at Misurata in the north.

Short-term trends 1976-2000

Trends of annual mean minimum temperature from 1976-2000 showed a rapid warming at all stations. Trends ranged between 1.27 and 0.21 °C/decade. Most trends were above 0.50 °C/decade (Tab. 20).

Tab. 20: Trends of annual mean minimum temperature (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1976-2000

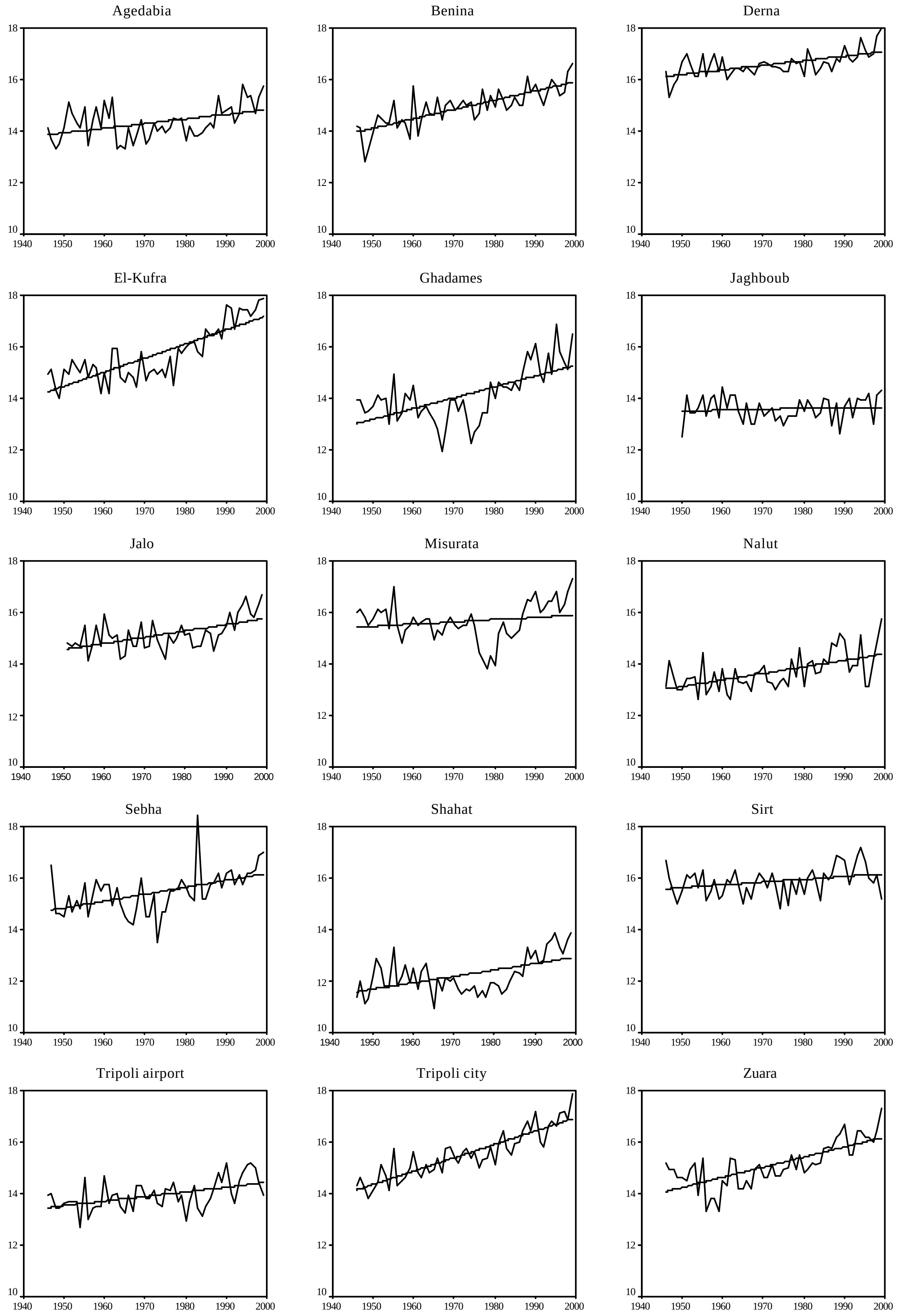
Station	Mean	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	14.6	**0.65**	2.37	3.54	***
Benina	15.4	**0.45**	2.07	3.09	**
Derna	16.8	**0.45**	2.21	3.57	***
El-Kufra	16.6	**1.11**	2.94	4.83	***
Ghadames	14.9	**1.12**	2.65	4.23	***
Jaghboub	13.6	**0.21**	1.08	2.10	*
Jalo	15.4	**0.69**	2.50	3.83	***
Misurata	15.7	**1.27**	2.90	4.70	***
Nalut	14.2	**0.37**	1.18	1.70	+
Sebha	16.0	**0.42**	1.35	3.39	***
Shahat	12.6	**1.09**	3.01	5.17	***
Sirt	16.1	**0.31**	1.19	1.67	+
Tripoli airport	14.2	**0.48**	1.71	2.44	*
Tripoli city	16.2	**0.89**	2.75	4.78	***
Zuara	15.8	**0.74**	2.62	4.14	***

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

It can also be noticed from Tab. 20 that the trends at nine stations were linear. Non-linear trends at the remaining six stations are due to the high inter-annual variabilities of minimum temperature (Fig. 22).

For significance, the trends in this period were very highly significance at 10 station, highly significant at level 0.01 at Benina, significant trends at level 0.05 at two stations, and weakly significant at Nalut and Sirt (Tab. 20).

Fig. 22: Inter-annual variabilities and trends of annual mean minimum temperature in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

Trends of mean maximum temperature

Long-term trends 1946-2000

Trends of annual mean maximum temperature ranged between 0.19 and -0.22 °C/decade. Positive trends were computed at eleven stations, while negative trends prevailed at four stations (Tab. 21). Trends at all stations were not linear due to the high inter-annual variability (Fig. 23). Most positive trends of mean maximum temperature in this period were not significant.

Tab. 21: Trends of annual mean maximum temperature (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

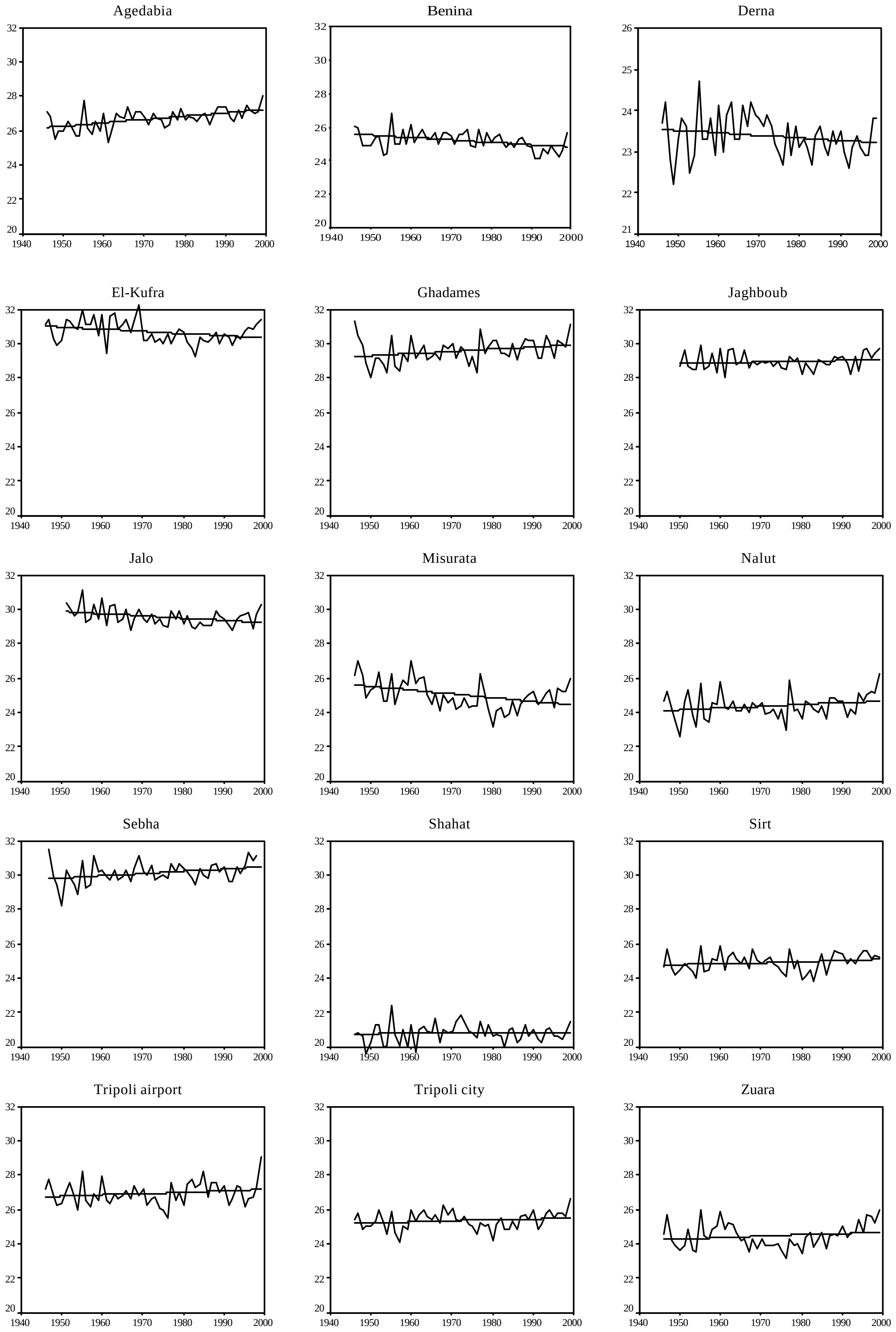
Station	Mean (°C)	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	26.7	**0.19**	1.79	3.85	***
Benina	25.2	**-0.14**	-1.34	-2.99	**
Derna	23.4	**-0.06**	-0.65	-1.65	+
El-Kufra	30.7	**-0.13**	-1.06	-2.04	*
Ghadames	29.6	**0.13**	0.99	2.46	*
Jaghboub	29.0	**0.04**	0.43	1.21	
Jalo	29.6	**0.13**	1.24	-2.31	*
Misurata	25.0	**-0.22**	-1.42	-2.57	*
Nalut	24.4	**0.11**	0.10	1.65	+
Sebha	30.2	**0.13**	1.07	2.10	*
Shahat	20.8	**0.02**	0.23	0.22	
Sirt	24.9	**0.06**	0.62	1.60	
Tripoli airport	26.9	**0.08**	0.65	1.03	
Tripoli city	25.4	**0.06**	0.63	1.17	
Zuara	24.5	**0.08**	0.62	1.69	+

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Short-term trends 1946-1975

Trends of annual mean maximum temperature were negative at eight stations ranging between -0.02 and -0.58 °C/decade, while positive trends at seven stations have been observed ranging between 0.05 and 0.24 °C/decade. Most positive maximum temperature trends were, however, weak. All trends except at Misurata in northern Libya were not linear because of high inter-annual variabilities (Fig. 23). No significant trends were shown at twelve stations, but the trends at Misurata, Jalo and Shahat were significant at level 0.001, 0.01, and 0.1, respectively (Tab. 22).

Fig. 23: Inter-annual variabilities and trends of annual mean maximum temperature (°C) in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

Tab. 22: Trends of annual mean maximum temperature (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-1975

Station	Mean (°C)	**Trend /decade**	T/noise	Test Z	Sig.
Agedabia	26.5	**0.20**	0.96	1.43	
Benina	25.4	**0.05**	0.27	0.74	
Derna	23.5	**0.12**	0.60	0.77	
El-Kufra	30.9	**-0.13**	-0.55	-1.06	
Ghadames	29.4	**-0.04**	-0.18	-0.39	
Jaghboub	29.0	**-0.02**	-0.09	-0.09	
Jalo	29.7	**-0.38**	-1.59	-2.60	**
Misurata	25.3	**-0.58**	-2.01	-3.41	***
Nalut	24.3	**-0.04**	-0.15	-0.68	
Sebha	30.0	**0.07**	0.26	0.62	
Shahat	20.8	**0.24**	1.08	1.82	+
Sirt	24.9	**0.09**	0.55	0.96	
Tripoli airport	26.8	**-0.02**	-0.94	-1.21	
Tripoli city	25.4	**0.14**	0.83	1.09	
Zuara	24.4	**-0.21**	-0.88	-1.32	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Short-term trends 1976-2000

Tab. 23: Trends of annual mean maximum temperature (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z), 1976-2000

Station	Mean (°C)	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	27.0	**0.29**	1.60	2.19	*
Benina	25.0	**-0.35**	-1.59	-2.57	*
Derna	23.2	**0.06**	0.39	0.25	
El-Kufra	30.4	**0.30**	1.46	2.14	*
Ghadames	29.8	**0.25**	0.93	0.77	
Jaghboub	29.0	**0.30**	1.51	2.13	*
Jalo	29.4	**0.11**	0.65	0.87	
Misurata	24.7	**0.43**	1.39	2.68	**
Nalut	24.5	**0.47**	1.48	2.41	*
Sebha	30.3	**0.26**	1.12	1.57	
Shahat	20.7	**0.01**	0.06	0.02	
Sirt	24.9	**0.42**	1.69	2.31	*
Tripoli airport	27.1	**0.22**	0.67	0.07	
Tripoli city	25.3	**0.55**	2.31	3.40	***
Zuara	24.6	**0.83**	2.74	4.52	***

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Positive trends of annual mean maximum temperature in this period prevailed at all study stations except one station (Benina -0.35 °C/decade) ranging between 0.06 and 0.83 °C/decade. Fig. 23 shows very highly significant and linear trends at Tripoli city and Zuara only, while not linear trends have been shown at the other remaining stations. Although the trends at most stations were not linear resulting from increasing inter-annual temperature variabilities, most of them were highly significant at level 0.01 and significant at level 0.05 (Tab. 23).

Trends of extreme events temperature

According to IPCC Third Assessment Report 2001, scientific bases, extremes are a key aspect of climate change. Changes in the frequency of many extremes (increases or decreases) can be surprisingly large for seemingly modest mean changes in climate. Moreover, changes in extremes are often most sensitive to inhomogeneous climate monitoring practices, making assessment of change more difficult than assessing the change in the mean. Climate, both at local and global scales, is not only characterized by the mean values of surface fields like temperature, but also by the frequency of occurrence of extreme events and by their intensity (TOMOZEIU, et al., 2002). Extremes of maximum and minimum temperature trends were investigated for the periods 1946-2000 and 1976-2000.

Long-term trends 1946-2000

Positive trends of extreme minimum temperatures have been observed at all reference stations in this period ranging between 0.04 and 0.82 °C/decade. Linear and very highly significant trends were shown at eight stations, while not linear trends prevailed at the remaining seven stations. Except at Ghadames, all trends were very highly, highly, significant and weakly significant (Tab. 24).

In contrast to extreme minimum temperature, the trends of extreme maximum temperature were negative or weakly positive at most stations in the period 1946-2000. Negative trends ranged between -0.11 and -0.26 °C/decade, positive trends between 0.01 and 0.14 °C/decade. All extreme maximum temperature trends were not linear. For the significance of trends, the trends at eleven stations were not significant; the remaining trends were at level 0.001, 0.05, 0.1, 0.1 of significance (Tab. 25).

Tab. 24: Trends of extreme minimum temperature (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

Station	Mean	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	9.6	**0.15**	1.03	2.13	*
Benina	10.6	**0.46**	2.77	6.98	***
Derna	13.2	**0.35**	2.51	6.30	***
El-Kufra	10.9	**0.82**	3.08	8.09	***
Ghadames	8.2	**0.53**	2.12	4.19	***
Jaghboub	9.2	**0.04**	0.33	0.37	
Jalo	10.6	**0.30**	1.90	3.87	***
Misurata	11.4	**0.16**	0.96	1.73	+
Nalut	8.5	**0.25**	1.48	3.08	**
Sebha	10.2	**0.25**	1.55	3.90	***
Shahat	8.3	**0.38**	2.41	5.34	***
Sirt	11.7	**0.16**	1.19	2.86	**
Tripoli airport	8.7	**0.29**	1.96	4.19	***
Tripoli city	10.8	**0.63**	2.85	7.08	***
Zuara	10.2	**0.49**	2.18	5.54	***

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Tab. 25: Trends of extreme maximum temperature (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z), 1946-2000

Station	Mean	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	34.2	**0.08**	0.52	1.31	
Benina	32.3	**-0.26**	-1.54	-3.56	***
Derna	31.0	**-0.20**	-0.90	-1.88	+
El-Kufra	36.7	**-0.08**	-0.61	-1.61	
Ghadames	36.6	**0.12**	0.86	1.69	+
Jaghboub	35.2	**0.00**	-0.01	-0.32	
Jalo	36.9	**-0.22**	-1.12	-2.02	*
Misurata	33.8	**-0.13**	-0.55	-1.02	
Nalut	32.3	**0.07**	0.41	1.17	
Sebha	36.6	**0.14**	0.87	1.62	
Shahat	28.5	**-0.11**	-0.63	-1.06	
Sirt	34.6	**0.02**	0.08	0.35	
Tripoli airport	35.8	**0.01**	0.06	0.09	
Tripoli city	34.2	**0.13**	0.71	1.53	
Zuara	33.9	**0.04**	0.17	0.19	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Short-term trends 1976-2000

Trends of mean extreme minimum temperature expressed a striking warming at all reference stations. The highest trend was 1.45 °C/decade at Misurata, while the lowest trend was 0.14 °C/decade at Sirt. It has also been observed that the trends at most stations were linear. The trends at eight stations were very highly significant at level 0.001. Significant trends at level 0.05 were computed at four stations, while the trends at Nalut and Sirt were not significant (Tab. 26).

Tab. 26: Trends of extreme minimum temperature (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1976-2000

Station	Mean (°C)	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	9.8	**1.00**	2.84	4.69	***
Benina	11.4	**0.52**	2.10	3.19	**
Derna	13.6	**0.36**	1.56	2.35	*
El-Kufra	12.3	**1.19**	2.94	5.42	***
Ghadames	9.2	**1.28**	2.58	4.31	***
Jaghboub	9.3	**0.35**	1.48	2.27	*
Jalo	10.9	**0.81**	2.38	3.51	***
Misurata	11.6	**1.45**	2.81	4.50	***
Nalut	8.9	**0.36**	0.87	1.42	
Sebha	10.6	**0.65**	2.02	2.22	*
Shahat	8.9	**1.03**	2.84	4.77	***
Sirt	12.0	**0.14**	0.42	1.47	
Tripoli airport	9.2	**0.43**	1.29	2.04	*
Tripoli city	11.6	**1.24**	2.69	4.42	***
Zuara	11.1	**0.85**	2.45	3.94	***

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

For mean extreme maximum temperature changes, positive trends prevailed at eight stations ranging between 0.77 and 0.03 °C/decade, while negative trends at the remaining seven stations ranging between -0.50 and -0.10 °C/decade, respectively. The trends at most stations were not linear and not significant (Tab. 27).

A change in time of either the mean value of temperature or the frequency and intensity of its extremes can affect substantially the ecosystems, the society and the economy (TOMOZEIU, et al., 2002).

Tab. 27: Trends of extreme maximum temperature (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1976-2000

Station	Mean	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	34.3	**-0.12**	-0.32	-0.10	
Benina	32.0	**-0.50**	-1.43	-1.92	+
Derna	30.7	**-0.48**	-1.19	-1.89	+
El-Kufra	36.6	**0.22**	0.75	1.02	
Ghadames	36.8	**-0.10**	0.38	-0.10	
Jaghboub	35.3	**0.03**	0.08	0.02	
Jalo	36.7	**-0.28**	-0.75	-1.02	
Misurata	33.6	**0.32**	0.71	1.47	
Nalut	32.3	**0.69**	1.63	2.36	*
Sebha	36.7	**0.35**	1.14	1.27	
Shahat	28.3	**-0.47**	-1.19	-1.57	
Sirt	34.6	**0.30**	0.71	1.37	
Tripoli airport	35.9	**-0.15**	-0.33	-0.90	
Tripoli city	34.2	**0.77**	2.33	3.86	***
Zuara	33.9	**0.62**	1.04	1.39	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Changes of mean temperature range

Long-term trends 1946-2000

Mean annual temperature range results from the respective of maximum and minimum temperatures. Negative trends were computed at all study stations except at Jaghboub ranging between 0.01 and -0.68 °C/decade (Tab. 28). Negative trends of temperature range temperatures at most stations result from the increasing mean minimum temperatures more than the increasing mean maximum temperatures.

Fig. 24 shows the linear and very highly significant trends at Benina, Derna, El-Kufra, Ghadames, Jalo, Misurata, Nalut, Tripoli city and Zuara, highly significant was showed at Shahat. The trends at Sebha and Tripoli airport were significant, while at Agedabia, Jaghboub and Sirt the trends were not linear and not significant.

Tab. 28: Trends of annual temperature range (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

Station	Mean	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	12.4	**-0.01**	-0.11	-0.76	
Benina	10.3	**-0.50**	-2.97	-7.76	***
Derna	6.8	**-0.24**	-2.09	-4.88	***
El-Kufra	15.0	**-0.68**	-2.93	-6.84	***
Ghadames	15.5	**-0.29**	-1.64	-3.62	***
Jaghboub	15.4	**0.01**	0.08	0.02	
Jalo	14.4	**-0.38**	-2.7	-6.13	***
Misurata	9.4	**-0.31**	-1.84	-4.76	***
Nalut	10.7	**-0.14**	-1.21	-3.32	***
Sebha	14.7	**-0.16**	-0.86	-2.34	*
Shahat	8.5	**-0.22**	-1.53	-3.17	**
Sirt	9.0	**-0.05**	-0.4	-0.81	
Tripoli airport	13.0	**-0.11**	-0.74	-2.16	*
Tripoli city	4.9	**-0.25**	-3.07	-7.97	***
Zuara	9.3	**-0.30**	-1.90	-4.33	***

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

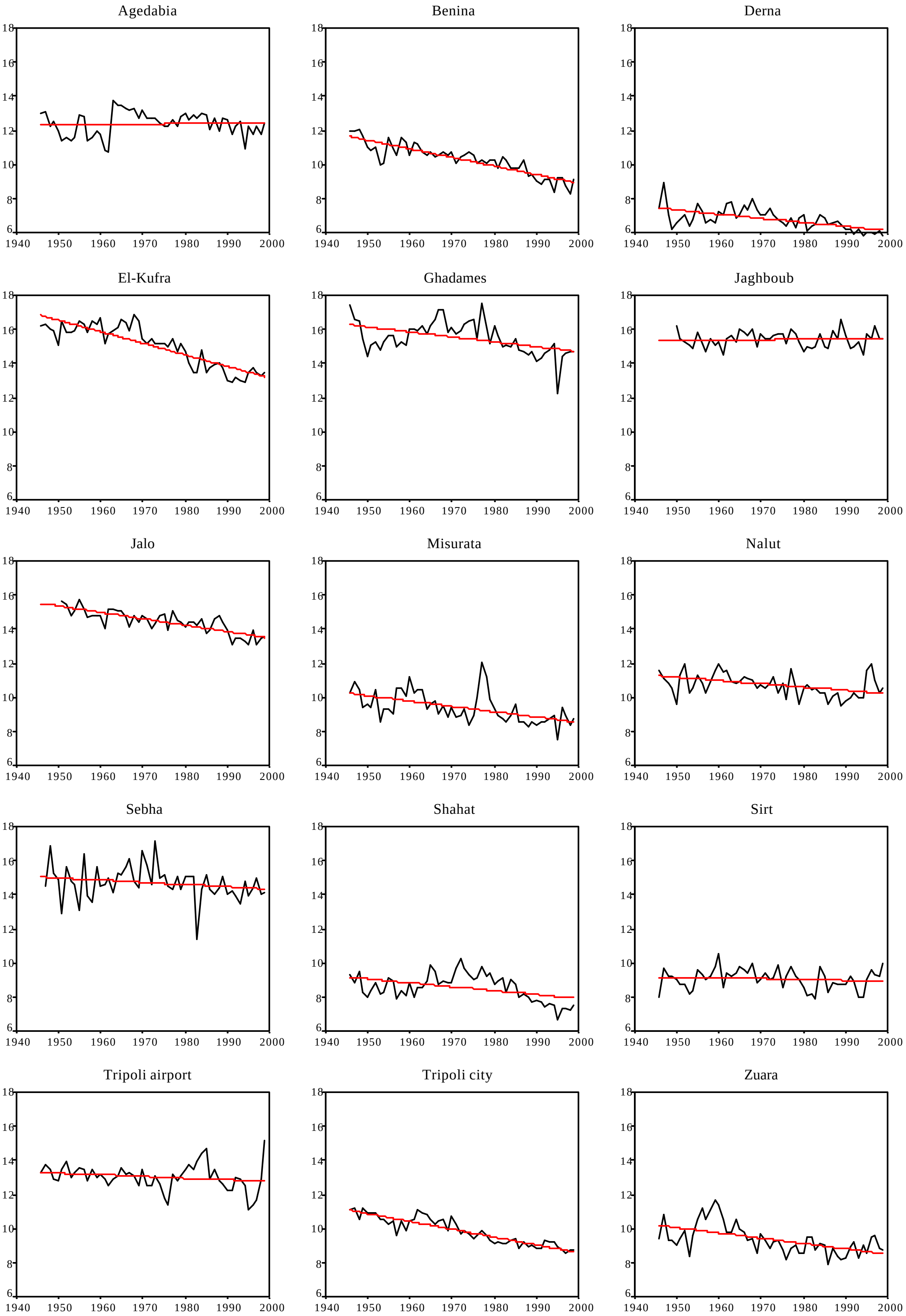
Short-term trends 1976-2000

Tab. 29: Trends of annual temperature range (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1976-2000

Station	Mean	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	12.4	**-0.35**	-1.67	-2.44	*
Benina	9.5	**-0.79**	-2.80	-4.30	***
Derna	6.4	**-0.39**	-2.30	-3.49	***
El-Kufra	13.8	**-0.80**	-2.45	-3.50	***
Ghadames	15.0	**-0.87**	-2.16	-3.79	***
Jaghboub	15.4	**0.09**	0.40	0.45	
Jalo	14.0	**-0.58**	-2.30	-3.25	**
Misurata	9.0	**-0.85**	-2.00	-2.57	*
Nalut	10.4	**0.13**	0.46	0.10	
Sebha	14.3	**-0.16**	-0.46	-1.65	+
Shahat	8.2	**-1.09**	-3.02	-5.54	***
Sirt	8.9	**0.11**	0.42	0.62	
Tripoli airport	13.0	**-0.28**	-0.62	-1.37	
Tripoli city	9.1	**-0.35**	-2.48	-3.88	***
Zuara	8.8	**0.08**	0.41	0.60	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Fig. 24: Inter-annual variabilities and trends of annual temperature range (°C) in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

Trends of annual temperature range from 1976-2000 showed negative Z values (decreasing trends) at 11 stations ranging between -1.09 and -0.16 °C decade, while positive Z values (increasing trends) prevailed at four stations ranging between 0.08 and 0.13 °C/decade. The trends were linear at eight stations in this period, while not liear trends were observed at the remaining seven stations (Fig. 24). Not linear trends due to high inter-annual variabilities. Trends were very highly significant at six, highly significant at one, significant at two, weakly significant at one station while not significant trends were noticed at the remaining five stations (Tab. 29).

Seasonal temperature trends

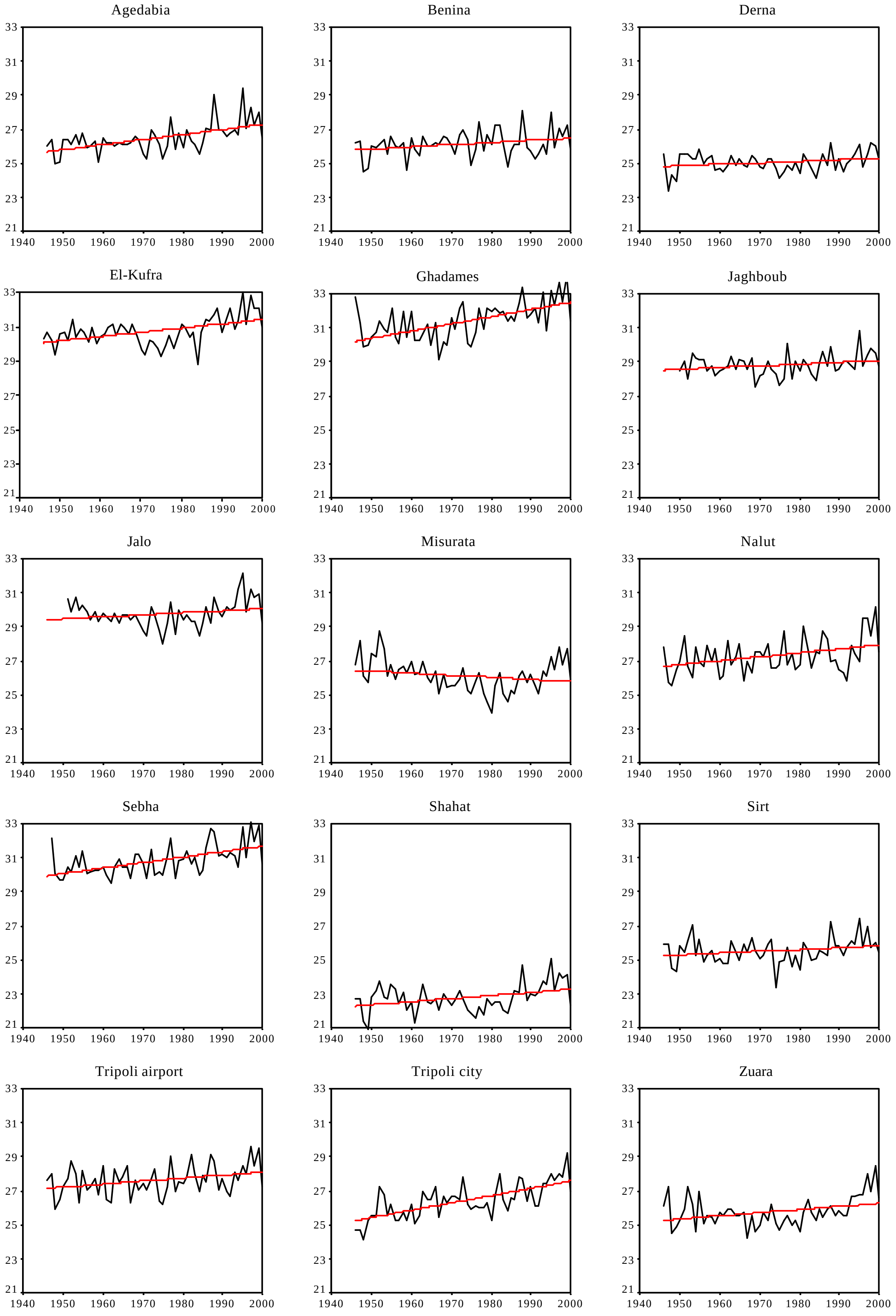
It can be strikingly seen from the seasonal temperature trends in Libya that warming mostly occurred in summer and autumn in contrast to the global observations identifying warming mostly in winter and spring. Trends of seasonal temperatures at all reference stations have been computed for all seasons - winter = December, January and February; spring = March, April and May; summer = June, July and August; autumn = September, October and November- for the period 1946 - 2000 and the period 1976 - 2000.

Long-term trends 1946-2000

Fig. 25 and Tab. 30 show the trends of temperature for *summer* from 1946-2000. Positive trends were computed at all stations except at Misurata which was negative (-0.16 °C/decade). The lowest positive trend in this period was 0.09 °C/decade, while the highest was 0.43 °C/decade. All trends in summer were not linear except Tripoli city because the inter-annual temperature variabilities were very high resulting high standard deviation. Trends were very highly significant at five stations, significant at four stations, weakly significant at one station, while they were not significant at the remaining five stations (Tab. 30).

In *winter*, the trends of temperature in general were weakly positive or negative at most stations. Weakly positive trends were computed at seven stations. High inter-annaul temperature variabilities have been shown at all stations (Fig. 26), therefore all trends in winter were not linear. The trends were not significant at all stations in this period except at Zuara and Nalut which were highly and weakly significant, respectively (Tab. 31).

Fig. 25: Inter-annual variabilities and trends of summer temperatures in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

Tab. 30: Temperature trends (°C) in summer (T/decade), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

Stations	Mean	**T/decade**	T/ Noise	Test Z	Sig.
Agedabia	26.5	**0.30**	1.89	4.10	***
Benina	26.1	**0.13**	0.94	1.18	
Derna	25.0	**0.09**	0.86	0.79	
El-Kufra	30.7	**0.25**	1.62	3.46	***
Ghadames	31.4	**0.37**	1.84	3.94	***
Jaghboub	28.8	**0.10**	0.81	1.25	
Jalo	29.8	**0.12**	0.75	0.68	
Misurata	26.2	**-0.16**	-0.94	-2.16	*
Nalut	27.2	**0.21**	1.17	2.03	*
Sebha	30.9	**0.32**	1.91	3.86	***
Shahat	22.8	**0.18**	1.22	1.85	+
Sirt	25.5	**0.10**	0.75	1.63	
Tripoli airport	27.6	**0.17**	1.07	2.01	*
Tripoli city	26.4	**0.43**	2.31	5.04	***
Zuara	25.8	**0.18**	1.14	2.50	*

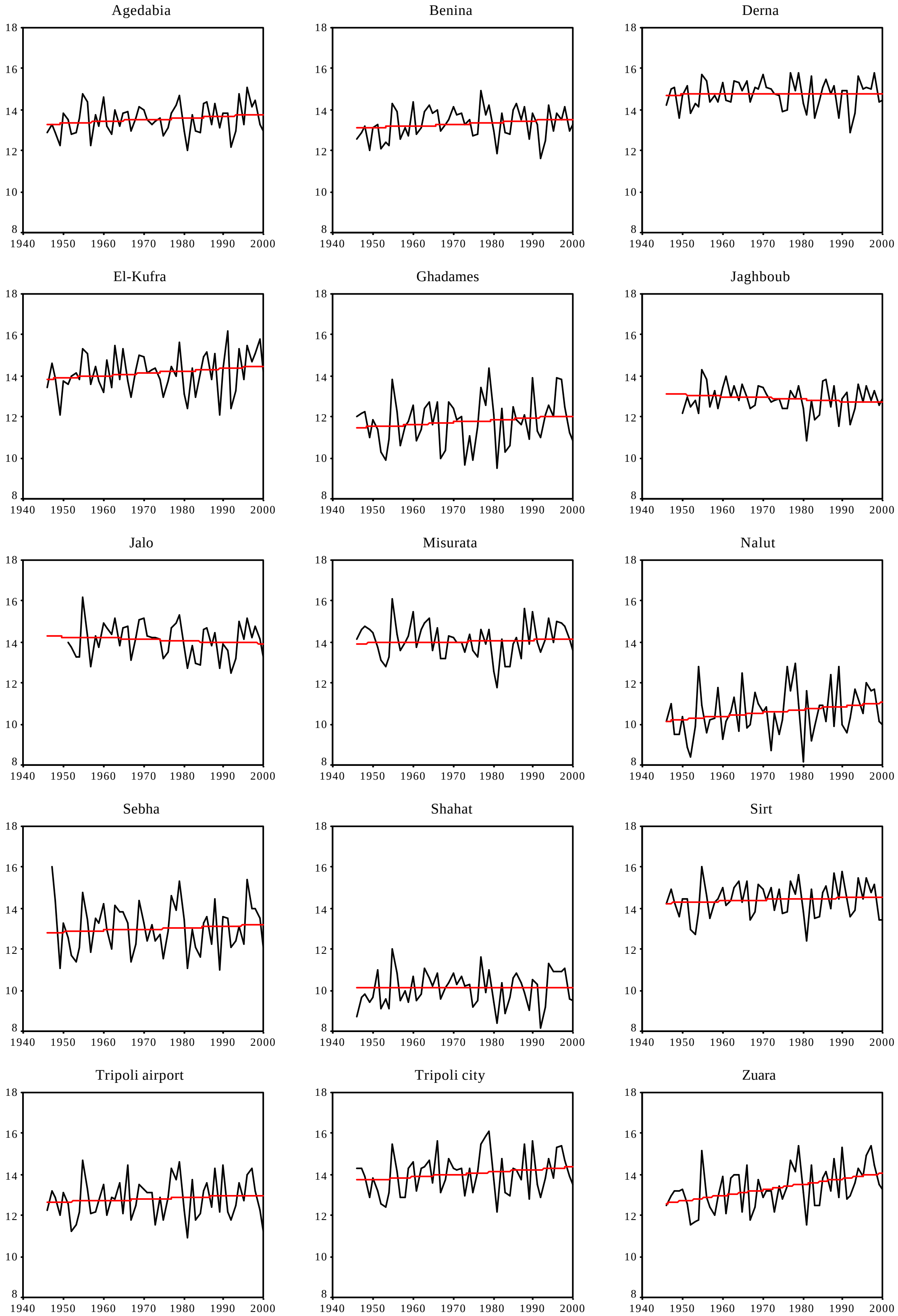
Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Table 31: Temperature trends (°C) in winter (T/decade), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

Stations	Mean	**Trend/decade**	T/ Noise	Test Z	Sig.
Agedabia	13.5	**0.09**	0.69	1.46	
Benina	13.3	**0.08**	0.60	1.39	
Derna	14.8	**0.01**	0.08	0.42	
El-Kufra	14.2	**0.11**	0.63	1.56	
Ghadames	11.8	**0.11**	0.52	0.97	
Jaghboub	12.9	**-0.08**	-0.60	-0.59	
Jalo	14.1	**-0.07**	-0.42	-0.70	
Misurata	14.1	**-0.01**	-0.08	-0.24	
Nalut	10.5	**0.17**	0.80	1.84	+
Sebha	13.1	**0.07**	0.32	0.16	
Shahat	10.1	**0.05**	0.35	1.19	
Sirt	14.4	**0.06**	0.40	0.84	
Tripoli airport	12.8	**0.07**	0.40	0.92	
Tripoli city	14.0	**0.12**	0.68	1.27	
Zuara	13.3	**0.27**	1.42	3.22	**

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Fig. 26: Inter-annual variabilities and trends of winter temperatures in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

Table 32: Temperature trends in autumn (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

Stations	Mean	**Trend/decade**	T/ Noise	Test Z	Sig.
Agedabia	22.2	**0.26**	1.46	3.22	**
Benina	22	**0.15**	1	2.31	*
Derna	22.3	**0.08**	0.7	1.64	
El-Kufra	23.8	**0.22**	1.01	2.63	**
Ghadames	22.7	**0.34**	1.48	3.15	**
Jaghboub	22.5	**0.13**	0.68	1.68	+
Jalo	23.4	**0.15**	0.82	1.58	
Misurata	22.8	**0.03**	0.16	0.01	
Nalut	20.5	**0.21**	1.13	2.49	*
Sebha	23.9	**0.21**	0.98	2.35	*
Shahat	18.3	**0.17**	1.06	2.45	*
Sirt	22.8	**0.19**	1.31	2.8	**
Tripoli airport	22.3	**0.18**	1.07	2.38	*
Tripoli city	22.6	**0.29**	1.55	3.68	***
Zuara	22.1	**0.35**	1.88	3.96	***

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Table 33: Spring temperature trends (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

Stations	Mean	**Trend/decade**	T/ Noise	Test Z	Sig.
Agedabia	19.9	**0.18**	1.14	2.62	**
Benina	18.8	**0.09**	0.64	1.69	+
Derna	17.9	**0.04**	0.35	0.76	
El-Kufra	24.2	**0.25**	1.50	3.14	**
Ghadames	21.7	**0.28**	1.48	3.05	**
Jaghboub	21.0	**0.01**	0.06	0.89	
Jalo	22.3	**0.03**	0.18	0.49	
Misurata	18.5	**-0.07**	-0.50	-1.21	
Nalut	17.9	**0.17**	0.83	1.29	
Sebha	23.3	**0.27**	1.46	3.05	**
Shahat	15.0	**0.10**	0.66	1.59	
Sirt	18.9	**0.02**	0.16	0.87	
Tripoli airport	19.0	**0.07**	0.49	0.96	
Tripoli city	18.7	**0.41**	2.04	4.58	***
Zuara	18.1	**0.17**	1.30	2.75	**

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

The behavior of temperature trends in *autumn* expressed positive trends at all study stations. Trends ranged between 0.03 °C/decade as lowest trend and 0.35 °C/decade at Zuara as highest trend. All temperature trends in autumn were not linear. Very highly significant trends at Tripoli city and zuara, high significant trends at Agedabia, El-Kufra, Ghadames and Sirt, significant trends at Benina, Nalut, Sebha, Shahat and Tripoli airport were computed, while the trends at Jalo and Misurata were not significant (Tab. 32).

In *spring*, positive trends have been observed at all stations from 1946 to 2000 except at one station which weakly negative trend (-0.07 °C/decade). Positive trends ranged between 0.01 and 0.41 °C/decade. Not linear trends were shown at all stations except at one (Tripoli city) which was linear and at level 0.001 of significance (very high). Trends at 14 stations were not linear explaind by the high inter-annual temperature variabilities in spring. Though the trends at five stations were not linear, they were highly significant and weakly significant at Benina, while the trends at Derna, Jaghboub, Jalo, Misurata, Nalut, Shahat, Sirt and Tripoli airport were not significant (Tab. 33).

Short-term trends 1976-2000

Remarkably large seasonal variations of temperature were observed for the period 1976 to 2000. *Summer* is clearly shown as the governing season responsible for the annual temperature increase from 1976-2000. Temperature trends in summer showed the highest rate of warming at 0.96 °C/decade at Zuara and the lowest rate at 0.04 °C/decade at Benina (Tab. 34). In absolute values, summer temperatures increased between 2.40 °C and 0.10 °C at Zuara and Benina, respectively.

It can also be seen that the temperature trends were strongly positive at all stations except one station with a weakly positive trend. The trends were not linear at ten stations explained by the high inter annual variabilities (Fig. 27), while at El-Kufra, Misurata, Shahat, Tripoli city and Zuara were linear. Trends at three stations were at level 0.001 (very highly significant), at four stations at level 0.01 (highly significant), at two stations at level 0.05 (significant) and at Ghadames and Jaghboub at level 0.1 (weakly significant), while the trends of summer temperature were not significant from 1976-2000 at the remaining four stations (Tab. 34).

Concerning temperature trends in *winter* from 1976-2000, positive trends were computed at nine stations ranging between 0.05 and 0.49 °C/decade at Sirt and Misurata, no trend at Derna, while negative trends prevailed at five stations ranging between -0.04 and -0.18 °C/decade at Sebha and Tripoli airport (Tab. 35).

Tab. 34: Temperature trends in summer (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1976-2000

Stations	Mean (°C)	**Trend/decade**	T/ Noise	Test Z	Sig.
Agedabia	27.0	**0.60**	1.51	2.41	*
Benina	26.3	**0.04**	0.12	0.23	
Derna	25.1	**0.42**	1.73	2.60	**
El-Kufra	31.1	**0.87**	2.18	3.59	***
Ghadames	32.1	**0.55**	1.49	1.71	+
Jaghboub	29.0	**0.33**	1.15	1.66	+
Jalo	30.0	**0.64**	1.73	2.46	*
Misurata	25.9	**0.80**	2.03	2.99	**
Nalut	27.5	**0.35**	0.91	0.86	
Sebha	31.3	**0.46**	1.03	1.59	
Shahat	23.0	**0.84**	2.83	3.86	***
Sirt	25.7	**0.50**	1.31	2.71	**
Tripoli airport	27.9	**0.25**	0.72	1.12	
Tripoli city	26.9	**0.81**	2.10	3.11	**
Zuara	26.0	**0.96**	2.53	4.16	***

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

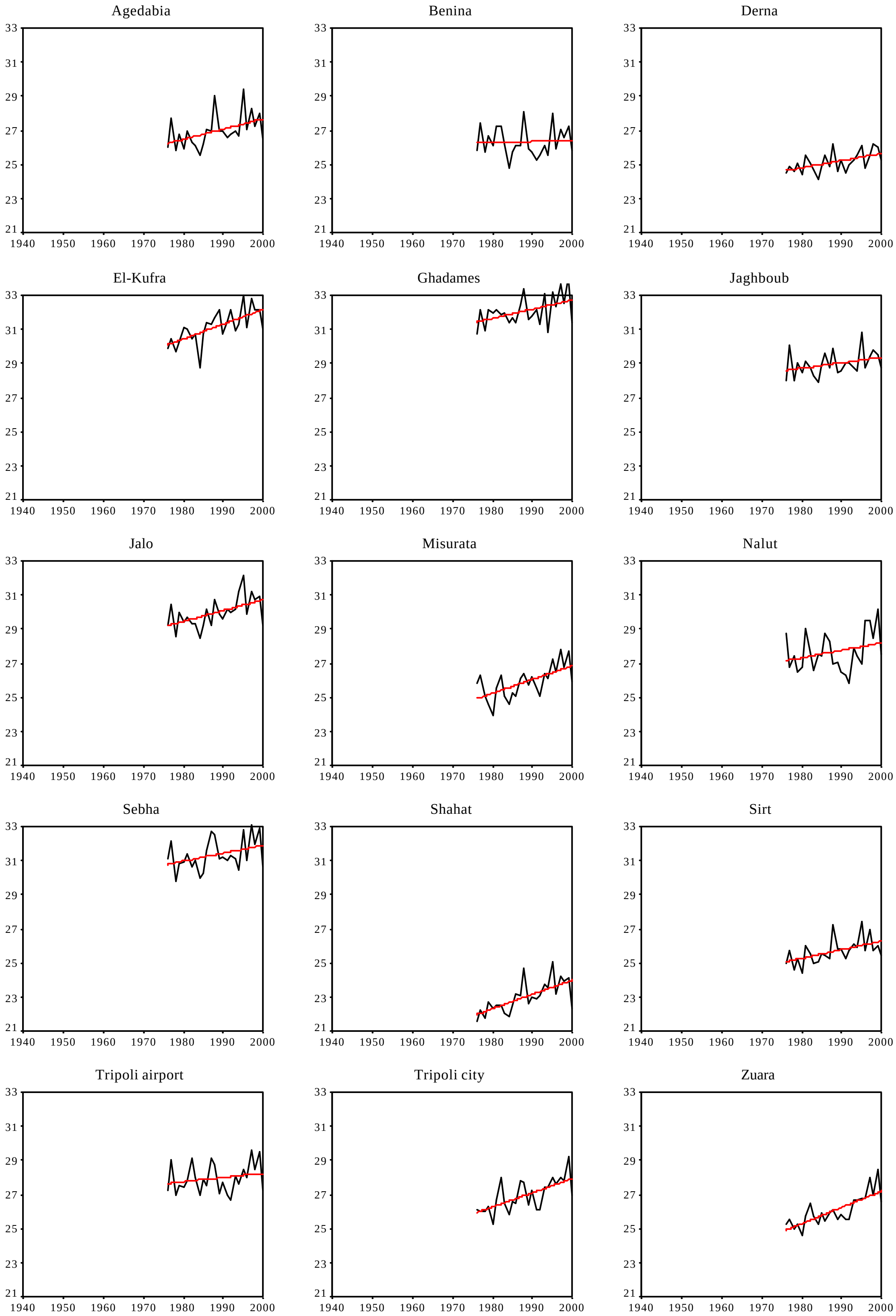
Tab. 35: Temperature trends in winter (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z), 1976-2000

Stations	Mean (°C)	**Trend/decade**	T/ Noise	Test Z	Sig.
Agedabia	13.6	**0.14**	0.41	0.59	
Benina	13.4	**-0.09**	-0.27	-0.33	
Derna	14.7	**0.00**	0.00	0.00	
El-Kufra	14.3	**0.41**	0.87	1.40	
Ghadames	12.0	**0.03**	0.07	0.02	
Jaghboub	12.7	**0.13**	0.42	0.56	
Jalo	13.9	**0.02**	0.06	0.16	
Misurata	14.0	**0.49**	1.27	1.69	+
Nalut	10.9	**-0.15**	-0.31	-0.28	
Sebha	13.1	**-0.04**	-0.07	0.00	
Shahat	10.1	**0.13**	0.33	0.63	
Sirt	14.5	**0.05**	0.14	0.00	
Tripoli airport	13.0	**-0.18**	-0.41	-0.47	
Tripoli city	14.2	**-0.13**	-0.28	-0.37	
Zuara	13.8	**0.20**	0.48	0.73	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

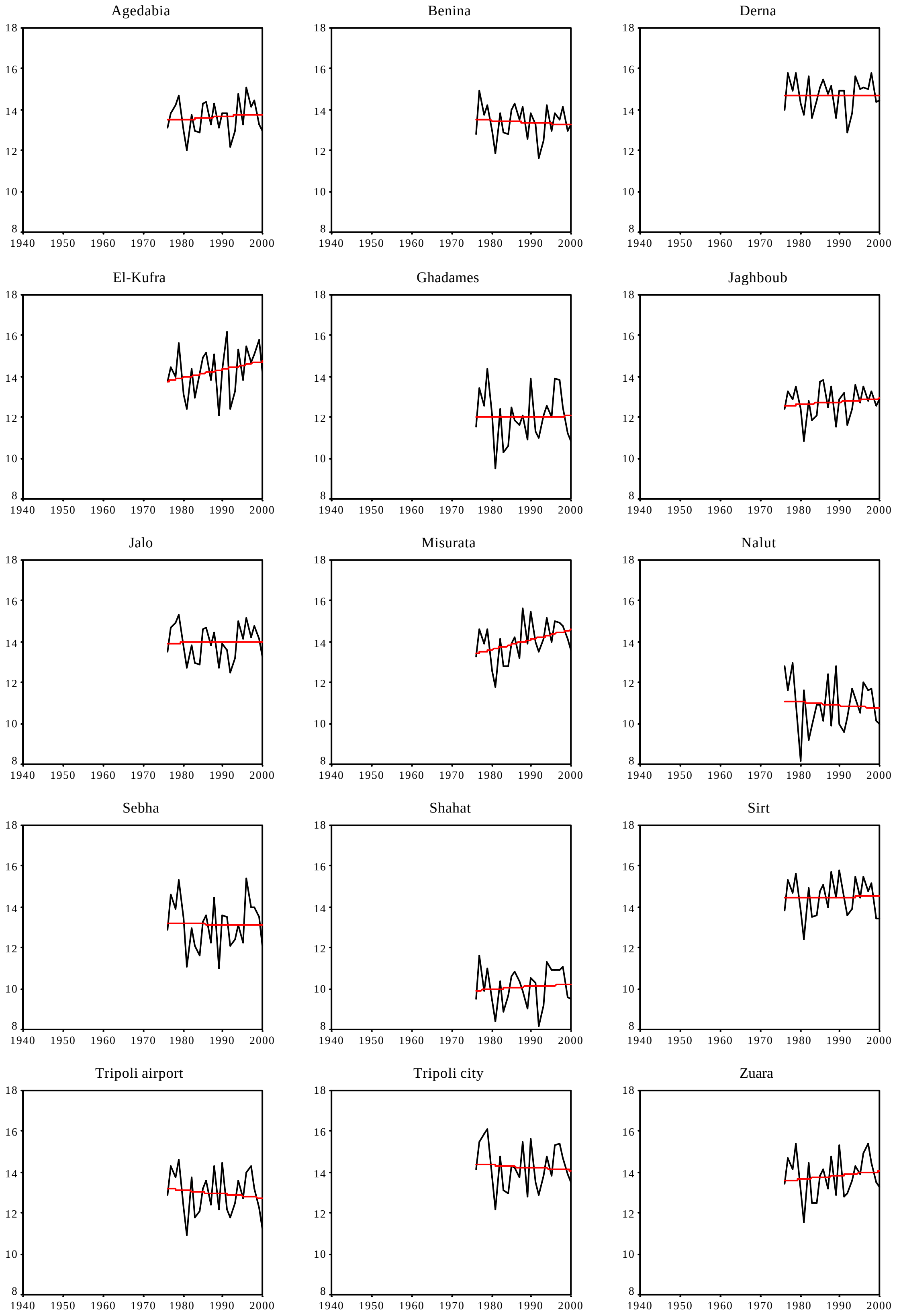
All trends were not linear (Fig. 32) and not significant except Misurata with weakly significant at level 0.1. Such observations widely differ from the global observations on

Fig. 27: Trends and inter-annual variabilities of summer temperatures (°C) in Libya, 1976-2000



Data source: Libyan Meteorological Department, Tripoli

Fig. 28: Trends and inter-annual variabilities of winter temperatures (°C) in Libya, 1976-2000



Data source: Libyan Meteorological Department, Tripoli

warming. In Libya, summer and autumn show most notably the greatest extent of warming, in contrast to the global observations that express winter and spring warming.

Autumn was clearly shown together with summer as the governing seasons responsible for the annual temperature increase at all reference stations over the recent period 1976-2000. Autumn showed the highest rate of warming at 1.24 °C/decade at Misurata, while the lowest trend was 0.48 °C/decade at Derna. In absolute values, autumn temperatures increased at a maximum of 3.10 °C. It can also be seen that the trends of autumn temperature were strongly positive at all study stations (Tab. 36).

Tab. 36: Temperature trends in autumn (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1976-2000

Stations	Mean (°C)	**Trend/decade**	T/ Noise	Test Z	Sig.
Agedabia	22.6	**0.84**	2.26	3.79	***
Benina	22.2	**0.54**	1.64	2.16	*
Derna	22.4	**0.48**	1.79	2.58	*
El-Kufra	24.1	**0.96**	2.27	3.77	***
Ghadames	23.4	**1.11**	2.09	3.34	***
Jaghboub	22.6	**0.62**	1.84	2.6	**
Jalo	23.6	**0.76**	2.03	2.9	**
Misurata	22.7	**1.24**	2.64	4.35	***
Nalut	20.9	**0.77**	1.63	2.57	*
Sebha	24.3	**0.87**	2.17	3.63	***
Shahat	18.5	**0.72**	1.9	2.79	**
Sirt	23.0	**0.86**	2.39	3.75	***
Tripoli airport	22.6	**0.76**	1.82	3	**
Tripoli city	23.0	**1.18**	2.42	4.04	***
Zuara	22.7	**1.14**	2.55	4.37	***

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

The trends at most stations from 1976-2000 were linear and high significant (Tab. 36).

In *spring*, positive trends have been observed at most stations ranging between 0.02 and 0.86 °C/decade. The trends at three stations only were negative ranging between -0.16 and -0.26 °C/decade. Not linear trends prevailed at most stations explained by the high standard deviation. Most temperature trends in spring from 1976-2000 were not significant, very highly at level 0.001 of significance at one station, highly significant at two stations and significant trend at one station (Tab. 37).

Tab. 37: Temperature trends in spring (°C), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1976-2000

Stations	Mean (°C)	**Trend/decade**	T/ Noise	Test Z	Sig.
Agedabia	20.1	**0.10**	0.27	0.44	
Benina	18.9	**-0.26**	-0.72	-1.10	
Derna	17.9	**0.00**	-0.01	-0.05	
El-Kufra	24.6	**0.24**	0.62	0.44	
Ghadames	22.1	**0.75**	1.63	2.51	*
Jaghboub	21.0	**-0.14**	-0.39	-0.56	
Jalo	22.3	**0.02**	0.05	0.16	
Misurata	18.3	**0.65**	1.86	2.71	**
Nalut	18.2	**0.66**	1.30	1.62	
Sebha	23.7	**0.29**	0.77	1.27	
Shahat	15.1	**0.13**	0.36	0.42	
Sirt	19.0	**-0.16**	-0.47	-0.05	
Tripoli airport	19.1	**0.22**	0.63	1.01	
Tripoli city	19.1	**0.86**	2.29	3.75	***
Zuara	18.3	**0.71**	2.14	3.25	**

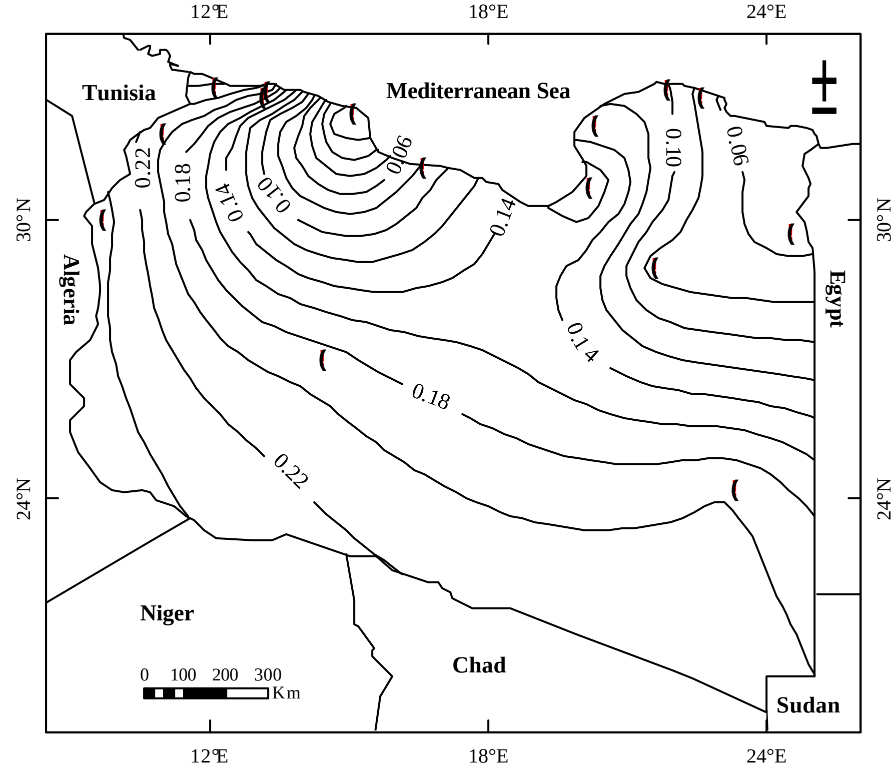
Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

3.2.1.2 Spatial changes of temperature

Most study stations are located in northern Libya and little information was available for southern Libya which must be taken into account to investigate the spatial changes of temperature over Libya. Temperature has increased over most Libya from 1946-2000 and most of the increase has occurred in the minimum temperatures.

Remarkably large spatial variations of mean annual temperatures were observed from north to south over Libya explained by several factors (urban heat island in cities located in northern Libya, greenhouse gases resulted from oil industries, cloud cove amount changes). All trends of mean annual temperature were positive except at one station (Misurata) in northern Libya (Fig. 29). Trends of mean *minimum* temperatures were positive over all Libya. On the other hand, mean *maximum* temperature trends were weakly positive or negative at all study stations. As for seasonal spatial temperature changes from 1946-2000, trends were positive at all station in autumn but higher in northern Libya. In summer and spring all stations were positive except Misurata in the north, while in winter most of trends were negative (Misurata in the north, Jaghboub and Jalo in the middle) or weakly positive at Derna and Shahat in northeastern Libya.

Fig. 29: Regionalization of mean annual temperature trends (°C) in Libya, 1946-2000



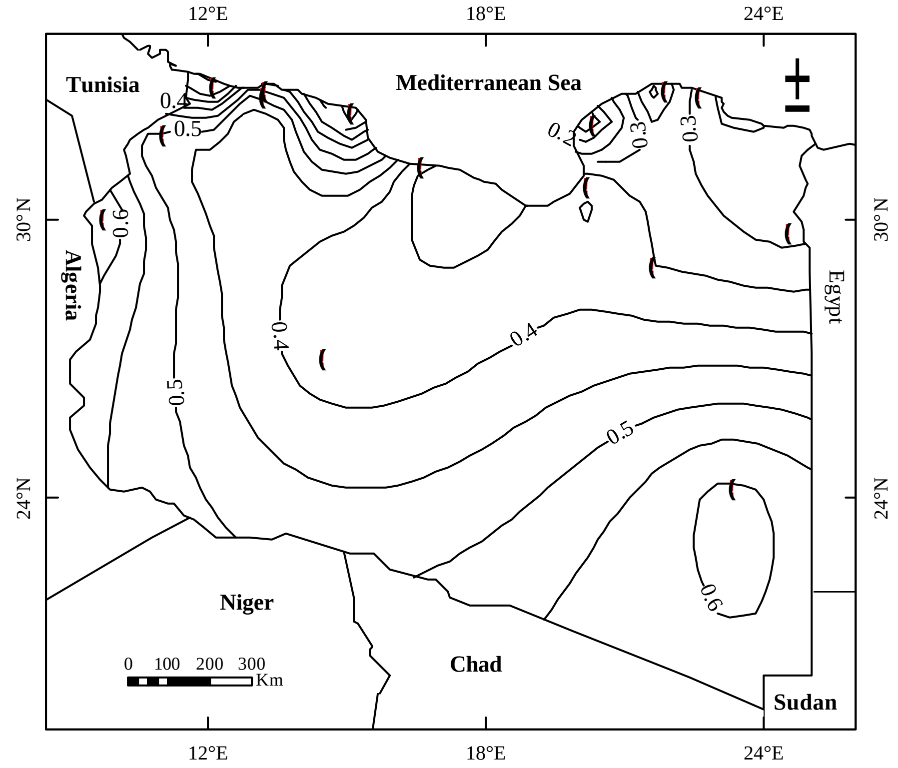
Data source: Libyan Meteorological Department, Tripoli

As for seasonal spatial temperature changes in the long-term period, trends were positive at all stations in autumn but higher in northern Libya. In summer and spring, all stations were positive except Misurata in the north, while in winter most of trends were negative (Misurata in the north, Jaghboub and Jalo in the middle) or weakly positive at Derna and Shahat in northeastern Libya.

Over the period 1976-2000, positive annual (Fig. 30), minimum and maximum temperature trends have been noticed over all Libya, except Benina in the northeastern Libya for which a negative trend of maximum temperature was computed.

Seasonally, summer and autumn temperature trends were positive over all Libya. In winter, negative trends prevailed mostly over northern Libya (Tripoli airport, Tripoli city and Binina) as well as in Sebha in the south-western Libya while positive trends prevailed over the middle and the south. In spring, positive trends have been observed at most stations.

Fig. 30: Regionalization of mean annual temperature trends (°C) in Libya, 1976-2000



Data source: Libyan Meteorological Department, Tripoli

3.2.2 Observed precipitation changes

3.2.2.1 Temporal precipitation trends

The annual precipitation total, which is other important climate element in the present study, has changed during the last 54 years. The statistical analysis of reliable instrumental data was demonstrating marked changes of precipitation at all stations under study over the long-term period 1946-2000 and the short-term period 1976-2000. The trends of annual precipitation, annual precipitation intensity and seasonal precipitation were computed by the least square method and trend-noise ratio value >1.96, as well as by the non-parametric Mann-Kendall test for trend to elaborate the behaviors of precipitation changes in Libya.

Changes of annual precipitation totals

Long-term period 1946-2000

Positive trends of the annual precipitation totals have been observed at ten stations from 1946-2000. The highest positive trend was 3.85 mm (resp. 24.21 %) per decade at

Jaghboub (being an oasis in eastern Libya) with annual precipitation total of 15.9 mm only. Positive trends ranged between 7.09 and 0.09 %/decade. Negative trends were computed at five stations ranging between -9.50 and -1.41 %/decade. The inter-annual precipitation variabilities were very high ranging between 123 and 24 %, so that all trends were not linear over this period (Fig. 31), all precipitation trends were not significant except at Jaghboub which shown a high significant trend (Tab. 38).

Tab. 38: Trends of annual precipitation total (mm and %), trend.-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

Station	Annual	**T/decade (mm)**	**T/decade (%)**	T/N	**Variability (%)**	Test Z	Sig.
Agedabia	145.4	**10.31**	**7.09**	0.87	**43**	1.43	
Benina	265.5	**0.25**	**0.09**	0.02	**31**	-0.21	
Derna	269.5	**2.23**	**0.83**	0.14	**162**	0.89	
El-Kufra	2.0	**-0.19**	**-9.50**	-0.3	**106**	-1.03	
Ghadames	31.9	**-0.45**	**-1.41**	-0.06	**103**	0.60	
Jaghboub	15.9	**3.85**	**24.21**	1.18	**113**	3.11	**
Jalo	9.3	**0.16**	**1.72**	0.08	**31**	0.13	
Misurata	274.3	**2.99**	**1.09**	0.19	**56**	0.07	
Nalut	148.5	**9.51**	**6.40**	0.62	**123**	1.20	
Sebha	9.0	**-0.39**	**-4.33**	-0.13	**24**	1.31	
Shahat	559.3	**-14.86**	**-2.66**	-0.6	**47**	-1.47	
Sirt	187.3	**12.25**	**6.54**	0.76	**37**	1.23	
Tripoli airport	277.2	**-4.89**	**-1.76**	-0.26	**30**	-0.61	
Tripoli city	335.9	**11.82**	**3.52**	0.63	**47**	1.30	
Zuara	238.6	**7.65**	**3.21**	0.37	**47**	0.75	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

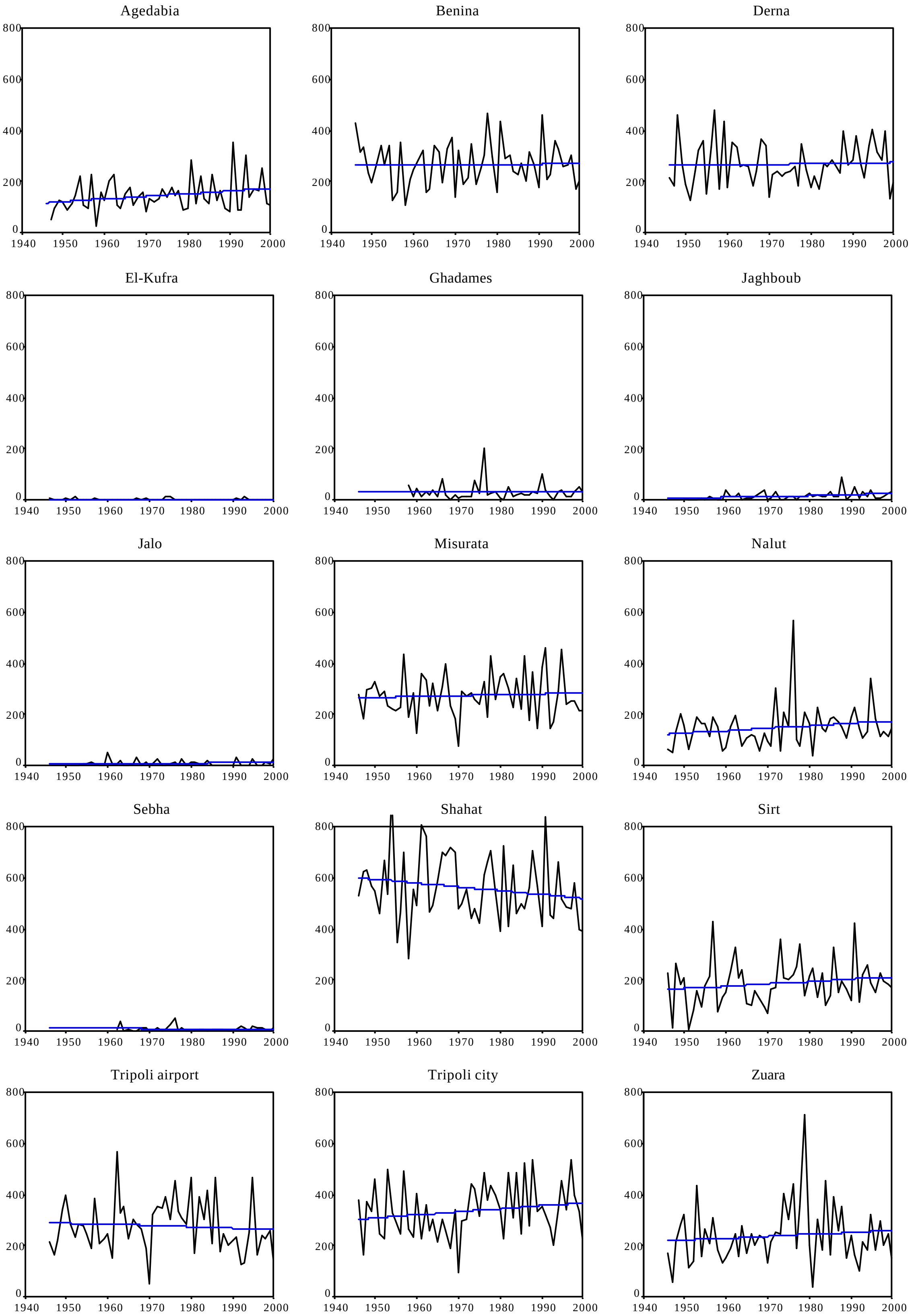
T/decade = trend of precipitation per decade (mm) and (%) decadal

Variability (%) = (standard deviation/mean annual precipitation totals)*100

Short-term period 1976-2000

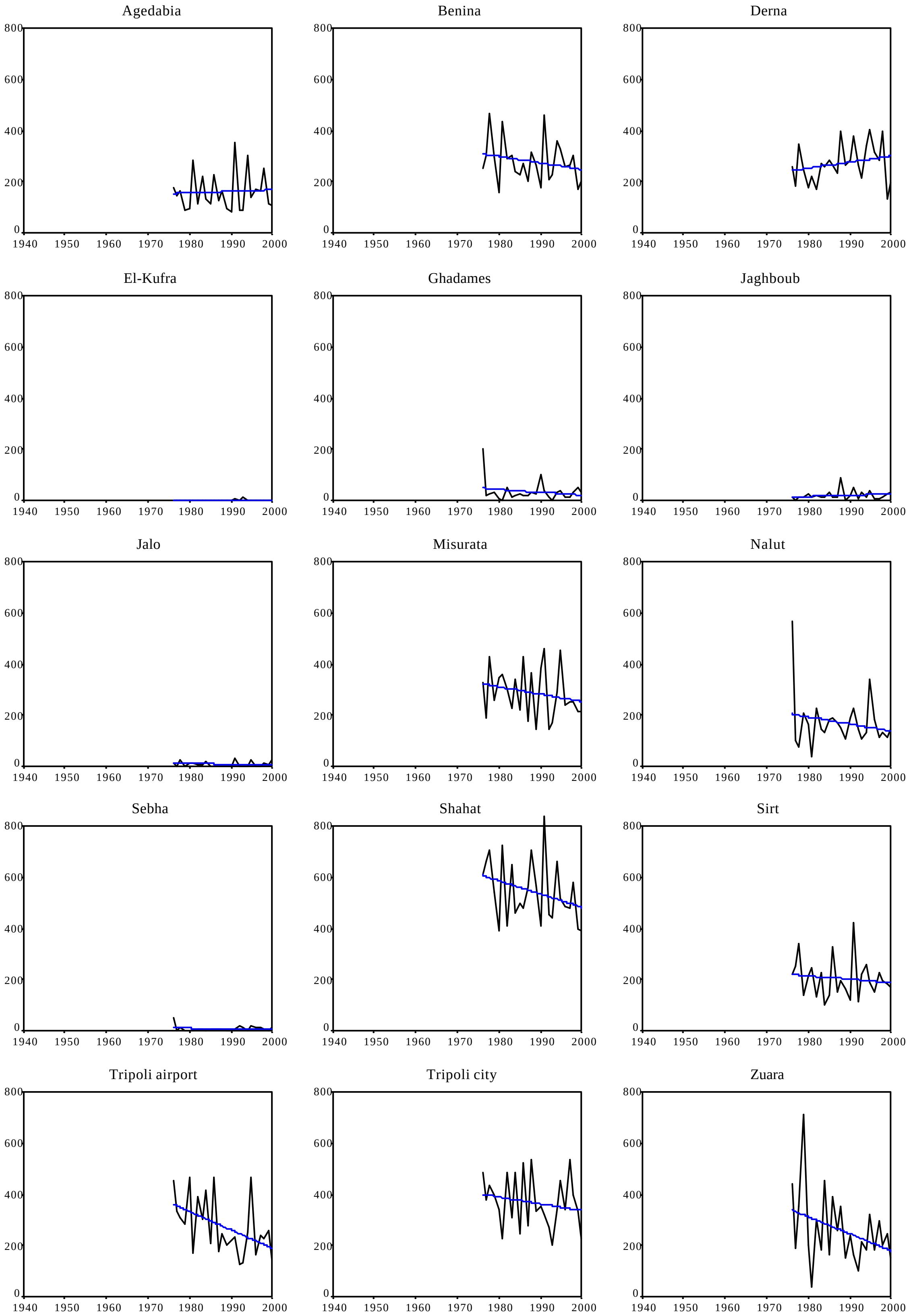
Negative trends of the annual precipitation total have been computed at most stations from 1976-2000 ranging between 71.9 mm (resp. 26.1 %) and 0.2 mm (resp. -2.1 %) per decade. Positive trends were shown at only four stations; the highest positive trend was at 23.4 mm (resp. 8.6 %) per decade (Tab. 39).

Fig. 31: Inter-annual variabilities and trends of annual precipitation (mm) in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

Fig. 32: Inter-annual variabilities and trends of annual precipitation (mm) in Libya, 1976-2000



Data source: Libyan Meteorological Department, Tripoli

Tab. 39: Trends of annual precipitation total (mm and %), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1976-2000

Station	Annual	**T/decade (mm)**	**T/decade (%)**	T/noise	Test Z	Sig.
Agedabia	161.0	**5.1**	**3.2**	0.17	0.02	
Benina	278.8	**-25.5**	**-9.1**	-0.73	-1.07	
Derna	271.7	**23.4**	**8.6**	0.75	1.33	
Elkufra	1.6	**0.7**	**43.4**	0.58	0.83	
Ghadames	34.7	**-11.1**	**-32.0**	-0.66	-0.89	
Jaghboub	20.4	**4.2**	**20.5**	0.53	1.07	
Jalo	9.4	**-0.2**	**-2.1**	-0.05	-1.01	
Misurata	288.3	**-28.8**	**-10.0**	-0.71	-1.00	
Nalut	171.3	**-27.8**	**-16.2**	-0.66	-0.61	
Sebha	8.9	**-0.8**	**-9.0**	-0.18	-1.64	
Shahat	544.6	**-52.1**	**-9.6**	-1.02	-1.56	
Sirt	204.1	**-13.0**	**-9.4**	-0.41	-0.54	
Tripoli airport	275.6	**-71.9**	**-26.1**	-1.56	-2.08	*
Tripoli city	368.5	**-26.5**	**-7.2**	-0.63	-0.89	
Zuara	259.5	**-66.7**	**-25.7**	-1.15	-1.52	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 38

All trends were not linear explained by the high inter-annual variabilities in this period (Fig. 32). All annual precipitation total trends were also not significant except one station (Tripoli airport) which was at level 0.05 of significance.

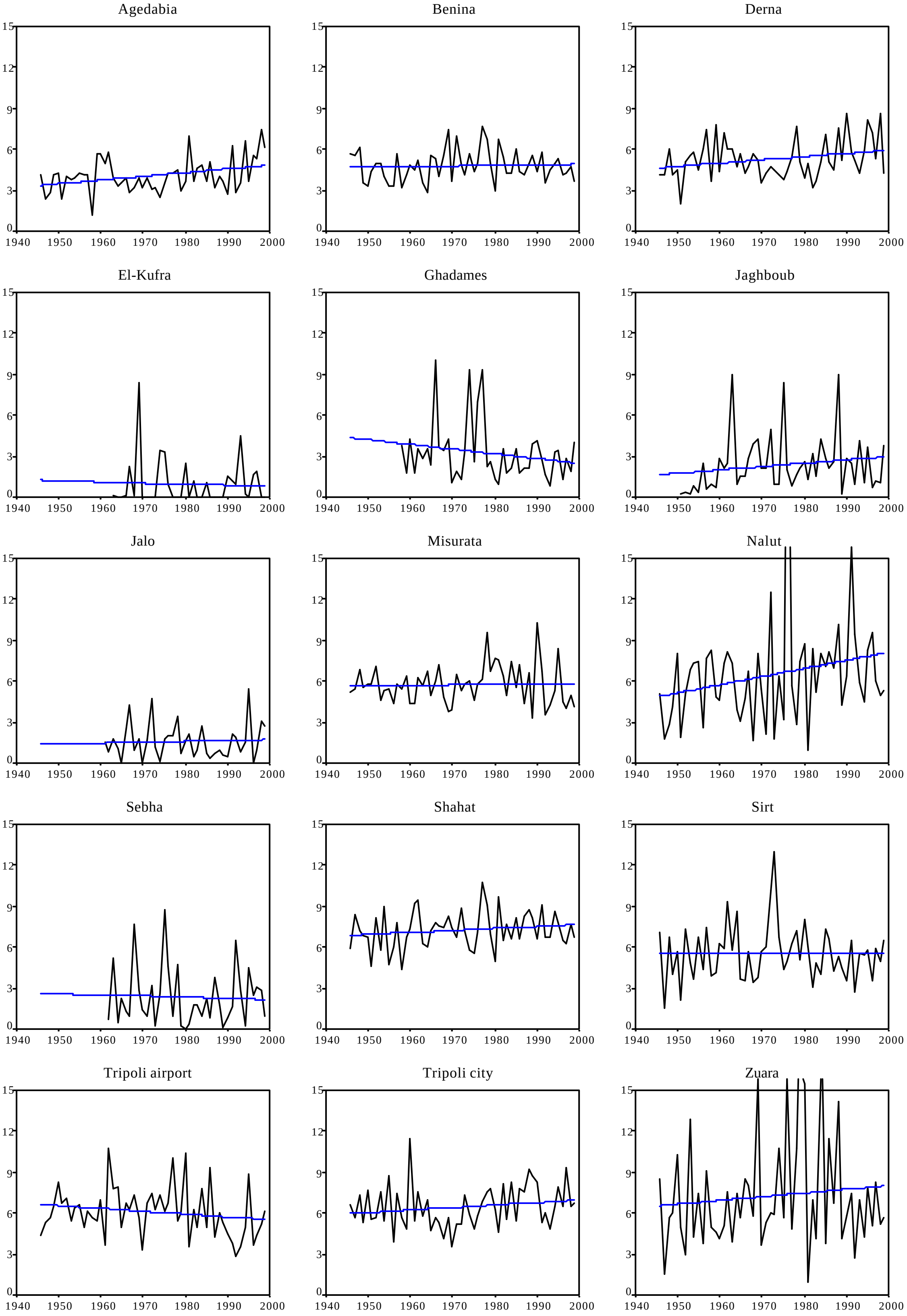
Changes of annual precipitation intensity

Precipitation intensity is very important in precipitation studies because of its important role of precipitation efficiency as a main source of water. Agriculture lands in Libya can be affected in a large degree by precipitation intensity through the soil erosion especially in northern parts.

Long-term period 1946-2000

Tab. 40 shows positive trends at ten stations. The highest positive trend was 1.20 mm/day/decade. Negative trends were shown at five stations. The lowest trend was -0.65 mm/day/decade at Ghadames. All trends of precipitation intensity were not linear because the inter-annual variabilities of precipitation intensity were very high from 1946-2000 (Fig. 33). For significance, most trends were not significant, only at Jaghboub the trend was significant at level 0.05 and were weakly significant at Nalut, Tripoli airport and Tripoli city.

Fig. 33: Inter-annual variabilities and trends of annual precipitation intensity mm/day/decade in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

Tab. 40: Trends of annual precipitation intensity (mm/day/decade), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

Station	Intensity	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	4.1	**0.29**	1.20	1.62	
Benina	4.8	**0.04**	0.18	0.30	
Derna	5.3	**0.24**	0.86	1.47	
El-Kufra	1.0	**-0.08**	-0.17	-0.18	
Ghadames	3.2	**-0.40**	-0.65	-1.18	
Jaghboub	2.4	**0.29**	0.57	2.15	*
Jalo	1.6	**0.05**	0.16	0.16	
Misurata	5.8	**0.03**	0.30	0.04	
Nalut	6.5	**0.54**	0.72	1.94	+
Sebha	2.3	**-0.08**	-0.19	-0.10	
Shahat	7.3	**0.14**	0.57	0.83	
Sirt	5.6	**-0.01**	-0.01	-0.12	
Tripoli airport	6.1	**-0.21**	-0.62	-1.77	+
Tripoli city	6.5	**0.19**	0.62	1.66	+
Zuara	7.3	**0.26**	0.34	0.72	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 38

Short-term period 1976-2000

Tab. 41: Trends of annual precipitation intensity (mm/day/decade), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1976-2000

Station	Intensity	**Trend/decade**	T/noise	Test Z	Sig.
Agedabia	4.6	**0.65**	1.10	1.17	
Benina	4.9	**-0.67**	-1.40	-1.87	+
Derna	5.7	**0.73**	1.06	1.72	+
El-Kufra	0.7	**0.28**	0.58	0.90	
Ghadames	2.9	**-0.84**	-1.01	-0.35	
Jaghboub	2.4	**0.09**	0.11	0.12	
Jalo	1.6	**0.17**	0.32	0.05	
Misurata	6.1	**-1.12**	-1.38	-2.16	*
Nalut	7.9	**-1.68**	-0.7	-0.32	
Sebha	2.1	**0.33**	0.44	0.92	
Shahat	7.6	**-0.43**	-0.76	-1.02	
Sirt	5.3	**-0.37**	-0.63	-0.62	
Tri. airport	5.8	**-1.17**	-1.28	-1.84	+
Tripoli city	7.0	**0.16**	0.28	0.60	
Zuara	8.2	**-3.06**	-1.38	-1.12	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 38

Opposite to the long-term period 1946-2000, short-term period 1976-2000 showed negative trends at most stations. Tab. 41 expresses negative trends of the annual precipitation intensity at eight stations ranging between -0.37 and 3.06 mm/day/decade, while positive trends prevailed at the remaining seven stations ranging between 0.09 and 0.73 mm/day/decade. All trends of precipitation intensity were not linear. The trends were not significant at eleven stations, significant at Misurata, while they were weakly significant at Benina, Derna and Tripoli airport.

It has been observed from the behavior of precipitation intensity trends over both periods 1946-2000 and 1976-2000 that all trends were not linear and most of them were not significant. Positive trends prevailed at most stations in the long-term period, in contrast to the more recent period in which negative trends at most stations have been observed.

Trends of seasonal precipitation

Precipitation in Libya occurs in three seasons: winter, autumn and spring, while summer is dry. The trends of seasonal precipitation at 13 stations were computed for winter (December, January, February), spring (March, April, May) and autumn (September, October, November) over the period 1946-2000 and the period 1976-2000.

Long-term trends 1946- 2000

Trends of precipitation totals in *winter* showed positive trends at most stations ranging between 8.47 mm (resp. 8.44 %) and 0.24 mm (resp. 0.17 %) per decade. Negative trends prevailed at only four stations (Tab. 42). Although Jaghboub and Jalo locate in Sahara desert, the trends at them were strongly positive over this period. All trends were not linear explained by high precipitation variabilities in winter (Fig. 34). No significant trends were seen at all stations except one station (Jaghboub).

In *spring*, precipitation increased at nine stations ranging between 25.16 %/decade and 2.90 %/decade. Decreasing trends were noticed at four stations (Tab. 43). High inter-annual temperature variabilities at all stations have been shown (Fig. 35), so that all precipitation trends in spring were not linear according to trend-noise ratio value >1.96. The trends were not significant at all stations except at Agedabia and Jaghboub which were significant at level 0.05.

Tab. 42: Trends of precipitation totals in winter (mm and %) per decade, trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

Station	Mean	**T/decade (mm)**	**T/decade (%)**	T/Noise	Test Z	Sig.
Agedabia	100.4	**5.28**	**5.26**	0.01	1.14	
Benina	174.0	**-1.40**	**-0.81**	0.00	-0.30	
Derna	100.4	**8.47**	**8.44**	0.01	0.82	
Ghadames	13.7	**0.38**	**2.80**	0.00	0.06	
Jaghboub	9.9	**2.96**	**29.72**	0.03	3.43	***
Jalo	4.5	**0.56**	**12.47**	0.01	0.30	
Misurata	146.5	**0.24**	**0.17**	0.00	0.21	
Nalut	50.3	**-1.32**	**-2.62**	0.00	-0.02	
Shahat	326.2	**-8.46**	**-2.59**	-0.01	-1.30	
Sirt	103.4	**6.90**	**6.67**	0.01	1.10	
Tripoli airport	139.0	**-7.05**	**-5.07**	-0.01	-1.41	
Tripoli city	174.4	**4.46**	**2.56**	0.01	0.30	
Zuara	103.5	**5.89**	**5.69**	0.01	1.42	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 38

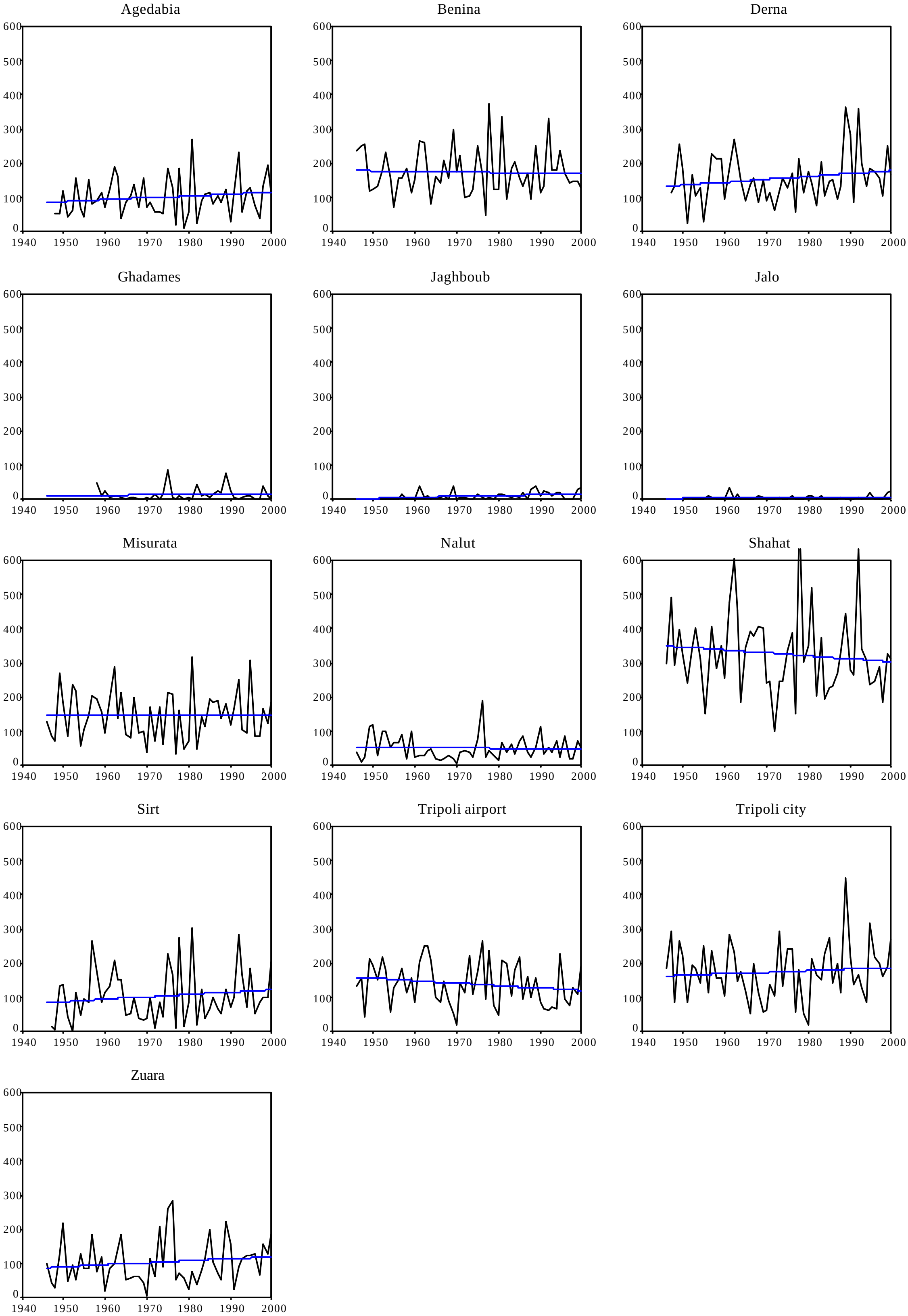
Table 43: Trends of precipitation totals in spring (mm and %) per decade, trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

Station	Mean	**T/decade (mm)**	**T/decade (%)**	T/Noise	Test Z	Sig.
Agedabia	18.1	**2.16**	**11.94**	0.79	2.29	*
Benina	35.7	**2.26**	**6.32**	0.51	1.18	
Derna	38.6	**-0.32**	**-0.83**	0.00	-0.18	
Ghadames	11.2	**-0.75**	**-6.72**	0.00	-0.56	
Jaghboub	4.3	**1.07**	**25.16**	0.02	2.10	*
Jalo	2.8	**0.08**	**2.90**	0.00	0.00	
Misurata	33.7	**-0.23**	**-0.68**	0.00	-0.15	
Nalut	56.2	**4.82**	**8.58**	0.01	1.55	
Shahat	99.1	**3.67**	**3.70**	0.01	0.41	
Sirt	22.2	**2.52**	**11.33**	0.01	1.34	
Tripoli airport	49.2	**3.46**	**7.03**	0.01	1.49	
Tripoli city	47.8	**3.41**	**7.13**	0.01	0.93	
Zuara	36.9	**-1.20**	**-3.26**	0.00	-0.62	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 38

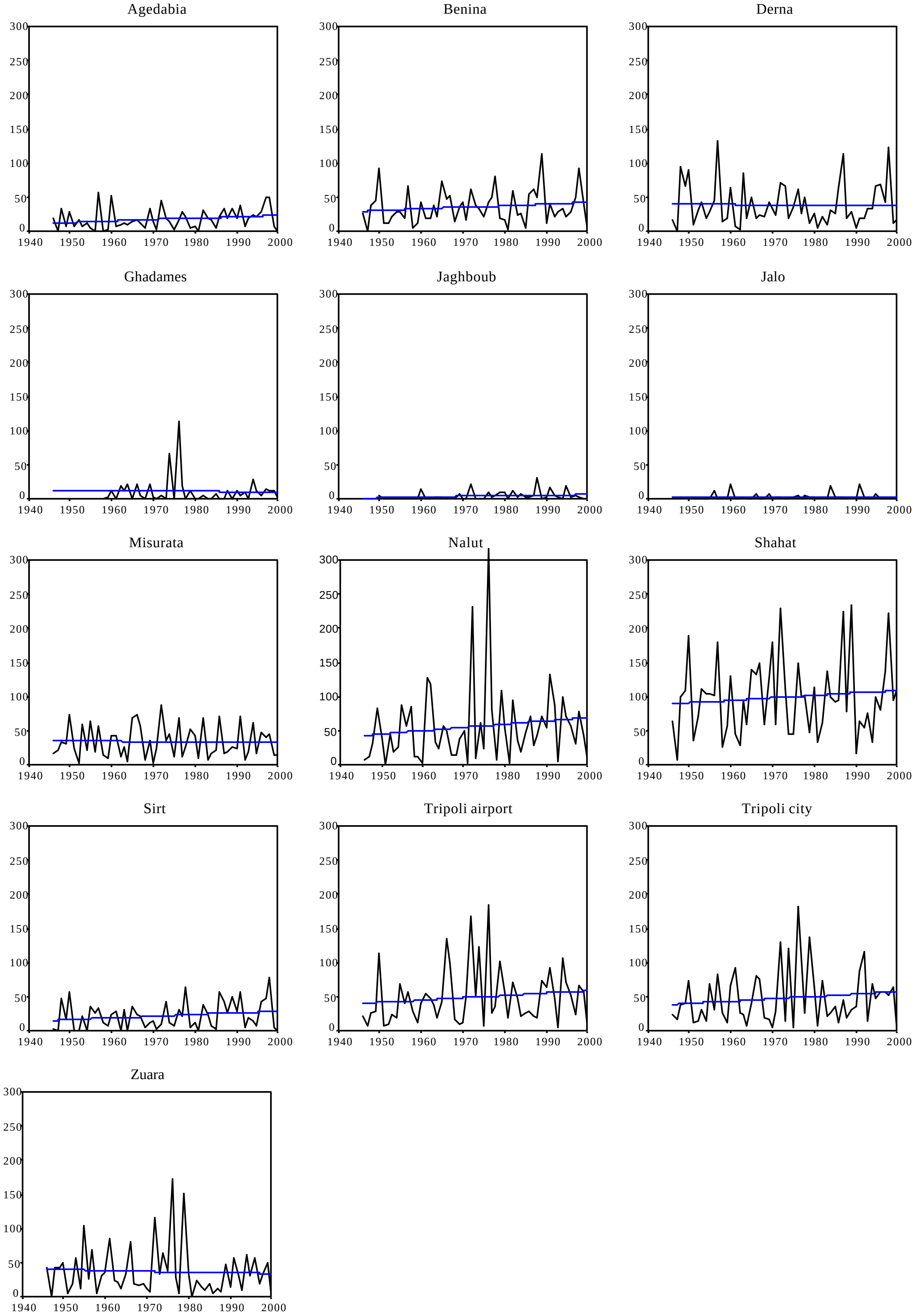
In *autumn*, negative trends of precipitation have been observed at seven stations expressing decreasing precipitation between 7.22 mm (resp. 5.47 %) at Shahat in northeastern Libya and 0.05 mm (resp. 2.97 %) per decade at Jaghboub in eastern Libya, while positive trends were computed at six stations ranging between 6.56 mm (resp. 16.54 %) at Nalut in western Libya and 0.65 mm (resp. 1.05 %) per decade at Sirt in northern Libya (Tab. 44). Trends of precipitation total in autumn were not linear (Fig. 36) and not significant at all study stations except the trend at Jalo which was significant trend.

Fig. 34: Inter-annual variabilities and trends of winter precipitation totals (mm) in Libya, 1946-2000



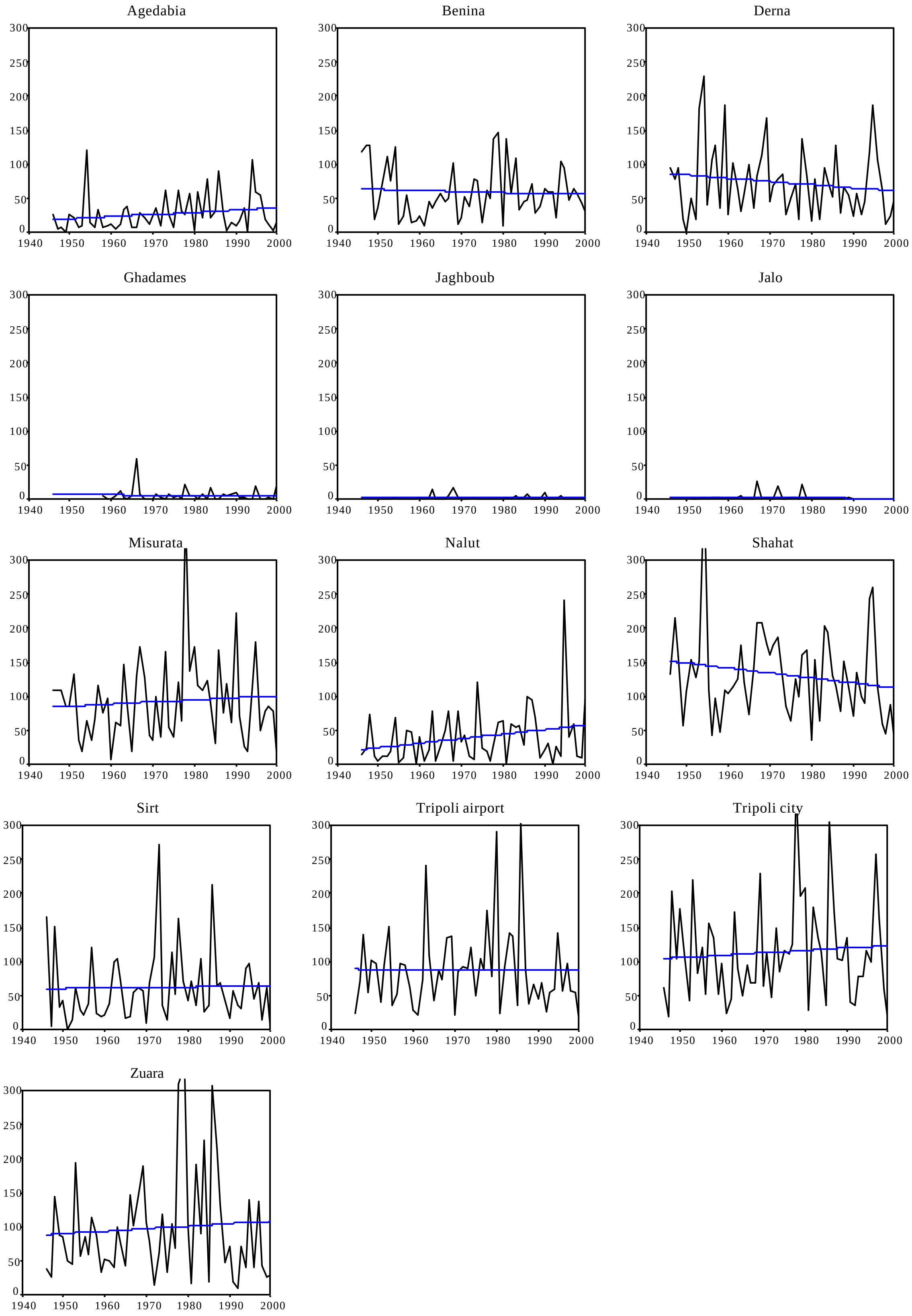
Data source: Libyan Meteorological Department, Tripoli

Fig. 35: Inter-annual variabilities and trends of spring precipitation totals (mm) in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

Fig. 36: Inter-annual variabilities and trends of autumn precipitation totals (mm) in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

Tab. 44: Trends of precipitation totals in autumn (mm and %) per decade, trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

Station	Mean	**T/decade (mm)**	**T/decade (%)**	T/Noise	Test Z	Sig.
Agedabia	27.2	**3.18**	**11.67**	0.01	1.46	
Benina	59.3	**-1.37**	**-2.31**	0.00	-0.26	
Derna	73.2	**-4.70**	**-6.42**	-0.01	-0.99	
Ghadames	6.0	**-0.35**	**-5.80**	0.00	-0.52	
Jaghboub	1.7	**-0.05**	**-2.97**	0.00	0.04	
Jalo	2.1	**-0.47**	**-22.13**	-0.01	-2.35	*
Misurata	92.5	**3.02**	**3.27**	0.01	0.24	
Nalut	39.7	**6.56**	**16.54**	0.02	1.42	
Shahat	132.0	**-7.22**	**-5.47**	-0.01	-1.24	
Sirt	61.7	**0.65**	**1.05**	0.00	0.65	
Tripoli airport	88.4	**-0.12**	**-0.14**	0.00	-0.58	
Tripoli city	113.8	**3.55**	**3.12**	0.01	0.36	
Zuara	98.2	**3.66**	**3.73**	0.00	0.16	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 38

Short-term trends 1976-2000

Remarkably large variations were seen among the different seasons over the period 1976 to 2000. Concerning precipitation totals in *winter*, Tab. 45 shows positive trends at 9 stations due to Mann-Kendall test for trend (test Z), while negative trends prevailed at Benina, Nalut, Shahat and Tripoli airport. Non-linear trends were seen at all stations applying trend to noise ratio. Trends at most study stations of winter precipitation were not significant in this period.

Opposite to winter, precipitation trends in *spring* were negative at eight stations in the period 1976-2000 ranging between -0.88 mm (resp. -28.39 %) and 30.50 mm (resp. -44.46 %) per decade. Positive trends prevailed at five stations. Non-linear trends prevailed at all stations due to trend-noise ratio value >1.96. Except the trend at Jalo, all precipitation trends were not significant in this period (Tab.46).

Trends of precipitation total in *autumn* were negative at all stations except at Nalut and Jaghboub which showed 21.75 and 5.00 % per decade, respectively. All trends showed also not linear explained by high precipitation inter-annual variabilities in autumn. Applying Mann-Kendall test for trend, the trends of autumn precipitation total in the period 1976-2000 were significant at level 0.05 for Jalo, Misurata, Tripoli airport and Zuara and at level 0.1 for Sirt and Tripoli city, while they were not significant for the remaining seven stations (Tab. 47).

Tab. 45: Trends of precipitation totals in winter (mm and %) per decade, trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1976-2000

Station	Mean	**T/decade (mm)**	**T/decade (%)**	T/Noise	Test Z	Sig.
Agedabia	105.7	**10.96**	**10.37**	0.41	1.19	
Benina	173.9	**-6.43**	**-3.70**	-0.20	-0.12	
Derna	169.6	**25.42**	**14.99**	0.78	0.91	
Ghadames	13.7	**0.95**	**6.93**	0.13	0.09	
Jaghboub	13.0	**6.25**	**48.08**	1.36	1.82	+
Jalo	5.1	**2.65**	**51.96**	0.90	0.00	
Misurata	147.8	**12.14**	**8.21**	0.39	0.35	
Nalut	53.7	**-8.23**	**-15.33**	-0.52	-0.07	
Shahat	322.4	**-32.32**	**-10.02**	-0.58	-0.44	
Sirt	114.1	**6.85**	**6.00**	0.20	1.38	
Tripoli airport	132.5	**-24.78**	**-18.70**	-0.91	-1.26	
Tripoli city	183.0	**34.11**	**18.64**	0.91	0.91	
Zuara	109.4	**16.54**	**15.12**	0.62	2.17	*

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 38

Tab. 46: Trends of precipitation total in spring (mm and %) per decade, trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1976-2000

Station	Mean	**T/decade (mm)**	**T/decade (%)**	T/Noise	Test Z	Sig.
Agedabia	21.1	**4.71**	**22.32**	0.83	1.21	
Benina	39.3	**0.08**	**0.20**	0.01	0.02	
Derna	37.5	**7.20**	**19.20**	0.57	0.91	
Ghadames	11.4	**-7.08**	**-62.11**	-0.76	-0.94	
Jaghboub	6.1	**-1.28**	**-20.98**	-0.43	-1.38	
Jalo	3.1	**-0.88**	**-28.39**	-0.38	-2.03	*
Misurata	33.1	**-3.14**	**-9.49**	-0.35	-0.33	
Nalut	68.6	**-30.50**	**-44.46**	-0.99	-0.44	
Shahat	102.2	**5.97**	**5.84**	0.25	0.07	
Sirt	27.6	**1.53**	**5.54**	0.17	0.00	
Tripoli airport	53.3	**-10.57**	**-19.83**	-0.65	-0.35	
Tripoli city	55.8	**-17.77**	**-31.85**	-1.00	-0.54	
Zuara	36.0	**-13.83**	**-38.42**	-0.79	-0.44	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 38

Autumn and spring were clearly shown as the governing seasons responsible for decreasing of annual precipitation total over the period 1976-2000 at most stations in Libya.

Tab. 47: Trends of precipitation total in autumn (mm and %) per decade, trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1976-2000

Station	Mean	**T/decade (mm)**	**T/decade (%)**	T/Noise	Test Z	Sig.
Agedabia	34.1	**-7.75**	**-22.73**	-0.64	-1.59	
Benina	64.7	**-15.40**	**-23.80**	-1.00	-1.24	
Derna	65.2	**-1.75**	**-2.68**	-0.09	-0.54	
Ghadames	5.7	**-0.20**	**-3.51**	-0.07	-0.31	
Jaghboub	1.4	**0.07**	**5.00**	0.07	0.2	
Jalo	1.4	**-2.10**	**-150.00**	1.13	-2.23	*
Misurata	106.4	**-38.99**	**-36.99**	-1.34	-2.22	*
Nalut	48.1	**10.46**	**21.75**	0.50	0.16	
Shahat	121.5	**-13.41**	**-11.04**	-0.54	-1.61	
Sirt	65.0	**-22.01**	**-33.86**	-1.14	-1.75	+
Tripoli airport	93.5	**-38.45**	**-41.12**	-1.26	-2.08	*
Tripoli city	128.8	**-36.17**	**-28.08**	-1.06	-1.85	+
Zuara	117.7	**-72.03**	**-61.20**	-1.48	-2.13	*

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 38

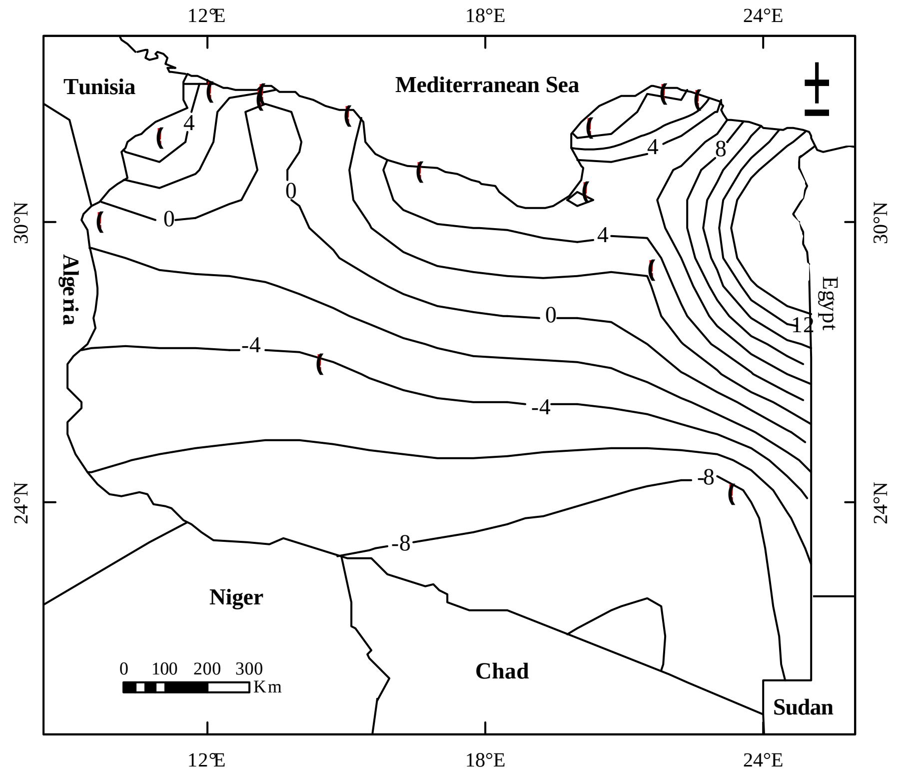
3.2.2.2 Spatial changes of precipitation

Most stations under study are located in the northern parts of Libya and little information was available for the southern parts which must be taken into account to elaborate the spatial changes of precipitation. Remarkably variations have been observed in distribution of annual precipitation total changes over Libya.

In the long period 1946-2000, the trends were negative over southern Libya at -9.50 and -4.33 %/decade for El-Kufra and Sebha. Over northern parts, precipitation increased at some stations such as: Tripoli city (3.52 %/decade) and Zuara (3.21 %/decade), and decreased at others such as: Tripoli airport (-1.76 %/decade) and Shahat (-2.66 %/decade). The map values can be seen as broadly indicative of conditions which may exist in annual precipitation trends over Libya in the period 1946-2000. Generally, precipitation increased in northern Libya, while decreased in southern Libya (Fig. 37).

Over the period 1976-2000, the trends of annual precipitation total were negative over most Libya indicating decreasing of precipitation at eleven stations (Tab. 39), while positive trends were computed only at El-Kufra, Jaghboub Agedabia and Derna. Fig. 38 shows the distribution of annual precipitation trends over Libya over the period 1976-2000, increasing trends in the east and south, while decreasing trends in the west and north.

Fig. 37: Regionalization of mean annual precipitation trends (%) in Libya, 1946-2000



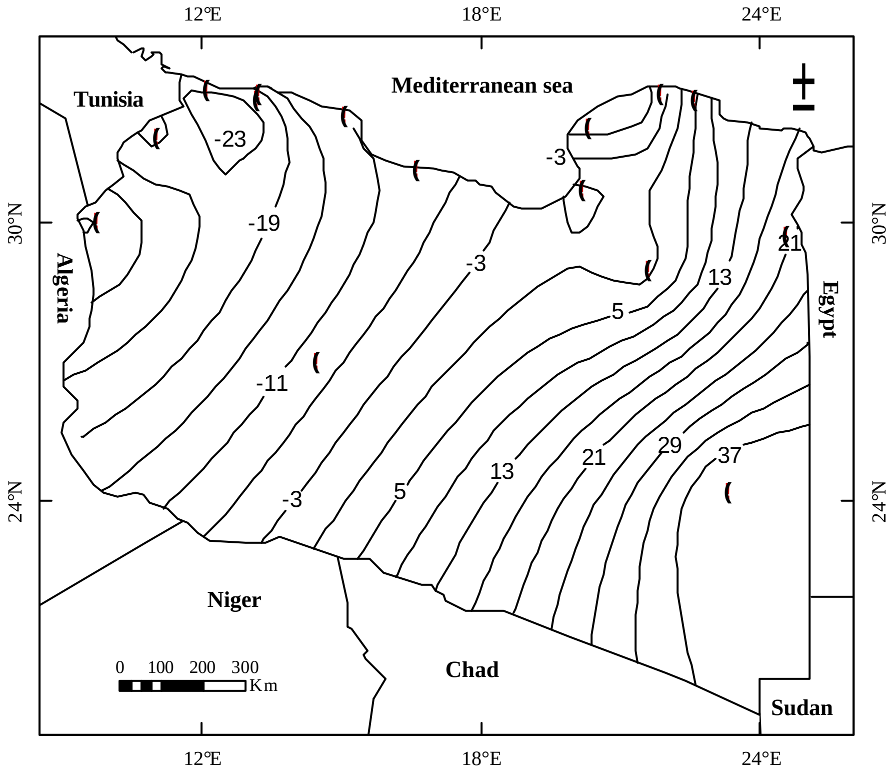
Data source: Libyan Meteorological Department, Tripoli

As for seasonal; spatial precipitation changes from 1946-2000 showed negative trends over northern Libya (Benina, Nalut, Shahat and Tripoli airport) in winter. Over the period 1976-2000, winter precipitation increased over all Libya except in the northeast at Benina and Shahat and in the south of coastal zone at Nalut and Tripoli airport.

For *spring*, all study stations showed positive trends of annual precipitation in the long-term period except at four stations in northern Libya (Derna, Ghadames, Misurata and Zuara), while negative trends prevailed at most stations in the period 1976-2000.

In *autumn*, negative trends were expressed at most stations in southern Libya, while positive trends showed at most stations in northern Libya in the period 1946-2000. Over the period 1976-2000, negative trends prevailed at all study stations in Libya except at Jaghboub in the east and at Nalut in the west but the trends were higher in northern Libya.

Fig. 38: Distribution of mean annual precipitation trends (%) in Libya, 1976-2000



Data source: Libyan Meteorological Department, Tripoli

3.2.3 Observed changes of mean annual relative humidity

Long-term trends 1946-2000

Negative trends prevailed at eight stations ranging between -1.88 and 0.30 %/decade at El_Kufra and Benina, respectively, while positive trends of mean annual relative humidity were shown at seven sations ranging between 0.14 and 1.32 %/decade at Jalo and Tripoli city, respectively (Tab.48). As a result of high inter-annual variabilities of annual relative humidity at all stations, the trends were not linear, expressed by a trend-to-noise-ratio >1.96, (Fig. 39).

For significance: trends at Agedabia, shahat and Tripoli city were very high significant; high significant trends were computed at El-Kufra, Misurata, Sebha, Sirt and Tripoli airport); while the trends at Benina, Derna, ghadames, Jaghboub, Jalo, Nalut and Zuara were not significant in this period.

Tab. 48: Trends of annual mean relative humidity (%), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

Station	Annual	**T/decade (%)**	T/Noise	Test Z	Sig.
Agedabia	61.8	**-1.18**	-1.76	-3.68	***
Benina	65.3	**-0.30**	-0.47	-0.93	
Derna	72.0	**-0.35**	-0.62	-0.96	
El-Kufra	29.3	**-1.88**	-1.74	-3.26	**
Ghadames	33.8	**0.23**	0.19	0.92	
Jaghboub	48.2	**0.61**	0.71	1.53	
Jalo	45.2	**0.14**	0.21	0.36	
Misurata	70.8	**-1.06**	-1.78	-3.07	**
Nalut	50.7	**0.45**	0.52	0.63	
Sebha	33.9	**-1.27**	-1.76	-2.82	**
Shahat	68.9	**-0.88**	-1.71	-3.86	***
Sirt	70.4	**-0.71**	-1.49	-3.14	**
Tripoli airport	61.8	**1.16**	1.39	3.20	**
Tripoli city	64.8	**1.32**	1.66	3.40	***
Zuara	73.1	**0.27**	0.49	0.90	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Trend/decade = trend of mean annual relative humidity % per decade

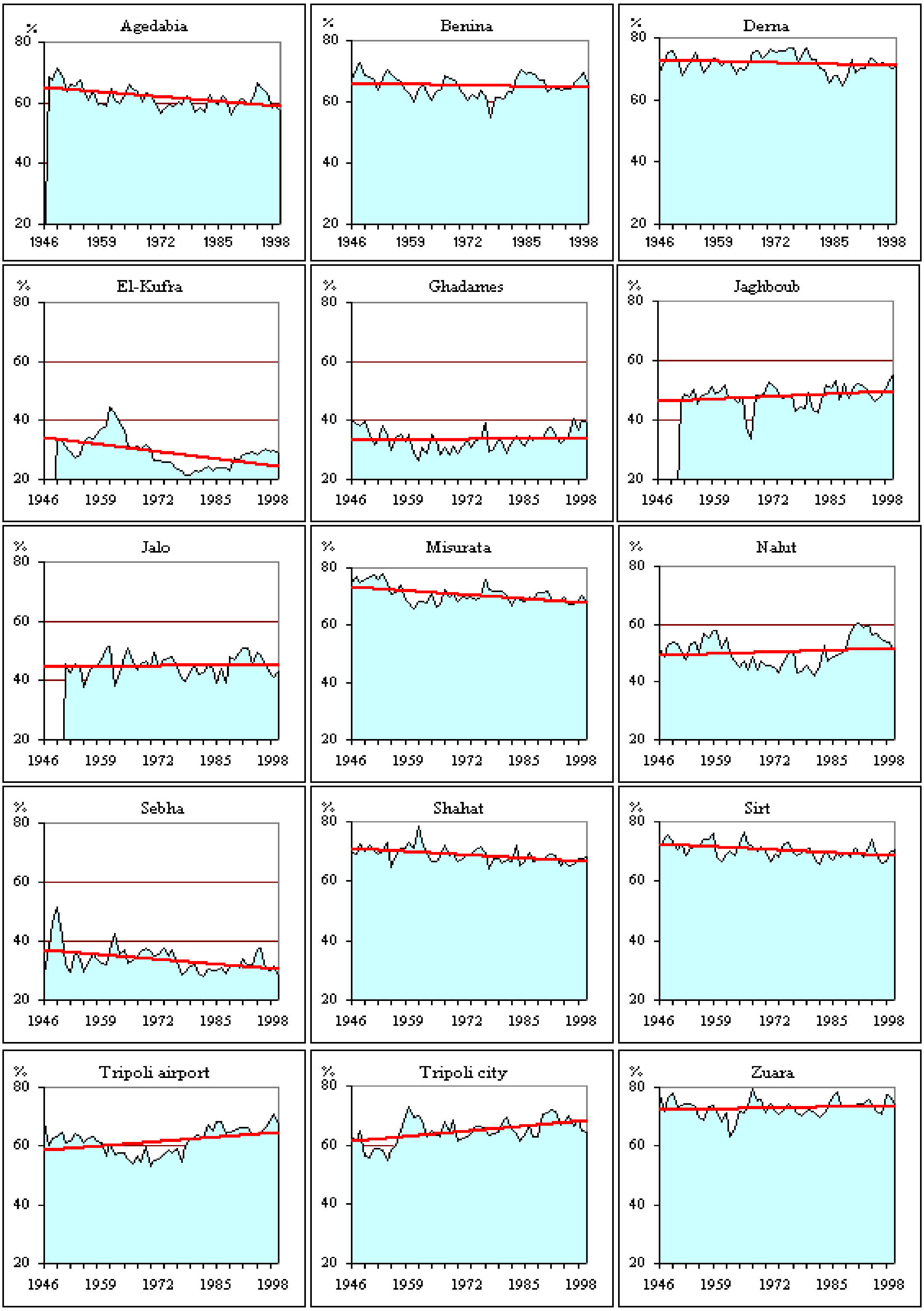
Short-term trends 1976-2000

Tab. 49: Trends of annual mean relative humidity (%), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1976-2000

Station	Annual	**T/decade (%)**	T/noise	Test Z	Sig.
Agedabia	60.3	**0.78**	0.70	0.72	
Benina	65.1	**2.48**	1.58	2.16	*
Derna	71.0	**-1.14**	-0.85	-0.95	
El-Kufra	25.7	**3.93**	2.98	4.94	***
Ghadames	34.6	**2.63**	1.90	3.00	**
Jaghboub	48.7	**2.80**	1.84	2.38	*
Jalo	44.7	**1.78**	1.13	1.61	
Misurata	69.9	**-1.73**	-1.87	-2.81	**
Nalut	51.5	**5.76**	2.33	3.40	***
Sebha	31.3	**1.12**	1.08	1.44	
Shahat	67.3	**-0.18**	-0.23	0.00	
Sirt	69.2	**0.20**	0.25	0.05	
Tripoli airport	64.7	**3.42**	2.25	3.70	***
Tripoli city	66.4	**1.49**	1.13	1.29	
Zuara	73.5	**1.70**	1.66	2.73	**

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 48

Fig. 39: Inter-annual variabilities and trends of annual mean relative humidity (%) in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

Positive trends were computed at most stations, while negative trends prevailed at only three stations (Derna, Misurata and Shahat) from 1976-2000. The highest trend was 5.76 % per decade at Nalut in western Libya and the lowest trend was -1.73 % per decade at Misurata on Mediterranean coast. Annual mean relative humidity trends were not linear at most stations. Trends at El-kufra, Nalut and Tripoli airport were linear and very high significant. It can be observed that the trends were high significant at Ghadames, Misurata and Zuara, and significant trends at Benina and Jaghboub (Tab. 49). Mean annual relative humidity increased, in general, at most stations over the period 1976-2000 especially in southern and middle Libya.

3.2.4 Observed changes of annual cloud amount totals

Clouds are an internal component of the climate system. The presence and variations of cloud coverage effects are closely related to atmospheric humidity (SUN, et al., 2000: 4341). Annual total cloud amount trends in Libya were computed in both periods 1946-2000 and 1976-2000.

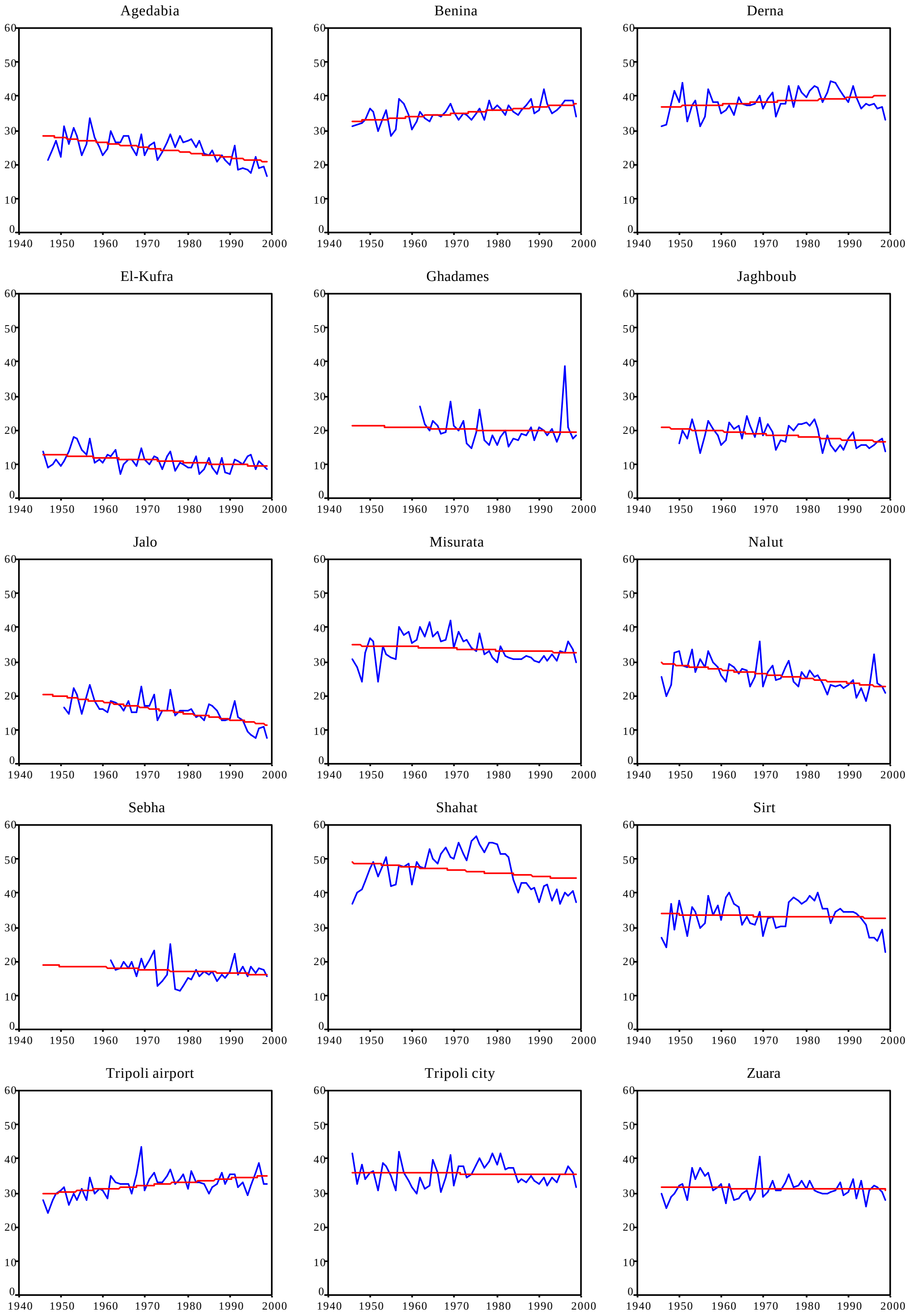
Long-term trends 1946-2000

Tab. 50: Trends of annual cloud amount totals (Oktas and %), trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1946-2000

Station	Annual	**Trend/decade (Oktas)**	**T/decade (%)**	T/noise	Test Z	Sig.
Agedabia	24,5	**-1,45**	**-5,92**	-1,99	-4,17	***
Benina	35,1	**0,97**	**2,76**	1,92	4,25	***
Derna	38,4	**0,63**	**1,64**	1,00	1,71	+
El-Kufra	11,1	**-0,66**	**-5,95**	-1,39	-2,75	**
Ghadames	20,0	**-0,38**	**-1,90**	-0,32	-1,46	
Jaghboub	18,4	**-0,80**	**-4,35**	-1,28	-2,40	*
Jalo	15,6	**-1,69**	**-10,83**	-2,26	-4,94	***
Misurata	33,7	**-0,44**	**-1,31**	-0,62	-2,23	*
Nalut	26,0	**-1,30**	**-5,00**	-1,77	-4,53	***
Sebha	17,1	**-0,54**	**-3,16**	-0,68	-0,82	
Shahat	46,5	**-0,91**	**-1,96**	-0,85	-1,10	
Sirt	33,3	**-0,23**	**-0,69**	-0,29	-0,78	
Tripoli airport	32,2	**0,99**	**3,07**	1,63	3,74	***
Tripoli city	35,6	**-0,12**	**-0,34**	-0,20	-0,45	
Zuara	31,3	**-0,16**	**-0,51**	-0,31	-0,40	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Fig. 40: Inter-annual variabilities and trends of annual cloud amount totals (Oktas) in Libya, 1946-2000



Data source: Libyan Meteorological Department, Tripoli

It can be seen that the annual cloud amount totals decreased at most stations from 1946-2000, an increase was observed only at Benina, Derna and Tripoli airport. It can also be noticed that very highly significant trends were computed at three stations, highly significant trend at El-Kufra, significant trends at Jaghboub and Misurata and weakly significant trend at Derna, while the trends at six stations were not significant (Tab. 50). All trends were not linear in this period except at Agedabia and Jalo (Fig. 40).

Short-term trends 1976-2000

Negative trends of annual cloud amount prevailed at most stations over the period 1976-2000 ranging between -7.95 oktas (resp. -17.83 %) per decade at Shahat on Jebal El-Akhdar and -0.16 oktas (resp. -0.48 %) at Tripoli airport. Positive trends were seen only at four stations (Tab. 51). Non-linear trends were seen at eight stations, while linear trends were shown at seven stations. For significance, very highly significant trends were observed at Agedabia, Jalo, Shahat and Sirt; highly significant trends at Derna, Jaghboub and Tripoli city; significant trends at Nalut, Sebha and Zuara, while not significant trends were computed at Benina, El-Kufra, Ghadames, Misurata and Tripoli airport.

Tab. 51: Trends of annual cloud amount totals, trend-noise ratios and Mann-Kendall test for trend (Test Z) in Libya, 1976-2000

Station	Annual	**T/decade (Oktas)**	**T/decade (%)**	T/noise	Test Z	Sig.
Agedabia	22.7	**-4.64**	**-20.44**	-2.86	-4.79	***
Benina	36.6	**0.76**	**2.08**	0.85	0.89	
Derna	39.9	**-2.63**	**-6.59**	-2.02	-3.20	**
El-Kufra	9.9	**0.03**	**0.30**	0.04	0.00	
Ghadames	19.4	**1.52**	**7.84**	0.75	1.49	
Jaghboub	17.7	**-3.11**	**-17.57**	-2.27	-2.81	**
Jalo	13.7	**-3.57**	**-26.06**	-2.41	-3.75	***
Misurata	32.0	**-0.44**	**-1.38**	-0.50	-0.55	
Nalut	23.9	**-1.56**	**-6.53**	-1.15	-2.38	*
Sebha	16.4	**0.88**	**5.37**	0.70	2.03	*
Shahat	44.6	**-7.95**	**-17.83**	-2.87	-4.86	***
Sirt	33.8	**-5.70**	**-16.86**	-2.88	-5.06	***
Tripoli airport	33.5	**-0.16**	**-0.48**	-0.16	-0.65	
Tripoli city	35.8	**-2.64**	**-7.37**	-2.09	-2.83	**
Zuara	31.2	**-1.33**	**-4.26**	-1.43	-1.97	*

Data source: Libyan Meteorological Department, Tripoli.

Explanation: see Tab. 10

3.2.5 Observed climate changes over all-Libya

Principle component analysis was applied to construct All-Libya climate changes for the elements (temperature, precipitation, relative humidity and cloud cover). The 50-years time series of data for all fifteen stations was taken to compute climate trends over Libya as a whole over the long-term period 1951-2000 and the 25-years time series of data for all fifteen stations was taken to compute climate trends over Libya as a whole in the short-term periods 1951-1975 and 1976-2000.

3.2.5.1 Observed temperature changes over all-Libya

According to Principle Component Analysis (PCA) values, highly increasing and significant linear trends of 0.35, 0.50 and 0.28 °C/decade were identified in the period *1951-2000* for annual, minimum and summer temperatures, respectively (Tab. 52). In absolute values, mean annual warming of 1.75 °C, mean minimum warming of 2.50 °C and mean summer warming of 1.40 °C were observed.

Tab. 52 expresses also the seasonal trends of temperature over all-Libya showing lightly positive trend of 0.07 °C/decade for winter temperature, weakly positive trend of 0.02 °C/decade for maximum temperature, positive trend of 0.29 °C/decade for autumn and the trend was positive at 0.18 °C/decade for spring. Negative trends of extreme maximum temperature and mean annual range temperature were computed. Most trends are not linear due to trend-to-noise-ratio values >1.96 (Fig. 41).

Table 52: Trends of annual, minimum, maximum and seasonal temperatures for all-Libya, trend-noise ratios and Mann-Kendall test for trend (Test Z) according to PCA values, 1951-2000

	Trend/decade	T/noise	Test Z	Sig.
Mean annual	**0.35**	1.72	3.56	***
Mean minimum	**0.50**	2.38	4.99	***
Extreme minimum	**0.59**	2.84	6.71	***
Mean maximum	**0.02**	0.10	0.41	
Extreme maximum	**-0.11**	-0.54	-0.94	
Temperature range	**-0.58**	-2.79	-6.49	***
Winter (Dec.-Feb.)	**0.07**	0.32	0.79	
Spring (Mar.-May)	**0.18**	0.86	1.71	+
Summer (Jun.-Aug.)	**0.28**	1.37	2.21	*
Autumn (Sep.-Nov.)	**0.29**	1.40	2.84	**

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Positive minimum temperature trend and negative annual temperature range trend were linear and very highly significant. The trends of mean annual, autumn, summer and spring were at level 0.001 (very high), 0.01 (high), 0.05 (significant) and 0.1 weakly significant, respectively.

For the short-term period *1951-1975*, highly decreasing trends of -1.28, -0.46 and -0.42 °C/decade were identified for summer, minimum and mean annual temperature, respectively (Tab. 53). In absolute values, temperature decreased of 3.20 °C in summer, of 1.15 °C for minimum and of 1.05 °C for annual mean temperature. Tab. 53 expresses also positive trend for winter temperature at 0.33 °C/decade, positive trend at 0.15 °C/decade for spring temperature, while the trends were negative at -0.33 and -0.30 °C/decade for autumn and maximum temperatures, respectively. All trends in this period were not linear and not significant except in summer which was weakly significant (Fig. 39).

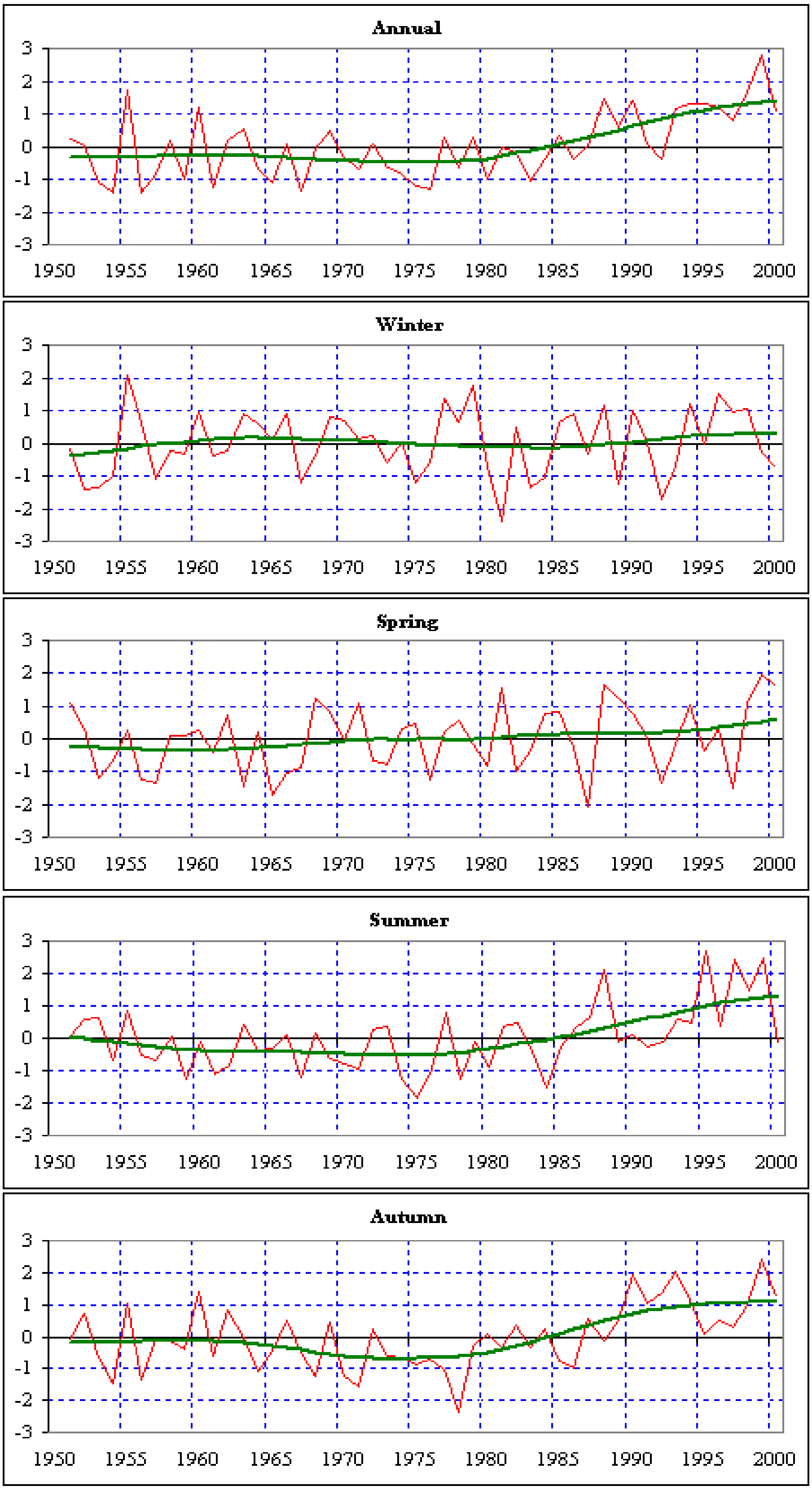
Table 53: Trends of annual, minimum, maximum and seasonal temperatures for all-Libya, trend-noise ratios and Mann-Kendall test for trend (Test Z) according to PCA values, 1951-1975

	Trend/decade	T/noise	Test Z	Sig.
Mean annual	**-0.42**	-0.15	-0.44	
Mean minimum	**-0.46**	-0.12	-0.72	
Mean maximum	**-0.30**	-0.13	-0.26	
Winter (Dec.-Feb.)	**0.33**	0.12	0.30	
Spring (Mar.-May)	**0.15**	0.37	0.58	
Summer (Jun.-Aug.)	**-1.28**	-0.38	-1.70	+
Autumn (Sep.-Nov.)	**-0.33**	-0.79	-1.42	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Over the recent period *1976-2000*, strongly positive and significant linear trends of 1.04, 1.20, 0.88, and 0.99 °C/decade were observed for annual, minimum, summer and autumn temperatures, respectively (Tab. 54). In absolute values, mean annual warming of 2.60 °C, mean minimum warming of 3.00 °C, mean summer warming of 2.20 °C and mean autumn warming of 2.47 °C were computed. Tab. 54 expresses also the trends of maximum, winter and spring temperatures, showing positive trends of mean temperature at 0.11, 0.62 and 0.36 °C/decade in winter, maximum and spring, respectively. Maximum temperature trend was significant but not linear (Fig. 41), while in winter and autumn, the trends were not linear and not significant. High decreasing and significant linear trend of mean annual range temperature was computed in this period.

Fig. 41: All-Libya temperature trends of mean annual and seasonal and inter-annual variabilities with low-pass filter (25 years) according to PCA values, 1951-2000



Data source: Libyan Meteorological Department, Tripoli

Tab. 54: Trends of annual, minimum, maximum and seasonal temperatures for all-Libya, trend-noise ratios and Mann-Kendall test for trend (Test Z) according to PCA values, 1976-2000

	Trend/decade	T/noise	Test Z	Sig.
Annual	**1.04**	2.50	3.76	***
Minimum	**1.20**	2.85	4.64	***
Extreme minimum	**1.28**	2.94	5.13	***
Maximum	**0.62**	1.54	2.31	*
Extreme maximum	**0.13**	0.30	0.42	
Temperature range	**-1.25**	-2.86	-4.69	***
Winter (Dec.-Feb.)	**0.11**	0.22	0.3	
Spring (Mar.-May)	**0.36**	0.87	1.28	
Summer (Jun.-Aug.)	**0.88**	1.87	2.59	**
Autumn (Sep.-Nov.)	**0.99**	2.37	3.90	***

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

3.2.5.2 Observed precipitation changes over all-Libya

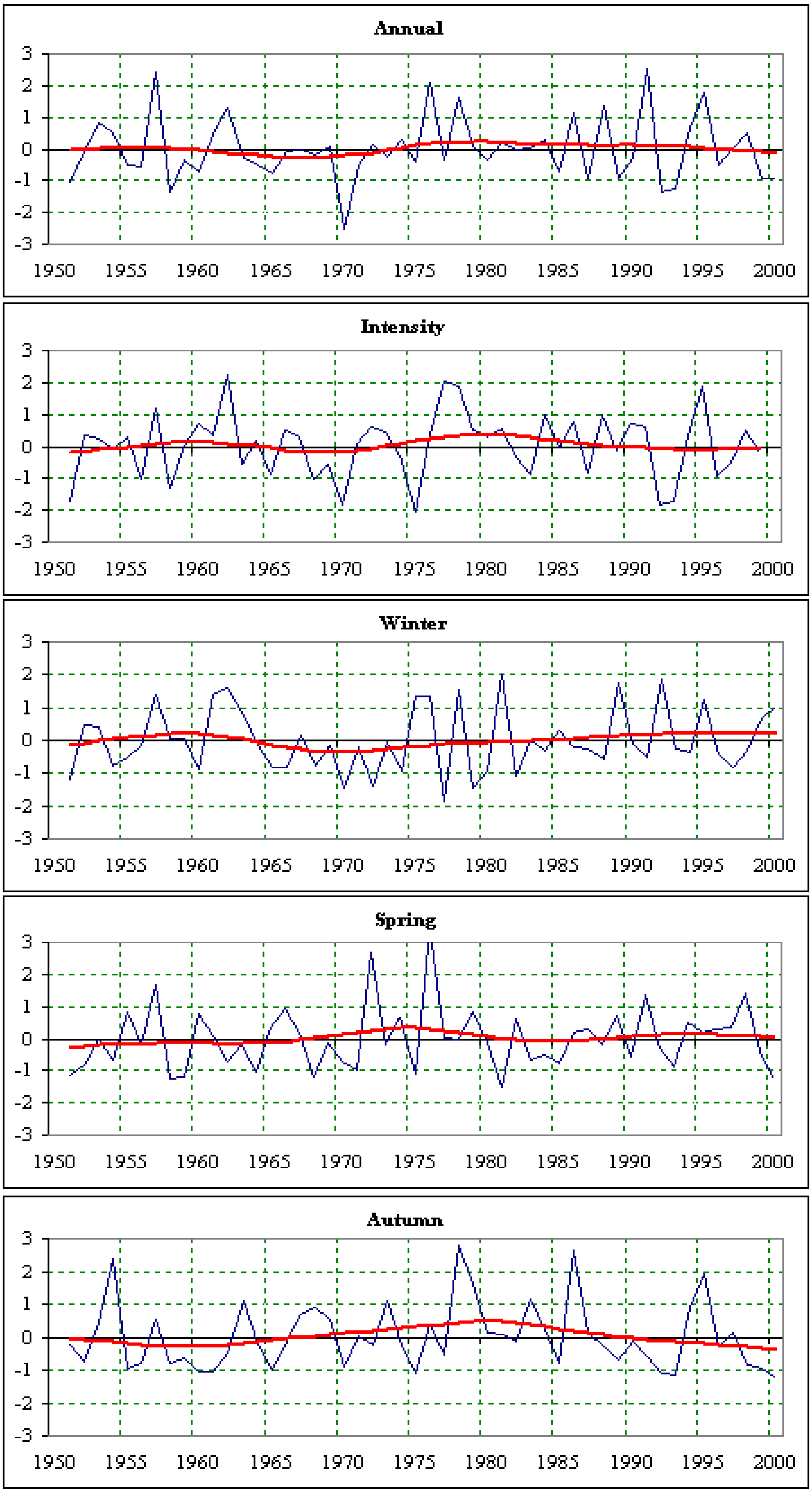
Two observations must be taken into account: the first is most study stations are located in northern Libya, and the second is there is precipitation in Libya concentrates in the north. Trends of annual precipitation total, the annual intensity as well as seasonal precipitation were elaborated over all-Libya from 1951-2000 applying Principal Component Analyses (PCA) based on precipitation data at all study stations showing weakly positive and not significant trends of 0.03, 0.03, 0.06 and 0.07 mm/decade for annual total, annual precipitation intensity, winter precipitation and spring precipitation, respectively. No trend was seen for autumn precipitation. All precipitation trends were not linear in this period (Fig. 42). Trend of annual precipitation total over all-Libya was negative at -.20 mm/decade, not linear and not significant in the period 1951-1975.

Tab. 55: Trends of annual precipitation, intensity and seasonal precipitation over all-Libya, trend-noise ratios and Mann-Kendall test for trend (Test Z) according to PCA values, 1951-2000

	Trend/decade	T/noise	Test Z	Sig.
Annual	**0.03**	0.13	0.23	
Intensity	**0.03**	0.14	0.54	
Winter (Dec.-Feb.)	**0.06**	0.30	0.23	
Spring (Mar.-May)	**0.07**	0.35	1.04	
Autumn (Sep.-Nov.)	**0.00**	0.00	-0.15	

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Fig. 42: Inter-annual variabilities and trends of all-Libya for annual, annual intensity and seasonal precipitation with low-pass filter (25 years) according to PCA values, 1951-2000



Data source: Libyan Meteorological Department, Tripoli

In the period 1976-2000, positive trend for winter precipitation at 0.17 mm/decade, while negative trends of -0.36, -0.51, -0.24 and -0.62 mm/decade for annual total, annual intensity, spring and autumn precipitation, respectively were computed. All trends are not linear explained by high inter-annual precipitation variabilities and not significant except for autumn precipitation which was linear and high significant trend.

Table 56: Trends of annual precipitation, annual intensity and seasonal precipitation over all-Libya (mm/decade), trend-noise ratios and Mann-Kendall test for the trend (Test Z) from according to PCA values, 1976-2000

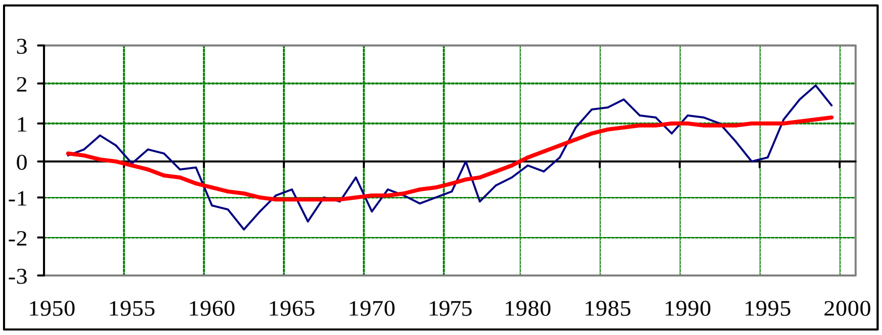
	Trend/decade	T/noise	Test Z	Sig.
Annual	**-0.36**	-0.79	-1.24	
Intensity	**-0.51**	-1.16	-1.56	
Winter (Dec.-Feb.)	**0.17**	0.38	0.58	
Spring (Mar.-May)	**-0.24**	-0.58	-0.21	
Autumn (Sep.-Nov.)	**-0.62**	-1.32	-2.64	**

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

3.2.5.3 Changes of mean annual relative humidity over all-Libya

According to Princeple Componant Analysis (PCA) values, a positive and significant trend of 0.40 % per decade can be identified for the annual mean relative humidity over all-Libya for the long-term period 1951-2000 (Tab. 57). In absolute value, annual relative humidity increased about 2 % from 1951-2000. Non-linear trend from 1951-2000 was shown (Fig. 43). Negative trend over the period 1951-1975 was seen, while positive, very highly significant and linear trend of 1.17 % per decade was computed in the recent period 1976-2000.

Fig. 43: Trends of mean annual relative humidity and inter-annual variabilities with low-pass filter (25 years) over all-Libya according to PCA values, 1951-2000



Data source: Libyan Meteorological Department, Tripoli

Tab. 57: Trends of mean annual relative humidity for all-Libya, trend-noise ratios and Mann-Kendall test for trend (Test Z) according to PCA values, 1951-2000 and 1976-2000

period	**Trend/decade**	T/noise	Test Z	Sig.
1951-2000	**0.40**	1.93	3.73	***
1976-2000	**1.17**	2.68	4.14	***

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

3.2.5.4 Changes of cloud amount over all-Libya

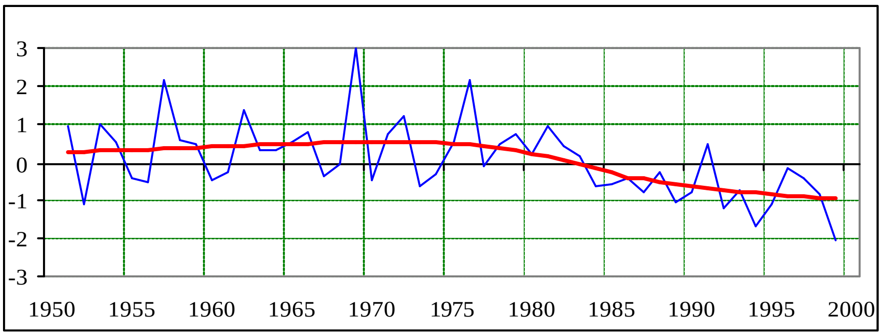
According to Princeple Componant Analysis (PCA) values, Annual cloud amount totals decreased over all-Libya in the period 1951-2000, the trend was very highly significant at level 0.001. In the period 1976-2000, very highly significant negative trend (-1.11 Oktas/decade) was computed. In absolute value, the annual cloud amount totals over all-Libya decreased about 2.77 Oktas from 1976 to 2000. The trend for the long period was not linear, while in the period 1976-2000, it was linear (Tab. 58 and Fig. 44).

Table 58: Trends of annual cloud amount totals for all-Libya, trend-nose ratios and Mann-Kendall test for trend (Test Z) according to PCA values, 1951-2000 and 1976-2000

period	**Trend/decade**	T/noise	Test Z	Sig.
1951-2000	**-0.32**	-1.57	-3.68	***
1976-2000	**-1.11**	-2.55	-3.75	***

Data source: Libyan Meteorological Department, Tripoli. Explanation: see Tab. 10

Fig. 44: Trends of annual cloud amount totals for all-Libya and inter-annual variabilities with low-pass filter (25 years) according to PCA values, 1951-2000



Data source: Libyan Meteorological Department, Tripoli

3.3 Libya and global climate changes

3.3.1 Temperature

To compare the global warming with the recent temperature changes in Libya, mean of global annual and seasonal temperatures have been analyzed based on global temperature data after JONES, et al., 2001 for the periods 1951-2000, 1946-1975 and 1976-2000.

Over the period 1951-2000, mean annual temperature in all-Libya increased of 0.35 °C/decade, while the trend was 0.08 °C/decade for the globe and 0.09 °C/decade of mean annual temperature in Africa.

For seasonal temperatures, the trends of all-Libya were 0.07, 0.18, 0.28 and 0.29 °C/decade for winter, spring, summer and autumn, respectively, while for the globe seasonal temperature trends were 0.11, 0.10, 0.08 and 0.08 °C/decade for winter, spring, summer and autumn, respectively. It can be followed that annual and seasonal temperature trends over Libya were higher than the global trends.

Annual temperature trend for Libya was more than three times compared with the global one. It can also be noticed, from the behaviors of seasonal temperature trends in Libya, that warming mostly occurred in summer and autumn in contrast to the global observations identifying warming mostly in winter and spring in the long period from 1951-2000. In the period 1951-1975, strongly negative trend at -0.42 was computed for mean annual temperature over all-Libya, while weakly positive trend at 0.01 °C/decade of the global mean annual temperature.

Mean annul temperature over Africa increased weakly at 0.01 °C/decade in the same period. For the period 1976-2000, mean annual temperature trends accounted of 0.18, 0.23 and 1.04 °C/decade for globe, Africa and all-Libya, respectively. Notably, the annual temperature increase in Libya corresponds with the global warming but the trend over Libya was higher than over globe and Africa. All-Libya mean annual temperature trend was more than five times compared with the global annual temperature trend in the more recent period 1976-2000.

Generally, it can be said that warming over Libya was similar in magnitude to the global increase. Globally, the 1990s was the warmest decade and 1998 the warmest year in the last century. In Libya, it has also been observed that the 1990s was the warmest decade, while 1999 was the warmest yeas. In seasonal respect, the bulk of warming in Libya occurred in summer (0.88 °/decade) and autumn (0.99 °C/decade), while winter (0.21 °C/decade) and spring (0.36 °C/decade) were the governing seasons for the global annual temperature increase over the period 1976-2000.

3.3.2 Precipitation

Precipitation as a global mean has risen by slightly more than 2 % (STEITZ, and CHANDLER, 1997). Large areas of equatorial Africa experienced to increase in winter precipitation of 50-100 % over parts of eastern Africa, with decrease in summer over parts of the Horn of Africa. However, there are some summer precipitation increases for the Sahel region (McCARTHY, et al., 2001). For all-Libya, annual precipitation total increased of 0.03 mm/decade over the period 1951-2000, while decrease trend of 0.36 mm/decade over the period 1976-200 was computed.

4. Causes of climate change

Changes in the state of the climate system can occur due to external reasons such as variation in the sun's output and continental drift or due to internal reason such as changes in the concentrations of atmospheric gases, volcanic activity, and atmospheric-oceanic oscillations. Climate changes naturally occur in all timescales due to changes in atmospheric and ocean circulation, solar output and volcanic activities. Qualitative comparisons suggest that natural causes produce little warming to fully explain the 20th century warming scenario (HOUGHTON, et al., 2001). Climate forcing by changes in solar irradiance and volcanism has likely caused fluctuations in global and hemispheric mean temperatures. The interlinked nature of the climate system ensures that there are feedbacks; a change in one component leads to a change in most, if not all, other components (BUCHDAHL, 1999: 12). Climate is dominated by a balance among numerous interacting physical processes in the ocean, the atmosphere, and the land surface. Locally, as well as globally, climate is subject to change in all time-scales. This variability in climate is due to various feed back mechanisms among the immeasurable number of climatic variables. Anomalies in one part of the climate system will produce anomalies in others (MGELY, 1984: 1).

It seems to be very difficult to put apart man-induced changes from natural ones, as natural changes are not yet well understood (DONAIRE, 2000: 140). Reconstructions of climate causes in the 20th century indicate that the natural climate forcing probably increased during the first half of the 20th century and the direct effect of variations in solar forcing over the 20th century was about 20-25 % of the change in forcing due to increases in the well-mixed greenhouse gases (HOUGHTON, et al., 2001). The changes observed over the last several decades are mostly due to human activities, and some changes are also reflecting natural variability (CICERONE, et al., 2001: 1). Since 1951, the observed warming can be explained by a combination of the changes in greenhouse gases, sulphate aerosol particles and ozone, all of which result from human activities (ALEXANDER, et al., 2000: 5).

This chapter discusses several natural and human causes of climate change globally and in Libya as below.

4.1 Continental drift

Continental drift is one of the natural causes that affect global climatic system. The separation of the landmasses (continents) can change the flow of ocean currents and winds, which affected the climate at large scales. This drift of the continents continues even currently; the Himalayas are rising by about 1 mm every year because the Indian land mass is moving slowly but steadily towards the Asian land mass (TERI, 2004). Continental movements affect the heat exchange on the earth, the landmasses are moving toward the northern hemisphere, drifting apart changes their latitude which influences the amount of solar radiation and materials escaping into the atmosphere from these activities affect the atmospheric composition (BROOKS, 1991).

4.2 Orbital forcing

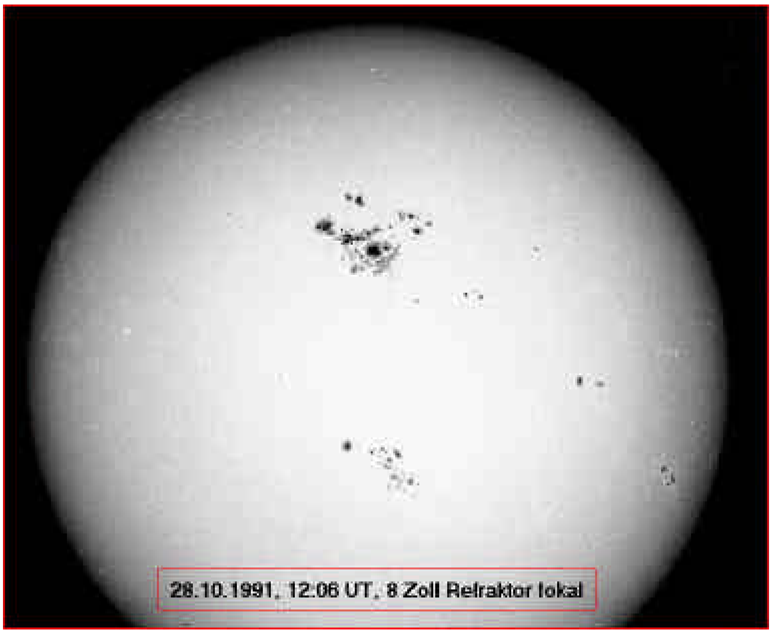
Changes in the orientation and position of the earth in relation to the sun have caused the spectrum of sunlight reaching the earth's surface to vary over time. These changes of orbital variations are primarily responsible for the cycle of ice ages and inter-glacials that have repeatedly caused changes in the global environment (ALVERSON, et al., 2001: 13). Slow variations in the earth's orbit affect the seasonal and latitudinal distribution of solar radiation (HOUGHTON, et al., 1990). Changes in the tilt of the earth can also affect the severity of the seasons; more tilt means warmer summers and colder winters; less tilt means cooler summers and milder winters. This gradual change in the direction of the earth's axis, expressing the so-called precession, is responsible for changes in the climate (TERI, 2004).

4.3 Variation in solar output

Sun is the main source of energy for the earth's climate system. Thus, any change in solar output will result in changes of insolation and generation of heat energy which drives the climate system. Changes in the output of energy from the sun, such as the variability over the 11-year solar cycle, may also change the ratio between the energy absorbed by the earth and the energy emitted causing the radiative forcing on climate (HOUGHTON, et al., 1990). Measurements made during the early 1980s showed a decrease of 0.1 % in the total amount of solar energy reaching the earth over just an 18-month period. If this trend is to extend over several decades, it could influence global climate. Numerical climatic models predict that a change in solar output of only 1 %/century would alter the earth's average temperature by 0.5-1.0 °C (PIDWIRNY, 2004). A 1 % change of solar constant result in a change in equilibrium temperature of 0.6 °C, while a 2 % increase causes up to a 10 % increase in the rate of precipitation, and of evaporation as well. Change in precipitation rate resulting from changes in the solar constant is not uniform in all latitudes, but it is distinctly small in low-latitudes and relatively large in mid- and high-latitudes (LOCKWOOD, J.G. 1977: 105).

Solar variability remains a controversial mechanism of climate change; the best known solar cycle is the variation in the sunspots number over an 11-year period. Sunspot cycles are thought to be related to solar magnetic variations, and a double magnetic cycle (approximately 22 years) can also be identified. It is of course possible that the approximate 11-year cycle identified in many climate records is caused by some unknown internal oscillation and not by external solar forcing (BUCHDAHL, 1999: 16). Sunspots appear as dark spots on the surface of the sun (Fig. 45). They have a lower temperature than the surrounding photosphere. Sunspots radiate less energy than the undisturbed photosphere of the sun and are therefore visible as dark spots.

Fig. 45: Photograph of sunspots taken on 28 October 1991, 12:06 UT, with an 8 inch refractor at focus

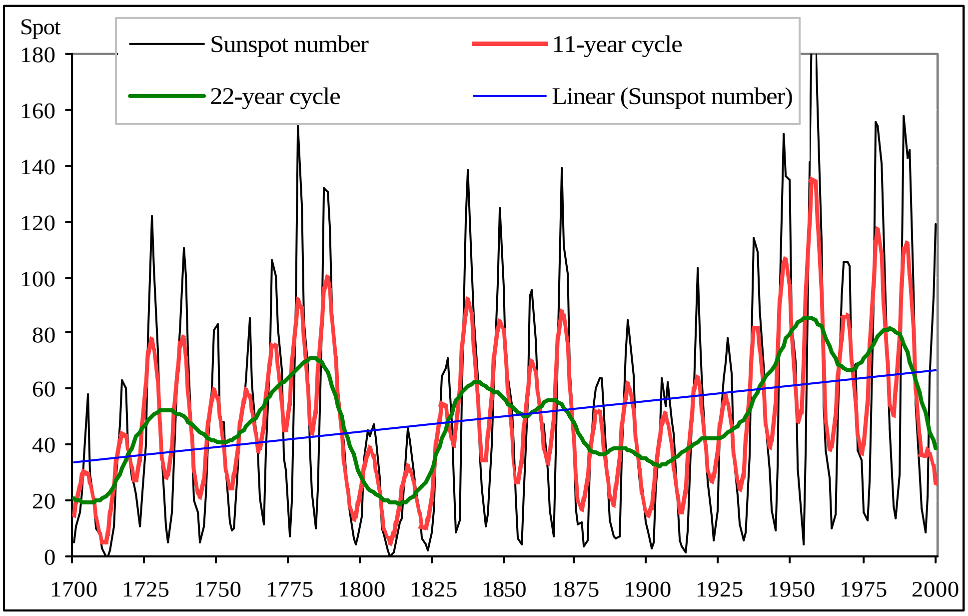


Source: PAECH W, 1991: Institut für Erdmessung, Astronomische Station, Universität Hannover http://www-gik.bau-verm.uni-karlsruhe.de/~fags/sidc003.htm. Accessed 05.01.2004

In 1848 the Swiss astronomer JOHANN RUDOLPH WOLF introduced a daily measurement of sunspot number; his method, which is still used today, counts the total number of sunspots visible on the face of the sun and the number of groups into which they cluster (NOAA National Geophysical Data Center, 2004).

Periodic fluctuations in solar output, as indicated by sunspots, have long been a source of controversy in term of their possible meteorological significance. Solar radiation received as the ground surface varies as a results of internal factors in the earth-atmosphere-system (BARRY, 1977: 117). Fig. 46 shows the sunspot number over the period 1700-2000, identifying an 11-year cycle, a double magnetic 22-year cycle and the behavior of trend.

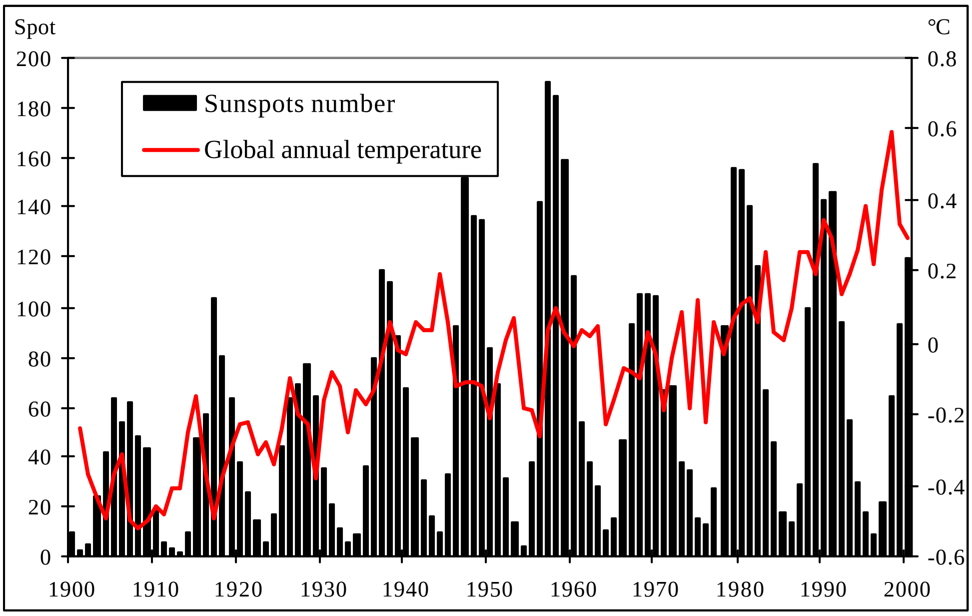
Fig. 46: Inter-annual variabilities of sunspot number, 11-years cycle, double magnetic 22-years cycle and the behavior of trend, 1700-2000



Data source: NOAA National Geophysical Data Center, 2004

Based on global annual temperature data (JONES, et al., 2001) and sunspot number data (NOAA National Geophysical Data Center, 2004), the link between them over the 20th century was elaborated applying correlation coefficient after Pearson. The coefficient was significantly positive (0.27). It can also be noted that the effect of sunspots number on temperature change was higher over the first half of the 20th century 1901-1950 than the second one 1951-2000 (Fig. 47). The postulated solar-irradiance variations may explain a fraction of the earth's inter-annual temperature variabilities, but their effects are most evidently long-term temperature trends on hemispheric and global special scales (HOYT and SCHATTEN, 1997: 179).

Fig. 47: Tele-connection between global mean annual temperature and sunspot number over the 20th century



Data source: JONES, et al. 2001 and NOAA National Geophysical Data Center, 2004

For Libya, correlation coefficients (after Pearson) between sunspot number and climate parameters (temperature and precipitation) were computed at three stations (El-Kufra, Shahat and Tripoli city) as well as for all-Libya, from 1951-2000, showing no significant correlations between sunspots number and mean annual temperatures.

Tab. 59: Correlation coefficients (after Pearson) between sunspot number and mean annual temperature in Libya, 1951-2000

	El-Kufra		Shahat		Tripoli city		All-Libya	
	Correlation	Sig.	Correlation	Sig.	Correlation	Sig.	Correlation	Sig.
Annual	0.03	0.81	-0.05	0.74	-0.10	0.47	0.03	0.82
Summer (JJA)	0.00	0.98	-0.10	0.51	-0.23	0.10	-0.12	0.39
Winter (DJF)	-0.13	0.37	-0.25	0.08	-0.05	0.75	-0.12	0.39

Data source: Libyan Meteorological Department and NOAA National Geophysical Data Center, 2004

In seasonal terms, correlation coefficients were weakly negative for winter and summer temperatures except at El-Kufra in summer. For mean annual temperature, weakly negative correlation coefficients were observed at Shahat and Tripoli city, and a weakly positive coefficient at El-Kufra and for all-Libya (Tab. 59).

It can be followed that there is no effect of solar variations on climate change over Libya in the second half of the 20th century. This observation corresponds with the all reconstructions which suggest a rise in solar forcing[15] during the early decades of the 20th century with little change on inter-decadal time-scales in the second half (HOUGHTON, et al. 2001). The present short-term changes in climate cannot be caused by solar variability, but there is evidence for long-term solar variability (LOCKWOOD, 1977: 109).

4.4 Volcanic activities

For many years, the connection between large explosive volcanic eruptions and short-term climate change has been noticed; when a volcano erupts, large volumes of sulphur dioxide (SO_2), water vapour, dust, and ash are emitted into the atmosphere. These gases and dust particles partially block sun insolation leading to cooling and changing atmospheric circulation patterns.

Fig. 48: A huge cloud of volcanic ash and gas above Mt Pinatubo, on 12 June 1991, after the volcano eruption

Source: U.S. Geological Survey Fact Sheet 113-97.

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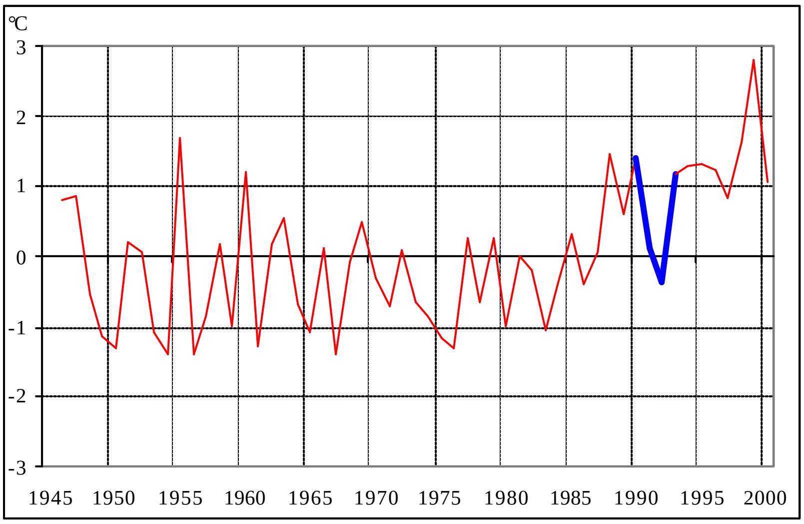
[15] Climate forcing can be identified as an imposed perturbation of earth's energy balance ((CICERONE, et al., 2001: 6)

Winds in the stratosphere carry aerosols and other gases rapidly even round the globe in mostly an eastern or western direction, while the movement northward and southward is always much slower so that the cooling can be brought about a few years after a major volcanic eruption (TERI, 2004), though the volcanic activity may last only a few days. In the 20th century, two significant climate modifying eruptions have occurred: El Chichon in Mexico in April 1982, and Mount Pinatubo in the Philippines on 12 June 1991. Of these two volcanic events, Mount Pinatubo had a greater effect on the earth's climate and ejected about 20 million tons of sulfur dioxide into the stratosphere (Fig. 48). It is believed that the Mount Pinatubo eruption was primarily responsible for the 0.8 °C drop in global annual average surface air temperature in 1992 (PIDWIRNY, 2004).

Mean annual temperature in Libya was affected by the eruption of Mount Pinatubo as 1992 and 1993 were the coldest years in the 1990s (Fig. 49).

Fig. 49: Mean annual temperature anomalies for all-Libya, according to PCA values



Data source: Libyan Meteorological Department, Tripoli

Other major volcanic eruptions have ejected large amounts of aerosols into the stratosphere. The largest eruptions were Tambora (Indonesia) in 1815, the Babujan islands in 1831, and Agung (Indonesia) in 1963 (HOYT, and SCHATTEN, 1997: 205). The most striking example was in 1816, often referred to as "the year without a summer" (SOON and YASKELL, 2003). Significant weather-related disruptions occurred in New England and Western Europe with killing summer frosts in the United States and Canada, these strange phenomena were attributed to a major eruption of the Tambora volcano in 1815 (TERI, 2004).

4.5 Atmospheric-oceanic oscillations

Changes in ocean circulation could be regarded as feedback resulting from orbital forcing. Ocean circulation has traditionally been viewed as an internal forcing mechanism in its own right and plays a crucial role in the regulation of the global climate system (BUCHDAHL, 1999: 19). Recent regional patterns of temperature changes have been shown to be related, in part, to the North Atlantic-Arctic Oscillation and possibly the Pacific Decadal Oscillation. Therefore, regional temperature trends can be strongly influenced by regional variabilities in the climate system and can depart appreciably from the global average. The 1910-1945 warming was initially concentrated on the North Atlantic. By contrast, the period 1946-1975 showed significant cooling in the North Atlantic, as well as much of the Northern Hemisphere, and warming in much of the Southern Hemisphere. High global temperature associated with the 1997/1998 El-Nino event stands out as an extreme event, even taking into account the recent rate of warming (HOUGHTON, et al., 2001).

Changes in the large-scale atmospheric circulation - as represented by the El Nino Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) would further affect the occurrence of extreme events (JACQUELINE, 2000). In the 1990s, strong El-Nino developed in 1991, lasted until 1995, and from fall 1997 to spring 1998. The formation of an El Nino is linked with the cycling of a Pacific Ocean circulation pattern known as the Southern Oscillation. After an El Nino event, weather conditions usually return back to normal. However, in some years the trade winds became extremely strong and an abnormal accumulation of cold water occurred in the central and eastern Pacific. This event is called La Nina. A strong La Nina occurred in 1988 (PIDWIRNY, 2004).

The behavior of ENSO has been unusual since the mid-1970s compared with the previous 100 years, with warm phase ENSO episodes being relatively more frequent, persistent, and intense than the opposite cool phase. This recent behavior of ENSO is reflected in variations in precipitation and temperature over much of the tropics and subtropics (HOUGHTON, et al., 2001).

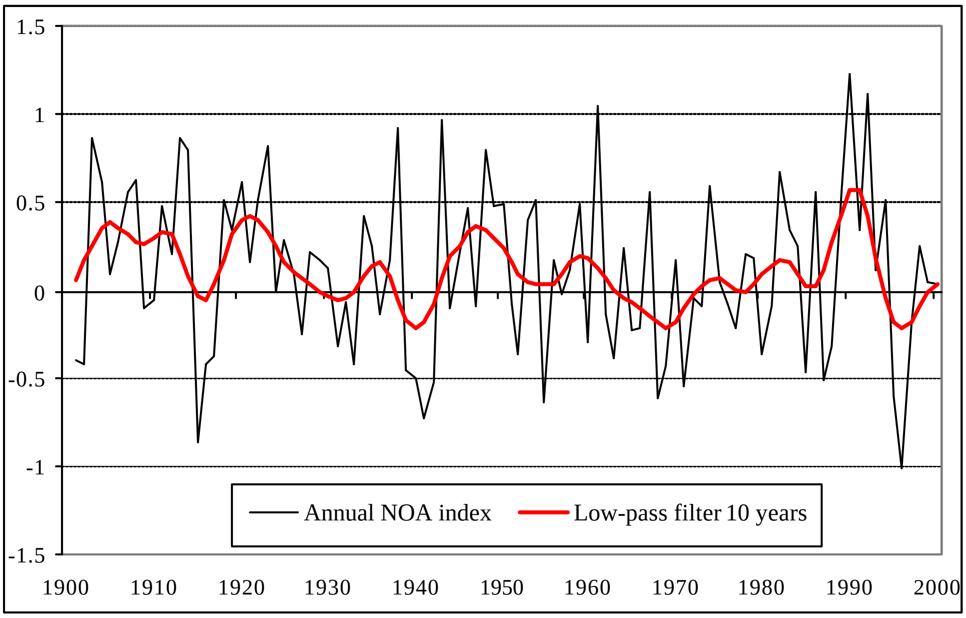
The high variability of precipitation can partly be explained by changes in atmospheric circulation, which in turn alter the storm tracks and precipitation distribution (LUTERBACHER and XOPLAKI, 2003: 146).

4.5.1 North Atlantic Oscillation (NAO)

North Atlantic Oscillation (NAO) is one of the major modes of Northern Hemisphere atmosphere variability. The NAO is now believed to be part of a wider-scale atmospheric Arctic Oscillation that affects much of the extra-tropical northern hemisphere (HOUGHTON, et al., 2001). It is particularly important in winter, when it exerts a strong control on the climate of the Northern Hemisphere.

The difference between the normalized sea level pressure over Azores at 30 °N and the normalized sea level pressure over southwest Iceland at 60 °N is a useful index of the strength of NAO (JONES, 2003a). From the early 1940s until the early 1970s, when the NAO index (NAOI) exhibited a decreasing trend, European temperatures in winter were frequently lower than normal. A sharp reversal has occurred over the past 25 years (Fig. 50), with unprecedented strongly positive NOAI values since 1980 and with sea level pressure anomalies (HURRELL, 1995: 676).

Fig. 50: Inter-annual and inter-decadal variabilities of NAOI, 1901-2000



Data source: NOAA National Geophysical Data Center, 2004

The effect of NAO on recent global warming can be identified through the correlation coefficient computed after Pearson, between NAOI and global mean annual temperature. The coefficient was weakly positive at 0.12 over the 20th century.

For Libya, negative correlation coefficients were calculated from 1951-2000 between the NAOI and mean temperature (annual and seasonal) at three stations and for all-Libya from 1951-2000 (Tab. 60). Negative correlations values indicate to the reversed relationship between NAO index and temperature changes in Libya.

Tab. 60: Correlation coefficients between NAO index and temperature in Libya

	El-Kufra		Shahat		Tripoli city		All-Libya	
	Correlation	Sig.	Correlation	Sig.	Correlation	Sig.	Correlation	Sig.
Annual	-0.26	0.06	-0.35	0.01	-0.18	0.22	-0.29	0.04
Summer (JJA)	-0.26	0.07	-0.43	0.00	-0.37	0.01	-0.47	0.00
Winter (DJF)	-0.51	0.00	-0.46	0.00	-0.48	0.00	-0.56	0.00

Data source: Libyan Meteorological Department and NOAA National Geophysical Data Center, 2004

In contrast to the NAO-mean annual temperature teleconnection over Libya, the relationship between NAO index and annual precipitation totals are generally positive. Weakly positive values are computed for annual precipitation, while seasonal precipitation show a higher correlation with NAOI, especially in winter. It can also be observed that the correlation coefficient was higher at Tripoli city than at Sirt and higher at Sirt than at Shahat, expressing a decreasing the effect of NAO over Libya from west to east (Tab. 61).

Tab. 61: Correlation coefficients (after Pearson) between NAO index and annual precipitation totals in Libya, 1951-2000

	Shahat		Sirt		Tripoli city	
	Correlation	Sig.	Correlation	Sig.	Correlation	Sig.
Annual	0.06	0.66	0.07	0.62	0.08	0.57
Spring (MAM)	0.23	0.10	0.30	0.03	0.23	0.10
Winter (DJF)	0.09	0.52	0.33	0.02	0.49	0.00
Autumn (SON)	0.16	0.25	0.10	0.50	0.35	0.01

Data source: Libyan Meteorological Department and NOAA National Geophysical Data Center, 2004

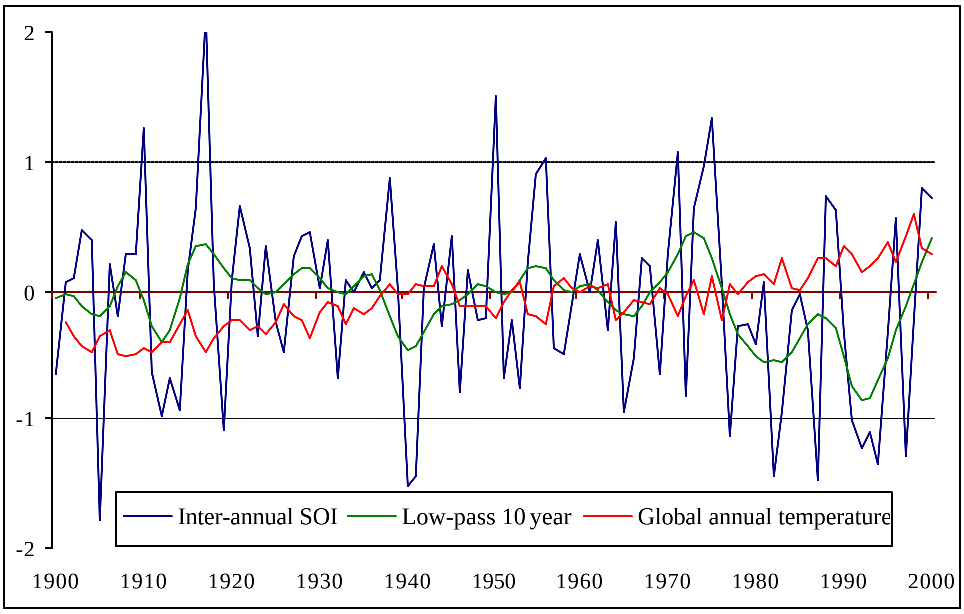
Over northern Africa, North Atlantic Oscillation (NAO) is a key factor responsible for the inter-annual variabilities of precipitation. Other continental-scale and sub-continental scale climate anomalies play significant roles in determining inter-annual and longer climate variability time scales (McCARTHY, et al., 2001).

North Atlantic Oscillation is linked to the strength of the Westerlies over the Atlantic and extra-tropical Eurasia. During winter, NAO displays irregular oscillations on inter-annual to multi-decadal time-scales. Since the 1970s, the winter NAO has often been in a phase that contributes to stronger Westerlies, which correlate with cold season warming over Eurasia. New evidence indicates that the NAO and changes in Arctic sea ice are likely to be closely coupled (HOUGHTON, et al., 2001).

4.5.2 El-Nino Southern Oscillation (ENSO)

El-Nino phenomenon, through interactions between the ocean and the atmosphere, is now widely recognized as the recurring cause of major natural perturbations to the climate system (KINMONTH, 1999: 257). The most dramatic and best defined pattern of inter-annual variabilities are the global set of climatic anomalies referred to as El-Nino Southern Oscillation (ENSO), an acronym derived from its oceanographic component, El-Nino, and its atmospheric component, the Southern Oscillation. The 1982/83 ENSO event was the most extreme in the 20th century. On the average, an ENSO event occurs about every four years, but the cycle is highly irregular; there are only two years between events, sometimes almost a decade (CANE, 1997). There is recent evidence that the teleconnection of ENSO has extended its reach into parts of the Mediterranean region in recent decades (LUTERBACHER and XOPLAKI, 2003: 134).

Fig. 51: Tele-connection between SOI and global mean annual temperatures, 1901-2000



Data source: JONES, et al. 2001 and NOAA National Geophysical Data Center, 2004

Southern Oscillation Index (SOI) is defined as the normalized pressure difference between Tahiti and Darwin (JONES, 2003b). The correlation coefficient (after Pearson) between the SOI and global annual temperature was weakly negative (-0.25) over the 20th century (Fig. 51).

In Libya, correlation between mean annual temperatures and the SOI were negative at El-Kufra, Tripoli city and for all-Libya since the early 1950s, while at Shahat the correlation was very weakly positive. From 1950-2000, negative correlations were calculated between the SOI and summer temperatures in contrast to winter temperatures which were computed a positive correlation to SOI at all three stations and for all-Libya (Tab. 62). No significant correlations between SOI and temperatures in Libya indicate to the weakly effect of Southern Oscillation.

Tab. 62: Correlation coefficients (after Pearson) between SOI and mean annual and seasonal temperatures in Libya, 1950-2000

	El-Kufra		Shahat		Tripoli city		All-Libya	
	Correlation	Sig.	Correlation	Sig.	Correlation	Sig.	Correlation	Sig.
Annual	-0.18	0.19	0.06	0.66	-0.08	0.58	-0.08	0.59
Summer (JJA)	-0.17	0.17	-0.01	0.95	-0.18	0.21	-0.14	0.31
Winter (DJF)	0.10	0.50	0.18	0.21	0.03	0.83	0.11	0.46

Data source: Libyan Meteorological Department and NOAA National Geophysical Data Center, 2004

In general, weakly links occur between SOI and precipitation over Libya (Tab.63). Weakly negative correlations for annual and seasonal precipitation were observed at Shahat. Negative links were computed for annual, spring and autumn precipitation, while a weakly positive correlation was for winter at Tripoli city. Negative correlations were noticed at Sirt for spring and winter precipitation and no correlations for annual and autumn.

Tab. 63: Correlation coefficients (after Pearson) between SOI and annual and seasonal precipitation totals in Libya, 1950-2000

	Shahat		Sirt		Tripoli city	
	Correlation	Sig.	Correlation	Sig.	Correlation	Sig.
Annual	-0.12	0.39	0.03	0.86	-0.04	0.79
Spring (SON)	-0.12	0.39	-0.18	0.21	-0.10	0.49
Winter (DJF)	-0.15	0.30	-0.11	0.43	0.15	0.31
Autumn (MAM)	-0.02	0.87	0.02	0.90	-0.20	0.17

Data source: Libyan Meteorological Department and NOAA National Geophysical Data Center, 2004

4.6 Cloud cover

The net effect of cloud cover on the surface radiative balance is still uncertain and there are no simple relationships between cloudiness and surface temperature (HARVEY, 1980: 519). The interaction of cloud amounts with radiation alters the surface–atmosphere heating distribution, which in turn drives atmospheric motion that is responsible for the redistribution of clouds (SUN, et al. 2000: 4341). With greater global cloud coverage, more incident radiation is reflected reducing radiative forcing and leading to a lowering of the global temperature (BUCHDAHL, 1999: 21).

Effects of cloud amounts effects on climate changes in Libya are very weak. Correlation coefficients (after Pearson) between cloud cover amount and the mean annual, minimum and maximum temperatures were elaborated at two stations (Benina and Tripoli city) from 1946-2000 (Tab. 64).

Tab. 64: Correlation coefficients (after Pearson) between cloud amounts and temperatures at Benina and Tripoli city, 1950-2000

Station	Benina		Tripoli city	
	Correlation	Sig.	Correlation	Sig.
Annual	-0.07	0.62	-0.26	0.06
Minimum	0.30	0.03	-0.14	0.32
Maximum	-0.53	0.00	-0.40	0.00

Data source: Libya Meteorological Department, Tripoli

The correlation coefficients between cloud cover amounts and mean minimum temperature were positive at Benina and weakly negative at Tripoli city, while it was negative for annual and maximum temperatures at both stations. It can also be seen that the increasing minimum temperature trend in northeastern Libya may be partly caused by the increase of cloud cover amount.

This simple picture of the cloud feedback is, however, complicated by the fact that clouds also serve to trap terrestrial infrared radiation, augmenting the greenhouse effect, and thus act as a positive feedback, also, to increased radiative forcing. High level clouds are expected to have a net positive feedback, with the effect of long-wave radiation absorption outweighing albedo effects. Clouds at high altitudes exist in colder air and tend to emit less radiation generating a stronger greenhouse effect. Low level clouds, on the other hand, probably have a net negative feedback effect (BUCHDAHL, 1999: 21).

4.7 Variations in atmospheric composition

Comparisons of records of solar radiation changes with volcanic eruptions, as well as modeling studies, show that these factors were responsible for most of temperature changes prior to the 20th century. However, the rate of temperature change over the last century cannot be explained without taking into account the increase in atmospheric greenhouse gases due to human activities (ALVERSON, et al., 2001: 16). The changing composition of the atmosphere, including greenhouse gases and aerosol content, is a major internal forcing mechanism of climate change.

The greenhouse effect is a natural phenomenon, without it the earth's temperature would be about 33 °C colder than currently at around 15 °C as a global mean. The problem, as first identified by ARRHENIUS in 1896, is that human activities, like driving cars, burning coal to heat and run factories, chopping down forests, and raising cattle have significantly increased the atmospheric concentrations of the greenhouse gases, namely carbon dioxide, methane and nitrous oxide (ROACH, 1997). An increase of CO_2 and other gases which allow sunlight to reach the earth's surface but prevent some of the infrared, respect heat-radiation given off by the earth from escaping into space.

The greenhouse gases H_2O, CO_2, O_3, N_2O, CH_4 and others affect directly on climate. H_2O is adjusted by the water circulation over evaporation and precipitation and is concentrated in the troposphere. CO_2, CH_4 and N_2O increased from 280, 0.80 and 0.28 ppm, respectively, before beginning of the industrialization until today 370, 1.75 and 0.32 ppm, respectively (FABIAN, 2002: 23). Recent global warming may result from combination of greenhouse gases and increase in cloud cover amounts resulting mainly from CO_2 concentration. Since 1958, accurate measurements of the increasing CO_2 concentrations in the atmosphere have been made showing a fairly regular annual rate of increase at about 4 %, a doubling of CO_2 would lead to an average surface warming of about 2-4 °C with greater warming occurring in winter by the latter half of the 21st century (PITTOCK, et al. 1988: 306).

Monitoring of atmospheric concentrations shows that CO_2, as well as other greenhouse gases, increased during the past few decades (NOVELLI, et al., 1995: 32). Changes of greenhouse gas contents in the atmosphere can occur as a result of both natural and anthropogenic factors. Natural changes occur in numerous ways, most often in response to other primary forcing factors, while anthropogenic changes occur through the burning of fossil fuels, forest clearing and other industrial processes. Atmospheric concentrations of the principal anthropogenic greenhouse gases have increased significantly from the 18th century and have largely increased over the 20th century as a result of population growth, economic expansion, landuse pattern changes, deforestation, land clearing, agriculture, and the ever increasing consumption of fossil fuels (Tab. 65). The consumption of fossil fuels and expand industrial activities with a rapidly growing population, has led to a release into the atmosphere not only of increasing amounts of CO_2 but also a wide range of other gases components (GREGORY, 1988: 2).

Tab. 65: Change of greenhouse gases from 1750-2000

Substance	1750	2000
CO_2 , ppm	280	370
CH_4, ppb	800	1750
H_2, ppb	550	565
N_2O, ppb	284	315
CO, ppb	50	50-500
H_2O,	-------	to 20000
O_3, ppb	10-20	to 500
CH_3CL, ppt	550	550
CH_3Br, ppt	7	10

Source: FABIAN, 2002: 25

ppm (parts per million); ppb=parts per billion; ppt = parts per trillion

Rising dust particle quantities by wind and anthropogenic aerosol formation contributes to one rose the albedo (WELLBURN, 1997: 199). The presence of the added aerosols increases the effective albedo through reflection of sunlight incident on the stratosphere and thus leads to a cooling effect. The particulates also block emitted infrared radiation, but the albedo effect is generally larger (GILLILAND, 1982: 114).

Well-mixed greenhouse gases make the largest and best-known contribution to changes in radiative forcing over the last century. The dramatic warming of the 20th century correlates best and very significantly with greenhouse gas forcing (HOUGHTON, et al. 2001). There are a wide range of human activities that release greenhouse gases into the atmosphere. CO_2, CH_4, and N_2O together have contributed about 80 % of the additional climate forcing since the pre-industrial times. CO_2 contributed about 60 % among them (TERI, 2004). Any gas in the atmosphere that helps to hold in heat energy around the planet rather than letting it radiate into space is a greenhouse gas. The effect of the greenhouse on the temperature grounds interests us particularly in the next 10 to 100 years, which are therefore became slightly warmer. This effect, which can constitute 1 °C in individual cases, was considered during the data evaluation, the method of the correction leaves however in the global means an uncertainty of a tenth degree (KUHN, 1990: 32). The most significant greenhouse gases are briefly dealt with below:

4.7.1 Carbon dioxide[16]

CO_2 is naturally absorbed and released by the terrestrial biosphere as well as by the oceans. CO_2 is also formed by the burning of wood, coal, oil and natural gas, and these activities have steadily increased during the last two centuries since the Industrial Revolution (CICERONE, et al., 2001: 10). CO_2 is the main greenhouse gas emitted. It is considered as responsible for approximately half of greenhouse effects on climate change though there is some dispute as to the probable effect of a given increase in CO_2 concentration on the climate, due to the great complexity of the climate system (PITTOCK, et al., 1988: 306). Over the past three centuries, the concentrations of CO_2 have been increasing in the Earth's atmosphere because of human influences. Elevated concentrations are predicted to persist in the atmosphere for times ranging to thousands of years.

CO_2 is, however, not the only greenhouse gas that influences on global climate. Large natural variations of CO_2 have occurred in the geologic past, and these changes are correlated with general features of climate change (TAMARA, et al., 1999). Measurements of past concentrations in bubbles of air trapped in ice cores from Antarctica to Greenland show that pre-industrial concentrations were about 270 ppmv, and a doubling of the pre-industrial level is expected by the latter half of the 21st century (PITTOCK, et al. 1988: 306). Since 1751, CO_2 concentrations worldwide have increased from 6 mill. t to around 16 mill. t in 1800, 1068 mill. t in 1900 to extremely increase at 13,221 mill. t in the 20th century (MARLAND, et al., 2003). The trends of CO_2 concentrations increased from 1751-2000; it was 0.17 million t/year form 1750 -1800, 8.36 million t/year from 1801-1900 and 133.82 million t/year in the 20th century (Fig. 52). That means 542,137 million metric tons of CO_2 were being added to the atmosphere from 1901-2000.

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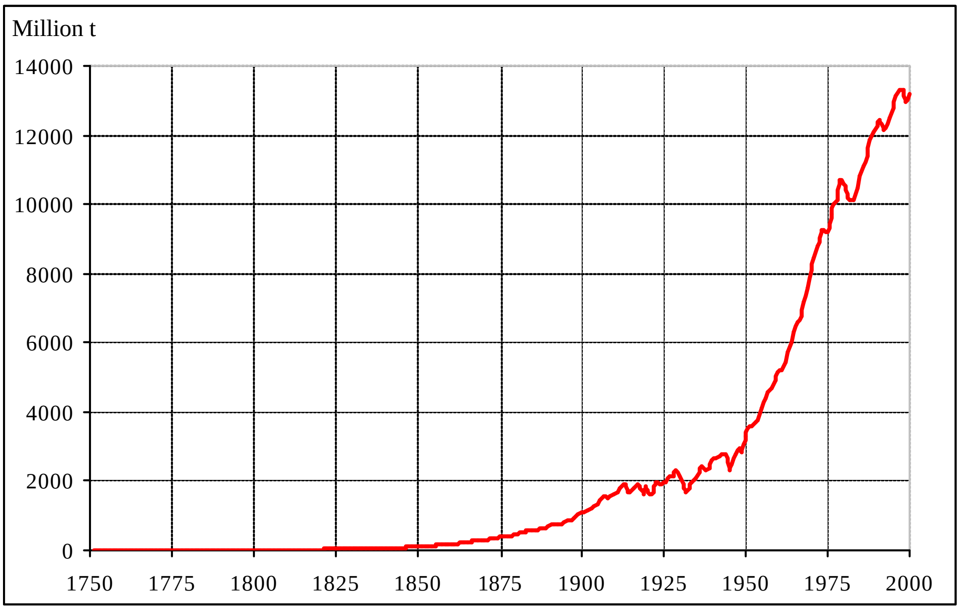
[16] The estimates of CO_2 were derived primarily from energy statistics published by the United Nations. Cement production estimates from the U.S. Department of Interior's Bureau of Mines were used to estimate CO_2 emitted during cement production. Emissions from gas flaring were derived primarily from U.N. data but were supplemented with data from the U.S. Department of Energy's Energy Information Administration, and with a few national estimates provided by MARLAND, et al., 2003; Global: http://cdiac.esd.ornl.gov/ndps/ndp030.html; Libya: http://cdiac.ornl.gov/ftp/ndp030/nation00.ems

Fig. 52: Total concentrations of global CO_2 (mill. t), 1750-2000



Data source: MARLAND, et al., 2003

The main sources of CO_2 emissions in the 20th century are shown in Tab. 66 explaining the largest contributor to emissions from fossil fuels followed by solid fuel consumption, while the smallest contributor is gas flaring.

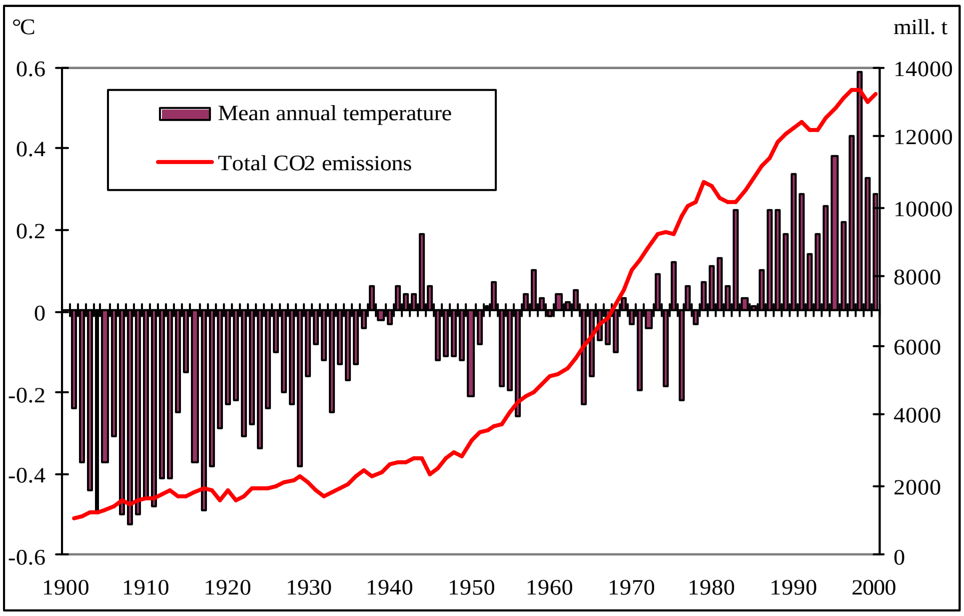
Tab. 66: Global CO_2 emissions from fossil-fuels, gas fuel consumption, liquid fuel consumption, solid fuel consumption, cement production, and gas flaring (mill. t), 1901-2000

Source	Total CO_2 emissions
Fossil fuels	271,066
Gas fuel consumption	33,199
Liquid fuel consumption	98,736
Solid fuel consumption	130,757
Cement production	5,510
Gas flaring	2,869
Total	542,137

Data source: MARLAND, et al., 2003

Correlation coefficient (after Pearson) was computed to determine the relationship between CO_2 emissions and global mean annual temperature in the 20th century. It is observed that the teleconnection between them was high, the correlation coefficient was significantly positive at 0.78 (Fig. 53).

Fig. 53: Global mean annual temperature anomalies and CO_2 concentrations in the 20th century



Data source: JONES, et al., 2001 and MARLAND, et al., 2003

In Libya, the total energy consumption was about 0.16 % of the world total energy consumption, the energy-related carbon emissions was about 0.2 % of world carbon emissions. Fuel share of energy consumption was oil (69.2 %) and natural gas (30.8 %). Fuel share of CO_2 is oil (71.5 %) and natural gas (28.4 %; EIA, 2004).

Tab. 67: Total CO_2 concentrations and the annual trend in Libya, 1950-2000 (1,000 t)

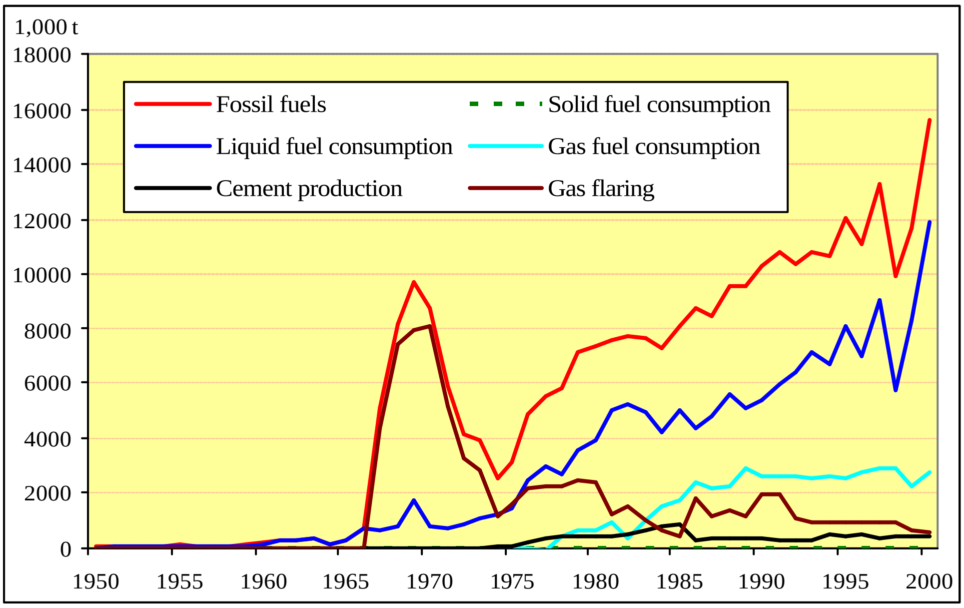
CO_2 emissions	Totals from 1950-2000	Annual trend
Fossil fuels	286,430.0	284.22
Solid fuel consumption	318.0	-33
Liquid fuel consumption	153,645.0	189.79
Gas fuel consumption	45,900.0	68.462
Cement production	11,117.1	12.545
Gas flaring	75,449.9	13,753

Data source: MARLAND, et al., 2003

The main source of CO_2 emissions from 1950-2000 is the energy sector which depends mainly on fossil fuels, followed by industrial emissions, chiefly from the cement industries. The largest contributor to CO_2 emissions in Libya is from fossil fuels followed by liquid fuel consumption, while the smallest contributor is solid fuel consumption (Tab.

67). It can also be noticed that the annual trend of CO_2 emissions was strongly positive for fossil fuels at 284,220 t/year followed by liquid fuel consumption 189,790 t/year, while the emissions of CO_2 from solid fuel consumption decreased at 33,000 t/year from 1950-2000 (Fig. 54).

Fig. 54: Total CO_2 emissions from different sectors in Libya, 1950-2000



Data source: MARLAND, et al., 2003

Total concentration of CO_2 has also increased in Libya from 1950-2000 (Tab. 68) showing an increase from 78,000 t in 1950 to 6271,400 t in 1975 and to 31182,200 t in 2000. Trend computations of total CO_2 emissions in Libya from 1950-2000 increased from 5684,500 t of carbon per decade in the long-term period 1950-2000 to 6721,700 t per decade over the period 1975-2000.

Increasing CO_2 emissions in more recent time have subsequently a pronounced effect on temperature increase over Libya. Correlation coefficients (after Pearson) were computed to elaborate the relationship between CO_2 emissions and mean annual temperatures at four stations as well as for all-Libya from 1950-2000 (Tab. 69) showing positive relationship at all stations and for all-Libya, the correlation coefficients were significantly positive.

Tab. 68: Total CO_2 emissions from fossil fuels, solid fuel consumption, liquid fuel consumption, gas fuel consumption, cement production and gas flaring in Libya, 1950-2000

year	Total CO_2 emissions (1,000 t)	year	Total CO_2 emissions (1,000 t)
1950	78.0	1976	9771.3
1951	92.0	1977	10966.1
1952	89.0	1978	11584.1
1953	136.0	1979	14178.8
1954	164.0	1980	14694.2
1955	234.0	1981	15155.5
1956	180.0	1982	15362.4
1957	170.0	1983	15305.8
1958	191.0	1984	14444.5
1959	235.0	1985	16056.1
1960	378.0	1986	17633.3
1961	653.0	1987	16932.1
1962	571.0	1988	19154.5
1963	799.0	1989	19114.2
1964	361.0	1990	20618.8
1965	554.0	1991	21600.1
1966	1434.0	1992	20720.7
1967	10093.4	1993	21695.9
1968	16438.6	1994	21408.9
1969	19390.0	1995	24156.1
1970	17614.1	1996	22260.0
1971	11781.9	1997	26586.5
1972	8256.6	1998	19894.7
1973	7832.0	1999	23345.5
1974	5040.7	2000	31182.2
1975	6271.4		

Data source: MARLAND, et al., 2003

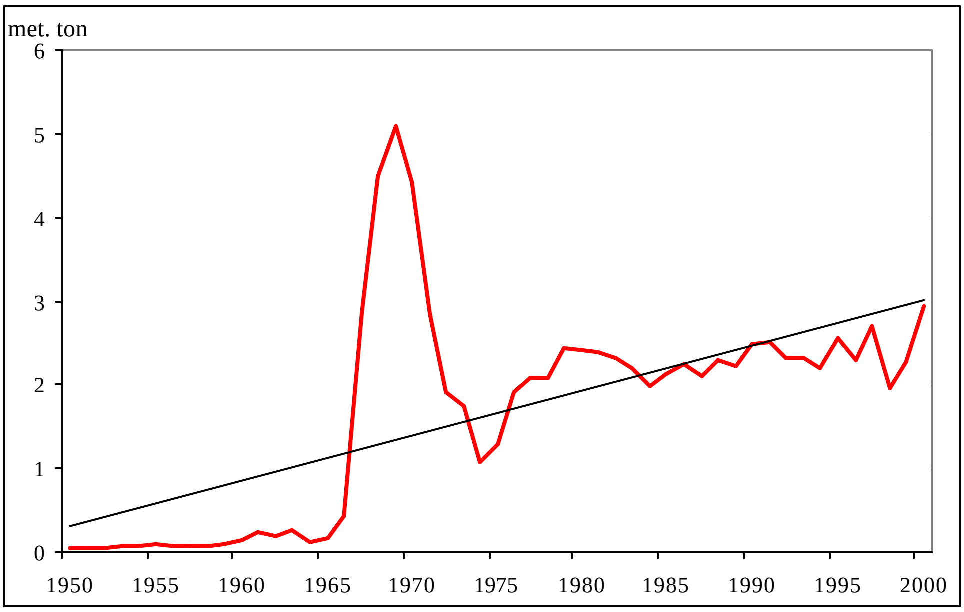
Tab. 69: Correlation coefficients (after Pearson) between CO_2 concentrations and mean annual temperatures in Libya, 1950-2000

Station	El-Kufra	Sebha	Shahat	Tripoli city	All-Libya
Correlation coefficient	0.49	0.56	0.29	0.72	0.52
Significance	0.00	0.00	0.04	0.00	0.00

Data source: MARLAND, et al. 2003 and Libyan Meteorological Department, Tripoli

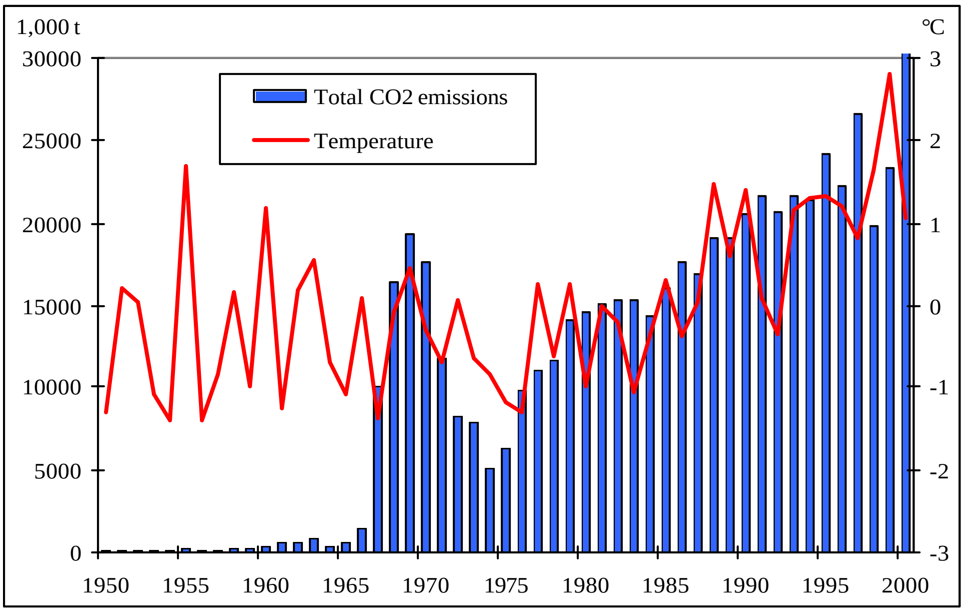
CO_2 emissions per capita increased in Libya at 0.05 t/year from 1950-2000 as a result of urbanization growth followed by increasing of energy use (Fig. 55).

Fig. 55: CO_2 emissions per capita in Libya, 1950-2000



Data source: MARLAND, et al., 2003

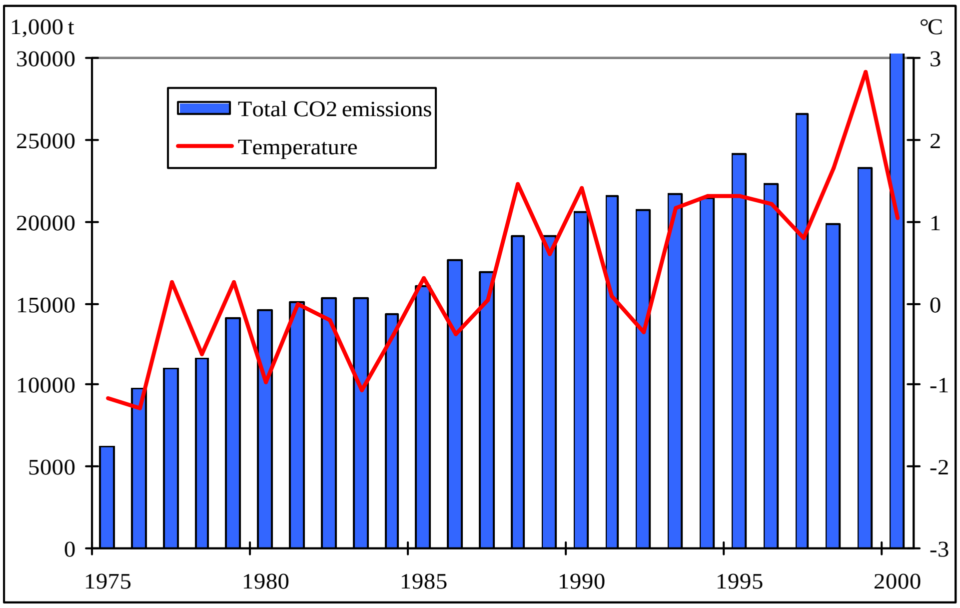
Fig. 56: CO_2 emissions compared with all-Libya mean annual temperatures, 1950-2000



Data source: MARLAND, et al., 2003 and Libyan Meteorological Department, Tripoli

Teleconnection between CO_2 concentrations and mean annual temperatures over all-Libya was investigated for two periods, 1950-2000 as a long-term (Fig. 56) and 1976-2000 as a short-term period (Fig. 57) showing a strong correlation but in the period 1976-2000 (which expresses the high period of high increase of temperature on a global scale), the correlation was stronger. It can be followed that the increasing CO_2 emissions are, by far, the largest present and future contributor to anthropogenic induced climate change.

Fig. 57: CO_2 emissions compared with all-Libya mean annual temperatures, 1976-2000



Data source: MARLAND, et al., 2003 and Libyan Meteorological Department, Tripoli

Both national (Libya) and international climate-change policies have embraced a multi-gas approach where a 'basket' of greenhouse gas emissions. In such approach, emissions of each gas are given relative weights and the sums of the weighted emissions are compared to some target value (SMITH, 2003: 261). Laboratory and glass house experiments on individual plants indicate that a doubling of CO_2 would lead to a 0-10 % increase in growth and yield for C_4 plants such as corn, sorghum and sugarcane, and a 10-50 % increase for C_3 plants which include wheat, rice, barley and many fruits and vegetables (PITTOCK, 1988: 310).

4.7.2 Aerosols

Aerosol is another product deriving from human activities, its particles are produced by industry power generation, automobiles, space heating and agricultural practices and so forth, aerosols are obvious additions to the atmosphere of large cities. Sulfate and carbon-bearing compounds associated with particles are two classes of aerosols that impact radiative balances, and therefore influence climate (CICERONE, et al., 2001: 11). Increase of atmospheric aerosol also affects the atmospheric energy budget by increasing the scattering of incoming solar radiation (BUCHDAHL, 1999: 21). Possible effects of aerosol loading are dependent on the absorption and scattering properties of the particles, their vertical distribution and the albedo. The evidence suggests that recent climatic trends have not been determined by the aerosol increase due to pollution although such effects may occur in the future (BARRY 1977:118).

In contrast to gases, aerosols may either warm or cool the surface air layer depending on their optical properties and their distribution with height. An overall warming of the surface air layer would lead to enhanced evaporation and cloud formation which would increase the planetary albedo but decrease the surface air temperature (BACH, 1979: 64).

Sulfate aerosol is solid compound commonly found in the atmosphere. The particles play an important role in reflecting, absorbing, and scattering incoming insolation. The source of these compounds is both natural and human-made. Most of the human-made particles come from the combustion of fossil fuels. Sulphate emissions increased steadily until World War I, and then leveled off, and increased more rapidly since the 1950s, though not as fast as greenhouse gas emissions. Under the almost monotonic increase in greenhouse gas forcing in recent decades, the ratio of sulphate to greenhouse gas forcing has probably been decreasing since 1960 (HOUGHTON, et al. 2001).

Unlike CO_2 with a residence time of 2-5 years resulting in a uniform atmospheric mixing ratio, aerosols with a mean tropospheric residence time of 9 years show regionally high concentrations near urban and industrial agglomerations and near areas with agricultural burning (BACH, 1979: 68).

It is also possible that dust may affect climate through its influence on marine primary productivity changes in atmospheric temperatures and in concentrations of potential condensation nuclei may affect convectional activity and cloud formation, thereby modifying precipitation amounts (GOUDIE and MIDDLETON, 2001: 180).

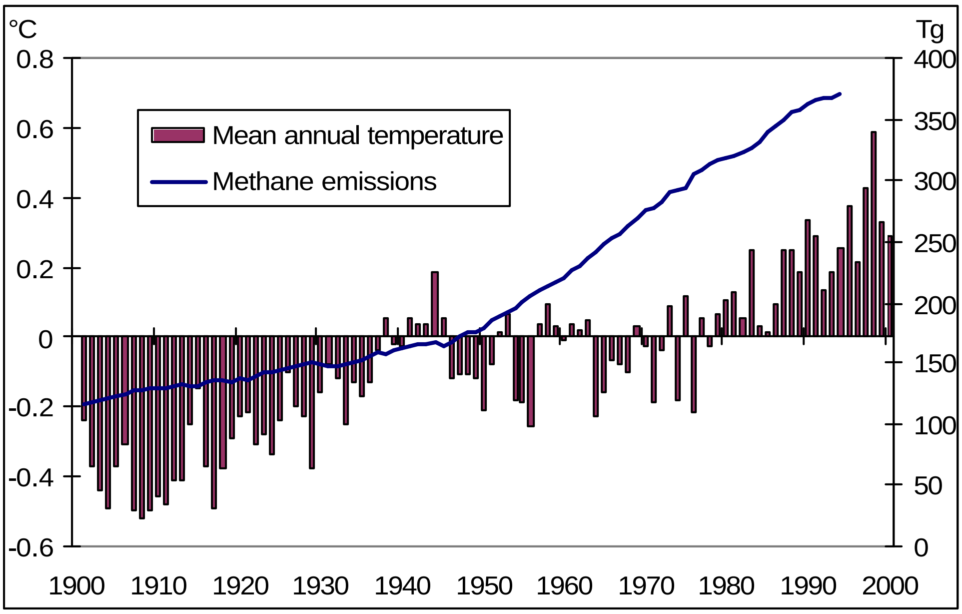
<u>*4.7.3 Methane*</u>

Methane (CH_4) is another important greenhouse gas in the atmosphere. Both CH_4 and CO_2 are more abundant in earth's atmosphere now than at any time during the past 400,000 years (CICERONE, et al., 2001: 11). Notably, a molecule of CH_4 is a more potent greenhouse gas than a molecule of CO_2. CH_4 is a greenhouse gas that remains in the atmosphere for approximately 9-15 years. CH_4 is over 20 times more effective in trapping heat in the atmosphere than CO_2 over a 100-year period and is emitted from a variety of natural and human-influenced sources (EPA, 2005).

About 25 % of all CH_4 emissions derive from domesticated animals. These animals produce CH_4 during the cud-chewing process. CH_4 is also emitted from landfills and other waste dumps and also emitted during the process of oil drilling, coal mining and from leaking gas pipelines (TERI, 2004).

There is a connection between CH_4 concentrations in the atmosphere and recent global warming. The teleconnection between CH_4 emissions and global mean annual temperature in the 20th century was elaborated (Fig. 58) showing a relatively high correlation coefficient (0.75). It is observed that the teleconnection between them was relatively high.

Fig. 58: Teleconnection between global mean annual temperatures and CH_4 concentrations in the 20th century



Global historical anthropogenic CH_4 emissions expressed in Tg. (teragrams; 1 Tg = 10^{12} g)
CH_4 data source: STERN, et al., 1998. Temperature data source: JONES, et al., 2001

4.7.4 Ozone

Ozone (O_3) affects climate, and climate affects ozone. Temperature, humidity, winds, and the presence of other chemicals in the atmosphere influence O_3 formation, and the presence of O_3, in turn, affects those atmospheric constituents (ALLEN, 2004). O_3 acts as a greenhouse gas by absorbing outgoing long wave radiation. It also absorbs solar radiation in particular the UV-B radiation. Changes in the vertical distribution of O_3 can perturb the solar and long-wave radiative forcing of the troposphere-surface climate system. It has been noted that a decrease in stratospheric O_3 prompts an increase in solar radiation available for absorption, and a cooling effect created by a lowering of downward long-wave radiation (MOHNEN, et al., 1995: 39).

O_3 influences both stratospheric and troposphere temperatures by absorbing solar radiation which would otherwise heat the earth’s surface. It creates the greenhouse effect by absorbing and remitting infrared radiation (HARVEY, 1980: 514). The impact of O_3 on climate forcing stands in striking contrast to the impact from other greenhouse gases that are more uniformly distributed throughout the troposphere. O_3 life times run generally to an order of days or weeks in the troposphere, but to many months in the lower stratosphere run. The climate forcing due to O_3 in not uniform and the impact on surface temperatures is more difficult to asses than for other well-mixed greenhouse gases (MOHNEN, et al., 1995: 40).

Observations show that over recent decades, the mid to upper stratosphere has cooled by 1-6 °C. This stratospheric cooling has taken place at the same time that greenhouse gas amounts in the lower atmosphere troposphere have risen (ALLEN, 2004).

4.8 Patterns of landuse

Deforestation, settlement expansion, agriculture, and other human activities have substantially altered and fragmented the landscape resulting change the atmospheric concentration of CO_2 which is the principal greenhouse gas, as well as affect local, regional, and global climate by changing the energy balance on Earth's surface. Farther model calculations show that a 50 % change of forests into agricultural land would increase the CO_2 emissions by 95 ppm) which would rise the global surface air temperature by 0.6 °C (BACH, 1979: 70). In 1980_s land became a small net sink for carbon, that is, the various processes storing carbon globally exceeded the loss due to tropical deforestation, which by itself as estimated to add 10-40 % as much CO_2 to the atmosphere as burning of fossil fuels (CICERONE, et al., 2001: 11)

There are many ways by which mankind can influence the heat balance of the earth, for example, when a forest is cleared for pastoral and agriculture lands. In Libya, 500,000 ha are cleared in Ainzarah, Elkurabolli, Misurata and Jebal El-Akhadar for seasonaly irrigated plantations (TECHNICAL CENTRE OF ENVIRONMENTAL PROTECTION, 1998: 15). Overgrazing in semi-arid areas bares soils of high albedo, which have a greater irradiative heat loss than adjacent vegetated areas (BARRY, 1977:118).

As a result, lands generally reflect more sunlight, since crops and grasses land usually absorb less than trees. Over-irrigation and inadequate soil drainage are the most common problems leading to water logging and thus induce salinization in northern Libya. This problem is caused by unsuitable selection of land for irrigation and poor irrigation management (BIN-MAHMOUD, et al., 2000).

Same is true when nomadic tribesmen allow their cattle or goats to overgraze on marginal lands, since the distribution of vegetation markedly increases the reflectivity of the surface. A number of anthropogenic causes of climate change in terms of their effect on mean surface temperature, and in some their effects on precipitation as well (KELLOGG, 1977: 237).

Italian colonization altered the patterns of landuse in Libya turning pastoral and rainfed agriculture lands in many parts to cultivated lands followed by deterioration of ecosystem especially in the coastal areas. Most of water wells in Jifara plain were dug by hand to about 15 meter, while the Italian people brought equipments that able to deg hundreds of wells some of which reached 750 m for irrigation (BAQI, 1991: 116).

4.9 Urban heat islands

An urban *heat island* is the name given to describe the characteristic warmth of both the atmosphere and surfaces in cities (urban areas) compared to their (non-urbanized) surroundings. The heat island is an example of unintentional climate modification when urbanization changes the characteristics of the Earth’s surface and atmosphere (VOOGT, 2004). The conversion of rural landscapes to urban landscapes is characterized by large emissions of gases, particles, water vapour, and the heat from many combustion processes (BACH, 1979: 69).

Clearly, the urban heat island can affect climate in urban areas, this effcet is not representative of larger areas. Over the last few decades, the observed increases in land air temperatures are, on the one hand, due to urban heat island related to the observed decrease in the diurnal temperature range and, on the other, due to a lower rate of warming observed over the past twenty years in the lower troposphere compared with the surface (HOUGHTON, et al. 2001).

As rapid urbanization-industrialization is overlapping with global warming, climate data from the urbanized areas might be contaminated with urban heat island effect (CHUNG, et al., 2004: 127). Extensive tests have shown that the urban heat island effects are no more than about 0.05 °C up to 1990 in the global mean annual temperature records (HOUGHTON, et al. 2001).

Regional urbanization and industrialization were believed to be more influential on the regional temperature than the global warming from 1951-2000 (CHUNG, et al., 2004: 128). In Libya, weak effects of urban heat island on climate may appear only in Tripoli city and Ben-Ghazi where most of Libya’s people are resided.

5. Impacts of climate change

The effects of such factors on estimates of the impacts of climate change have only been poorly explored if misleading assessments of adaptation strategies to climate change impacts are to be avoided, future studies should consider the impacts of natural multi-decadal climate variability alongside those of human-induced climate change (HULME, et al., 1999: 688). This recent intensification of concern has derived from many disasters which are caused by climate change such as droughts, floods and hurricanes. Thus, there is a growing social awareness of climatic hazards across the globe which did not really exist previously (GREGORY, 1988: 1).

Even more troubling are concerns about the possible relationship between climate change and the frequency as well as intensity of extreme weather events, like hurricanes, typhoons, droughts, and floods. Estimations indicate weather-related damage in 1999 totaled at $67 billion worldwide. Likewise, weather-related damage in the 1990s increased five fold from the 1980s (USAID, 2000). It has also been estimated that the 1982-83 El-Nino Southern Oscillation (ENSO) event was responsible for $8 billions in damages and the loss of two thousand lives (Cane, 1997: 2). Over 700,000 people died in the 1980s as a direct result of hazardous weather events. Hence, natural weather events such as storms (hurricanes), floods and drought are, in all respects, major disasters. Sometimes, they destroy hard-won economic achievements in developing countries, throwing the economy into chaos (BEDRITSKY, 1999: 176).

Global climate change is likely to result in changes of the hydrological cycle including increases in storms and droughts, changes in both the amount and geographical distribution of precipitation. This in turn affects agricultural crops patterns and food production, having a severe effect on food intake per capita, particularly in the developing countries (EEAA, 1999: 61) threatening food security and increasing poverty.

Changing precipitation patterns may put freshwater resources at risk, water scarcity is endemic and changes in the water balance would have substantial implications for agriculture and water supplies, loss of already scarce vegetation cover, increased desertification and associated socio-economic impacts. Changes of precipitation could also lead to widespread flooding in certain regions of the world while inflicting drought in other regions altering the ecosystems. Excessive precipitation, which may occur in some parts, has serious negative effects on road networks and air transport. A warmer earth could lead to the spread of diseases such as malaria and dengue, and increase heat-related mortality, deaths caused by extreme weather events. Changes in the frequency, timing and duration of heat waves affect agricultural yields and they increase the number and variety of insect pests (ROACH, 1997).

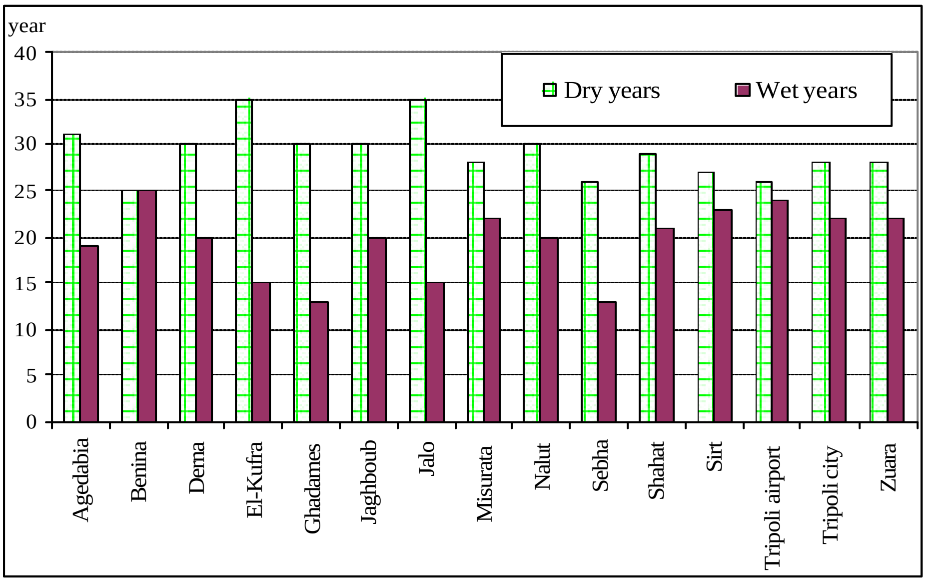
Changes in climate would have severe impacts not only on distribution of human beings but also on the quality of their life. It may lead to industrial relocation, resulting either from sea-level rise in coastal-zone areas or from transitions to agro-ecological zones. If sea-level rise occurs as a result of climate change, the effect on many harbors and ports will be quite devastating economically for many coastal-zone countries (McCARTHY, et al., 2001). Although all areas will be affected, the type and extent of impacts experienced will vary markedly depending on local circumstances.

In arid and semi-lands, which serves primarily as pastoral lands, precipitation is scanty and irregular, evaporation rate is very high, and the natural balance of plant life is fragile. As too much livestock feeds within these diminishing areas, plants disappear speedily under the stresses of overgrazing and lack of water. The consequence is that natural resource managers in arid and semi-arid environments must deal not only with low amount of precipitation but also with highly variable precipitation. Precipitation occurs less frequently in arid areas so that few if any adaptations have developed other than talking advantage of the diversified resource base that periodically results (SEELY, 1999: 1).

Libya is vulnerable to climate change because of prevailing arid and semi-arid climate conditions, recurrent droughts, inequitable land distribution, and overdependence on rainfed agriculture. Precipitation is the main parameter of climate which may control the socio-economic prospects. It begins usually in autumn to winter which is the rainiest season and end in spring, while a negligible precipitation occurs in summer. High precipitation variabilities and severe precipitation intensities over Libya may cause severe moisture stress on cultivated crops and reduce yields. As a common rule, precipitation in arid and semi-arid areas has in most cases negative effects. Due to high temperatures, most water evaporates without any benefit to agriculture, whereas a small percentage of precipitation only infiltrates to groundwater.

Over the 50-year period 1951-2000, precipitation data at 15 stations in Libya were analyzed to investigate the number of arid (below the average) and humid (above the average) years; as a result high inter-annual variabilities of precipitation were noticed and the number of arid years was greater than the humid years at 14 stations ranging between 35 arid years against 15 humid years at El-Kufra and 26 arid years against 24 humid years at Tripoli airport (Fig. 59, Tab. 70). The high inter-annual precipitation variabilities in Libya affect, without any doubt, rainfed agriculture and pastoral lands; additionally, it has also negative implications on water resources.

Fig. 59: Number of arid and humid years in Libya, 1951-2000



Data source: Libyan Meteorological Department, Tripoli

Tab. 70: Number of arid and humid years in Libya, 1951-2000

Station	Nr. of arid years	Nr. of humid years
Agedabia	31	19
Benina	25	25
Derna	30	20
El-Kufra	35	15
Ghadames	30	13
Jaghboub	30	20
Jalo	35	15
Misurata	28	22
Nalut	30	20
Sebha	26	13
Shahat	29	21
Sirt	27	23
Tripoli airport	26	24
Tripoli city	28	22
Zuara	28	22

Data source: Libyan Meteorological Department, Tripoli

Severe precipitation intensities have serious implications on soil in Libya. Soil is subject to severe, moderate and light water erosion as shown in Tab. 71.

Tab.71: Areas affected by water erosion in Libya, (ha)

Type of erosion	Light (>10 %)	Moderate (10-25 %)	Severe (25-50 %)	Total
Western areas	165,600	164,600	64,500	304,700
Middle areas	------	2,453	------	2,453
Eastern areas	241,700	41,500	1,700	284,900
Total	407,300	208,553	66,200	592,053

Source: GENERAL ENVIRONMENTAL AUTHORITY, 2002: 210

Although precipitation may be limited to a few days, extreme precipitation intensities may lead to disastrous floods damaging agriculture and even resulting in loss of lives (e. g. El-Migenin wadi flood in September 1969 and El-Kharwaa wadi flood in December 1983; GENERAL ENVIRONMENTAL AUTHORITY, 2002: 239). Seasonality of precipitation most strikingly characterizes across all-Libya, it can also be considered as a limiting factor for rainfed agriculture.

Increasing temperature comes also soil erosion and leads to increase wind speed, which in turn increases amount of Saharan dust blown off and causing health and economic problems. In spring and autumn, strong southerly winds – namely the so-called Gibli - blow from the desert, filling the air with sand and dust and raising the temperature to over 50 °C in some areas, for example 53 °C at Tripoli airport in 1996 (KREDEGH, 2002: 126). Strong Gibli winds cause soil erosion in Libya (Tab. 72) transferring a big amount of sand from Sahara desert to the northern parts of Libya.

Tab. 72: Areas affected by wind erosion in Libya, (ha)

Type of erosion	Light	Moderate	Severe	Totals
Western areas	180,000	266,400	136,400	582,800
Middle areas	160,838	49,494	4,402	214,734
Eastern areas	53,500	8,400	200	62,100
Totals	394,338	324,294	141,002	859,634

Source: GENERAL ENVIRONMENTAL AUTHORITY, 2002: 210

Gibli has drastically effects on Libya in many ways to agriculture, human health, and national economy. It has been observed that Gibli sand storms increased in recent decades shown by the number of sand storms in northwestern Libya from 1965-1997 (Kredegh, 2002: 115). Increasing number of sand storms is explained by the recent climate change scenario, by decreasing precipitation and increasing temperature, followed by overgrazing and over-cultivation in marginal lands which cause severe soil erosion. Increase frequencies of dust events reflect some of environmental changes.

The most affected sectors by climate change, according to IPCC, Third Assessment Report 2001, are water resources, coastal zones, agriculture, rangeland and livestock, human health, human settlements, forest, bio-diversity species, communities and ecosystems and fisheries. These adverse impacts represent real threats on sustainable development, especially in developing countries.

Climate in Libya played a substantial role in determining land uses and in forming the sensitive water balance rarely achieved in most area owing to precipitation variabilities and seasonality. It is to be shown that Libya is affected by climate change in many ways, in particular crop production and food security, pastoral lands and livestock production, water resources, human health, population emigration and settlement, natural resources management and biodiversity.

5.1 Impacts on crop productions and food security

Seasonal patterns of solar radiation, temperature, air humidity, atmospheric CO_2 concentration and soil conditions are the main determinants for agricultural production (ROETTER, and VAN DE GEIJN, 1999: 651). Crop production is primarily affected by climatological variables, uneven precipitation distribution and prolonged arid period will lead to the further development of soil salinization and soil erosion, losses of fertile soil will increase (SCHÄFER, 2001). Changes in soil properties, arising from climate change, will have profound implications for agriculture given both the time scales and spatial coverage over which soil processes can operate (ROUNSEVELL, et al., 1999: 683). Increasing drought will lead to significant declines in agricultural productivity in many developing countries and the loss of food security will increase their vulnerability to drought. Unfortunately, most of the vulnerable developing countries, such as Libya, are already troubled by crucial imbalances between rapidly growing populations and existing constraints on food-production capabilities (SWEARINGEN, 1992: 401).

The ability to absorb climatic change effects varies from country to other because of the different social and environmental context. Lack of understanding of the societal context of drought hampers the ability of governments to cope with potential increases in drought that may result from global warming (SWEARINGEN, 1992: 403).

Biophysical effects of climate change on agricultural production may be positive in some agricultural systems and regions, and negative in others, and these effects will vary over time. There is a wide consensus that climate change will worsen food security, mainly through increased extremes and temporal-spatial shifts (McCARTHY, et al., 2001). Agriculture can be affected by climate change through high temperature and recurrent extreme events whichl reduce crop yield, temperature variabilities may induce changes of crop distribution, and temperature can negatively affect marginal lands through soil erosion, as well as increases ambient CO_2 concentration would directly affect plant growth (PITTOCK, 1988: 310). It can also be expected that climate change causes plant diseases, such as fungal diseases, and insect pests such as locusts and aphids. Although the exact magnitude of this CO_2 fertilization is uncertain, positive outcomes prevail. Considering the positive effects of CO_2 on crop growth an increase in productivity can be projected, but its magnitude remains uncertain (SCHÄFER, 2001).

Given the fact that sharp fluctuations in agricultural production and imports are common features in arid and semi-arid countries where irrigation coverage is low, the overall impact of water scarcity resulting from climate change on the world food market can be substantial (YANG and ZEHNDER, 2001: 1320). Expected higher prices for food imported from developed countries as a result of global climate changes would aggravate their vulnerability to impacts of climate change and lead to a deterioration in levels of food security. For example, yields of grains and other food crops could decrease substantially across the Mediterranean region due to increased frequency of drought, climate changes associated with a doubling of CO_2 could cause yield losses of over 20 % for wheat, corn and other coarse grains (JACQUELINE, 2000). In coastal areas, large areas of productive land may be lost through flooding, saline intrusion and water logging.

Precipitation is, however, only one of the factors influencing productivity as well as sustainability. Agricultural drought is the deficiency or absence of precipitation that affects the normal functions of the agricultural year. Crop droughts refer to insufficient precipitation for at least part of the growing season (SEELY, 1999: 3). Agricultural drought occurs when water supply is insufficient to cover crop water requirements and can threat farmers even when precipitation levels indicate that meteorological drought is not occurring

(SWEARINGEN, 1992: 402). Other aspects of climate such as temperature, evaporation, cloud cover and wind also affect the response of agricultural and other natural resources.

Libya already experiences a deficit in food production and depends mainly on food import. In the middle of 1990s Libya imported about 60 % from its food requirements (SCHLIEPHAKE, 2004: 211). Agricultural production constitutes only a small percentage (8.6 %) of the GDP of Libya (CIA, 2004). Arable land is only 1.815 million ha, out of which, permanent crops cover 335,000 ha (figures for 2001, FAO, 2002: 4). The areas under irrigation were estimated at 435,000 ha in 1989-1991 and increased to 470,000 ha in 1999-2001 (FAO, 2002: 17). These areas include large scheme project, settlements and smallholder farms, while most of cultivated lands are under rainfed agriculture and pastures (BIN-MAHMOUD et al., 2000). Most of the arable and pastoral lands occupy the northern semi-arid parts of Libya, while deserts in southern Libya are subject to frequent periods of drought. Principal crops cultivated in Libya are wheat, potatoes, barley, citrus fruits, dates, and olives. With the depletion of non-renewable groundwater resources, irrigated areas are in Libya unlikely to increase, but may decrease. Imbalance between rapidly growing population and food-production capability can be observed by wheat production, consumption and decreasing of self-sufficiency in Libya (Tab. 73).

Tab. 73: Growth of wheat requirements in Libya, 1990-2000

Year	Population (1000)	Wheat production (1000)	Amount consumed (1000)	Gap (1000)	% of self-sufficiency
1990	4,202	185	682	427	27
1995	5,112	185	830	645	22
2000	6,220	185	1,010	825	18

Source: NATIONAL COMMITTEE TO COMBAT DESERTIFICATION, 1999

Precipitation across Libya is mostly <100 mm/year expressing a great severity of dryness and drought conditions with even some years experience no precipitation at all. Distribution of total annual precipitation over time and space is clearly expressing the scarcity of precipitation over most parts of Libya. An increase in precipitation variability can rapidly reduce agricultural productivity and alter the composition of steppes and grassland. Libya is chiefly a desert country characterized by arid and semi-arid climate types which played a substantial role in determining landuses and in forming the sensitive water balance rarely achieved in most areas. Under these limitations, the various drought factors produced specific chemical properties and soils which are naturally and characteristically fragile. Agricultural land is, therefore, limited to less than 2 % of Libya's total area. Moreover, these factors had implications on the composition and distribution of the natural plant cover which only produces fodder for 35 % of animal food requirements (NATIONAL COMMITTEE TO COMBAT DESERTIFICATION, 1999). Precipitation is generally inadequate to meet the water demand of crops and is considered as the most limiting factor for landuse especially due to the high potential evaporation in Libya.

Hot, dry sandstorms called Gibli have direct and indirect implications on food crops in Libya: for example the sand storm blown on 24-28 June, 1994, seriously affected crop production: 24,735,000 Libyan dinars[17] loss of vegetable, 48,446,000 Libyan dinars of fruit, and 7,600,000 Libyan dinars of beans (KREDEGH, 2002: 127); this means a total loss of 90,579,000 Libyan dinars by sandstorms in only four days. Indirect negative effect of sandstorms can be observed through soil erosion in northern parts of Libya; the areas which are affected by wind erosion in Libya are 859,964 ha (GENERAL ENVIRONMENTAL AUTHORITY, 2002: 210)

Variabilities of harvest and production and cropping areas of two major food crops in Libya were elaborated from 1968-2001 to detect the effect of climate change on food crops. Wheat production does not meet the current demand, and each year additional amounts have to be imported. The rapid growth of population and the limited area for agriculture as well as a decreasing economically active farm population (Tab. 74) increase the vulnerability of food production to climate change in Libya.

Table 74: Population and percentages of economically active population

Year	Population in agriculture (1,000)	% of economically active population
1990	783	11.0
1995	697	8.0
2001	651	5.6

Source: FAO, 2002: 20

Inter-annual variabilities of wheat harvest area can be seen in Libya (Fig. 60) explained mainly by precipitation inter-annual variabilities because the irrigated area is limited and most of wheat area is cultivated under rainfed conditions. It can also be observed that wheat production is high in comparison with the harvest area in many years and vice-versa attributing to variability of seasonal precipitation or an increase of the irrigated area

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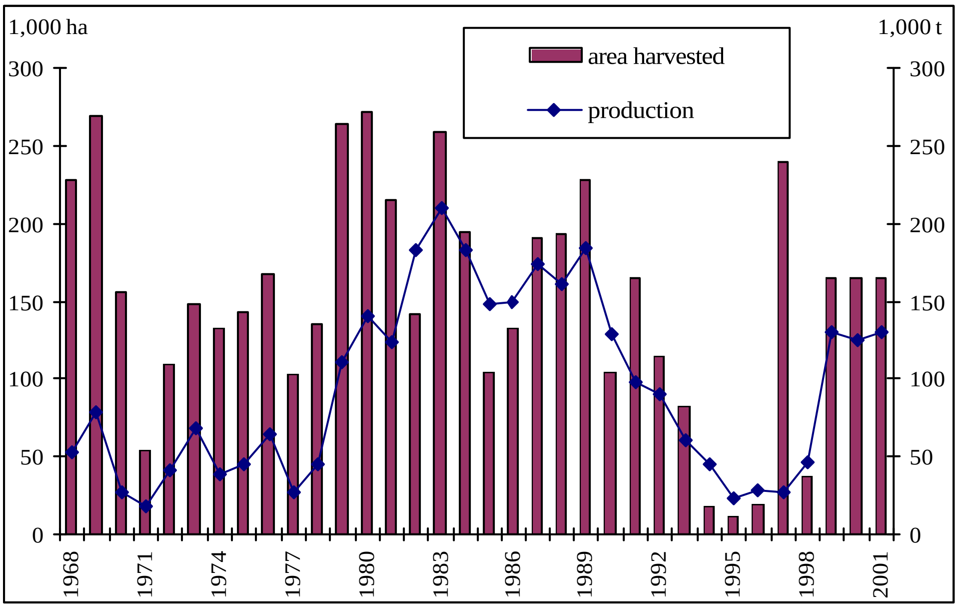
[17] Libyan dinar per U.S, $ was: 1.2929 (2003), 1.2707 (2002), 0.6051 (2001), 0.4994 (2000), 0.3936 (1999) (CIA, 2004).

in some years as high precipitation variabilities, recurrent droughts and over-dependence on rainfed agriculture affect wheat production.

Fig. 60: Harvest areas and production of wheat in Libya, 1968-2001



Data source: 1968-1990: AGRICULTURE RESEARCH CENTER, 1992. 1991-1998: ELZAEDY and ELTAHER, 2000. 1999-2001: FAO, 2002

The critical precipitation limits of wheat were some 30 % higher than those for barley. Additionally, barley ripens and can be harvested earlier than wheat; these characteristics make barley less vulnerable to arid conditions during the early onset of summer (SWEARINGEN, 1992: 406).

Cultivated as rainfed agriculture in Libya, barley relies mainly on precipitation. As a result, barley is highly vulnerable to climate changes, seasonal shifts, and precipitation patterns. Any warming leads to an increasing water stress. Increased temperatures would increase evapotranspiration which is likely to increase crop water requirements and lower yields. Variabilities of precipitation negatively affect barley. Mean annual barley production was 117,656 t from 1968-1990, while its production was very low at 100,000, 71,000, 87,000, and 83,000 t in 1979, 1980, 1984, and 1985, respectively (AGRICULTURE RESEARCH CENTER (Tripoli), 1992).

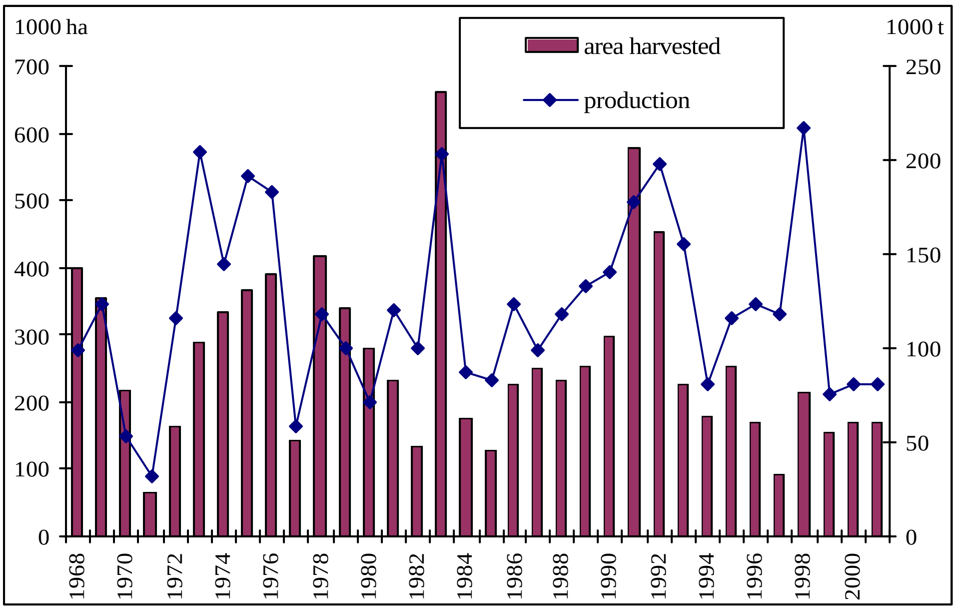
To clarify the effects of precipitation variabilities on barley, correlation coefficients (after Pearson) were computed between harvest areas under barley, its productions and annual total precipitation at eight stations in northern Libya where barley was planted from 1968-2001 (Tab. 75). It has been observed that the harvest area and production of barley correlated positively with precipitation at all stations except Zuara and Tripoli airport. Highly significant correlation for harvest area and precipitation was computed at Shahat which records the heaviest precipitation among all stations.

Tab. 75: Correlation coefficient (after Pearson) between annual precipitations at selected stations and harvested areas and production of barley in Libya, 1968-2001

Station	Harvested area		Production	
	Correlation coefficient	Significance	Correlation coefficient	Significance
Agedabia	0.28	0.12	0.29	0.10
Benina	0.31	0.08	0.10	0.60
Derna	0.31	0.07	0.35	0.05
Misurata	0.15	0.41	0.09	0.63
Shahat	0.44	0.01	0.12	0.50
Sirt	0.28	0.11	0.34	0.06
Tripoli airport	0.02	0.92	0.00	0.98
Zuara	0.05	0.79	-0.01	0.98

Data source: 1968-1990: AGRICULTURE RESEARCH CENTER, 1992. 1991-1998: ELZAEDY and ELTAHER, 2000. 1999-2001: FAO, 2002

Fig. 61: Harvest areas and production of barley in Libya, 1968-2001



Data source: 1968-1990: AGRICULTURE RESEARCH CENTER, 1992. 1991-1998: ELZAEDY and ELTAHER, 2000. 1999-2001: FAO, 2002

Variabilities of barley-harvest areas and barley production are explained by high inter-annual and intra-annual variabilities of precipitation (Fig. 61) showing a barley production in comparison with the harvest areas in many years and, vice-versa.

As Gibli winds leads to increase temperatures (e.g. 1995 and 1996 when during sandstorms temperature climbed at 53 °C at Tripoli airport and 51 °C at Zuara) with speed above 80 km in most areas, Gibli sandstorms destroyed most crops especially vegetables like paprika, tomatoes and fruit in northwestern Libya (KREDEGH, 2002: 126). Gibli winds may affect food crops through transferring the locust from desert to the cultivated areas in Libya. Climate change may also affect scheduling of the cropping season, as well as the duration of the growing period of the crop (SCHAEFER, 2001).

Food production would be affected by other climate impacts such as desertification, increased fire risk, spread of pests and diseases and changes in the global markets. Even in the absence of climate change, basic food security in developing countries such as Libya is likely to deteriorate due to a combination of population growth, land use changes and water scarcity.

Livestock production in Libya will be affected by climate change; deterioration in the quality of rangeland associated with higher concentrations of atmospheric carbon dioxide and due to changes in areas of rangeland as climate boundaries moves northwards. In North Africa, most of the steppe rangeland under semi-arid condition could give way to desert by 2050 or earlier (JACQUELINE, 2000).

Domestic livestock play an important role in Libya. Sheep and goats, in particular, have an importance that goes beyond the production of meat. Climate change affects animal feed availability, livestock pastures and forage crop production and quality, additionally, the direct effects of weather and extreme events on animal health, growth, and production (ROETTER, and VAN DE GEIJN, 1999: 652).

Climate change in Libya may increase the vulnerability of livestock due to shortage of water resources, increased salinity in northern parts, and loss of grazing sites. As a result of precipitation variabilities and high temperature, the pastoral lands are inconstant in quantity and in quality resulting annual variabilities of animal numbers (Tab. 76).

Most of pastoral lands in Libya are opened without any controls that accelerate overgrazing followed by desertification. Consumers could benefit from climate change if there are increases in global output and national markets are free to respond to changes in international prices (YATES, and STRZEPEK, 1998: 284).

Table 76: Cattle, sheep and goats in Libya, 1981-2000

year	Cattle (1000)	Sheep and goats (1000)
1981	180	5,500
1982	210	4,800
1983	180	4,800
1984	190	5,000
1985	200	5,500
1986	140	5,000
1987	90	4,500
1988	95	4,500
1989	102	5,000
1990	120	5,200
1991	150	5,500
1992	130	5,000
1993	155	6,220
1994	140	6,260
1995	145	6,400
1996	145	7,200
1997	142	8,420
1998	180	8,800
1999	190	6,800
2000	143	7,000

Source: UNITED NATIONS, 1993: Statistical Yearbook, 38: 416; United Nations, 2002: Statistical Yearbook, 46: 360

5.2 Impacts on water resources

Climate changes could exacerbate existing problems of water resources and cause a decline in water quality through increasing concentrations of pollutants and sea water intrusion on coastal groundwater aquifers. The changes of precipitation combined with increased evaporation would directly reduce runoff and groundwater levels. The problem of water resources will be compounded by increases in demand driven by socio-economic factors. Problems of saline intrusion would be further exacerbated by reductions in runoff and by increased withdrawals in response to higher demands.

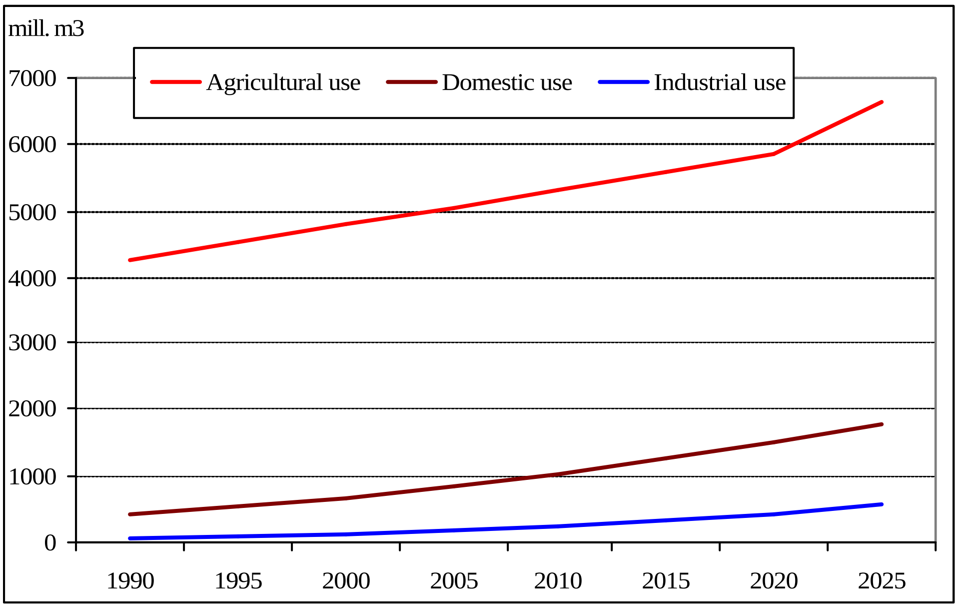
In Libya, annual renewable water resources are 6 km^3/year and the annual total fresh water withdrawal is 4.6 km^3. The biggest user of water in Libya is agriculture (87 %) followed by domestic use (11 %) and industrial use (2 %; HIRJI and IBREKK, 2001). Large increases in water demand (Tab. 77, Fig. 62) with very little recharge from precipitation have strained Libya’s groundwater resources resulting in declines of groundwater levels and its quality, especially on Mediterranean coastal areas where most of the agriculture, domestic and industrial activities are concentrated.

Table 77: Water resources demand by different users in Libya, 1990-2025 (projected), mill. m^3

	1990	2000	2010	2020	2025
Agricultural use	4,275	4,800	5,325	5,850	6,640
Domestic use	408	647	1,015	1,512	1,759
Industrial use	74	132	236	422	566
Total	**4,757**	**5,579**	**6,576**	**7,784**	**8,965**

Source: GENERAL ENVIRONMENTAL AUTHORITY, 2002: 66

Fig. 62: Development of water demand in Libya, 1990-2025



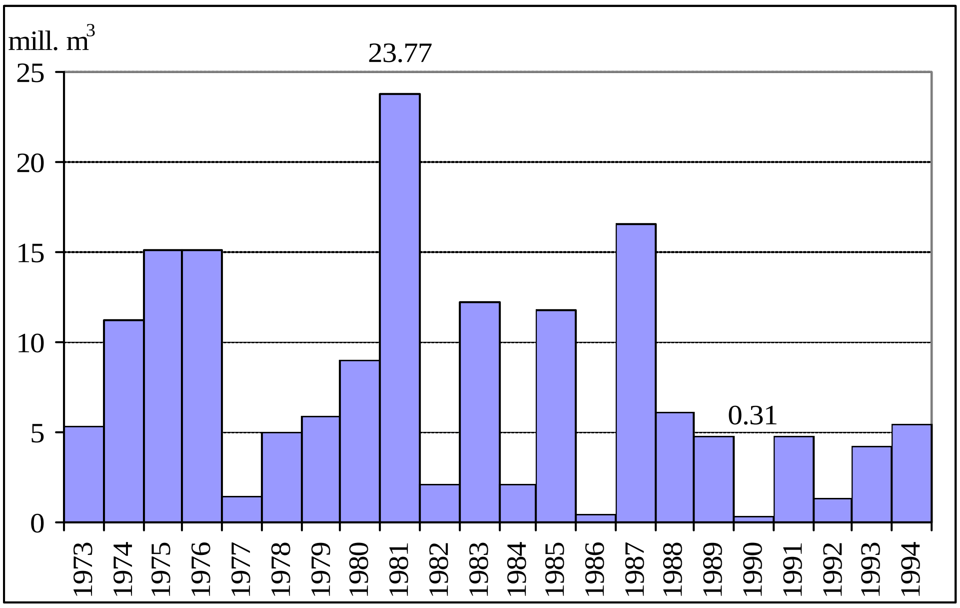
Data source: GENERAL ENVIRONMENTAL AUTHORITY, 2002: 66

The growth of water demand has a marked impact on the water resources of Libya which suffered serious depletions and quality deterioration (ABUFAYED and EL-GHUEL, 2001: 48). The common benchmark for water scarcity is 1000 m^3/year/person. In Middle East and North Africa, 53 % of the people are said to live with less 100 m^3/year/person (JACQUELINE, 2000). Water availability in Libya is very below and does not amount to 1000 m^3/year/person. Renewable resources per person were 538 and 154 m^3/year/person in 1960 and 1990, respectively, and are expected farther to shrink to only 55 m^3/year/person in 2025 (HIRJI and IBREKK, 2001).

Seasonal changes of precipitation affect supply of surface runoff through the effects on the precipitation efficiency which depends mainly on temperature and evaporation. Deficient precipitation is reflected by an absence of permanent rivers or streams in Libya. The total mean annual runoff in the dry wadis in the northern parts of Libya is controlled by annual precipitation; for example El-Majenin lake does not store constant water every year from precipitation; part of it either evaporates or contributes to recharge groundwater aquifers.

It can be deduced that the amount of surface water in Libya varies sharply due to precipitation. In humid years, a large amount of water can be stored and, vice-versa, e.g. in 1981, the amount of reserved water in El-Majenin lake was 23.77 mill. m^3, while 1990 was the lowest one (0.31 million m^3) from 1973-1994 (Fig. 63).

Fig. 63: Inter-annual variability of reserved water in El-Majenin Lake, 1973-1994



Data source: EL-SHERIEF, 1995

High evaporation rate reaching up to 100 % is an additional challenge facing water resources in arid and semi-arid lands. A combination of salt water intrusion due to sea level rise and increased soil salinity due to increased evaporation are expected to reduce the quality of shallow groundwater supply, excessive demand already contributes to saline intrusion problems in many parts in northern Libya. Water deficit has been aggravated by water level declines and quality deterioration especially around agricultural lands and urban areas where excessive using of groundwater gave way to seawater intrusion. Water level declines at more than 1 m/year and total dissolved solids exceeded 9,000 milligram/liter over the last four decades (ABUFAYED and EL-GHUEL, 2001: 49). As a result of sea level rise, some water supplies became unusable due to the penetration of salt water into coastal aquifers (Jifara Plain, Sirt, Jebal El-Akhdar). Thus, monitoring, analyzing and forecasting variation of climate are of prime importance particularly for policy- and decision makers (MGELY, 1984: 3). Changing temperature and precipitation regimes cause changes in the water budget. As a result, irrigation and flood control system, water storage, and hydroelectric installations as well as for a production systems are seriously affected.

5.3 Impacts on human health

Just a few common remarks were given about the impact of climate change on human health in the present study. Various sources concerned with the impact of weather on human mortality and well-beings express a controversial opinion on the magnitude and specific nature of the impact as well as on the role of acclimatization (KALKSTEIN and VALIMONT, 1987). Human health is predicted to be adversely affected by projected climate change, increasing of temperatures will extend the habitats of vectors of diseases such as malaria and high temperatures of coastal waters could aggravate cholera epidemics in coastal areas (McCARTHY, et al., 2001).

Climate change is only one of the many factors that are discussed to have significant influence on human health, for example temperature extremes (both hot and cold) appear to increase mortality. Medical disorders such as bronchitis, peptic ulcer, adrenal ulcer, glaucoma, goiter, eczema, and herpes zoster are related to seasonal variations in temperature. Humidity has an important impact on mortality since it influences the body's ability to cool itself by means of evaporation of perspiration (KALKSTEIN and VALIMONT, 1987). Current evidence suggests that inter-annual and inter-decadal climate variabilities have a direct influence on the epidemiology of vector-borne diseases. Temporal and spatial changes in temperature, precipitation and relative humidity which are expected to occur under different climate change scenarios will affect the biology and ecology of vectors and intermediate hosts and consequently the risk of disease transmission (GITHEKO, et al., 2000: 1136).

Direct negative effects of climate change on human health will arise from increasing extreme weather events (such as heat waves, floods, drought, and sand storms) Most series implications come indirectly through the effects of climate change on prevalence of infectious diseases, water quality and food security. Generally, the combination of warming and pollution would lead to an upsurge in respiratory illness among urban populations, while extreme weather events could increase death and injury rates. Water shortages and damaged infrastructure would increase the risk of cholera and dysentery (JACQUELINE, 2000). Cholera is a water- and food-borne disease and has a complex mode of transmission. Flood causes contamination of public water supplies, and drought encourages unhygienic practices because of water shortage. Extreme weather events such as El-Nino have been associated with increased episodes of diarrhea (McCARTHY, et al., 2001). Increasing relative humidity and temperature decrease the human activity level, and may reduce human productivity resulting from health problems.

The greatest effect of climate change on disease transmission is observed at the extremes of the temperature range at which transmission occurs for many diseases that lie in the range 14-18 °C at the lower end and 35-40 °C at the upper end. Warming above 34 °C generally has a negative effect on the survival of vectors and parasites. In addition to the direct influence of temperature on the biology of vectors and parasites, changing precipitation patterns can also have short- and long-term effects on vector habitats (GITHEKO, et al., 2000: 1137).

Fig. 64: Saharan dust off Libya and Tunisia

Source: NASA (2003)

Increased dust pollution has direct adverse impacts on human health, installations and equipment. Airborne mineral dust generated from the land surface has significant impacts on human health in Libya. Sandstorm over northwestern Libya lasting for 12 hours on 29.03.2002 with speed 70 km affected human health through charging the air with 387 microgram/m^3 pollutants, against a safe level by WHO at 120 microgram/m^3/day (KREDEGH, 2001: 124). A large plume of Saharan Desert dust (tan pixels) was blowing northward off the coast of Libya and spreading over much of the Mediterranean Sea on October 3, 2003 (Fig. 64). Vector borne diseases in Libya may be a significant risk in some locations during the transmission season (April through October; CIA, 2004).

Urban environment plays an important role in mediating people's exposure to airborne dust and also to temperature extremes. The growing urban heat island in the cities tends to aggravate the risk of more frequent heat waves as well as their impacts. Variability in summer nighttime minimum temperature combined with lack of acclimatization, high humidity, and poorly ventilated and insulated housing stock may be the most important factor in urban heat deaths. Elderly and very young people, people in ill health and poor people are most likely to be affected by climate change (McCARTHY, et al., 2001).

5.4 Impacts on human settlements

Climate changes affect human settlements, especially urban settlements with high population density, and suffer from poor in safe water and public health services. Rapid urbanization may farther increase the vulnerability to all disasters. Migration and resettlement may be the most threatening short-term effects of climate change. Migration may occur as a result of loss of livelihood and land degradation. Drought, sandstorms, and other climatic extremes may affect settlements and infrastructure.

The vulnerability of human settlements to climatic events is most serious in developing countries, where high population densities and growing urban congestion are likely to increase the sensitivity to potential magnitude of natural disasters. Changes in production systems may lead to industrial relocation or employment reductions. Migration may be a preferred response to threatened loss of housing or employment (IPCC, 1990). Review of sanitary facilities now rather than later will not only be beneficial to communities now but in the long run will be cost saving for long-term health delivery services (McCARTHY, et al., 2001). Global sea level will rise as oceans expand and glaciers melt, around much of the Mediterranean coast, sea level could rise by close to 1 meter by 2100 affecting some low-lying coastal areas would be lost through flooding or erosion (JACQUELINE, 2000).

Semi-arid areas have supported nomadic societies that migrate in response to annual and seasonal rainfall variations. Nomadic pastoral systems are intrinsically able to adapt to fluctuating and extreme climates provided they have sufficient scope for movement and other necessary elements in the system remain in place (DESANKER, 2002). In Libya, population and urbanization increased sharply in the second have of the 20th century, it generated impacts on natural resources and the environment (water and soil) which are very vulnerable to climate change. Over 80 % of Libya's population resides along a mild thin strip on its 1,900 km long Mediterranean coast which also contains the country's most fertile lands and its major industrial projects (ABUFAYED and EL-GHUELM, 2001: 48).

Because of the vast oil wealth of Libya, significant improvements in the standard of living can be observed. Population is unevenly distributed across the country (2000): 87.6 % live in urban areas, mostly on the coast. Some of Libyan's people still live in nomadic or semi-nomadic groups in the plains and desert. Urban population in Libya increased from 69.6 % in 1980 to 87.6 % in 2000 (Tab. 78).

Tab. 78: Urban and rural population in Libya, 1980-2000

Year	Urban %	Rural %
1980	69.6	30.4
1990	82.4	17.6
1995	85.3	14.7
2000	87.6	12.4

Source: United Nations, 1993: Statistical Yearbook, 38: 71; UN, 2002: Statistical Yearbook, 46: 46

The depletion of surface and underground water resulting from climate change, in addition to irrigation of large tracts of land may lead to the uprooting of local people from their traditional lands and adverse environmental impacts of reservoir development (KINUTHIA, 1997: 5). Farmers engage in unemployment-induced migration to urban centers as one of the strategies for coping with scarcity. But related to anthropogenic-induced global warming, migration has been considered only since recent times. Life at the desert margins is adjusted to stresses resulting from climatic variation. Responses to long-continued drought, overgrazing and cultivation vary according to small- and large-scale differences in soil, slope, and past landuse (GROVE, 1977: 303).

5.5 Impacts on biodiversity

Climate change is one of several threats include increasing land-use conversion and subsequent destruction of habitat; pollution; and the introduction of exotic (nonnative) species. Land-use conversion from wild habitat to agricultural, grazing and logging uses, for example, leads to habitat loss, fragmentation, and introduction of exotic species—all of which adversely impact biodiversity. Given this multitude of stress factors on biodiversity, climate change may exacerbate the stress on environmental systems beyond recovery (DESANKER, 2002).

Climate change will affect ecosystems through the associated increase in CO^2, sea level rise and changes of climate in different ways. The higher ambient CO_2 concentrations which favour some plant and animal species over other, together with climatic changes, will lead to changes in species compositions in natural vegetation, and in many farming environments. As a consequence, it may be necessary in some areas to switch from one crop to another and to change weed control strategies (PITTOCK, 1988: 312).

Loss of biodiversity is a consequence of climate change at the local and global level. Land use changes as a result of population and development pressures will continue to be the major force of land cover changes affecting the distribution and productivity of plant and animal species. Losses of biodiversity are accelerated by climate change; projected climate change is expected to lead to altered frequency, intensity, and extent of vegetation fires, with potential feedback effects on climate change (McCARTHY, et al., 2001).

Almost all aspects of human society are dependant on climate; human life would mostly be affected by climate change, either directly or indirectly as the effects cascade through the socio-economic system. The combined impacts could cause a much more serious risk to human well-being than the effects on any individual sector (JACQUELINE, 2000). Plants will naturally attempt to adapt by migrating, assuming the landscape is not too fragmented.

Coastal zone flooding and erosion will particularly affect mangroves. Particularly in limited areas where sharp climatic gradients occur, such as in case of many nature reserves designed to protect endangered species, changing climate may render the reserves inappropriate and threaten the extinction of some species of plants and animals (PITTOCK 1988: 313). There are also secondary impacts of climate change, among them recurrent drought might decrease the ability of trees to resist pests. In theory, some other plant species could keep up with the rate of climate change, but in practice their ability to establish themselves elsewhere will be constrained by the extent of desertification and by human land uses. As a result, many valuable species and habitats may be lost (JACQUELINE, 2000). Climate change may lead to biome shifts. Certain landuse practices, such as shifting cultivation, bush burning or overgrazing have been very destructive of the flora, and it is hardly possible to distinguish between primary and secondary growth.

Although Libya was known as the breadbasket of the Roman Empire for its output of grains, climatic changes have eroded its agricultural productivity. Today, most of Libya supports only sparse growth or is without any vegetation at all. Most of Libya has either little or no vegetation. Date palm, olive and orange trees grow in the oases, and junipers and mastic trees are found in higher lands. The only areas of natural forest are in the coastal parts (Jebal Al-Akhdar), where the forests are characterized by juniper and mastic species. Shrub lands occur on the Jebal Naffusah with predominant species being non-woody shrubs such as asphodel. Inland, vegetation is mainly confined to oases where date palms predominate. Acacia species are sparsely scattered in desert regions. Libya has larger areas of plantation forest than natural forest. Much of this has been planted in sand dune stabilization projects, particularly in the Jifara Plain and Jebal Naffusah, or as windbreaks (THE WOOD EXPLORER, 2004).

Only a few large mammals are found in Libya. Wildlife includes desert rodents, hyenas, gazelles, and wildcats. Eagles, hawks, and vultures are common (ENCARTA, 2005). Climate change affects biodiversity in Libya, several kinds of animals and plants have recently disappeared. Conservation of animal and plant varieties will be a serious issue, as some nature reserves and national parks become increasingly inappropriate climatically for the species they were meant to protect. Loss of genetic diversity which might follow could have long-term implications for plant breeding and medical research and development (PITTOCK, 1988: 313).

6. Case study: Desertification of Jifara Plain

6.1 Drought and desertification

The notion of desertification was probably first introduced by AUBREVILLE (1949) who evaluated the alarming degradation of land through erosion and other processes resulting from mismanagement by the resource-poor farmers of Africa (REICH, et al., 2001). Desertification has emerged as an issue of global concern over the last few decades. The definition of desertification due to United Nations Conference on Desertification held in Nairobi 1977 is “diminution or destruction of the biological potential of land, and can lead ultimately to desert-like conditions”. Consultative Meeting on the Assessment of Desertification in Nairobi in 1990 suggested: “Desertification is land degradation in arid, semi-arid and dry sub-humid areas resulting from adverse human impact” (NASR, 1999: 5). In this context, the term ‘land’ includes a whole ecosystem comprising soil, water, vegetation, crops and animals while the term ‘degradation’ implies reduction of resource potential by one or a combination of degradation processes including (erosion and sediments), the amount and diversity of natural vegetation, and salinization. However, the process of desertification is not alone confined to the dry lands of the tropics or economically developing regions (LAL, 2001: 37).

Desertification should be restricted to processes where the ecological potential is seriously damaged or even destroyed by human exploitation under the given climatic conditions in arid, semi-arid and possibly sub-humid lands (MENSCHING, 1986: 10). At least half the countries on globe have been affected, at least to some degree, by desertification associated with aridity (GLANTZ, 1977: 8). Globally, every year an additional 200,000 km^2 of productive lands are converted by desertification to the point of yielding nothing (ABAHUSSAIN, et al., 2002: 522). Desertification processes affected about 46 % of whole Africa (REICH, et al., 2001). Desertification is a gradual process by which the productivity of land is reduced. It is also going through several stages before reaching the final one, which is an irreversible change. Natural threshold changes exist-historical events as well as current geo-socio-economic changes- which either provoke or keep constant the intensity of desertification process (ODINGO, 1990: 24). Desertification is of wide-spread interest among the international community; part of it results from the fact that one-ninth of the surface of the earth is affected by desertification, it has severe financial and societal consequences including property damage, increased health and safety hazards, and decreased agricultural productivity. The increasing use of desert shrub lands by humans for habitation, agriculture, industry, and recreation increases the amount of arid land directly impacted (OKIN, et al., 2001: 124).

Unlike desertification, there is no universally accepted definition of drought. The term drought is associated with prolonged precipitation deficiency or lack of soil moisture. Drought embraces a phenomenon with diverse, complex origin, indeterminate onset, defuse, creeping nature and an ability to occur virtually anywhere on the globe. All definitions point to the same basic phenomena: a shortfall in precipitation that results in water shortages (SWEARINGEN, 1992: 402). THORNTHWAITE (1947) defined drought as a condition in which the amount of water needed for evapotranspiration exceeds the amount available in the soil, due to the lack of precipitation. The U.S. Weather Bureau (1953) defined drought as a period of dry weather sufficient in length and severity to cause at least partial crop failure. The Indian Meteorological Department described an annual precipitation of 75 % of normal or less as drought, and 50 % or less as severe drought (MGELY, 1984: 52).

The most common definitions have attempted to qualify drought as the temporary situation when the demand of water exceeds the supply available from various resources, while most of the definitions of desertification have broadly reflected some degree of land degradation processes (OGALLO, 1994: 18). Drought is an inevitable part of normal climate changes and should be considered as a recurring, albeit unpredictable, environmental feature which must be included in planning (THUROW and TAYLOR, 1999: 413).

It can be said that drought is a natural phenomenon and occurs when precipitation is significantly below normal for a long time (usually a season or more). Desertification is a more deadly enemy than drought because it threatens the whole ecological basis of production in the affected lands. It is keenly felt in arid regions as it adversely affects the precariously maintained farm and pasture lands (KASSAS, 1987: 389).

Jifara Plain experiences a stress on its natural resources (water and soil) in recent decades as a result of heavy population growth and increasing food demand. Indicators of desertification in Jifara Plain are developed by the author from the field work, from the published data, and satellite images ‘The Multispectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper plus (ETM+).

Desertification in Jifara Plain was explained using spectral enhancement (indices) which are used extensively in vegetation analysis to identify the differences between various vegetation classes. In many cases, judiciously chosen indices can highlight and enhance differences that can not be deduced using normal digital image processing. Such indices have been preprogrammed in the Image Interpreter Menu included within ERDAS IMAGINE 8.7: Infrared/red (IR/R), Vegetation Index, Normalized Difference Vegetation Index (NDVI), Iron Oxide (LEICA GEOSYSTEMS, 2003: 182).

6.2 Manifestations of desertification

Increasing rates of desertification are being experienced in many rigions, as demonstrated by the degradation and depletion of natural resources, the shortage and poor quality of water, the fall in the productivity and the settlement expansion. Desertification appears also through sand dune movements and deterioration of vegetation cover.

Traditional landuse of Jifara Plain expressing a serious degree of aridity are mainly range land, rainfed agriculture, and irrigated agriculture. Although settled agriculture was developed at early date, the scale of arable and orchard cultivations was limited to parts around coastal towns (BIN-MAHMOUD, et al., 2000). Due to TM (1989) and ETM+ (2000) images mosaics (Fig. 66), Jifara Plain experienced vegetation deterioration, settlement expansions and sand dunes encroachment. It can also be observed from mosaic images that the salty lands (Sebkha) increased in northwestern Jifara Plain and vegetation became more dispread and disappeared in many parts.

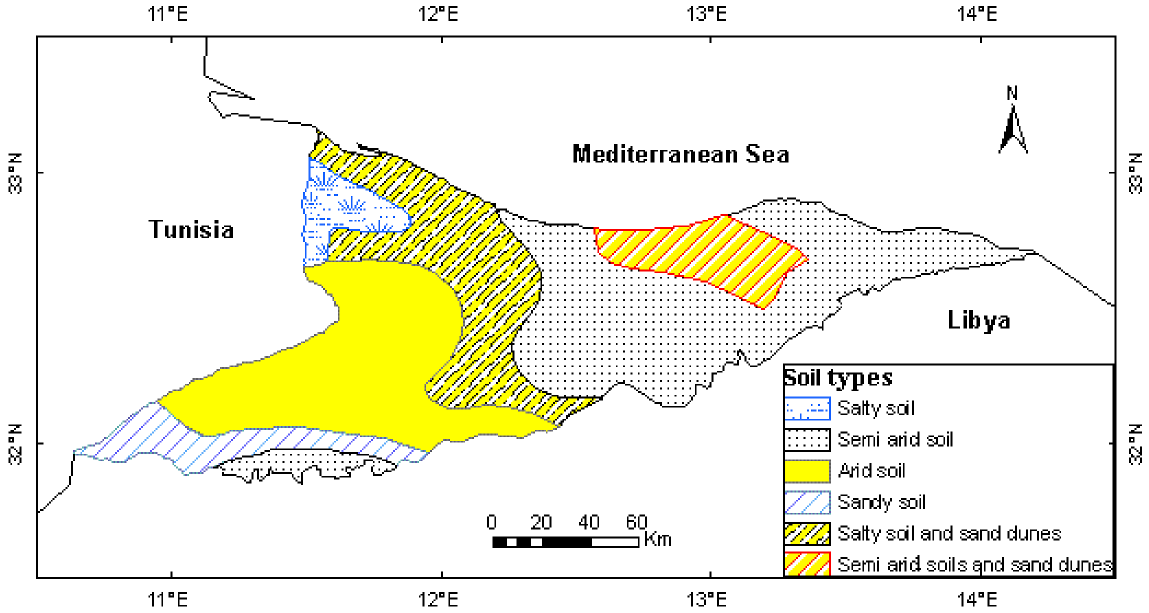
The main manifestations of desertification prevailing in Jifara Plain are discussed briefly.

6.2.1 Soil degradation

Soils of Jifara Plain are usually calcareous and often shallow, with huge areas of calcrete outcrops developed during the Pleistocene epoch. Gypsum encrustation is commonplace in the drier parts below an annual precipitation total of 200 mm. Saline soils are usually of the solontchak type in the low-lying areas in the northwestern parts of the Plain. Sandy arid and semi-arid soils prevail in the eastern parts of the Plain (Fig. 65). The soils of the plain are either entisols or aridisols which include psamments and orthents (BIN-MAHMOUD, et al., 2000).

Soils in western Libya (from Tunisia to Misurata in the east) are: inceptisols and entisols (49.1 %), aridisols (11.5 %), salorthids (10.7 %) and sandy soils (3 %; UNEP, et al., 1996: 266). Sandy soils bear more developed vegetation with a more regular and higher primary productivity than finer textured soils. Thus, profitably and commercials cultivated rainfed olive orchards are grown on deep sandy soils under as little precipitation as 200 mm/year in Tripoli area, but this is not possible without an additional runoff complement on silt soils (LE HOU´EROU, 2001: 108).

Fig. 65: Soil types in Jifara Plain



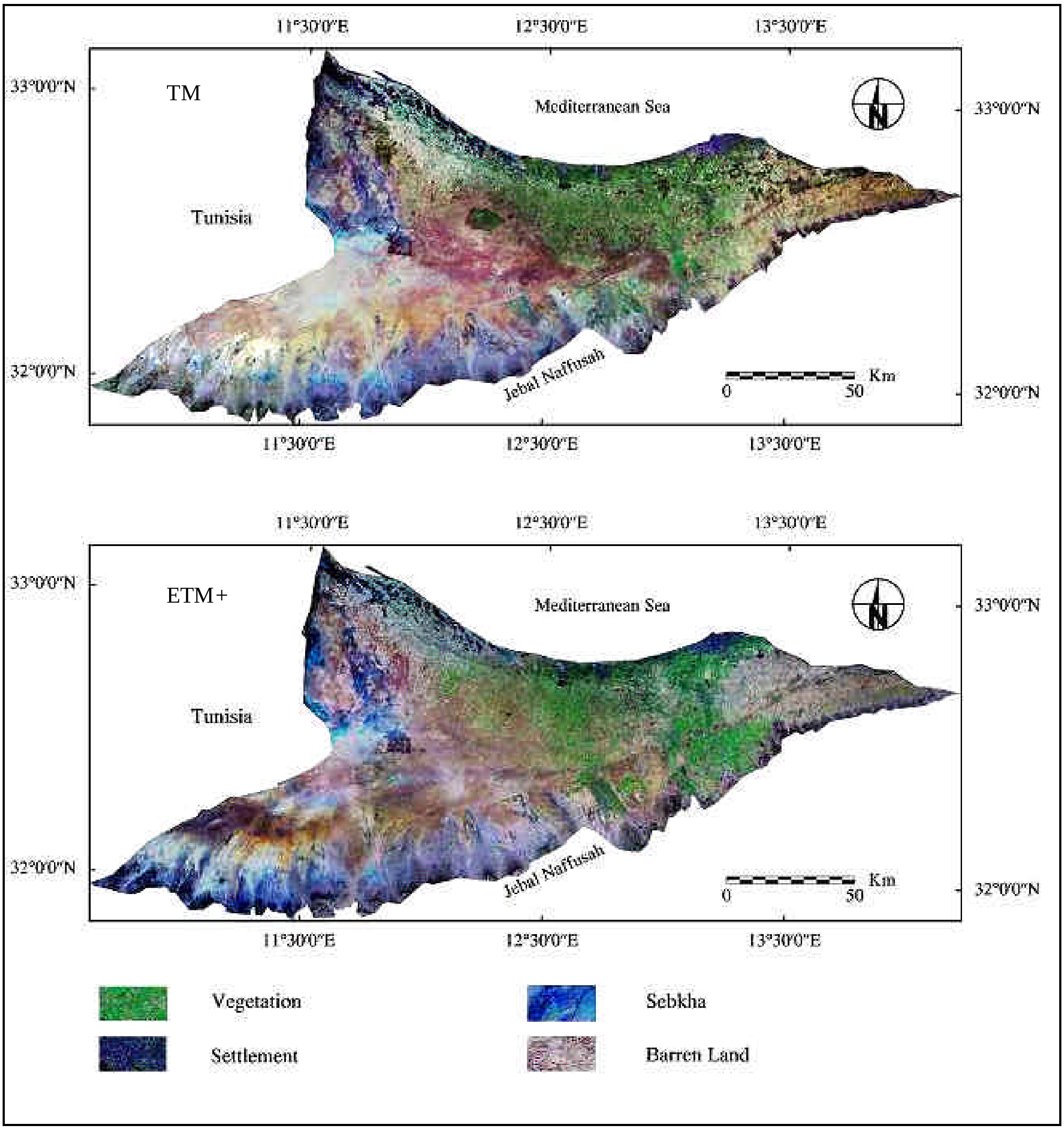
Source: AMANAT EL-TAKHTIET, 1978: 49

Soil degradation is the main threat of desertification, it is subjected to hazards of physical, chemical or biological changes that undermine the structure and functioning of the soil system, and may eventually lead to decline soil quality and permanent plant life becomes impossible, because of lack of water reserves in shallow soils. Various forms of soil degradation, often related to landuse practices that overtax the system, include erosion, salinization, water logging and chemical degradation (KASSAS, 1987: 391).

In spite of the dedication of significant human, financial and technological resources, degradation of dry lands continues unabated in both, developed and developing countries.

Many of its causes have been described, and the consequences have been extensively documented (DEBRA and JEFFREY, 2001: 1).

Fig. 66: Changes of landuse patterns in Jifara Plain using TM and ETM+ image mosaics, 1989-2000



Source: Global Land Cover Facility, 2002: http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp.

Mosaic ID zone (30-33 north) Platform Landsat, Sensor TM (mosaics 1987-1990)and ETM+ (mosaics 1999-2002), Projection (UTM 33), Datum (WGS84), Units (meters).

In many parts of Libya, soils experienced to degradation then decline of their fertilities which can be noticed from the decreasing productivity of wheat which is the principal cereal crop. The optimum yield for wheat cultivation in Libya was expected to be about 5 t/ha, but by the mid-1980s yields were only averaging about 0.5 t/ha (THE LIBRARY OF CONGRESS, 1987).

Salinity and alkalinization are the major procenes in arid and semi-arid lands; they affect about 24 % of Africa (REICH, et al., 2001). Coastal areas in Jifara Plain could even be more directly affected by salinization due to the increased penetration of sea water into the groundwater aquifers. In Jifara Plain, increased human pressure on localized underground aquifers causes seawater intrusion in the coastal zones, in irrigated areas imbalance between excessive irrigation and inefficient drainage causes water logging and secondary salinization.

Soil salinization and alkalization occurs in case of irrigated lands, with inadequate leaching of salts contained in the soil or added in irrigation water (photo 1). salinization and alkalization of soils prevail on northwestern Jifara Plain where soils are converted to saline soils explained by the salinity of groundwater used for irrigation and the result of faulty technology in water development schemes such as using too salty water on too heavy soils and insufficient drainage or even no drainage at all (LE HOU´EROU, 1977: 21).

Photo 1: Salinized soil in Ein Zarah area, southeastern Tripoli city, 12.10.2002

Fig. 66 shows the saline soils, known as Sebkha, along the coast of Jifara Plain; they are also found as scattered spots in northern parts and in the wadis. Salinization affects most of the irrigated lands in Jifara Plain.

Salinization and water logging commonly occur together where the soil is waterlogged and the upward movement of saline groundwater leaves salt on the surface when water evaporates. On soils that are not waterlogged salinization can still occur when water containing soluble salt particles moves from irrigation furrows into the ridges where crops are planted or to high spots in poorly leveled land. Irrigation which is also applied weakly permeable soils can lead to salinization in case of salty irrigation (PEREZ and THOMPSON, 1995).

The most dominant soil-degradation process in Jifara Plain is erosion; the potential for erosion generally increases under arid and semi-arid climates where high intensities of precipitation and windstorms prevail. Western part of Libya, including Jifara Plain and Jebal Naffusah, that are considered most important for agricultural development in Libya, experience both, wind and water erosions. In the coastal areas, the areas which are subject to water erosion cover about 30 % of all lands which receives over 200 mm precipitation/year. In southern Jifara Plain, about 70 % (of Jebal Naffusah) experience water erosion (BIN-MAHMOUD, et al., 2000).

Desertified lands have been categorized into four classes according to their degree of desertification (slight, moderate, severe, and very severe). Land categorized as slightly desertified shows little or no degradation (less than 10 % loss in potential yield), moderately desertified land shows 10-25 %, severely desertified land 25-50 %, and very severely desertified land over 50 % degradation (NASR, 1999: 17).

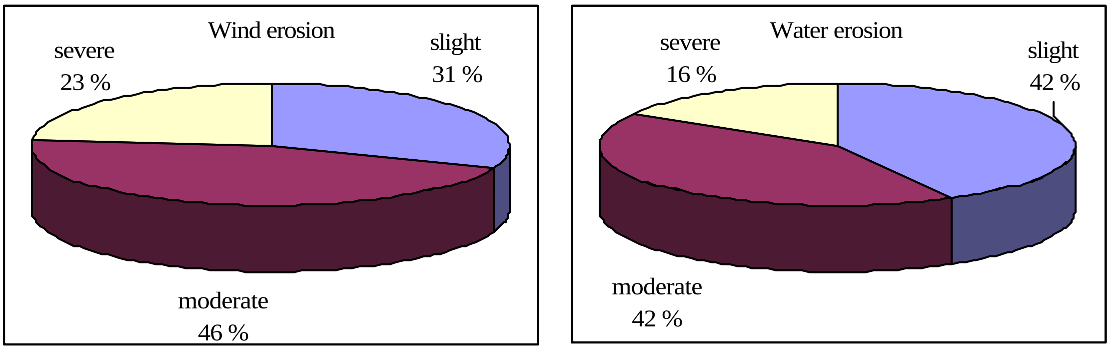
Tab. 79: Degree of water and wind erosions in western part of Libya, 1000 ha

Degree of erosion	Water erosion	Wind erosion
Slight	165.5	180.0
Moderate	164.6	266.4
Severe	64.5	136.4
Total	394.7	582.8

Source: GENERAL ENVIRONMENTAL AUTHORITY, 2002: 210

The degree of erosion in the western part of Libya (compressing Jifara Plain and Jebal Naffusah) shows that 394,700 ha and 582,800 ha have been affected by water and wind erosions, respectively, while very severe erosion is not shown in the western part of Libya (Tab. 79 and Fig. 67).

Fig. 67: Degree of water and wind erosions in western area of Libya (Jifara Plain and Jebal Naffusah)



Data source: GENERAL ENVIRONMENTAL AUTHORITY, 2002: 210

Soil vulnerability to degradation is affected by environmental considerations. First, agricultural activities are affected by factors such as soil type, climatic parameters and water resources. Irrigated arable farming can only take place where there is a source of water, either within a fluvial system or from groundwater. Second, natural factors which affect degradation processes occur at specific locations, even where the cause is the same (MIDDLETON and THOMAS, 1994: 57).

Photo 2: Soil left barren after cropping, Surman-Bear Ayad road, 17.10.2002

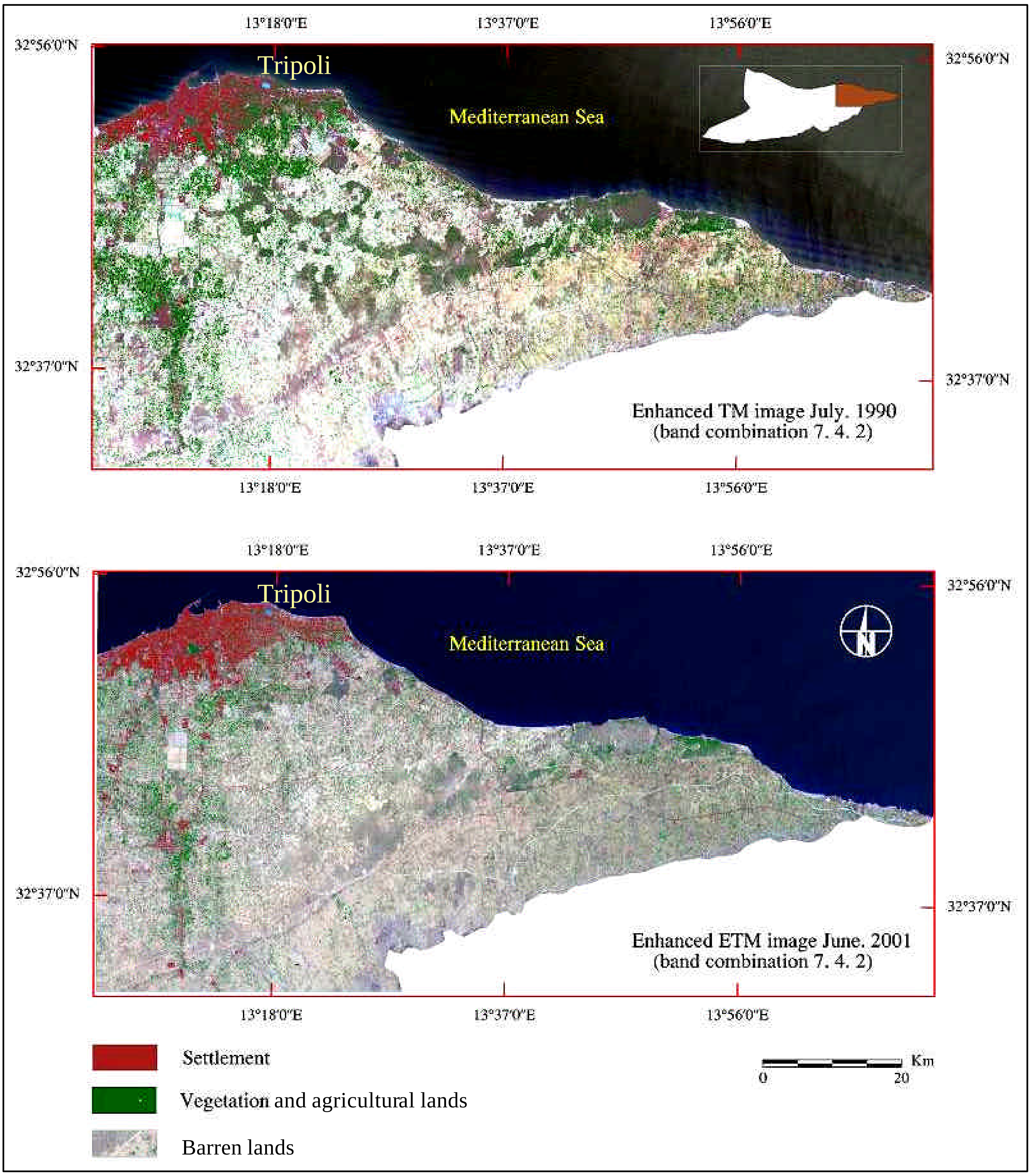
Another reason of land degradation is that, soils are left barren after cropping or after crop failure are subjected to wind erosion (photo 2). It is important to bear in mind how easily and quickly a soil, built up over long times, can be impoverished or destroyed by unsuitable methods of cultivation, and that once destroyed, little can be done to restore the soil. In sandy cultivated and fallow fields, erosion rates of 10 mm of top soil removed have been measured in southern Tunisia for example (LE HOU´EROU, 1977: 26).

Causes of increasing loss of topsoil are mainly the removal of protective vegetation cover by overgrazing and poor management practices on agricultural fields. Terrain deformation plays a smaller role in degraded soils on a large scale; however, it is dominant in some of the more vegetated regions showing a significant amount of soil degradation (FEDDEMA, 1999: 573). Removal of fine topsoil materials means the loss of the most productive and nutritious portions of the soil complex, while sterile sand accumulations cover plants and good soil. In addition, the blasting impact of moving sand harms young crops. Fine airborne particles may carry soil-borne diseases, irritate respiratory tracts of humans and animals, cause wear on machinery parts and reduce visibility (PEREZ and THOMPSON, 1995).

On rangelands where accelerate erosion processes, the gradual decrease in soil depth translates into a loss of soil moisture storage capability which, in turn, can increase both the frequency and length of periods without enough soil moisture for expected plant growth (THUROW and TAYLOR, 1999: 415). Soil depth had the greatest effect on recolonising plant cover, and depth was in turn affected by parent material. There is a critical soil depth necessary for plants to survive and if the soil is thinner, erosion processes will dominate.

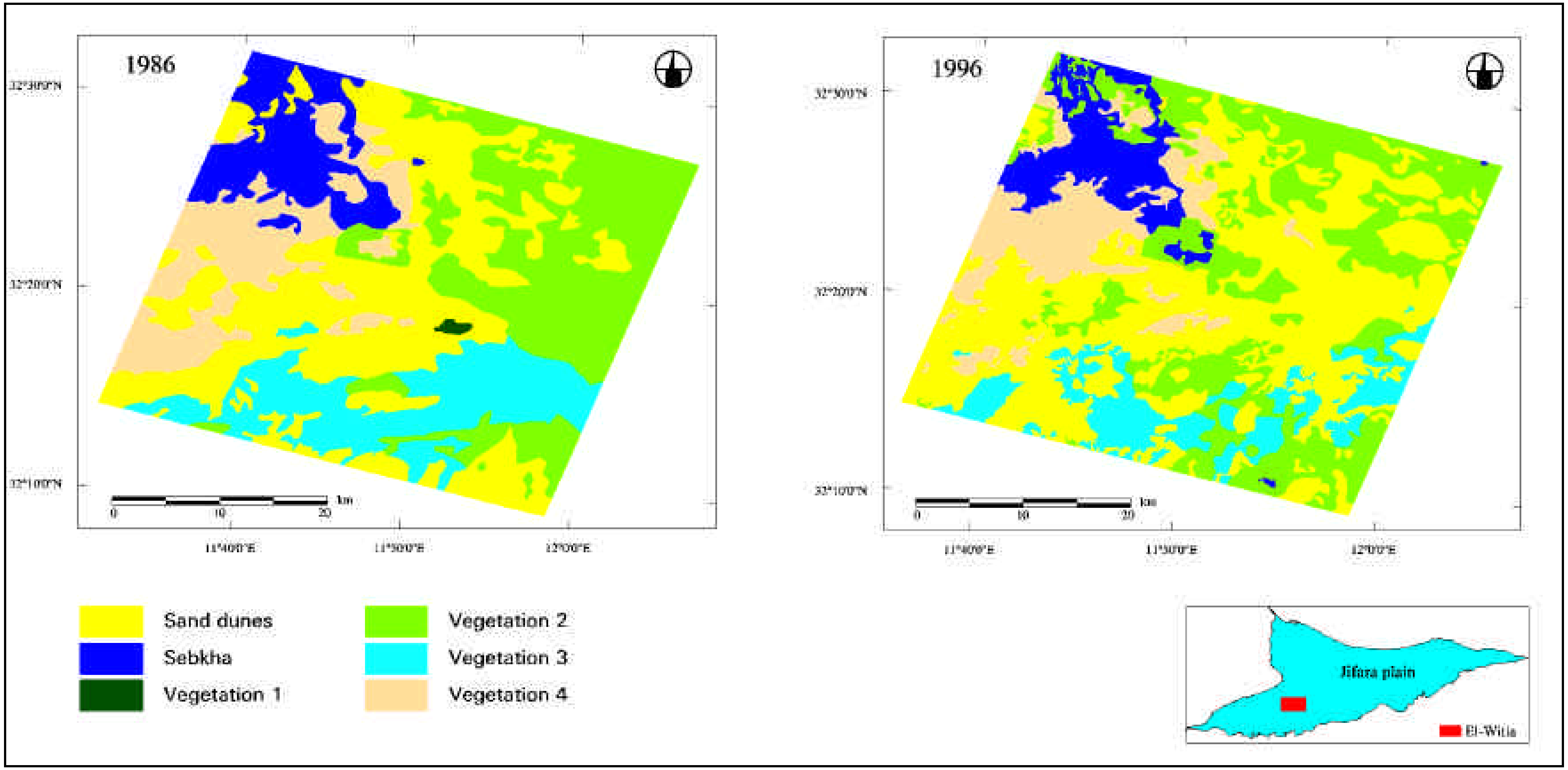
With consequent increase in runoff, sheet and gully erosion set on sloping ground, and the topsoil and its store are lost. The ability of a rain-shower to attack the structure of the top-soil and to erode the soil surface depends upon the size of the raindrops and on the intensity of the shower (WMO, 1983: 9). These changes result in an environment inhospitable to plant growth and less suitable as pasture. With continuing erosion, formerly productive lands may be lost through soil stripping and gully erosion (PEREZ and THOMPSON, 1995). Soil compaction and crusting are the most serious forms of physical degradation affecting several irrigated areas in Libya especially the sandy soils (BEN-MAHMOUD, et al., 2000).

Fig. 68: Soil degradation in eastern Jifara Plain using subpixel classification, 1990-2001



In arid zones, natural processes occur that, in the absence of solid benchmarks, can be easily confused with land degradation (DE PAUW, et al., 2000: 50). Low severity chemical degradation is widespread in Libya; it affects no more than 10% in northern parts where the primary process is nutrient depletion (MIDDLETON and THOMAS, 1994: 63). Fig. 68 which is based on Thematic Mapper (TM) and Enhanced Thematic Mapper plus

Fig. 69: Land degradation of El-Witia area, 1986-1996



Source: Modified after the Libyan Center for Remote Sensing and Space Science, Tripoli

Note: Vegetation is classified due to its intensity from 1-4

(ETM+) images show an increase of barren lands in eastern Jifara Plain between 1990-2000 as a result of devegetation and settlement expansion.

Soil degradation can be observed through the study of El-Witia area in the southwestern Jifara Plain which is carried out by Remote Sensing Center in Tripoli (BIN-MAHMOUD, et al., 2000). Changes of land classes in the 10-year period 1986-1996 were studied (Fig. 69 and Tab. 80).

It can also be seen a decrease of 31 % in soil (association 1) and of 52 % in vegetation cover, while an increase of 227 % in sand dunes, 38 % in soil (association 2) and 23 % in Sebkha (saline lands) areas have been elaborated.

Tab. 80: Changes of soil classes and land cover in El-Witia area (ha)

Class	Area in 1986	Area in 1996	difference ha	%
Soil association 1	66,008	44,890	-21,118	31
Soil association 2	96,727	134,142	37,415	38
Sebkha	1,991	2,453	462	23
Sand dunes	31,921	104,445	72,524	227
Vegetation cover	60,967	29,107	-31,859	52

Source: BIN-MAHMOUD, et al., 2000

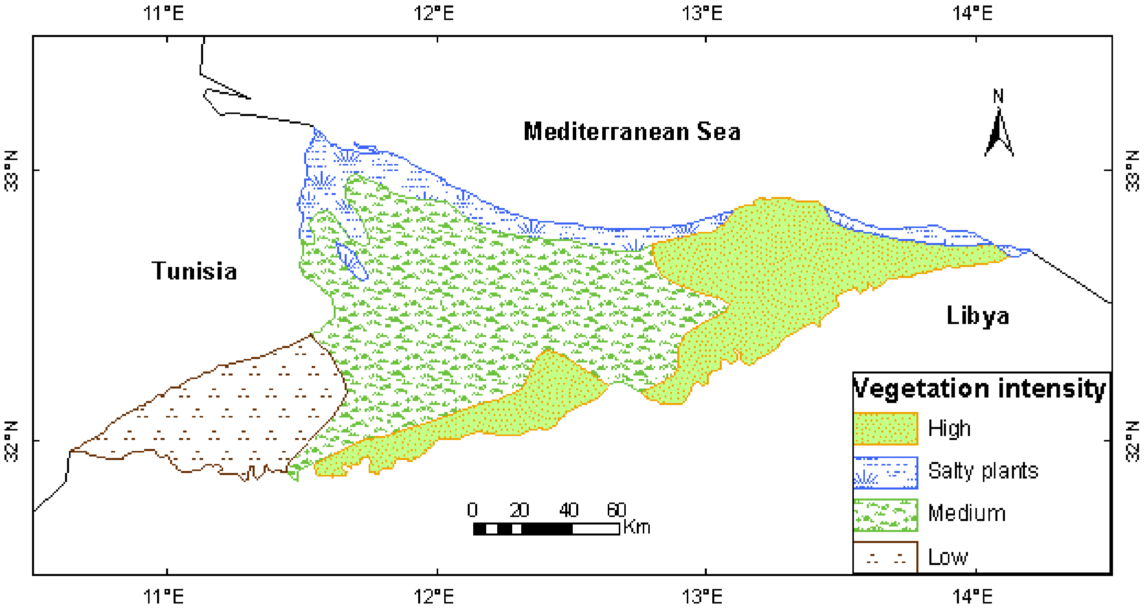
Note: Soil associated 1 and 2 due to the degree of fertility

6.2.2 Deterioration of vegetation

For centuries, human beings have cut down trees to clear space for land cultivation, or in order to use the wood for fuel. Desertification is not only soil degradation but also potential genetic deterioration of plants and livestock, the most widespread expression of land degradation is deterioration of vegetation. Removal of plant cover causes an increase in surface albedo and, in turn, affects the atmospheric energy budget in a way that intensifies subsidence and hence increases aridity (KASSAS, 1987: 390).

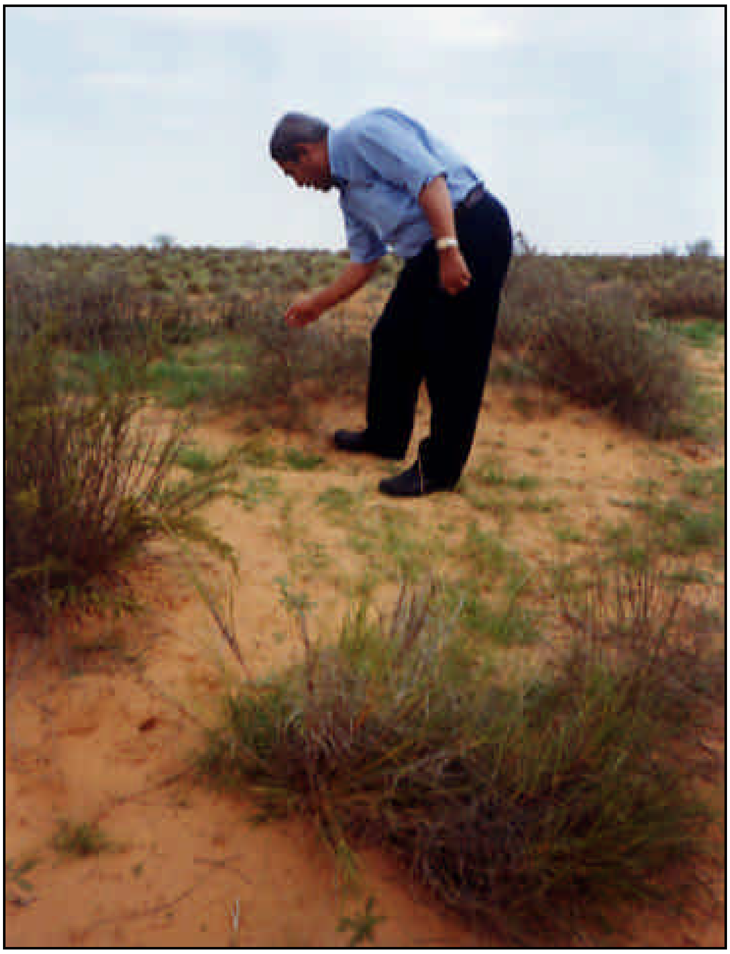
Deterioration of vegetation (devegetation) is considered as one of the desertification manifestations in Jifara Plain. Vegetation in the Plain like the arid lands in northern Africa is characterized by a defuse pattern of distribution and usually referred to as steppic (LE HOUEROU, 1977: 18). Due to erratic and highly variable of precipitation, this is very poor particularly in the areas of range lands which receive less than 200 mm precipitation/year in the middle and western parts of the Jifara Plain (Fig. 70).

Fig. 70: Vegetation intensity in Jifara Plain, 1977



Source: AMANAT EL-TAKHTIET, 1978: 55

Photo 3: State of vegetation in southern Jifara Plain, 4.11.2002



Generally, vegetation is sparse with little variety of species (photo 3) and can adapt with climate conditions. The species which do grow are more or less drought-resistant. Being xerophytes, they have a highly developed root system and their foliage is reduced to a minimum; their leaves are filiform, dry and shiny, the epidermis thickened and cutinized. Many species are spherical in shape, most of the bushes are spiny and prickly (MESSINES, 1952). Remaining of forest named pistacia atlantic grows in Jifara plain (UNEP, et al., 1996: 261).

In Jifara Plain, the steppe in the northern and eastern parts seems as spots and in the western part is negligible. The thinning and death of vegetation in dry season increases the extent of bare ground. This is followed, in turn, by a deterioration of the surface conditions that are vital to plant growth. Practices such as shifting cultivation, bush burning or overgrazing have been very destructive of the flora, and it is often difficult to distinguish between primary and secondary growth. The arid steppes of northern Africa are chiefly of a secondary nature, originated from a pristine xerophilous open forest and woodland through a over-grazing process which affects both soil and vegetation, via the nature and distribution of the organic matter in the soil profile. As a matter of fact, about 50 % of the steppes have been cleared for cultivation over the past 80 years (LE HOU´EROU, 2001: 126).

Photo 4: Deforestation in Elzawia area, in northern Jifara Plain, 03.11.2002

Over the last 200 years, deforestation increased because the timber industry became a globally profitable endeavor so that clearing of forests was accelerated for the purposes of industrial development. In the long term, this intensified deforestation is considered to be a serious challenge because the forest is unable to regenerate itself quickly (COUNTRYWATCH; 2000).

In recent decades, a large area of vegetation was cleared in Jifara Plain (photo 4) for increasing wheat or barley cultivation. In pastoral rangelands, there is an initial deterioration in the composition of pastures which are subjected to excessive grazing in dry periods. Jifara Plain has been significantly degraded in quantity and quality of vegetation. Vegetation destruction takes place by overgrazing and over cultivation, both activities being driven by the needs of rapidly growing population.

Although the classification of landuse into cropland, forest and grassland is difficult and the density of vegetation of cropland was higher than that of grassland, Landsat Multi-Spectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) have been analyzed using spectral enhancement (indices) infrared/red (IR/R), band 4/band 3, to detect the changes of vegetation cover in some parts of Jifara Plain. Fig. 71 shows the change detection in northern part of Jifara Plain from 1976-2001, it can be seen that the vegetation cover over an area of 758,026 ha was deteriorated during this period (Tab. 81).

Tab. 81: Changes of vegetation and agricultural areas in northern Jifara Plain due to analysis of landast MSS 1976, TM 1989 and ETM+ 2001 images, (ha), using IR/R indices

Intensity	1976	1989	2001
Light (ha)	185,886	125,292	115,208
High (ha)	72,391	60,940	59,429
Total (ha)	258,277	186,232	174,637

Devegetation for domestic use (such as fuel wood or charcoal production) is the least factor for land degradation if compared with other causes, while deforestation for agriculture in semi-arid lands around settlement areas (photo 5) is the main cause of land degradation in Jifara Plain. The destruction of forests around Tripoli city is shown during a 7-year period 1986-1993 (Fig. 72 and Tab. 82).

Fig. 71: Change detection of vegetation and agricultural lands in northern Jifara Plain using IR/R indices; 1976, 1989, 2001

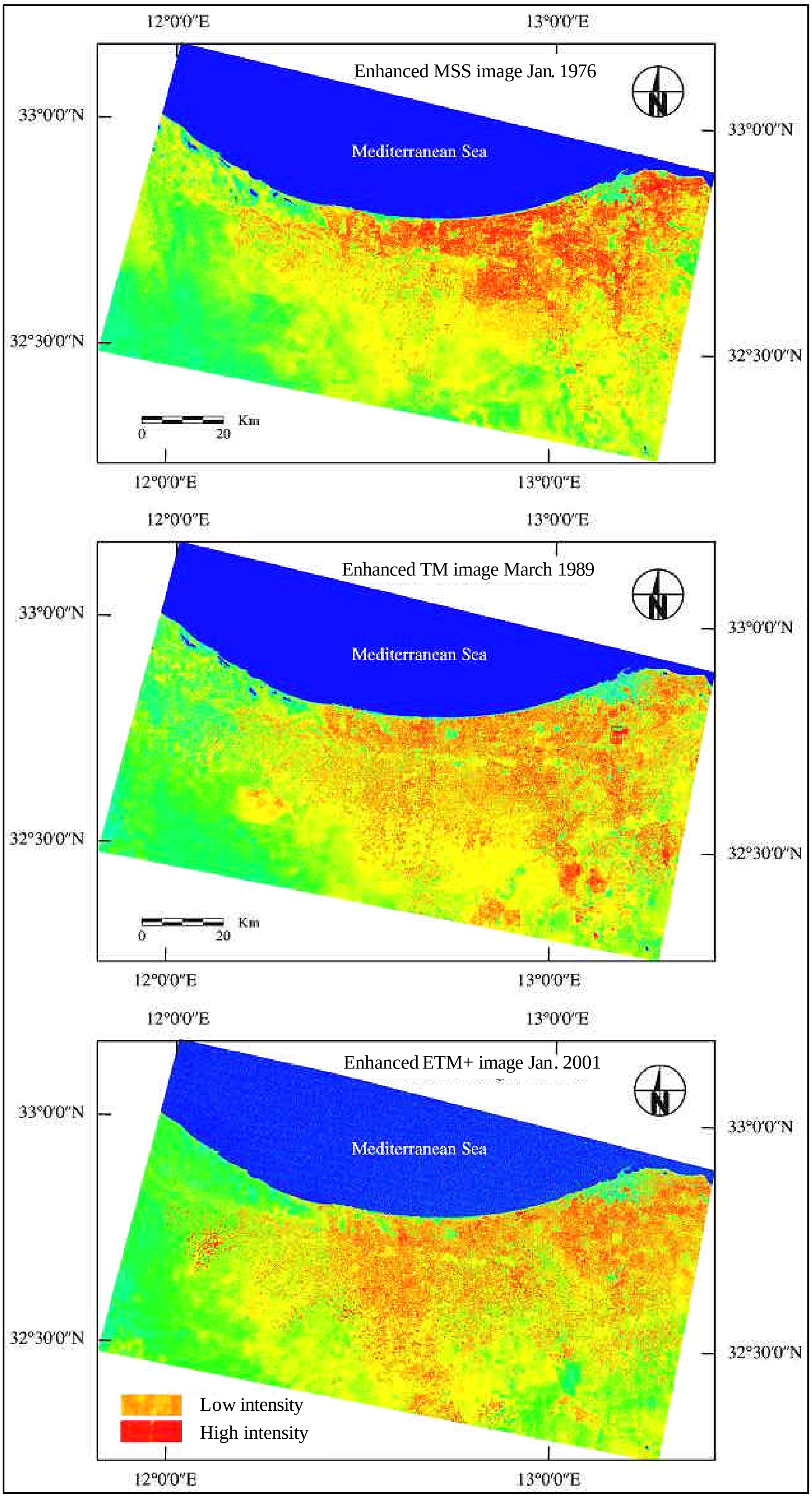
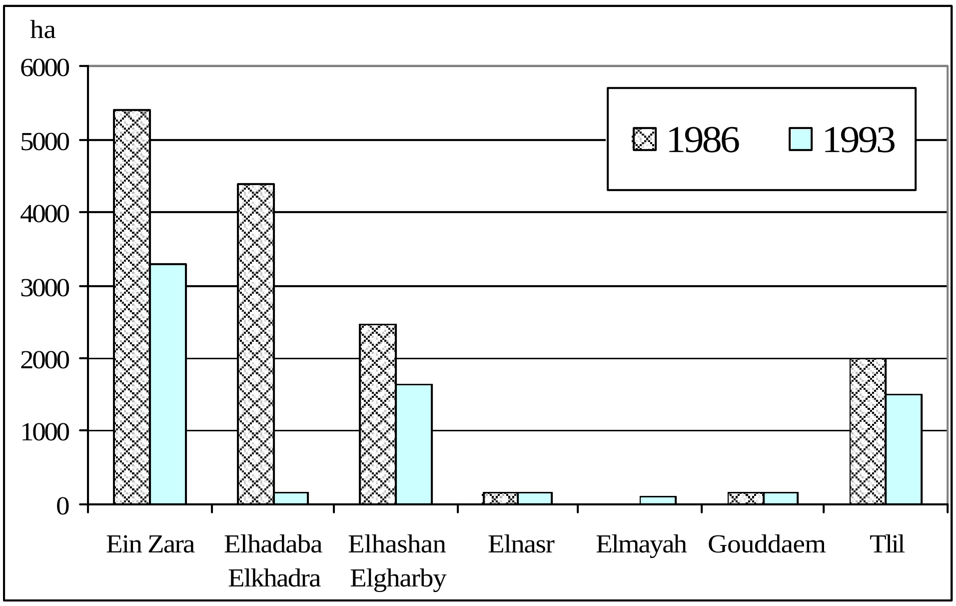


Photo 5: Vegetation deterioration in Elzawia, northern Jifara Plain, 17.10.2002

Fig. 72: Deforestation around Tripoli city, 1986-1993 (ha)



Data source: KREDEGH, 2002: 47

It can be deduced that the forest of Jifara Plain are subjected to severe destruction in Elhadaba Elkhadra and Ein Zara, most of the forest in the first case and about 40 % in the second case were cleared in seven years only. Moderate destruction at Elhashan Elgharby (33 %) and Tlil 25 % is observed, while the remaining forests were not experienced to destruction from 1986-1993. The deterioration of vegetation caused by people will affect them in many ways, for example it accelerates soil erosion followed degradation and deteriorates of food productivity, in addition, loss the source of CO_2 sink. In El-Witia area in the southwestern Jifara Plain, vegetation cover experienced to be reduced by 52 % during the 10-years period 1986-1996 (BEN-MAHMOUD, et al., 2000).

Table 82: Deforestation around Tripoli city in northern Jifara Plain, 1986-1993, (ha)

Area	1986	1993	deterioration
Ein Zara	5,412.0	3,298.0	2,114.0
Elhadaba Elkhadra	4,397.0	169.2	4,227.8
Elhashan Elgharby	2,467.0	1,643.2	823.8
Elnaser	155.6	155.6	0
Elmayah	104.6	104.6	0
Gouddaem	170.4	170.4	0
Tlil	2,000.0	1,500.0	500.0

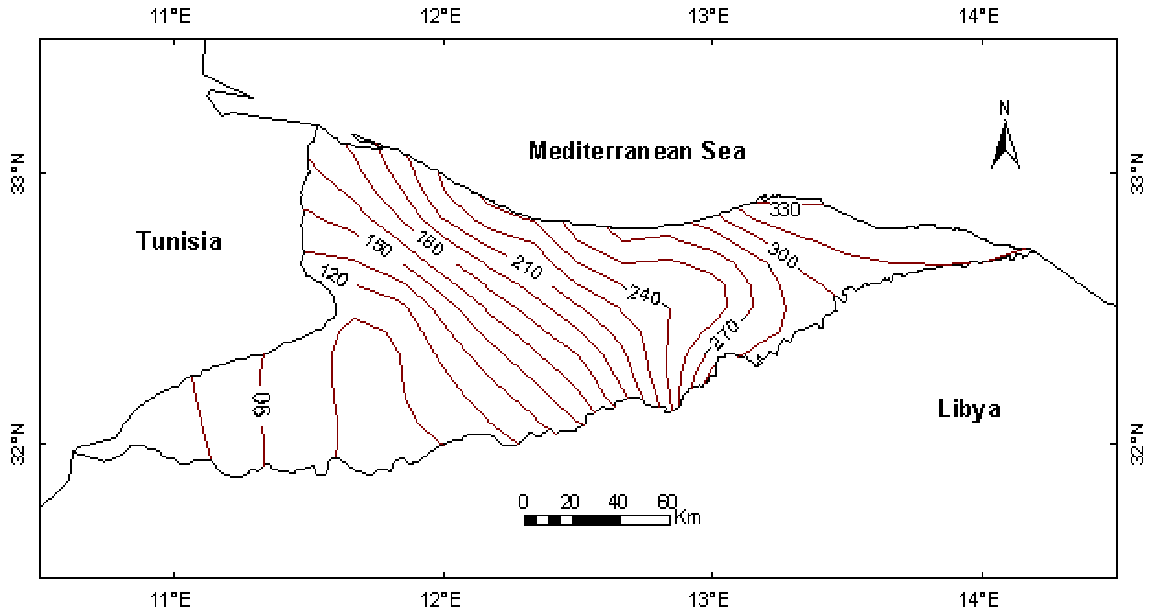
Source: KREDEGH, 2002: 47

6.2.3 Scarcity and pollution of water resources

Water resources in Jifara Plain consist of surface runoff and groundwater; surface runoff water reaches the plain through many wadis from the annual precipitation over Jifara Plain and Jebal Naffusah, the length of wadis does usually not exceed a few kilometers. Thirty two wadis have a catchment basin larger than 30 km^2 and only eight of these have a basin ranging from 300-700 km^2, for example the total catchment area of Al Hirah wadi is 80 km^2 and average total runoff along the foot of the Jebal Naffusah escarpment is 87.2 mill. m^3/year (PALLAS, 1980: 566). Only a few wadis can reach the sea. Surface water reservoirs have been constructed in the wadis by constructing dams in Jebal Naffusah to keep cities off from floods and soils off from erosion. The greatest part of surface water in these wadis infiltrates into the wadis beds or evaporates. The annual aquifer recharge by surface runoff dispersal and wadi bed infiltration is estimated to be not more than 800 million m^3 (KRUSEMAN and FLOEGEL, 1988: 775). Annual precipitation distribution across Jifara plain can be seen from Fig. 73, precipitation is often erratic, and a pronounced drought may extend over two years.

Jifara Plain is subjected to recurrent drought, for example, epic floods in 1945 left Tripoli under water for several days, and two years later an unprecedented severe drought caused the loss of thousands of head of cattle (THE LIBRARY OF CONGRESS, 1987).

Fig. 73: Annual precipitation distribution over Jifara Plain (isohyets)



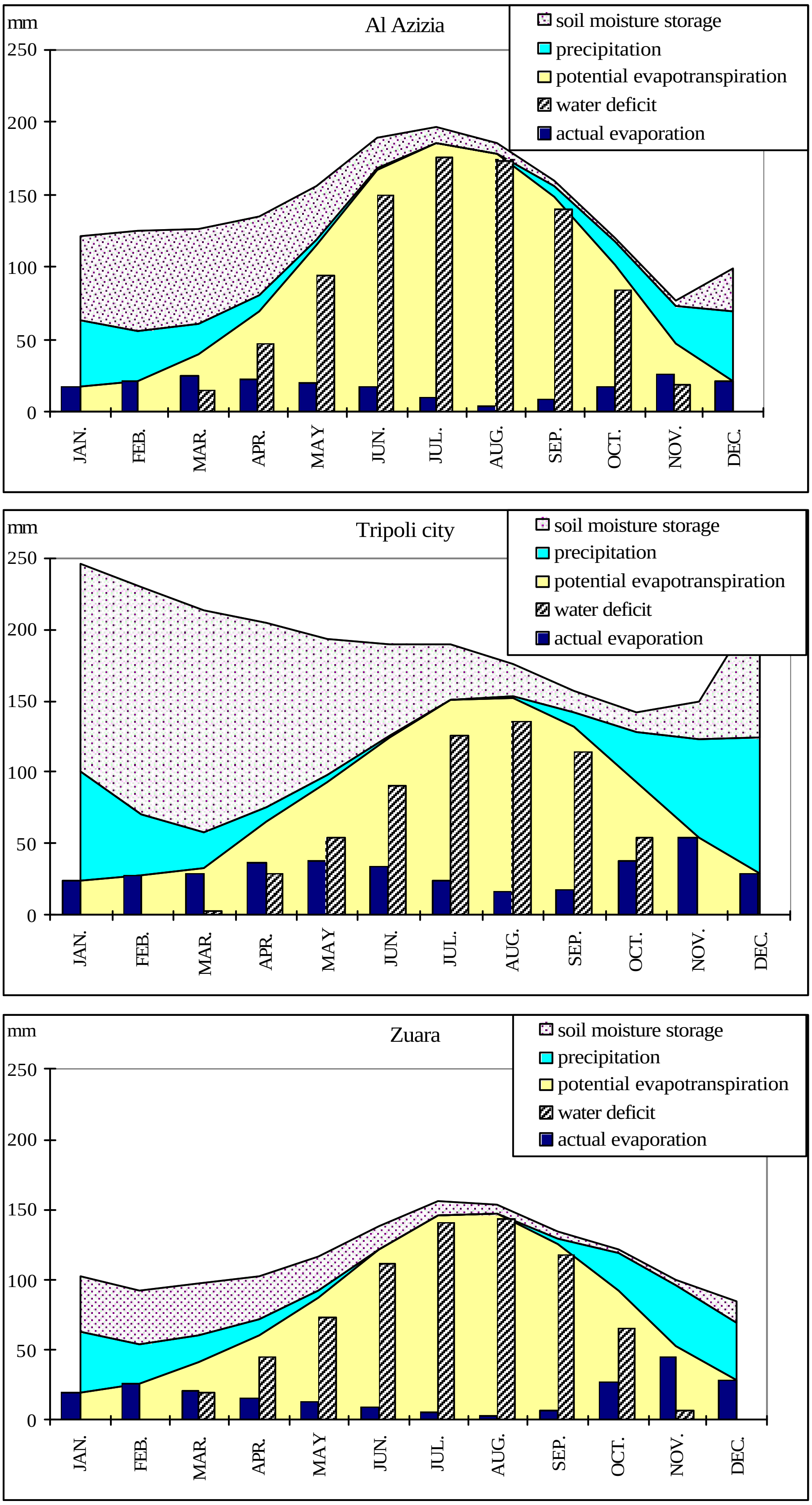
Data source: Libyan Meteorological Department, Tripoli

Jifara Plain suffers from severe hydrological drought; water behind dams experienced to be decreased or disappeared (GENERAL ENVIRONMENTAL AUTHORITY, 2002: 206) resulting from erratic and great variabilities of precipitation. Benefited precipitation in Jifara Plain is only 15-20 %, while lost water is 70-78 % through evaporation, 2 % waste to the sea and 5 % infiltrate into the soil (KSOUDH, 1996: 329). In addition, high temporal and spatial variabilities of precipitation lead to a greater variability of short duration runoff, accelerated soil erosion by water and high sediment transport rates. Water scarcity seriously affects pastoral and agriculture activities in Jifara plain.

Water balance, computed after Thornthwaite at three stations (Fig. 74), clarifies a big gap between precipitation and evapotranspiration. It can be noticed that water deficit prevails for nine, eight and nine months per year at Al-Azizia, Tripoli city and Zuara, respectively. It can also be seen that during summer, spring and autumn, water demand is greater than water supply by precipitation. As a result, vegetation suffers from deficiency of water, as well as soil moisture and accelerates water scarcity.

Groundwater is the major source of water in Jifara Plain. The upper aquifer (Miocene-Pliocene-Pleistocene) collects water under unconfined conditions and extends throughout the Plain; it is 100-150 m thick and contains good quality water in the central and eastern parts, the middle Miocene aquifer is well developed in the western part of the Plain and found at 70-120 m below the surface with thickness of the aquifer between 125-200 m.

Fig. 74: Water balance, after Thornthwaite, at three stations in Jifara Plain

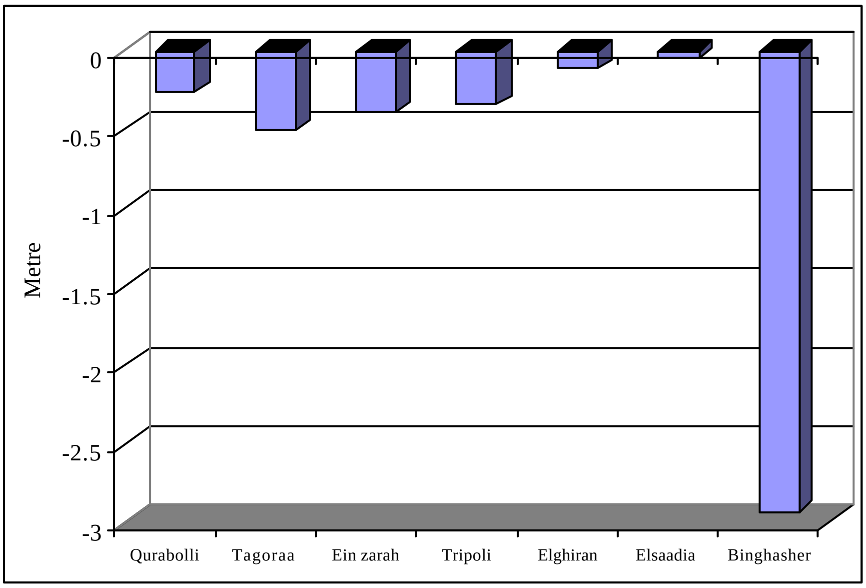


Data source: THORNTHWAITE, 1962: 117

Clay layers separate the aquifer from the quaternary and lower Miocene aquifers (SADEG, and KARAHANOLU, 2001: 1155). Ground water is mainly recharged from precipitation, infiltration from surface runoff which inflows from the south.

The scarcity of water was aggravated by water level declines and quality deterioration. Water level declines over 1 m/year in some parts (Fig. 75) and total dissolved solids have exceeded 9,000 mg/liter in the last four decades (ABUFAYED and EL-GHUEL, 2001: 49). Water levels have dropped at most parts and, along the southern boundary, drawdown of more than 30 meter is recorded. In addition, water levels often drop below sea level, presumably because of excessive discharge from a well field located in this profile (SADEG, and KARAHANOLU, 2001: 1161). In 1968, ground water level decreased 1 m in some areas around Tripoli and it was experienced to sea water intrusion (BAQI, 1991: 119).

Fig. 75: Annual decrease of groundwater in different parts of Jifara Plain

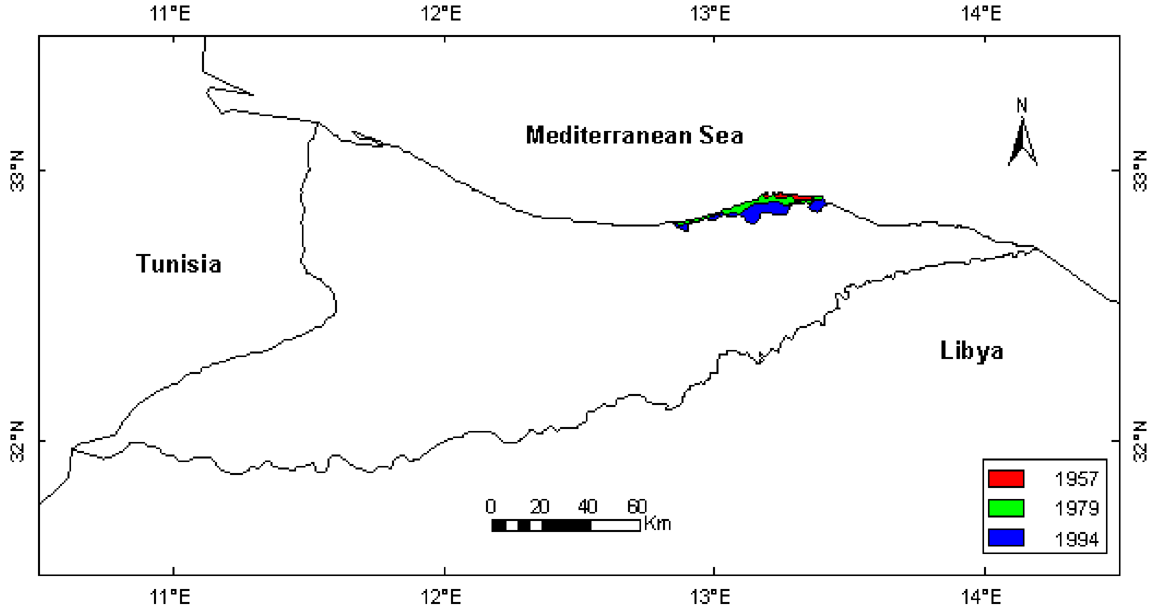


Data source: ELTANTAWI, 1998a, after, ELGHTISY, 1990

Over-extraction of groundwater in the coastal parts, particularly, in eastern Jifara Plain, has led to a continuous decline in the groundwater level and sea water intrusion which is estimated to be advancing at a rate of 100-250 m/year. If this over-extraction is not stopped or reversed, it is expected to deteriorate all productive aquifers by the near future (BIN-MAHMOUD, et al., 2000). A serious deficiency was thus produced between the natural water supply and the quantities exploited; it is estimated, for instance, that over one billion cubic meters are annually taken from the reservoir of Jifara Plain, where farming activities use up a share equivalent to almost 80 % of the total consumption (NATIONAL COMMITTEE to COMBAT DESERTIFICATION, 1999). Water deficit in Jifara Plain was 1281.5 million m^3 in 1998 or six times from groundwater safe use (GENERAL ENVIRONMENTAL AUTHORITY, 2000: 63).

Underground water in some parts under consistently heavy drainage started to run dry and turn increasingly saline. This aquifer forms the major source for domestic, industrial, and agricultural purposes for the Tripoli area. The seawater/freshwater interface would migrate landward leading to a very critical problem. Fig. 76 shows a noticeable change in the position of intrusion in the Tripoli area from 1957-1994 indicating landward migration of seawater. Along the Mediterranean coast water quality becomes poor where over-pumping has led to seawater intrusion. Observations during 1994 showed that a 375 mg/liter chlorine contour have migrated inland, reaching to a distance of 10 km from the coast in Gargaresh and Ein Zara (SADEG, and KARAHANOLU, 2001: 1152).

Fig. 76: Sea water intrusion in Tripoli area, 1957-1994

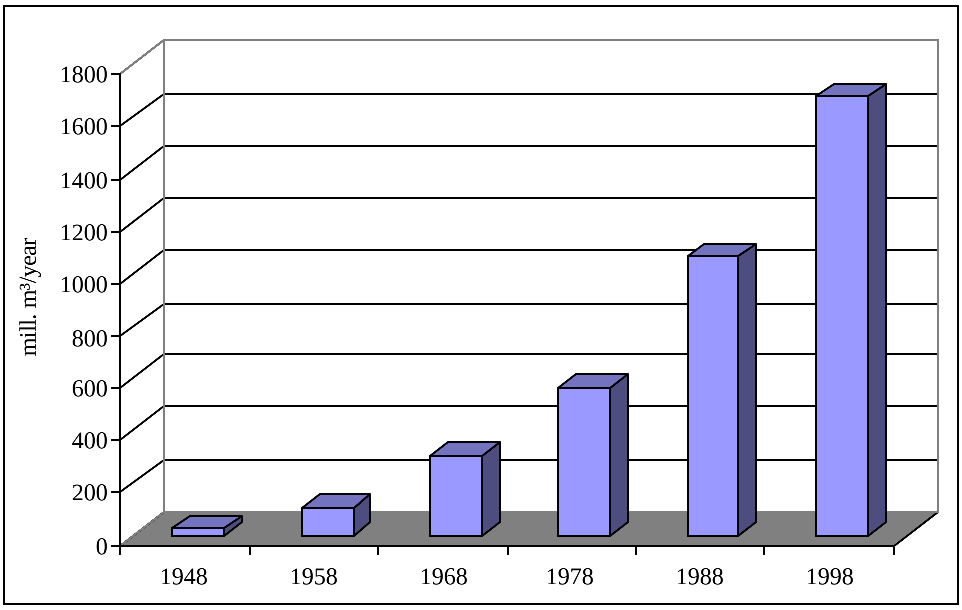


Source: BIN-MAHMOUD, et al, 2000

Groundwater is subject to excessive mining as it is located in the most populous and intensively agricultural region of Libya and because of its ever-increasing water demand from underground water resources. The main groundwater use is for irrigation (in 1998 1,472.5 mill. m^3) and for other purposes: livestock (4.3 mill. m^3), urban use (188.1 mill. m^3) and industry (10.1 mill. m^3; GENERAL ENVIRONMENTAL AUTHORITY, 2000: 60).

In recent years, the risk of seawater intrusion is continuously threatening coastal parts of the Plain that form one of the economically most significant areas in the country. High rates of urbanization and increased agricultural and economic activities have required more water to be pumped from the aquifer (Fig. 77). This pumping has continually increased the risk of seawater intrusion and deterioration of freshwater quality.

Fig. 77: Groundwater use in Jifara Plain, 1948-1998



Data source: NATIONAL SCIENTIFIC RESEARCH AUTHORITY, 1999: 39, EL-REJIBI, 1998: 13, and GENERAL ENVIRONMENTAL AUTHORITY, 2000: 60

Tab. 83: Groundwater quality in some parts of Jifara Plain

Well number	Site	Analysis date	Melted salt parts, ppm
70/24	Zura	24/5/1976	6,776
77/255	Zura	21/1/1979	24,740
80/171	Alesa	13/4/1981	10,000
76/272	Alesa	28/10/1999	7,236
87/82	Alakrabia	12/3/1989	6,000
87/83	Alakrabia	5/4/1989	5,800
87/84	Alakrabia	23/4/1989	6,000
77/72	Algamel	10/8/1977	2,191
77/73	Algamel	10/8/1977	6,056
77/74	Algamel	17/7/1977	4,100
76/284	Sebrata	12/7/1976	1,512
76/49	alogailat	13/4/1976	4,868

Source: INTERNATIONAL CENTER OF WATER, 1999

Groundwater subjected also to poor quality. In spite of safe limited of the total dissolved solids in water is 1500 ppm, it reached in Es-Sawani station 3,800 ppm and 23000 ppm in Zamzam stations, sea water ranged between 36,000-37,000 ppm (MGELY, 1994: 154). This means that the pollution of groundwater in some parts in Jifara Plain ranges between 3 to 15 times than the acceptable world standards (Tab. 83).

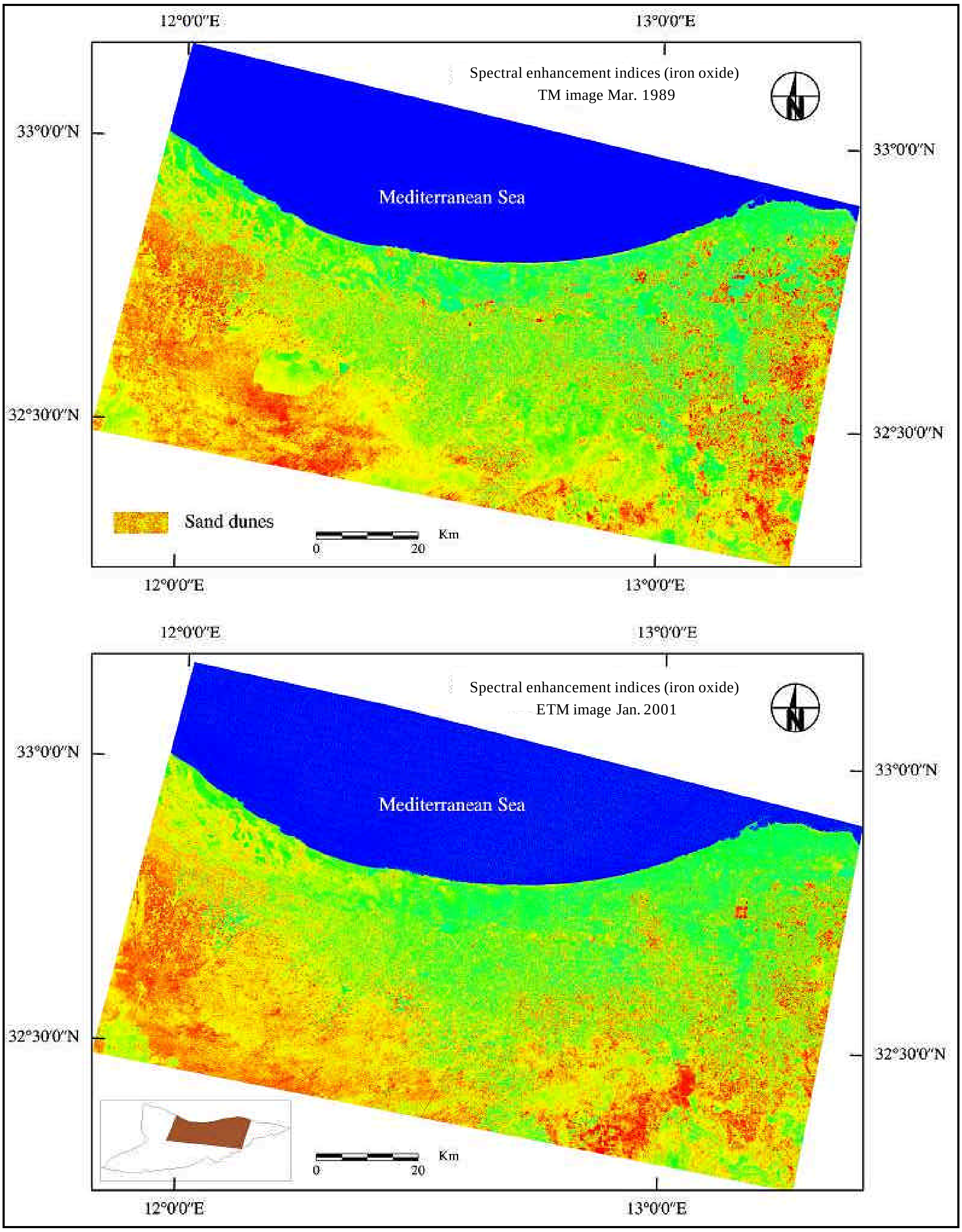
6.2.4 Sand dunes movements

There are two kinds of sand dunes in Jifara Plain, coastal and continental. For coastal sands, high continuous barriers are preferable; sea winds, blowing mainly from the northeast, form vast sea-shore dunes along the entire coastline from Zuara to Misurata, particularly at Side-Benur. The red sands (Heix) originate from the interior of the African continent composed mainly of very fine quartz granules, while sea white sands, with rounded, rough textured and more calcareous grains, are less able to retain water than the continental sand (MESSINES, 1952).

Photo 6: Sand drifts in southern Jifara Plain on the road to Tripoli, 04.11.2002

Deposition of sand downwind of the fields is a progressive process, with sand plumes lengthening in each successive image. The tiny particles of sands, blown gradually or by a storm over the inland hills are deposited over the entire plain (photo 6). In northwestern Libya, an area of 33,500 ha has been affected by sand dunes creeping (UNEP, et al., 1996: 274). When the gibli blows, the sky darkens and assumes a characteristic reddish color. The mobility of the sand presents a constant menace, imparting to Jifara plain, particularly the areas south and east of Tripoli. Monitoring study on El-Witia area showed an increase of 227 % in sand dunes formation during 10-years from 1986-1996 (BEN-MAHMOUD, et al., 2000).

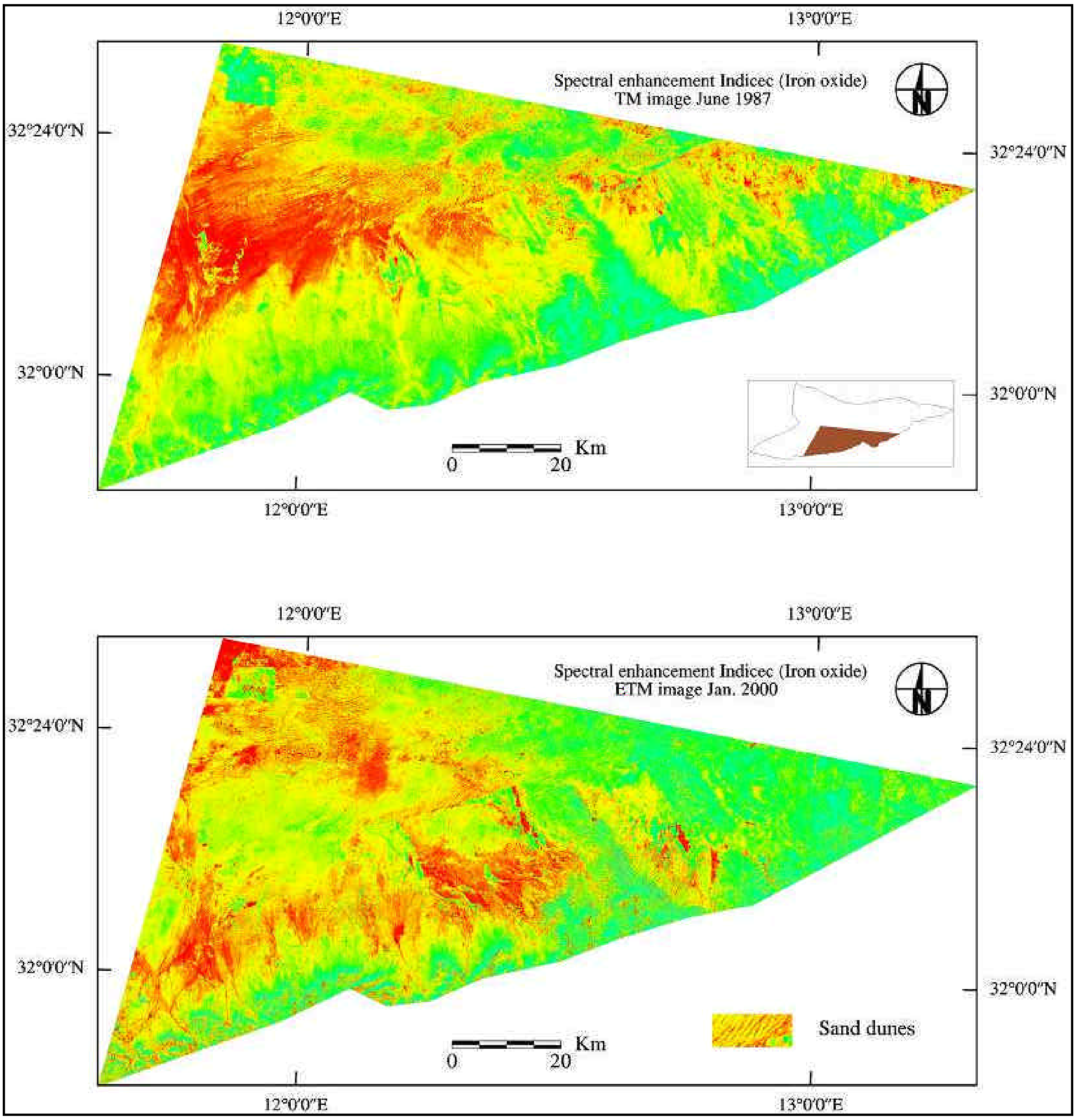
Fig. 78: Sand dunes movements in northern Jifara Plain, 1989-2001



Spectral enhancement indices (iron oxide)
TM image Mar. 1989

Spectral enhancement indices (iron oxide)
ETM image Jan. 2001

Fig. 79: Sand dunes movements in the southern of Jifara Plain; 1987-2000



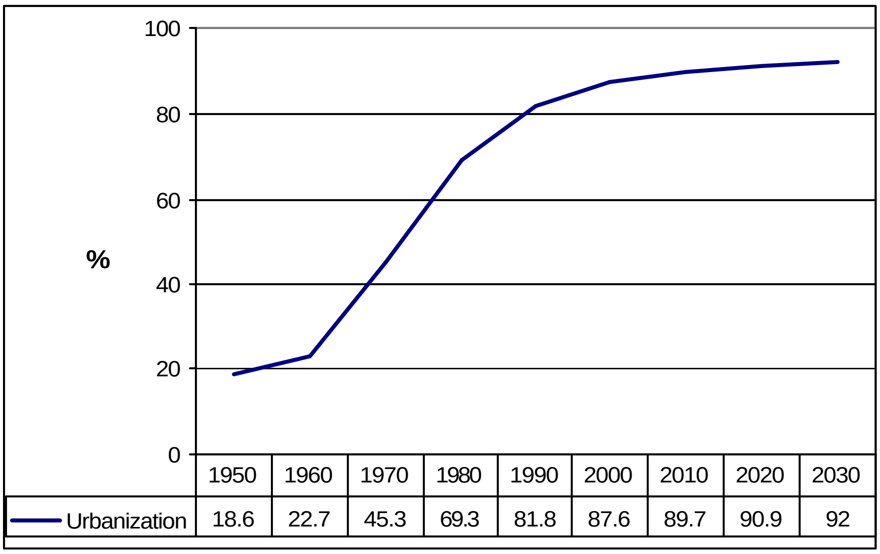
The arable lands in the coastal parts of Libya are steadily invaded by fine-grained, rust-red sand. Landsat images Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) have been analyzed using spectral enhancement (indices) Iron oxide, band 3 / band 1, to detect the movements of sands in northern and southern Jifara Plain (Figs. 78 and 79). It can be observed that the sand areas were expanded over Jifara plain from 1989-2001. In the northern Plain (over an area of 758,026.2 ha), the sand covered area has increased from 430,154.6 ha in 1989 to 450,636.3 in 2001. In southern Jifara Plain (over an area of 657,870.1 ha), the area which covered by sand has increased from 328,779.3 ha in 1987 to 347,541.6 ha in 2000.

Land degradation begins with the movement of unconsolidated sands. Landsat, TM and ETM images have revealed wave-like patterns on the ground surface facing the dominant wind directions, with widely distributed sand dunes extending from south and southwest to north and northeast. Ordinarily, there is bare steppe between these dune formations, which are still mobile and consist of pure sand. Sometimes the steppe itself overlies old deposits of sand which had once invaded the area and covered all other formations. This sandy, undulating terrain, sometimes leveled for the shifting cultivation of cereals, is still grazed by herds of small livestock (MESSINES, 1952).

6.2.5 Settlement expansion

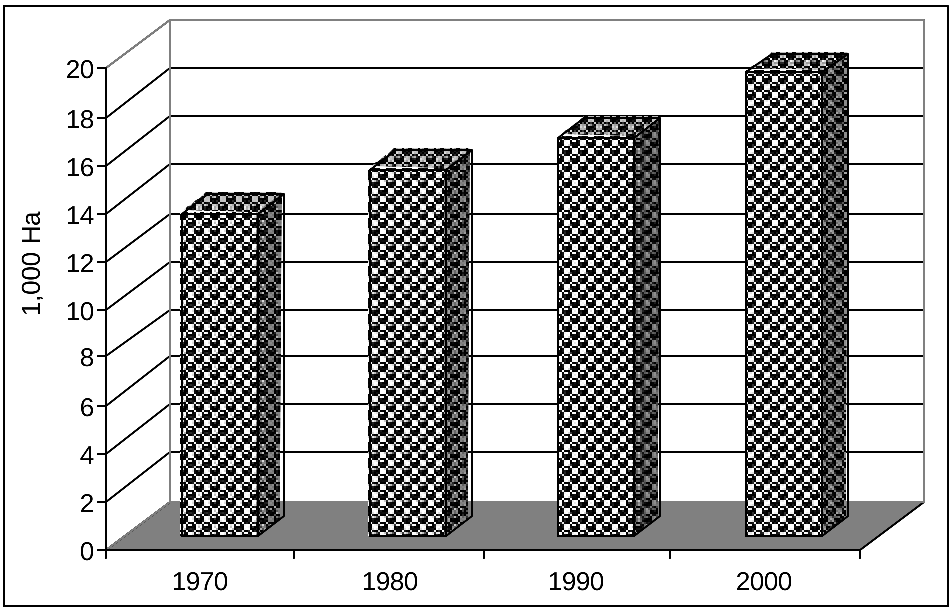
In Libya, over 25 % of highly fertile lands has been consumed by the expansion of urban areas where the average population growth stands at 8 % as opposed to 1 % in rural areas. The number of peasants who gave up farming to look for jobs in the oil industry and in urban areas rose dramatically throughout the 1955-1962 period (THE LIBRARY OF CONGRESS, 1987). As a result of rural people emigration and high standard life in urban areas, urbanization rates increased from 18.6 % in 1950 to 87.6 % in 2000 and expected to be 92 % in 2030 (Fig. 80).

Fig. 80: Changes in the urbanization rates in Libya (%), 1950-2030



Data source: BRAUCH, 2004: 175

Fig. 81: Built-up area expansion of Tripoli city, 1970-2000



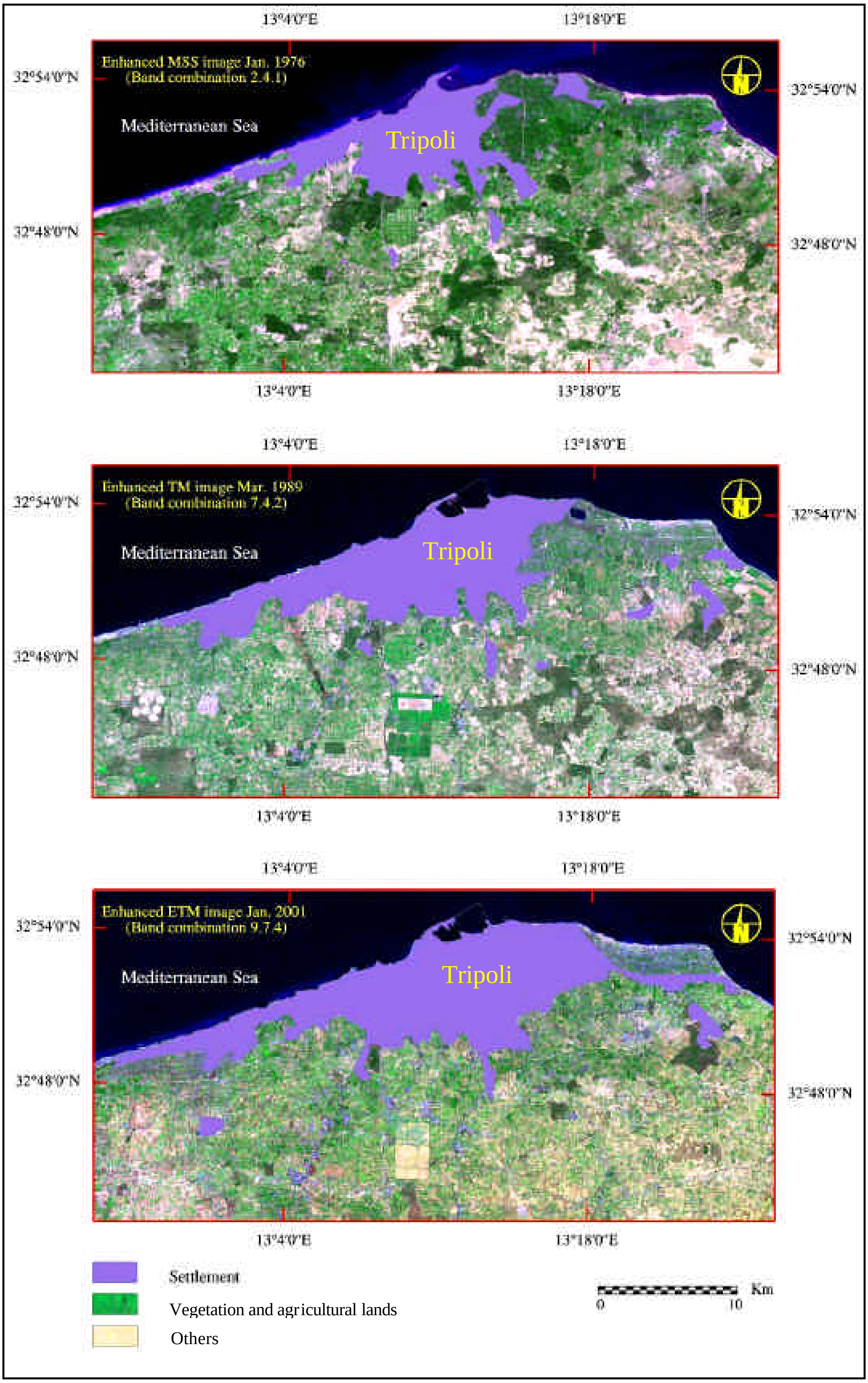
Data source: EL-ZANNAN, 2000: 84

Jifara Plain is heavily populated, mostly along the Mediterranean coast; it embraces Tripoli city, capital of Libya and some of the important towns such as: Zuara, Al-Zawia, El-Azizia, Surman, Sebrata, Qasr Al-Qarabulli, and Bin-Ghashir.

These settlements center are experienced to expansions as a result of population growth and migration. Built-up area of Tripoli city increased from 8,011.4 ha in 1966 to 19,236 ha in 2000 (EL-ZANNAN, 2000: 84; Fig. 81).

According to analysis of landsat images MSS, TM, ETM+, Tripoli built-up area increased from 10,536.7 ha in 1976 to 18,064.4 ha in 1989 and to 26,229,7 ha in 2001 (Fig. 82). The increasing settlement area accelerated desertification process in Jifara Plain because it has led to loss of agricultural land areas around cities. The emigrated people live outside cities on the fertility soils and increase the stress on the natural resources especially water resources resulted from increasing water demands. The uncontrolled settlement growth may also lead to rapidly increasing amounts of wastes (solid and liquid) causing pollution in land and water resources.

Fig. 82: Built-up area changes of Tripoli city 1976, 1989 and 2001



6.3 Causes of desertification

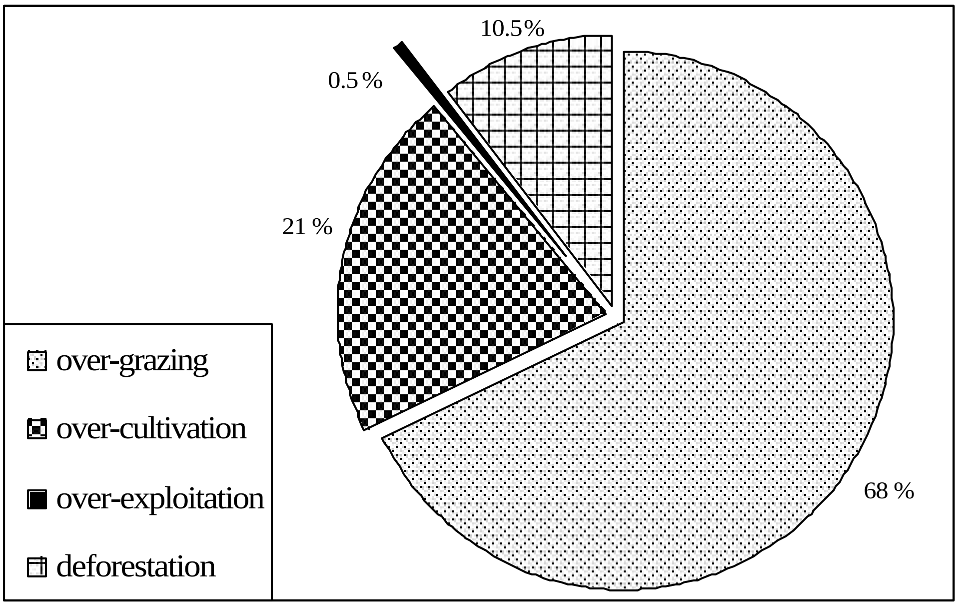
Desertification is more prone to dry land regions; it is caused by both climatic and anthropogenic factors. Evidence shows that certain arid, semi-arid, and dry sub humid areas have experienced decreasing of precipitation affecting negatively soil fertility and production of agriculture, livestock, forest, and rangeland (McCARTHY, et al., 2001). Fragile land and lack of sufficient precipitation can be added to the destruction of topsoil, though over-grazing and over-cultivation are the major cause of this type of land degradation. The vulnerability of land to desertification is mainly due to climate, state of the soil, water, and natural vegetation, and the ways in which these resources are used by human communities and their livestock. Water scarcity is also the main factor for dry lands. Lack and wasteful uses of water are fundamental causes of desertification and environmental degradation (SHARMA, 1998: 121).

Although arid ecosystems are extremely diverse in soils, topography, plants and animal assemblages, most of these systems share some fundamental characteristics due to the dominant role of moisture as a limiting factor. These characteristics can be used to make generalizations about the response of these systems to both natural and anthropogenic disturbances (DEBRA and JEFFREY, et al., 2001: 2). Unsustainable agricultural practices, overgrazing, and deforestation constitute the major anthropogenic factors that can drive desertification. Over-grazing or burning can lead to loss of vegetation cover and shallow eroded soils.

Unsustainable agricultural practices include short rotation of crops, undisciplined use of fire, and removal of protective crop residues. Over-grazing consists of running livestock at higher densities or shorter rotations than a sustainable ecosystem can support. Causes of desertification vary from place to place. In northern Africa, for example, overgrazing is the major cause of desertification, as 68 % of soil degradation result from it followed by over-cultivation (21 %), (Fig. 83).

In Jifara Plain, climate change, landforms, over-grazing and over-cultivation cause desertification. In addition, the increase of human pressure since the colonization era on localized underground water aquifers has caused sea water intrusion in the coastal areas. In irrigated areas, imbalance between excessive irrigation and inefficient drainage causes water logging and secondary salinization.

Fig. 83: Causes of soil degradation in North Africa



Data source: MIDDLETON, and THOMAS, 1994: 71

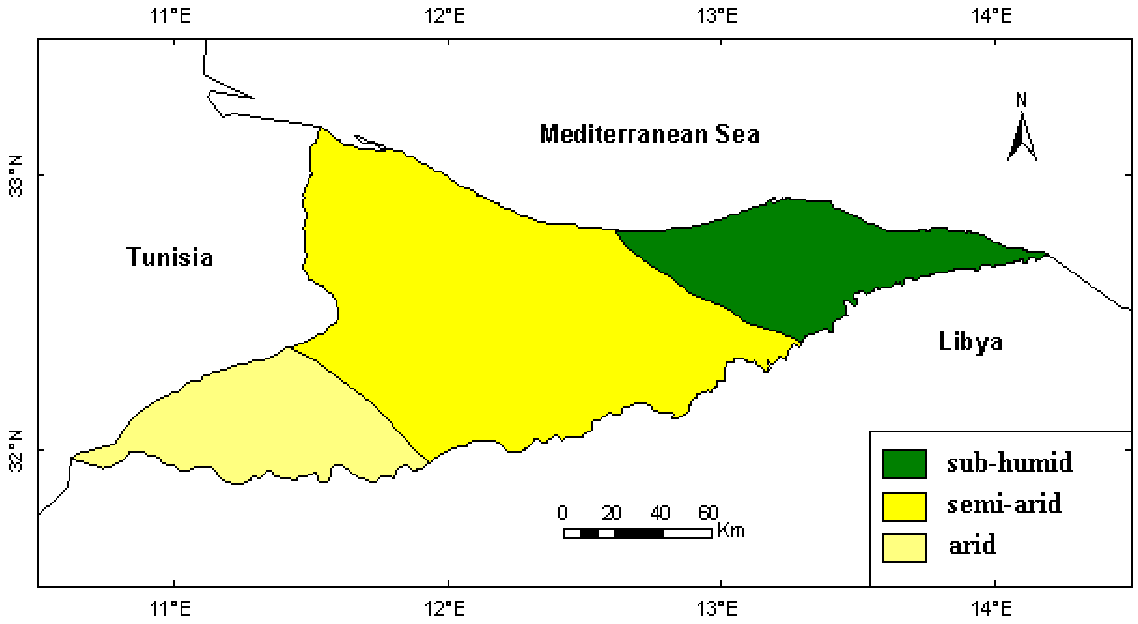
6.3.1 Climate change

The conditions of desertification are dictated by climatic factors since the process occurs mainly in arid, semi-arid and dry sub-humid regions. The reduction in moisture availability projected under climate change would both increase aridity of existing drylands and progressively shift the boundaries of areas susceptible to desertification (JACQUELINE, 2000).

According to the De Martonne climate classification, Jifara Plain is classified by arid climate in the west, semi-arid climate in the middle and dry sub-humid climate in the east (Fig. 84). These climate types are characterized by a high level of incident radiation, high seasonal temperature variations, low humidity and strong winds with frequent dust storms. Precipitation is generally intense and sporadic.

Higher temperatures could result in a reduction of soil fertility due to higher rates of decomposition and losses of organic matter, and could affect nutrient cycling (DUBIEF, 1971: 281). Precipitation and temperature data at 10 meteorological stations were elaborated to clarify the aridity index trends from 1975-2000 in Jifara Plain, after De Martonne (Tab. 84).

Fig. 84: Climate regions in Jifara Plain after the De Martonne climate classification



Data source: Libyan Meteorological Department, Tripoli

Table 84: Climate classification of Jifara Plain, after De Martonne

Station	Lat.	Long.	Aridity index	De Martonne climate type
Zuara	32.55	12.05	8	Semi-arid
Tripoli city	32.54	13.11	11	Sub-humid
El-Azizia	32.32	13.01	8	Semi-arid
El-Rabta	32.09	12.51	8	Sub-humid
El-Zawia	32.45	12.45	9	Sub-humid
Surman	32.45	12.35	9	Sub-humid
Tripoli Airport	32.40	13.09	9	Semi-arid
Gharian	32.04	13.01	12	Sub-humid
El-Zahraa	32.41	12.53	8	Sub-humid
El-Witia	32.28	11.42	3	Arid

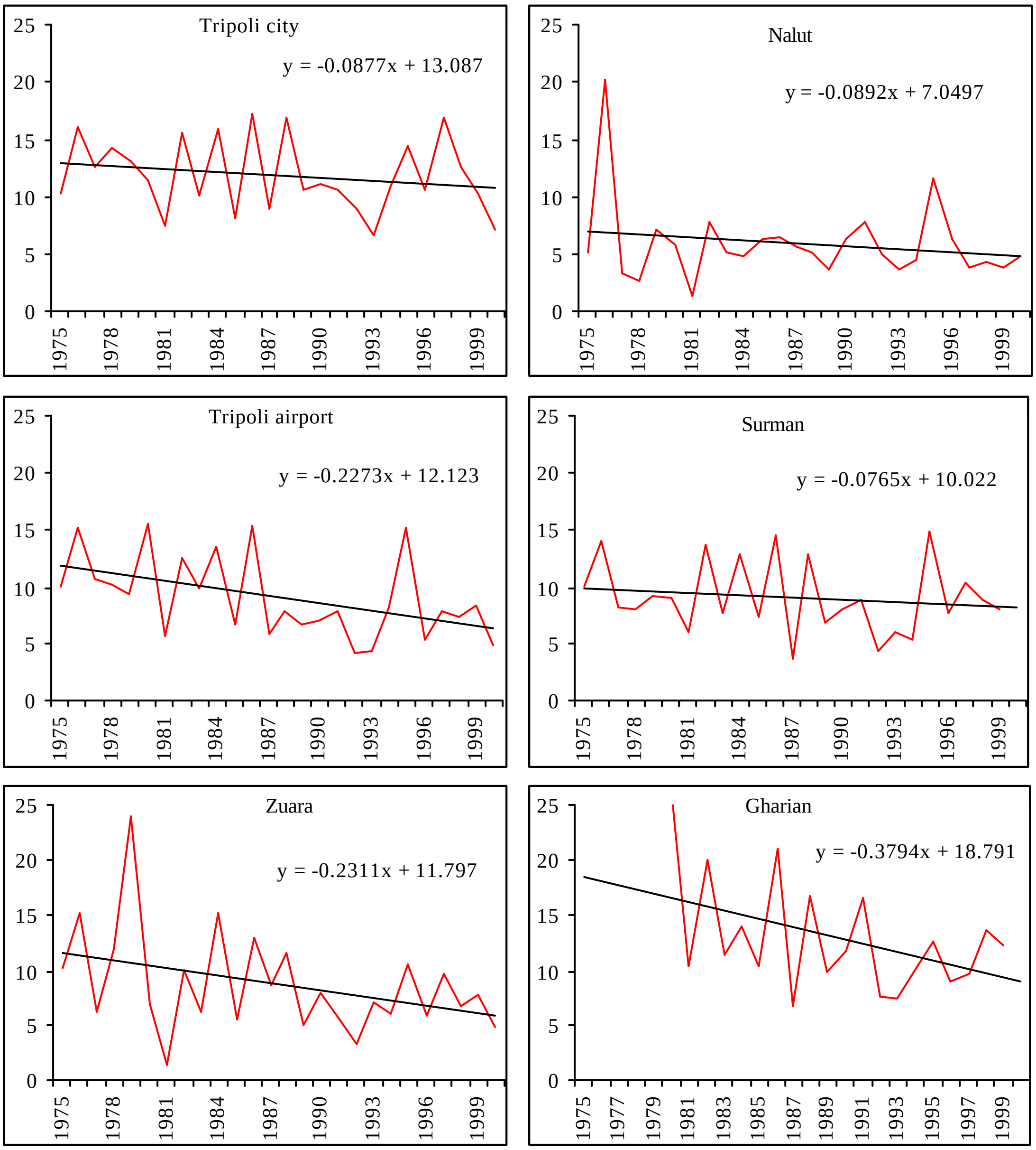
Data source: Libyan Meteorological Department, Tripoli

Aridity index: <5 = arid climate; 5-10 = semi-arid climate; 10-<20 = sub-humid climate; over 20 = humid climate

It can also be deduced that the arid climate prevails in southwestern Jifara Plain (El-Witia), semi-arid climate in the middle and west of the Plain (Zuara, Tripoli airport and El-Azizia), and sub-humid climate in the northeast of the Plain and on Jebal Naffusah (Tripoli city and Gharian), (Tab. 84). Because of increasing temperatures and decreasing precipitation (see chapter 3), negative trends of the aridity index were computed.

This behavior of aridity trends (Fig. 85) indicates a growing aridity with time which can accelerate desertification process in Jifara Plain. In semi-arid regions, extreme or intense precipitation events do occur which can transport large quantities of sediment, yet cover is needed to protect the soil from wind and water erosion which is incomplete (THUROW and TAYLOR, 1999: 414). The potential for desertification is still further enhanced through the direct effects of climate change on soil erosion, soil quality and salinization. Hazard of water erosion would also be made worse by any accompanying increasing precipitation intensity. Climate change leads to reduce the productivity of rangelands which are already under pressure from land use changes and population growth (JACQUELINE, 2000).

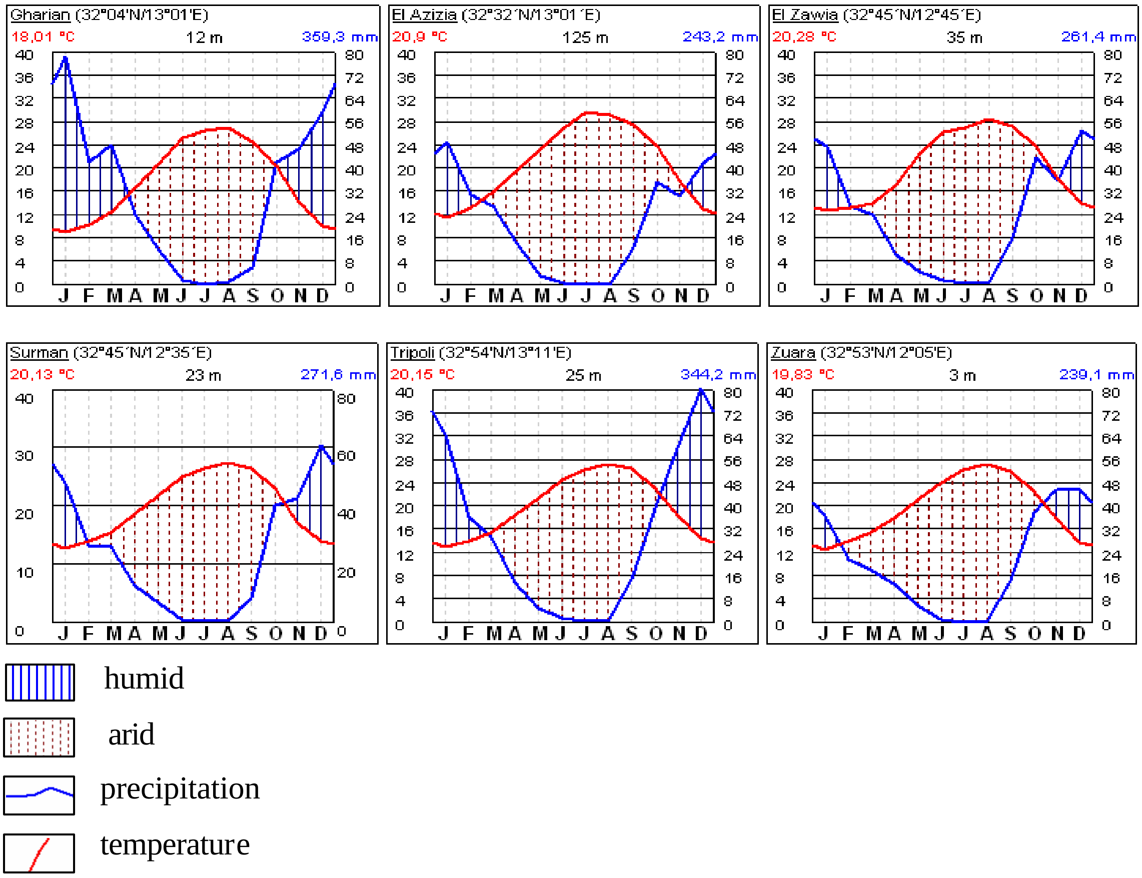
Fig. 85: Aridity index trends in Jifara Plain, after De Martonne, 1976-2000



Data source: Libyan Meteorological Department, Tripoli

As for intra-annual variations of arid and humid months in Jifara Plain, the aridity index was computed at six stations, after Walter and Lieth, this index reads as ***n=2t*** where (n) represents the monthly precipitation (mm), (t) temperature (°C), (Fig. 86).

Fig. 86: Arid and humid months in Jifara Plain, after Walter and Lieth



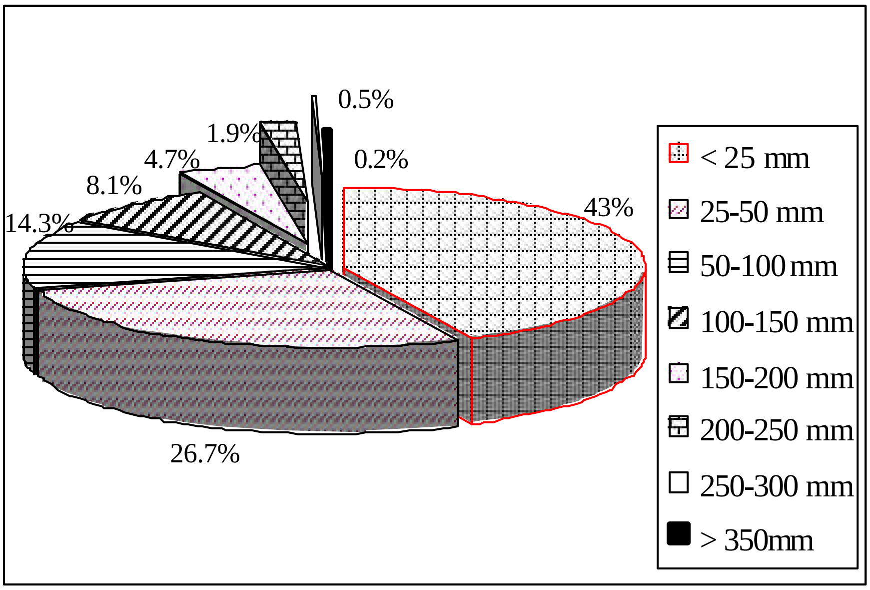
Data source: Libyan Meteorological Department, Tripoli

It can be observed that precipitation curves (blue lines) are considerably lower through out the year than the temperature curves (red lines) reflecting arid conditions over most of the yeas, the number of arid months ranged from seven months at Gharian on Jebal Naffusah in southern Jifara to nine at Zuara in the northwest. Humidity months concentrate in winter which is the rainiest season. There is a long period of water deficit from March to September through June with peak values of deficit in June, July, and August. Precipitation typically onsets in the Plain with a small amount in September, then increases until the peak rainy months December and January, afterwards it decreases until April with a small amount.

Throughout the Plain, precipitation is generally low and does not exceed 400 mm; more than 90 % of the Jifara Plain receives more than 150 mm/year (Fig. 87). Precipitation falls mostly as heavy showers and are lost to run-off. Furthermore, precipitation occurs irregularly, and is badly distributed over time. In addition, wide fluctuations occur over years and decades, frequently leading to drought.

A high rate of potential evapotranspiration further reducing yields; weeds growing more vigorously than cultivated crops and competing for scarce reserves of moisture. In trying to define a wet season or a season of reliable precipitation, it is necessary to consider not only the amount of precipitation but also its variability (LOCKWOOD, 1974: 118). Another source of desertification is caused by the action of raindrops. Barren salty, loamy or clay ground becomes sealed on the surface by the action of raindrops. Raindrops disperse the fine elements of surface soil aggregates (LE HOU´EROU, 1977: 20).

Fig. 87: Percentage shares of annual precipitation in Jifara Plain



Data source: BAQI, 1991: 125

Most precipitated water evaporates without any benefit, whereas a small percentage infiltrates to groundwater. It has also serious implications on soil erosion especially on Jebal Naffusah. Though precipitation may be limited, extreme precipitation intensities may lead to disastrous results damaging agriculture and even loss of lives (e.g. epic floods in 1945 over Tripoli) Tripoli was under water for several days, but two years later an unprecedented severe drought caused the loss of thousands of animals (THE LIBRARY OF CONGRESS, 1987).

Seasonality of precipitation is also considered a limiting factor for rainfed agriculture and pastoral lands. Representing the rainiest season with 50-70 % of the annual totals, winter precipitation decreases southwards due to the decreasing Mediterranean Sea effect. High variabilities of annual precipitation, intensity of precipitation and seasonality cause severe moisture stress on crops, reduce yields and negatively affect pasture lands. Furthermore, intra-annual precipitation distribution does, however considerably vary showing a variable amount of monthly precipitation which is recorded every year for the wettest month at Tripoli city (Tab. 85)

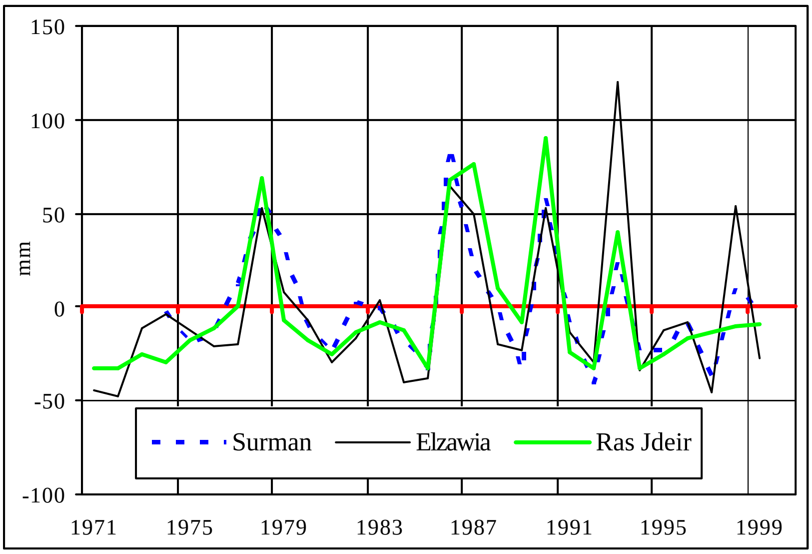
Tab. 85: Wettest months at Tripoli city, 1995-1999

Year	Wettest month	Total precipitation (mm)	% of annual total of the respective year
1995	January	186.2	41
1996	February	98.8	29
1997	October	130.7	25
1998	November	140.2	35
1999	December	104.3	31

Data source: Libyan Meteorological Department, Tripoli

Monthly precipitation totals also experience high inter-annual variabilities shown for example in November, which is very important to rainfed agriculture in Libya, at three stations in northern Jifara (Surman, Elzawia and Ras Jdeir) from 1971 to 2000 (Fig. 88).

Fig. 88: November precipitation variabilities at Surman, Elzawia and Ras Jdeir, 1971-2000



Data source: Libyan Meteorological Department, Tripoli

It can be identified that precipitation in November varies seriously in interannual respect. Precipitation is less than average at Elzawia in 21 years (1971-2000), at Surman in

13 years (1975-1999), and at Ras Jdeir in 22 years (1971-1999). These variabilities of November precipitation have negative effect on agriculture because it represents a limiting factor to the range of success for barley and wheat productions (MGELY, 1994: 157).

Recurrent or prolonged drought is a non-predictable climatic incidence; its effect is often dramatic as it causes wide-spread failure of food producing systems (KASSAS, 1987: 391). Drought occurs frequently in the areas affected by desertification; the relations between desertification and drought, on the one hand, and the human influence on the other are complex. Occasional droughts due to seasonal or inter-annual variations in precipitation and long-term droughts covering wide areas are both caused or aggravated by the influence of man on the environment. Drought may sharply reduce seal production and affect food security because soil erosion and desertification become more pervasive (SWEARINGEN: 1992. 403). As an example of occasional drought, the years 1927 and 1928 are considered. In Tripoli the annual precipitation total was only 196.7 mm in 1927, the period from November to May (1928) included 187 days without any rains. The 220-days continuing period from the start of April 1928 until November 1928 were only broken by a few isolated days of precipitation. The total amount of rain in 1928 reached 341.5 mm while over 100 days in the following year did not receive any rain and annual total was below the average (KANTER, 1967: 98).

Strong wind is considered a dangerous meteorological phenomenon; it can cause a significant damage, particularly for natural resources, as it is blowing dust accompanied by erosion of soils. Wind is a more frequent phenomenon in arid and semi-arid lands leading to degradation and a high degree of strong air pollution (WMO, 1983: 13).

In spring and autumn, strong southerly winds - Gibli - blow from the desert, filling the air with sand and dust and raising the temperature to about 50 °C in some parts. This distractive wind is one of the major erosion factors in the Jifara Plain transporting the eroded soils from one place to another. The dust transported from Sahara to Europe from Saharan was estimated at 80–120 mill. t/ year (GOUDIE and MIDDLETON, 2001: 186). Plantations suffer greatly from a prolonged subjection to southerly winds because of the greatly reduced relative humidity, leaves are withering and crops are destroyed (KANTER, 1967: 98).

6.3.2 Topography of Jifara Plain

Jifara Plain is characterized by a flat topography; it can be divided into three different parts: coastal strip (in the north), the central parts and the foot of Jebal Naffusah (mountain) in the south. Jifara Plain is covered by quaternary deposits with occasional outcrops of limestone hills belonging to the Azizia formation. Calcarenites, covered by coastal sandstones and brown silts, form the coastal strip. The central parts are covered mainly by poorly consolidated aeolian deposits mixed with brownish silts. The southern border of the central part interlocks with the foot-mountain strip, which is made up of fluvial coarser sediments (SADEG and KARAHANOLU, 2001: 1154). Jifara Plain elevates gradually southwrds and reaches about 400 m above mean sea level in the south and 700 m at some parts on Jebal (Fig. 89).

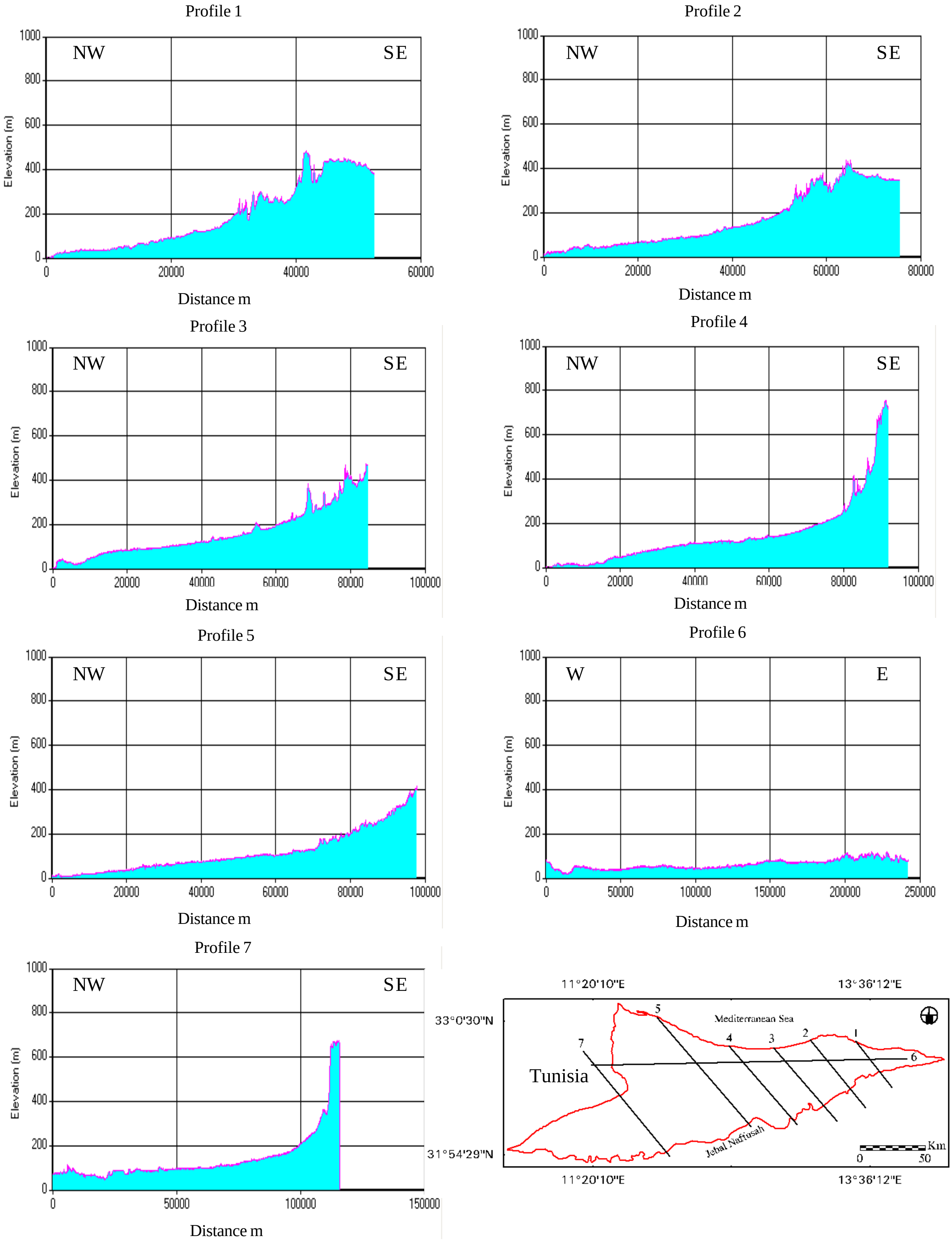
Seasonal streams (wadis) flow over the central part, drain the Jebal Naffusah and fan out in the Jifara Plain. Between Mediterranean Sea and Jebal Naffusah, 40 km of partly consolidated dunes are found, flowed by the flat spreading zones of the wadis that rise in Jebal Naffusah, the transition between Jifara Plain and Jebal Naffusah is very sharp west of Azizia-Gharian road and more gradual east of this road (KRUSEMAN and FLOEGEL, 1980: 764).

Landforms in Jifara Plain accelerate soil erosion followed by desertification. The beating action of precipitation on naked soil puddles the surface, which crusts when the sun comes out, reducing infiltration of water. Even water erosion, as expressed by rills and gullies can rapidly increase especially in southern Jifara Plain. Limited vegetation cover in the Plain cannot protect the soils from impacts of precipitation intensities, which tend to seal up and produce relatively large runoff volumes in relation to the absolute precipitation amounts; this in turn leads to an increase of soil erosion. Gullies may form on the lower parts of Jebal Naffusah slopes, impeding or preventing farming operations. Sediment deposited at the foot of slopes, fills waterways and aggravates flooding in low-lying areas. The flooding follows increased runoff from the slopes above (e.g. El-Majenin wadi dated 16.09.1969 and Al-Kharwaa wadi dated 22.12.1983) accelerating soil erosion in the southern Jifara Plain (GENERAL ENVIRONMENTAL AUTHORITY, 2002: 239).

Jebal Naffusah, at an elevation of 300-700 m, is neither high enough nor sufficiently continuous to prevent the gibli wind to blow over Jifara Plain from the south, occasionally with incredible violence, picking up, transporting, and depositing thousands of tons of sand

(MESSINES, 1952) affecting all human activities, especially agricultural crops and vegetation cover.

Fig. 89: Relief profiles in Jifara Plain using SRTM (189/37 and 190/38) images



6.3.3 Soil erosion

High intensities of soil erosion, by removal of fertile top soils, occur mainly in semi-arid and sub-humid areas (REICH, et al., 2001). Water erosion is a widespread process on steeper slopes of Jebal Naffusah because most of vegetation cover has been cleared by over-grazing and over-cultivation. The degree of water erosion is based on the precipitation characteristics (intensity and sesonality), the density of vegetation cover, degree of slopes, and soil moisture. In part, a consequence of the settlement of pastoral nomads (over-grazing), the expansion and intensification of arable farming (over-cultivation) and deforestation, which in places has led to soil erosion (MIDDLETON and THOMAS, 1994: 59).

Jifara Plain experiences both water and wind erosion with different degrees due to aridity, poor vegetation cover, land misused by man and wind regimes. Wind erosion is a big problem in the plain leading to soil degradation and affects agricultural and pastoral lands, urban areas and infrastructures. Over-grazing is the major cause of wind erosion; the grazing-induced deflation of top soil is a pervasive problem in coastal regions in Libya. Pastures are also suffering from enhanced wind erosion as they are converted to grain cultivation (MIDDLETON and THOMAS, 1994: 61). Soils that are severely affected by wind erosion are psaments, orthents, camborthids and non-soil formations such as sands and sand dunes; wind erosion can remove several centimeters from surface material per year in the areas that have sandy textured soils (BIN-MAHMOUD R. et al., 2000).

Both water and wind erosions work together, as redeposit silts from surfaces stripped by water erosion are particularly vulnerable to wind transport. Wind erosion starts with the movement of coarse soil particles in one part of a field, then progresses downwind with increasing severity as bouncing soil particles knock other particles into the air in a kind of progressive, increasing effect. Finer materials are lifted as dust into the air and carried away over long distances; coarser sandy materials drift over the surface until they are trapped by plants in accumulations of low, rounded hills and small dunes (PEREZ and THOMPSON, 1995).

6.3.4 Over-grazing

Desertification is attributed to overgrazing in arid and semi-arid lands because the animals are the major user of primary production. United Nations Environment Programme (UNEP) singled out human impact and, specifically, livestock grazing as the cause of the irreversible degradation which has prevailed during 1970s and 1980s (PEARCE, 1992). The uprooting of shrubs leads to the destruction of the soil structure and thus to accelerated erosion by wind and water. Over-grazing refers to the practice of allowing a large number of animals to graze at a location than it can actually support. Pastoral areas in Libya are estimated at 13.244 mill. ha out of which 4.773 mill. ha are in the western area (Jifara Plain and Jebal Naffusah). Grazing capacity in Libya is very low in comparison with the world because its deterioration and the high variabilities of precipitation (UNEP, et al., 1996: 273).

In Jifara Plain, pastoralists herd without any control in numbers or kinds of animals in spite of the fragility of the ecosystem (photo 7). There is a trend towards diminished flexibility as a result of increasing technological inputs arising from the push towards higher productivity. For instance, introduction of deep wells has improved the availability of water while increasing herd size and decreasing herd mobility, leading to local overgrazing and excessive trampling around the new watering points. Technological changes can accelerate desertification process through excessive demands on limited natural resources (PEREZ and THOMPSON, 1995).

Photo 7: Over-grazing in southern Jifara Plain, 04.11.2002

Livestock around the water sources may lead to a zonation of the impacts that animals have on vegetation communities, radiating out from the central point. The zones that result are called biospheres. If livestock numbers are allowed to proliferate, and are supported by the import of artificial feeds during times of drought and environmental stress, then the points may become desertified land (MIDDLETON and THOMAS, 1994: 71).

Overgrazing is also a factor causing the land to be stripped of its grasses. In 1976-1977, Jifara Plain was subjected to over-grazing followed by deteriorating the vegetation cover in many parts that led to a loss of a large amount of animals (Al-Adyoush, 2000: 68). At present, animal population densities are far beyond carrying capacity, the land is now over-grazed due to the six-fold growth in the number of animals during the latter half of the 20th century (UNCCD, 1999). The result is a progressive reduction in vegetation cover and increased soil erosion and salinity leading to a nearly irreversible loss of soil productive potential.

The effect of over-grazing on soil in Jifara Plain appears clearly during dry years, the soil which deprived of its vegetation cover, is blown away by the gibli wind. Many arid and semi-arid lands which are confronted with over-grazing and precarious agriculture, such as Jifara Plain, are subjected to uncertain precipitation, poor surface water and depletion of groundwater. In such areas human use of natural resources needs to be in balance with the carrying capacity of these resources (SHARMA, 1998: 121).

Over-grazing increases around the settlement areas, it is often related to the sedentarisation of nomadic herder. Expansion of cultivation and disruption of trade routes have undermined the traditional north-south seasonal migration of herders. The resulting disorganized utilization of grazing lands and the self-generated sedentarisation of many formerly nomadic groups has led to accelerated development of dunes and badlands after severe vegetation transformation in areas with permanent water supply or with sandy soils (MIDDLETON and THOMAS, 1994: 69). The nomadic and semi-nomadic pasture- farming has much less damage of the sedentary than combined tillage-animal production system and quasi-sedentary population in semi-arid lands (MENSCHING, 1986: 14).

6.3.5 Over-cultivation

Over-cultivation is an increasing population pressures on the fragile and vulnerable soils. It has been demonstrated around the world that low-input agriculture, particularly in the absence of appropriate conservation practices, leads to land degradation (REICH, et al., 2001). Over-cultivation of the rangelands exhausts the soil and removes trees that hold it. In addition, the inadequate drainage may lead to soil salinization and water logging as in northwestern Jifara Plain. Inappropriate soil management and extensive use of fertilizers and pesticides in irrigated areas increased soil and water deterioration. A clear indicator of rainfed cultivation in an area that should actually be used for grazing is the occurrence of dust storms, which means soil degradation.

The rate of land degradation increases if the land is poorly irrigated and the carrying capacity is exceeded. The use of modern ploughs in many steppe areas was bound to lead to disaster when lengthy periods of drought began (MENSCHING, 1986: 13). In many cases traditional food production had been sidelined by modern methods to cope the increasing population food needs (photo 8). For example, rainfed farming in Algeria and Tunisia has been pushed into increasingly marginal areas since the 19th century by using European agricultural machinery in appropriate to dry land ecosystems. Dry serial cropland continues to expand into the steppe using tractors for ploughs with consequent degradation largely due to wind action (MIDDLETON and THOMAS, 1994: 70).

Photo 8: Agriculture in sandy soil in Surman in northern Jifara Plain, 17.10.2002

High pressure on lands during the colonial period had two important consequences (SWEARINGEN: 1992: 404): First, as land was expropriated, many peasants were crowded onto smaller holdings. This trend reduced the ability of many smallholders to let part of the land lie fallow and thus significantly increased the vulnerability to drought. The primary purpose of fallowing in semi-arid region is to allow soil moisture to accumulate. The second was the desolating of peasants to marginal areas characterized by poor soils, unfavorable slops, and deficient precipitation. Since the Italian colonization (1929), more than half of irrigated areas in Libya are found in Jifara Plain experiencing more intensive farming.

The agricultural projects carried out in the Plain caused devegetation and eliminated the seasonal plants which protect soils followed by soil degradation and desertification. What makes it more badly; farmers have a tendency after a period of rainy years to extend their cropping onto even more marginal lands with higher climatic risks, they push back the pastoralists, as well as the introduction of a greater number of technical methods and external inputs (NATIONAL COMMITTEE TO COMBAT DESERTIFICATION, 1999). Under conditions of low moisture, low organic matter and rapid oxidation of humus, soil structure deteriorates more rapidly, particularly under continuous annual cropping using disc and moldboard ploughs (photo 9).

Photo 9: Plough by tractors in Jifara Plain, Surman-Bear Ayad road, 17.10.2002

Under over-cultivation, the topsoil becomes denser, less aerated and less pervious to rain and plant roots, at the same time, splash erosion causes crust formation and the capping of the topsoil, sealing the surface and erosion (DE PAUW, et al., 2000: 51). The traditional technology of agriculture, though environmentally more sensitive than modern agricultural machinery which prevailed in Libya. Intensive agriculture exhausts the natural fertility of the soil. In many cases, manure or artificial fertilizers are not available.

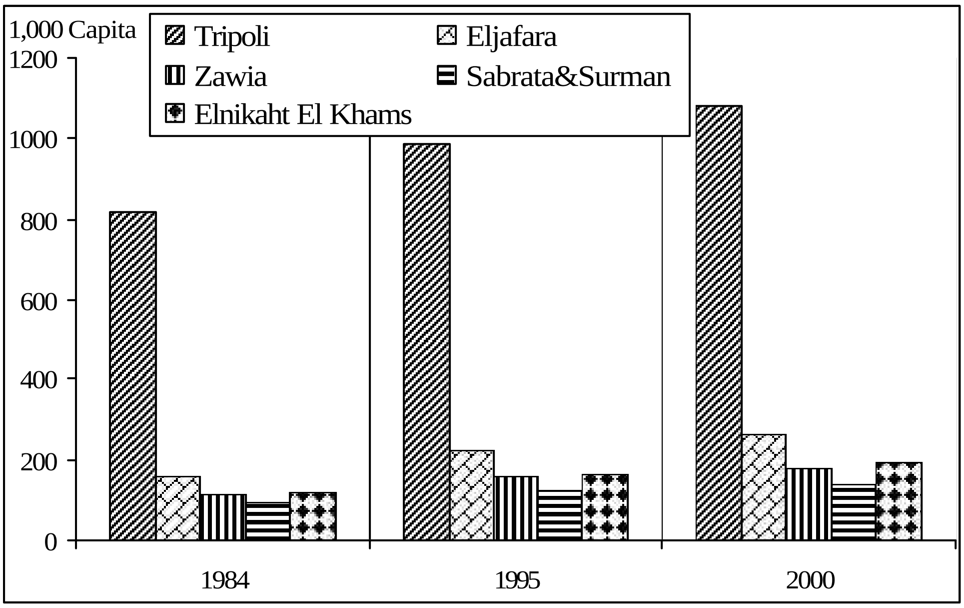
In Jifara Plain, farming and grazing are being increasingly erosive due to widening and excessive use of technical methods, for example it was on average one tractor for 885 ha in 1960, increased to one tractor for only 76 ha in 1985 (NATIONAL COMMITTEE TO COMBAT DESERTIFICATION; 1999). The availability of cheap pumps and lack of regulation of groundwater abstraction have allowed many farmers in the Plain to expand irrigation into the pastoral land to save their food needs. Removing vegetation before plough leads also to an increasing evaporation rate from the soil surface and exposes it to precipitation wash and then erosion especially in southwestern parts of Jifara Plain where sandy soil prevails and torrential precipitation can be occurred.

6.3.6 Population growth

Desertification results from a combination of man's excessive use of ecosystem that is inherently fragile or vulnerable to deterioration (KASSAS, 1987: 391). It occurs when people penetrate such environments and act there out of the need for survival, without an understanding of or proper regard for their sensitivities and limitations (PEREZ and THOMPSON, 1995). The problem of rapidly increasing population in Libya, which is more than 3 % annually, considering among the highest worldwide, pressures on the fragile and vulnerable soils translating into overexploitation of water, land and pasture resources through over-cultivation, overgrazing, deforestation and poor irrigation practices. The resulting erosion and degradation of productive lands has led to food insecurity. An increasing water demand for social, agricultural, and industrial developments has accelerated groundwater deterioration.

The increase population of Jifara Plain (Fig. 90) is a major force for settlement expansion on agricultural lands. Emigrations from the rural to the urban areas, especially in case of Tripoli city, exacerbate desertification; emigrated people prepared their land to agriculture clearing its vegetation and leaved it without adequate farmers, then it experiences to erosion and degradation. Modern societies may also threat the dry lands in many ways; they need roads and highways, constructing pipelines and canals, establishing factories, and buildings. Quarrying process in the coastal parts of Jifara Plain (Photo 10) to build new buildings for people affect the ecosystem through accelerating seawater intrusion, agriculture and animals health. This process is practiced in the coastal parts of Jifara Plain (Elzawia, Surman, Sebrata and God Adam).

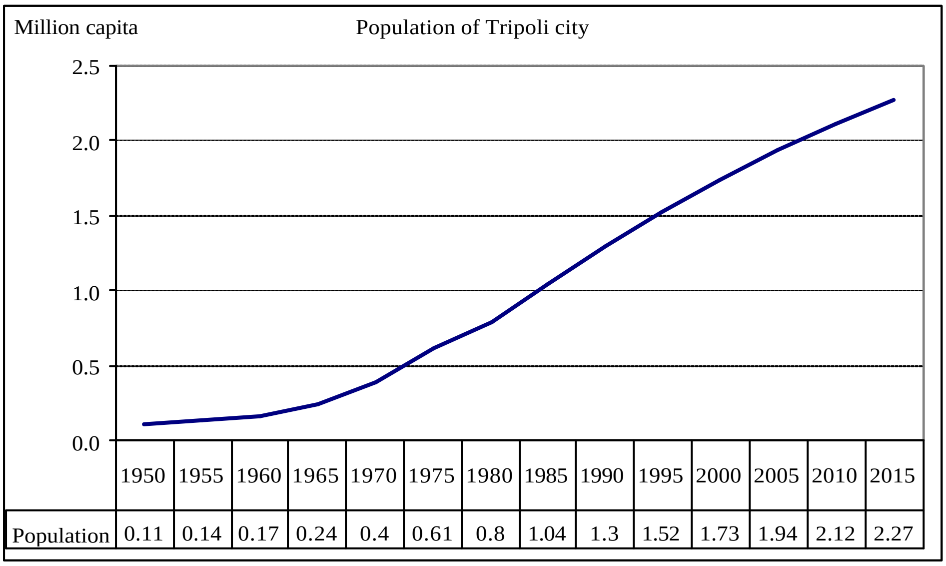
Fig. 90: Population growth in Jifara Plain, 1984-2000



Data source: NATIONAL INFORMATION AUTHORITY OF LIBYA, 2002

Photo 10: Quarrying process in the coastal strip of Jifara Plain, 17.10.2002

Fig. 91: Population growth of Tripoli city, 1950-2015 (million capita)



	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2015
Population	0.11	0.14	0.17	0.24	0.4	0.61	0.8	1.04	1.3	1.52	1.73	1.94	2.12	2.27

Data source: BRAUCH, 2004: 176

Fig. 91 expresses the increasing and prediction of Tripoli's population from 1950-2015, it can be noticed that the growth is sharp from 1960, the increasing population needs increasing food supply followed by intensification of the agriculture leading heavy, concentrated use of fertilizers and pesticides. The destruction of vegetation has always proceeded from regions under human influence in response to the need for agricultural areas, roads, watering places, firewood, etc (NASR, 1999: 27).

Growing human population in many areas has led to wholesale tree cutting in place of the collection of dead wood (MIDDLETON and THOMAS, 1994: 70), it is probably the most important domestic, principally used in households for cooking, but is also an important fuel for certain rural and small industries. The most fundamental problem is that human activities are already seriously degrading the environment as a life support system, through their key role in desertification, over-extraction of water from aquifers and pollution.

6.4 Desertification effects

Climate change might exacerbate desertification through spatial and temporal changes of temperature, precipitation, solar insolation, and wind systems. Conversely, desertification aggravates CO_2-induced climate change through releasing it from cleared and dead vegetation and through the reduction of the carbon sequestration potential of desertified land (McCARTHY, et al., 2001). Saharan dust has an important impact on climatic processes, nutrient cycles, soil formation and sediment cycles. In recent decades, the frequency of Saharan dust events has varied markedly in response to climatic factors such as drought and anthropogenic disturbance of desert marginal surfaces. Nonetheless, the Sahara's major dust sources are little affected by human activities and are in fact located in areas that receive very low precipitation totals (GOUDIE and MIDDLETON, 2001: 179).

Soil degradation impacts the global carbon cycle through its effect on landuse change and reduction in vegetation cover. There exists a strong link between soil quality, soil organic carbon content, and desertification. Further, these adverse effects of decline in soil quality are more severe in hot and dry than in cold and moist environments. Desertification leads also to decline in soil structure and reduction in aggregation, decline in soil structure leads to emission of carbon from soil to the atmosphere (LAL, 2001: 39). Groundwater resources are impacted by prolonged droughts and changes in land cover and landuse, in a complex interaction of human activity and population growth rates, climate, and environmental responses.

Desertification reduces soil fertility, particularly base caution content, organic matter content, pore space, and water-retention capacity. Desertification also reduces crop productivity, leading to long-term declines in agricultural yields, livestock yields, plant standing biomass, and plant biodiversity. These changes reduce the ability of the land to support people, often sparking an exodus of rural people to urban areas (McCARTHY, et al., 2001). Desertification has also significant implications on livestock industry and the national economy. It accelerates migration from rural to urban settlement areas as the land cannot support the original inhabitants.

7. Projections and mitigations of climate change and desertification

7.1 Outlook: climate change projections

IPCC predicted increasing global annual temperature at 1.4-5.8 °C from 1990-2100. However, this global average will widely integrate various regional responses, such as the likelihood that land areas will warm much faster than ocean temperatures (NOAA, 2004). Based on the temperature trend from 1976-2000, which is the warmest period in the last century, the global annual temperature will increase at 1.8 °C in the 21st century. On the other hand, the Atmosphere-Ocean General Circulation Model (AOGCM) experiments, applying the mean change and range of global average surface air temperature from 1961-1990, estimated change of temperature at +1.3°C upto the mid-21st century (2021-2050) ranging between +0.8 to +1.7 °C explained by greenhouse gases and sulphates (McCARTHY, et al., 2001).

Climate change scenarios for Africa, based on results from several general circulation models, indicate future warming across Africa in the 21st century ranging from 0.2 °C (low scenario) to more than 0.5 °C per decade (high scenario). Warming is greatest predicted over the interior of semi-arid margins of the Sahara and central southern Africa (HOUGHTON, et al. 2001). Results of four equilibrium experiments indicate that temperatures over the Mediterranean region, as a whole, could rise by about 3.5 °C until the latter half of the 21st century in response to a doubling of CO_2 (JACQUELINE, 2000).

As for climate change projections in Libya, in the absence of major shifts in policy, economic growth, energy prices, and consumer trends, temperature and precipitation trends over both study periods 1945-2000 and 1976-2000 give a clear indicator for increasing temperature at all station in the 21st century; only at Misurata, the long-term trend is negative. It can also be deduced that the projection of temperatures in Libya is highly based on the trends computations over the period 1976-2000. The mean annual temperature of all-Libya is computed to increase at about 1 °C from 2000-2050 based on temperature increase from 1976-2000 (Tab. 86). The projection of temperature in the 21st century in Libya is corresponding with the global temperature trend projection.

For precipitation, increasing totals are experienced at ten stations in the long-term period (1951-2000), while the remaining five stations only had decreasing precipitation (Tab. 86). In contrast to long-term projection of precipitation, the short-term projection shows decreasing of precipitation at eleven stations, while it experiences increasing values at only four stations.

Tab. 86: Projection trends upto 2050 of annual mean temperature and annual precipitation totals in Libya based on 1946-2000 and 1976-2000 trends

Station	Temperature projection (°C) in 2050 based on 1946-2000 trends	Temperature projection (°C) in 2050 based on 1976-2000 trends	Precipitation (%) projection in 2050 based on 1946-2000 trends	Precipitation (%) projection in 2050 based on 1976-2000 trends
Agedabia	1.0	2.1	35.5	16.0
Benina	0.6	0.4	0.5	-45.5
Derna	0.3	1.2	4.2	43.0
El-Kufra	1.0	3.1	-47.5	217.0
Ghadames	1.3	3.3	-7.1	-16.0
Jaghboub	0.3	1.4	121.0	102.5
Jalo	0.4	1.8	8.6	-10.5
Misurata	-0.3	4.1	5.5	-50.0
Nalut	1.0	2.2	32.0	-81.0
Sebha	1.0	1.9	-21.5	-45.0
Shahat	0.6	2.3	-13.3	-48.0
Sirt	0.5	1.7	32.7	-47.0
Tripoli airport	0.7	1.5	-8.8	-130.5
Tripoli city	1.6	3.5	17.6	-36.0
Zuara	1.2	3.9	16.1	-128.5

Data source: Libyan Meteorological Department, Tripoli

Over the next 100 years, the global mean annual temperature is expected to change between 0.5 and 1 °C because of natural causes (BAES, et al., 1981: 91), while the anthropogenic causes will be the main reason of the climate change because of increasing greenhouse gases arisen from the population growth, whereas global population will be nine billion in 2030. Consequently, the world-wide energy consumption will rapidly increase. Therefore, CO_2 concentrations, upto the year 2050, will be doubled and methane will also be increased, leading to an increase of temperature of 2 °C in the 21st century (ENDLICHER, 1997: 55).

The future growth of CO_2 concentrations in the atmosphere, which is the main gas, depends primarily on the rate of fossil fuel consumption and the manner in which the carbon cycle responds to the resulting flux of CO_2 (SKINNER, 1981: 89). Globally, by the end of the 21st century, CO_2 is expected to rise from 490 to 1260 ppm or 75-350 % above the pre-industrial concentrations (NOAA, 2004). By 2010, there will be a 34 % increase in carbon emissions from the 1990 levels, in the absence of major shifts in policy, economic growth, energy prices, and consumer trends (COUNTRYWATCH, 2000). According to U.S. Environmental Protection Agency (EPA) model, CO_2 concentrations will increase at 30-150 % by the year 2100 contributing further rise in global temperatures of about 5 degrees (ROACH, 1997).

The projection of CO_2 trend based on 1901-2000 indicates increasing global CO_2 concentrations of 1,338.2 mill. t/decade in the 21st century. For Libya, the projection based on 1950-2000, indicates increasing CO_2 concentrations of 5.685 mill. t/decade. Like CO_2, most other greenhouse gases will increase in the 21st century. For example, the trend projection of global methane based on 1901-1995 deduced an increase at 28.2 mill. t/decade in the 21st century. Even if emission rates of greenhouse gases are stabilised, temperatures would be continued to climb for several decades (JACQUELINE, 2000).

Global warming will increase the water cycle rate; change the distribution of precipitation, causing more droughts and floods as well as to increase the vulnerability to natural hazards in many countries. Precipitation is also expected to increase over the 21st century, particularly at northern mid-high latitudes, though the trends may be more variable in the tropics (NOAA, 2004).

Future changes of seasonal precipitation in Africa are less well defined. Under the lowest warming scenario, few areas will be experienced to changes in winter precipitation that may exceed two standard deviations of natural variability by 2050. The exceptions are parts of equatorial east Africa, where precipitation may increase by 5-20 % in winter and decrease by 5-10 % in summer (McCARTHY, et al., 2001).

Around much of the Mediterranean basin, sea level could rise close to 1 meter by 2100. Consequently, some low-lying coastal areas would be lost by flooding or erosion, while rivers and coastal aquifers would become more salty (JACQUELINE, 2000). Snow extent and sea-ice are also projected to decrease further in the northern hemisphere, and glaciers and ice-caps are expected to continue to retreat resulting from global warming (NOAA, 2004).

7.2 Mitigation of climate change

7.2.1 International efforts to mitigate climate change

Over the 1990s, significant progress has been made relating to national capacity building and institutional development in the field of climate change. United Nations through many of its different conventions, programs and organizations plays the main role in initiating the world concerns with climate change. In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was signed by 150 nations at the Earth Summit in Rio de Janeiro and entered into force on 21.03.1994. The main objective of the convention is the deep cut in emissions that required stabilizing the atmospheric concentrations of greenhouse gases. Therefore, all countries need to find ways to meet their development requirements, at the same time, to minimize their greenhouse gas emissions.

In Bonn, 1996, the chairman of the IPCC, BERT BOLIN, announced that reductions undertaken solely by industrialized countries will not be sufficient to limit global warming unless developing countries begin to reduce the rates at which they are increasing their use of fossil fuels as well. Developing countries argued they will not agree to new limitations until the industrialized nations have set their legally binding targets (HUGHES, 1997)

In November 1997, the parties to the UNFCCC adapted the Kyoto Protocol in which industrialized countries are committed to reduce their GHG emissions by 5 % below the base year 1990 as a first commitment to be achieved within period 2008-2012. The Kyoto Protocol is the first legally binding international agreement that places limits on emissions from industrialized countries. The major greenhouse gas emissions addressed in the Protocol include CO_2, nitrous oxide, hydro-fluorocarbons, per-fluorocarbons, sulfur hexafluoride, and methane (COUNTRYWATCH, 2000). The Protocol also established international emissions trading, joint implementation between developed countries, and a clean development mechanism to encourage joint emission reduction projects between developed and developing countries (MOHSEN, 1999).

By 1999, the International Energy Outlook projected that Eastern Europe and parts of Asia are expected to show a marked decrease in their level of energy related CO_2 emissions in 2010. Nations with the highest emissions, specifically the U.S., the EU and Japan, are anticipated to reduce their emissions by up to 8 % from 1990 levels by 2012. Many participant countries have resigned themselves to the reality that the goals of the Kyoto Protocol cannot be achieved without U.S. involvement (COUNTRYWATCH, 2000). The

United States which with 4 % of the global population is responsible for 20 to 25 percent of global GHG emissions (HUGHES, 1997) rejected the Kyoto Protocol. The latest round of international climate negotiations is known officially as the 10th Conference of the Parties to UNFCCC which took place from 6-17th December 2004 in Buenos Aires, Argentina. The Framework Convention was agreed at the Earth Summit in Rio de Janeiro, Brazil, in 1992, and it has been ratified by 189 countries (GREENPEACE, 2005).

Libya cooperated with United Nations and the international organizations to mitigate climate change. It has signed and ratified a number of international and regional agreements which effectively established a policy framework for actions to mitigate climate change such as: Montreal Protocol on substances that deplete the ozone layer, Libya has signed on 16.09.1987 and has ratified on 11.07.1990. Libya has ratified the Vienna Convention for Ozone Protection on 09.10.1990. It has signed UNFCCC on 05.06.1992, and has ratified on 14.6.1999 (GENERAL ENVIRONMENTAL AUTHORITY, 2002: 39). In December 1997, Libya was one of the representatives from 160 signatory nations to the UN Framework Convention on Climate Change while attending a meeting in Kyoto, Japan, and reached an agreement, called the Kyoto Protocol.

7.2.2 Reduction of greenhouse gas emissions

The "greenhouse effect" is the earth's trapping of infrared radiation or heat. Scientists have linked the greenhouse effect to the emission of two primary sources, or "greenhouse gases" CO_2 and CH_4 (BURNS, et al., 1997: 433). The reduction of greenhouse gas emissions is considered as the key of climate change mitigation. Several programs of GHGs reduction were carried out by many research centers and organizations. Many actions and measures were taken to encourage the utilization of more efficient, less GHGs-emitting technologies worldwide. Nations around the world have held many conferences to monitor and assist the problem. While some economic forecasters see this as an opportunity to boost economy through the implementation of new technologies, others see it costing billions of dollars through taxes and the loss of thousands of jobs at the closure of polluting industries (ROACH, 1997).

Stabilization of CO_2 concentrations require reducing the emissions at 50-70 % other gases would also have to be reduced significantly or even stopped completely if atmospheric concentrations are to be stabilized as well and the risk of climate change reduced

(JACQUELINE, 2000). UNFCCC stipulated the main objective to stabilize greenhouse gas concentrations within the atmosphere using advanced energy sources and technologies, as well as international cooperation in implementation and regulation. This stabilization process would facilitate the natural adaptation of ecosystems to face climate change effects. Greenhouse gases can also be reduced by improving energy efficiency using cleaner energy sources and technologies, efficient production and transmission of energy and promoting renewable energy in electricity generation using wind and solar energy (EEAA, 1999: 95).

Sink actions of CO_2 can also be carried to dominate the emissions through the increase of CO_2 absorption capacity because the world in the past few decades experienced the loss of world carbon sinks (mainly deforestation). This includes planting and maintaining suitable types of trees along the roads and the inner cities, as well as along the water drains. Forests and high biomass producing crops are also an important sink for carbon dioxide. For most parts of Libya, the afforestation of some 250,000 ha, two nature reserves and five national parks were established in several outstanding environmental regions, covering a substantial area of 134,000 ha (NATIONAL COMMITTEE TO COMBAT DESERTIFICATION, 1999).

7.2.3 Adaptation of climate change and sustainable development

The scopes for adapting both the rate of climate change and the uncertainty over the extent of the expected changes make adaptation difficult, particularly in many areas such as infrastructure development, where planning timescales are long in relation to the timescales of predicted climate changes (McCARTHY, et al., 2001). In parallel to adaptation and mitigation efforts, capacity building pertaining to climate change, including training, education and awareness, is a crucial pre-requisite for any serious effort in that manner. For example, clean air policies alleviate health hazards. Modern technologies and approaches in agriculture and water resources management are very crucial for climate change adaptation.

Adaptation Strategies according to IPCC Third Assessment Report, 2001 are:

Refinement of early warning systems to enable timely remedial measures; shared basin management, necessitating international agreements; water resource management; intensified monitoring to improve data reliability; intensive research into energy usage and alternate renewable energy at household and industrial levels; intensive research into design of infrastructure facilities to withstand extreme events; intensive research into flood control management technology, innovation in building designs (e.g., to minimize urban flooding), research and commencement of coastal defense facilities and others.

Researches on sustainable development play positive and effective roles in climate change mitigation. This may be achieved by exploring the optimum use of the available resources and lands through an integrated system of conservation and development measures matched to the natural and environmental conditions (NATIONAL COMMITTEE TO COMBAT DESERTIFICATION, 1999). Sustainable development strategy needs to include climate change. It is contended that, for sustainable development strategies, policies should put the welfare of people at the center of the development agenda (McCARTHY, et al., 2001).

7.3 Outlook: Desertification projections of Jifara Plain

Future population projections indicate that population in Libya will exceed 10 mill. in 2025; more than 90 % of them will live in urban areas. On the one hand, increasing population needs a rapid achievement of increasing agricultural and animal productions. On the other hand, it leads settlement expansion with loss of fertile lands. Economic and social interactions will, therefore, play an essentially valuable role in determining the overall framework for the future of agriculture and animal productions in the 21st century. In Jifara Plain, increasing population growth associated with limited natural resources (especially water resources and fertile soils) and high precipitation variabilities accelerate, without any doubt, desertification in the future.

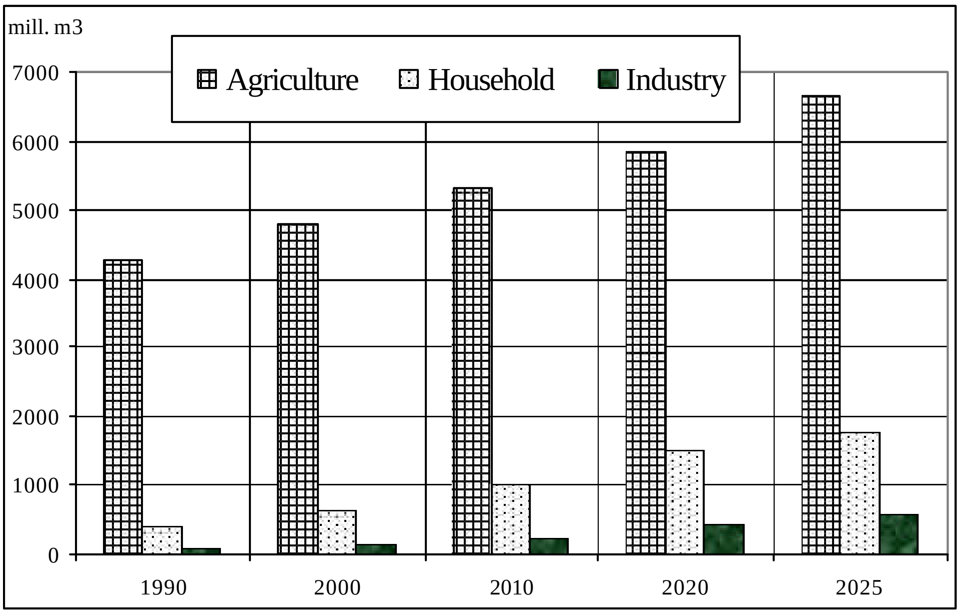
Under the increasing population, water deficit will increase in response to increasing water demands for domestic, industrial and agricultural purposes. In Libya, as a whole, water demands will increase from 5,579 mill. m^3 in 2000 to 8,965 mill. m^3 in 2025 leading to a water deficit of 4,735 mill. m^3 (NATIONAL ENVIRONMENTAL AUTHORITY, 2002: 67). Approximately half of water deficit in all-Libya will be in Jifara Plain which is inhabited by more than 50 % of total population. Water deficit of Jifara Plain in 1998 was 1,281.5 million m^3 denoting that the Plain will face water restrictions in the 21st century. So, discharges from the groundwater aquifer should be properly managed and the rate of the Sea water intrusion must also be reduced by developing new management policies for optimal use of freshwater in the aquifer.

Tab. 87: Utilities and deficit of water in Libya, 1990-2025, mill. m^3

	1990	2000	2010	2020	2025
Agriculture use	4,275	4,800	5,325	5,850	6,640
Drinking use	408	647	1,015	1,512	1,759
Industry use	74	132	236	422	566
Total needs	4,757	5,579	6,576	7,784	8,965
Available water	3,700	3,900	3,990	4,150	4,230
Water deficit	1,057	1,679	2,586	3,634	4,735

Source: GENERAL ENVIRONMENTAL AUTHORITY, 2002: 66

Fig. 92: Water demands in Libya, 1990-2025



Data source: GENERAL ENVIRONMENTAL AUTHORITY, 2002: 66

Tab. 87 and Fig. 92 show increasing water demands in Libya from 1990-2025, expressing most of water resources utilized in agriculture. It can also be seen that the available water in 2025 is less than half of water demands. In 1998, the available renewable fresh water per capita was 400 liters/day, it is decreased by population growth in 2004 to 350 liters and it is projected to be 300 liters in 2010 (SCHLIEPHAKE, 2004: 210).

Likewise water resources, most natural resources on Jifara Plain especially soils (overcultivation) and vegetation (overgrazing) will experience pressure resulting from population growth. These activities lead to devegetation and deforestation followed by soil degradation; consequently, soil is a vital, but fragile property. When vegetation is removed and precipitation occurs with high intensity as usual, the runoff water drained form Jebal Naffusah increases across the surface of the Plain causing floods and water erosion.

As a result of policies as well as the dictates of inheritance system in Libya, farmlands tend to be fragmented and too small to utilize water efficiently. This problem was especially severe in the long-settled Jifara Plain.

7.4 Desertification combat

Desertification process is varied and complex. Desertification can be combated by national and international plans and policies, sustainable development, appropriate natural resources management, application of appropriate technologies and financial supports.

7.4.1 National and international efforts

Desertification is considered one of the crucial issues of all concerned institutions at national, regional and international levels. Combat against desertification requires well-integrated national, regional and international efforts. The first global agenda on desertification, however, was developed by the United Nation Conference On Desertification (UNCOD), held in Nairobi (Kenya) in 1977. UNCOD established a plan of action to combat desertification in order to stimulate international action on the subject resulting from various factors including climate change and human activities (OGALLO, 1994: 20). A plan of action was prepared by United Nations Environment Programme (UNEP) focusing on the problems of people, emphasizing the need of urgency, and pointing out the situation deteriorates costs of rehabilitation. The problems are greatest in the poor countries at the desert margins where people rely directly on what the land can produce (GROVE, 1977: 306).

United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, in 1992, called upon the United Nations General Assembly to establish an Intergovernmental Negotiating Committee (INCD) to prepare a Convention to Combat Desertification (CCD), June 1994, in affected countries, particularly in Africa. United Nations Convention to Combat Desertification (UNCCD) was published by the Secretariat for the Convention to Combat Desertification (CCD), in Germany, 1999. The Convention was adopted and opened for signature in Paris in 1994. The convention entered into force in

1996, and some 120 countries are now Parties. The Conference of the Parties which is the Convention's supreme body, held its first session in Rome, in 1997, the second session in Dakar, in 1998, launching a global mechanism to obtain adequate financial and technological resources (NASR, 1999: 10). The Convention to Combat Desertification (which met in Senegal, December 1998) discussed, developed, and planned to fund a global action plan to combat the processes leading to desertification (REICH, et al., 2001).

The enlistment of community participation should not be thought of exclusively in terms of outside experts persuading people to do what the experts think is good for them. Local knowledge should also be enlisted. Sometimes the best procedure would be the elimination of obstacles to the good landuse practices that local people would otherwise prefer to carry out (PEREZ and THOMPSON, 1995). It can be argued that solutions for the desertification problems will ultimately rest with national decisions makers and will directly and primarily depend on national political, economic, and social conditions within those states directly affected by desertification. These socio-political factors are reinforced by other constraints of a more technical nature (GLANTZ, 1977: 11).

Libya was ranked during the 1960s and 1970s as a world pioneer in the field of desertification combat. It has signed the UNCCD on June 17, 1994 and ratified on July 22, 1996. Libya had paid significant efforts and implemented programs which can be considered under the mandate of environmental conservation in general and combating desertification in particular, e.g. in Jifara Plain, it established a settlement project named El-Majenin (8,000 ha) and treeing project in Bear Ayad in southern Jifara Plain (12,000 ha). Government of Libya established Natural Protectorates in many parts of the country (NATIONAL COMMITTEE TO COMBAT DESERTIFICATION, 2002).

7.4.2 Land management (soil conservation)

Soil erosion by wind and running water can be restricted by planting trees and grass along wadis sides. Also helpful are the construction of diversion banks and dams across the wadis and gullies. Sheet erosion which scours topsoil from wide areas can be countered with contour banks and ditches, grass-covered contour strips, and terraces. Hydrological constructions have been carried out on slopes and stream beds in Libya. Some examples are terraces, dams and water spreaders; strip cropping and contour cultivation practices have to prevent water erosion (BEN-MAHMOUD, et al., 2000).

During 1960s, Government of Libya has actively pursued an afforestation program accelerated in the 1970s. An estimated 213 million seedlings had been planted by 1977, about 33 million of them were fruit trees. Most reforestations have been done in western Libya (THE LIBRARY OF CONGRESS, 1987).

Landuse practices should also be combined with efficient marketing systems to make possibly an appropriate response to drought. It is ambiguous to use the unpredictability of drought as an excuse for inadequate planning decisions that have failed to take precipitation variability into account. Exposing the land to accelerate erosion hazard should be viewed as a managerial failure, instead of making drought a scapegoat for faulty policies (THUROW and TAYLOR, 1999: 418). Land users should also take advantage equally of wet years, employing them to replenish the ultimate agricultural resources, the fertility of the soil and the production of vegetation (PEREZ and THOMPSON, 1995).

The implementation of intensive soil conservation measures was carried out by establishing projects over an area of 192,000 hectares in the mountainous regions in northern Libya in order to combat water erosion and to stabilize sand dunes movements using oil derivatives and mechanical methods, for conversion into green belts. Water development projects were also established including steps for the utilization of surface water, in addition to the construction of thousands of reservoirs and tanks. Sixteen major dams with an estimated annual storage capacity of 300 mill. m^3 were constructed and over 100 mill. m^3 are treated annually for reuse in agriculture (NATIONAL COMMITTEE TO COMBAT DESERTIFICATION, 1999).

Government's long-term goals for the massive planting program include the growth of enough trees to meet its domestic lumber needs, which in the past had been met by imports. Short-term goals include soil conservation, reclamation, and the creation of windbreaks for crop and settlement protection (THE LIBRARY OF CONGRESS, 1987).

7.4.3 Sustainable development

There are many definitions of sustainable development, including this landmark one which first appeared in 1987: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs (THE WORLD BANK GROUP, 2001).

In order to achieve the objectives and requirements of sustainable development, it is therefore essential to provide more equal opportunities for the utilization of natural resources and food supply for the increasing population (NATIONAL COMMITTEE TO COMBAT DESERTIFICATION, 1999). Marginal lands outside these limits should be removed from cropping by acquisition, by financial inducements or by the establishment of forests, grazing or water-catchments reserves. Measures to combat desertification must ultimately be directed towards people, sustaining and improving their livelihoods. Thus, measures must be seen as having human and social dimensions. They must be inspired by an acknowledgment of dry land people's rights to acceptable standards of health, nutrition, education, livelihood and social well-being (PEREZ AND THOMPSON, 1995).

7.4.4 Scientific management of the pastoral and farming lands

Due to the harsh natural environment, arid and semi-arid climates and dominantly shallow soils on Jifara Plain, the ecosystem of the Plain is in most parts highly vulnerable to desertification. The main effects are attributed to overgrazing and overcultivation. Maintenance of vegetation that will sustain the pastoral system is the most obvious goal of landuse planning. Modern range-management practices and techniques were being used to prevent overgrazing and to make optimal use of the pastures. Thousands hectare of pastoral land had been fenced along the coastal region of Libya for use as cattle breeding stations as well as livestock-fattening pens (THE LIBRARY OF CONGRESS, 1987).

Expansion the safely cropped areas by introducing crops that are more resistant to extreme climate conditions and by improving methods of cultivation and water conservation play a critical role in the future policy and development of Jifar Plain and to combat desertification (BEN-MAHMOUD et al., 2000).

Consideration should be given to fencing rangeland areas in order to control stock movements and pastures that are particularly vulnerable. Increased meat production can be achieved without massive expansion of area grazed or size of the herds, namely by application of modern herd and animal diet management. In many situations, this would require a cultural shift from regarding livestock principally as an asset and symbol to regarding them as a production system.

Libya's efforts in the field of agriculture and animal production over the past decades can be viewed as intensive efforts to combat desertification. Allocations of over $15 billion were earmarked in 1990s for these efforts, mainly to carry out a vast series of agricultural, rural development and activities comprising the reclamation and development of some two million hectares of land and the implementation of 117 agricultural projects (NATIONAL COMMITTEE TO COMBAT DESERTIFICATION, 1999).

To combat desertification, irrigation system used must depend on quantity and quality of water resource available as well as on the characteristics of soils because these will determine drainage requirements and water availability to crops. In addition to water and soil, improved irrigation methods, mechanization, fertilization, plant protection and the selection of crops that use water more efficiently are important for facing desertification (BEN-MAHMOUD, et al., 2000).

7.4.5 Stop the movements of sands (stabilizing sand surfaces)

Sand movements can be countered by planting lines of shrubs and trees as barriers against wind. Cyanophella plant is the most important to fix sand dunes and to improve fertile soil in Libya. In 1978, Libya could fix about 52,868 ha of sand dunes (BAQI, 1991: 123). The first use of fixation with petroleum emulsion was applied in Libya in 1961; 125,000 ha have been stabilized by this method, in 1971, oil derivatives have been used to fix sand dunes (NATIONAL ENVIRONMENTAL AUTHORITY, 2002: 214). The method of sand fixation has been widely applied internationally thereafter.

Libya applied several methods to stop sand dunes encroachment as:

Sand dunes fixation by arid plants like Aristida, Pungens and Imperata cylindrical, and palm branches as obstacles against winds which bear sands

Hedges are established in a chess board pattern by setting the grass upright, buried in trenches at a depth of 15 cm.

Forest trees are then planted in the enclosures formed by hedges and fixation with synthetic rubber but this method needs large amount of water (UNEP, et al., 1996: 278). Vast expansion of rangelands and arable lands in Jifara Plain are steadily invaded by fine-grained, rust-red sand consisting entirely of quartz (BEN-MAHMOUD, et. al., 2000).

7.4.6 Water recourses management

Water development projects were also established as part of national programs and activities to combat desertification. The main objectives of water management are reduction of the water deficit and improving water quality that can be achieved through: the rainfall harvest and control of runoff by constructing more dams on wadis to store runoff waters and prevents flood hazards (BEN-MAHMOUD, et al., 2000).

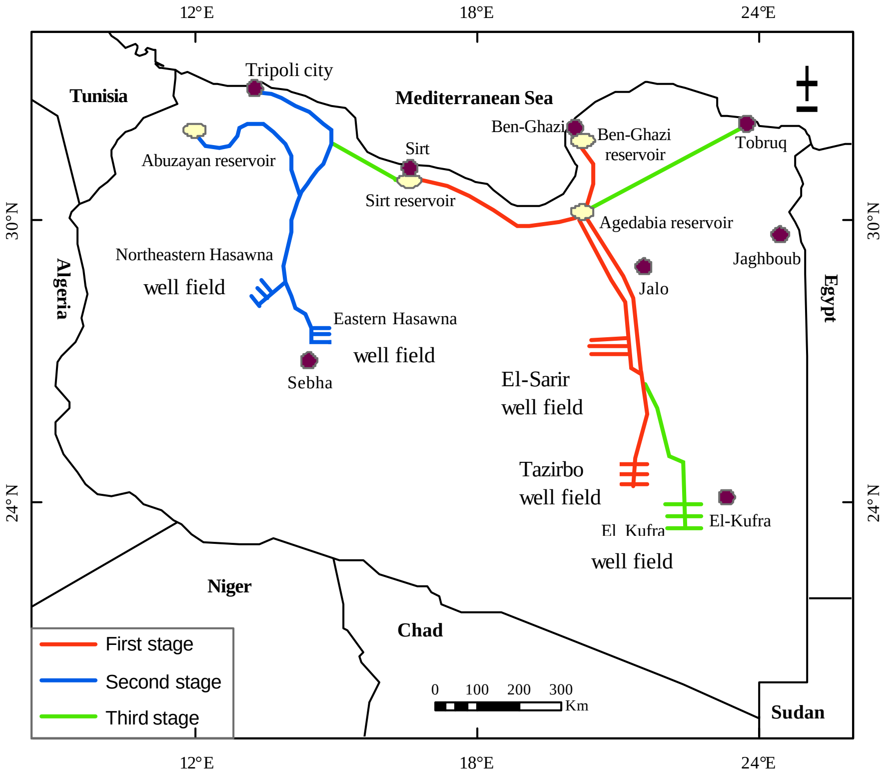
Wadis are heavily settled because their soils are often very suitable for agriculture, and the high water table in their vicinity makes them logical locations for digging wells. Libya has paid attention to this problem and has diverted water development projects, particularly around Tripoli (THE LIBRARY OF CONGRESS, 1987). Groundwater supplies must be kept in balance with the requirements of landuse to face the sea water intrusion.

Most of North Africa nations practice one or more water harvesting techniques intensively in order to collect and store rainwater for use in meeting plant demands as well as human and animal needs (NASR, 1999: 29). Also alternate sources of irrigation water are applied such as treated sewage water. Desalination will thus play an ever-increasing role in the future of Libya's development, not only to ensure the continuous supply of water to existing communities and industries in particular, but also to allow the development of new ones as well. Moreover, desalination has a special strategic role as a readily available, alternative standby source in cases of partial or total failure of the existing water sources (ABUFAYED and EL-GHUEL, 2001: 52).

7.4.7 The Great Man-Made River Project

The Great Man-Made River Project is large water development scheme (Fig. 93). It is considered the biggest project to combat desertification in Libya. Pumping large amount of groundwater in Jifara Plain has resulted in deterioration of groundwater quality and quantity. It alleviates the pressure on water resources in northern parts of Libya including Jifara Plain.

Fig. 93: The Great Man-Made River Project in Libya



Source: THE GREAT MAN-MADE RIVER WATER UTILIZATION AUTHORITY, 1996: 13

The Great Man-Made River Project which is four-meter-diameter pipes initially conveys two million m^3/day of water in its first stage to Sirt and Ben-Ghazi from well fields exploited proven reserves of high quality water at El-Sarir and Tazerbo in southeastern Libya, with a future expansion to a well field at Kufra and one million m^3/day of water from Jebal El-Hasawna well fields in southwestern Libya to Jifara Plain in the north for agricultural projects and industry purpose. This project was expected to cost $5 billion for the first two stages and has largely been spared from the cuts in development spending that have delayed many other projects in the 1980s (THE LIBRARY OF CONGRESS, 1987).

The period which is expected for The Great Man-Made River is 40 years in absence of the major shifts in water resources and population growth rate (SCHLIEPHAKE, 2004: 210).

Water from the desert wellfields (up to 5.7 milli. m^3/day) is planned to be used for municipal and industrial in the coastal cities which suffer from water scarcity, but principally at least 80 % of the Great Man-Made River water supply for agricultural purposes. Many agriculture projects in the western area depend on the Great Man-Mad River Project and its supply water (second stage; Tab. 88).

Tab. 88: Agricultural projects on the Great Man-Made River Project, second stage

Project	Irrigated area (ha)	Mill. m^3/year of irrigation water
Al- Qarabulli (agriculture)	4,175	45.0
Al-Hirah (settlement)	4,240	25.8
Al-Hay wadi (agriculture)	3,344	28.1
Bear Terfas (agriculture)	2,365	24.2
Abu-Shaibah (settlement)	1,000	6.1
Abu-Shaibah (production)	1,158	9.0
Almejinin wadi	1,800	9.5
Al-Hirah (Cows)	1,000	10.1

Source: GENERAL AUTHORITY OF THE GREAT MAN-MADE RIVER, 1996: 45

The first of the three planned phases in the construction of The Great Man-Made River was completed in 1991; Ben-Ghazi and Sirt were supplied with water. The second phase was completed in 1996 when water pipelines reached Tripoli city. The third phase is carried out due to the financial possibilities and the needs of water; the first part (El-Kufra-El-Sarir) will be operated in 2010, the second part (the first and the second phases were linked in 2000), all phases will be completed in 2015 (SCHLIEPHAKE, 2004: 212).

7.4.8 Enacting legislative acts to combat desertification

Libya has implemented several laws and legislative acts, with a number of ancillary and supplementary rules to regulate, to protect agriculture and rangelands, and to restrict urban development at the expense of agriculture lands, and to restrict the deterioration of water resources as well as to serve as an appropriate framework for the efforts made to combat desertification and achieve the objectives and requirements of sustainable development. The promulgation of such laws, legislative enactments, regulations and controls will, however, be insufficient in itself, as it is also crucial to supervise their implementation, monitoring and follow-up. The various inspection, protection and monitoring agencies require guidance concerning the significance and size of the different effects of desertification and its causes, as well as the potential role which they can play in alleviating the severe limitations and the ensuing pressures. Predictions of occasional spells of drought and shortages of natural resources in the affected areas are therefore required (NATIONAL COMMITTEE TO COMBAT DESERTIFICATION, 2002).

The followings are some of the laws and legislative acts to conserve natural resources and to combat desertification in Libya: governmental decisions no. 33 in 1970 and no. 46

in 1975 in order to protect agriculture lands from settlement expansion; law no. 5 in 1982 to protect pastoral and forests lands, modified by law no. 14 in 1992, and law no. 7 in 1982 for protection of the environment; law no. 3 in 1982 for controlling and limiting the over-exploitation of water resource use; law no. 15 in 1992 to protect vegetation which stabilizes sand dunes; and law no. 277 in 1997 to create the national committee to combat desertification (GENERAL ENVIRONMENTAL AUTHORITY, 2002).

7.4.9 Popular administration and participation

Popular awareness of desertification process and protection of natural resources (water and soil) endure as a major strategic to achieve the objectives and requirements of sustainable development. Action to combat desertification will largely be carried out by national organizations. In 1971, the national activities in Libya began after implementing the law no. 111 in 1970 (NATIONAL COMMITTEE TO COMBAT DESERTIFICATION, 2002).

In 1999, there were 102 national societies and institutions for environmental protection (GENERAL ENVIRONMENTAL AUTHORITY, 2002: 212). Natural resources management can successfully generate the positive and active participation of the inhabitants concerned, which begins with a sound diagnosis, continues through the stage of formulating and implementing the measures and arrangements needed to reduce the serious obstacles and pressures of which the fundamental elements of resources and land in general are exposed, and ends with appropriate development and investment activities (NATIONAL COMMITTEE TO COMBAT DESERTIFICATION, 1999).

8. Results and Recommendations

8.1 Results

The present study has revealed a number of results; the following are considered the main:

(1) Libya occupies a part of northern Africa between 20° to 34° N and 10° to 25° E.

(2) Libya's total population was at 5.3 million in 2001 including more than 500,000 non-nationals, almost 90 % of them living in the coastal region, and about 10 % live widely scattered oases in mid- and southern Libya.

(3) Lands of Libya are generally divided into northern coastal plain and high lands, isolated mountains and depressions in the south. Serir desert in the east, El-Hamada El-Hamra desert in the west are the most obvious geomorphological features in Libya.

(4) Climate of Libya is determined by contrasting Mediterranean and Sahara climates. More than 95 % is desert. Mean annual temperatures decrease gradually northward, in contrast to precipitation which decreases southward. Winter is the rainiest season 50-70 % followed by autumn and spring, while no or negligible precipitation occurs in summer. Climatic regions in Libya are: Arid desert climate (BWh) in mid- and southern Libya, Steppe climate (BSh) in northern Libya, and Mediterranean climate type (CSa) in northeastern Libya on Jebal El-Akhdar.

(5) Groundwater is the main water resource in Libya; it supplies about 88 % of the water needs. The Great Man-Made River Project is a massive project with four-meters-diameter pipes and a length of about 4000 km aiming to divert the groundwater from the southern basins to the coastal areas where about 90 % of Libya's population has settled.

(6) Climate change is every deviation from the normal having significance according to the actual use of statistical tests, while the term trend denotes climate change characterized by a smooth, monotonic increase or decrease of average values over the period of record.

(7) It is clearly identified that the 20th century was the warmest century during the past 1,000 years. Trend of the global mean annual temperature was 0.07 °C/decade. Warming pronouncedly occurred over two periods, 1910-1945 (0.14 °C/decade) and 1976-2000 (0.17 °C/decade). The bulk of global warming occurred in summer and autumn

from 1910-1946, while winter and spring were the governing seasons of global warming from 1976-2000. Minimum temperatures increased at nearly twice the rate of maximum temperatures.

(8) Global land precipitation has increased by about 2 % since the beginning of the 20th century. Though the increase is statistically significant, it is neither spatially nor temporally uniform. It was relatively stable, or slightly increased from 1900 to the early 1940s, then increased sharply from the mid-1940s to the mid-1950s and has remained relatively high over most of the land areas except the tropics, where precipitation decreased to below the 1900–1988 average in the 1970s and 1980s.

(9) Trends of mean annual temperature over Libya were positive at all study stations from 1946-2000 except at one, negative trends prevailed at most stations from 1946-1975, while strongly positive trends were computed at all study stations from 1976-2000 corresponding with the global warming trend. Positive trends of mean minimum temperatures were observed at all reference stations over the periods 1946-2000 and 1976-2000, while negative trends prevailed at most stations from 1946-1975. For mean maximum temperature, positive trends were computed from 1946-2000 and from 1976-2000 at most stations, while most trends were negative from 1946-1975. Minimum temperatures increased at nearly more than twice the rate of maximum temperatures at most study stations. Negative trends of mean temperature range were computed at most stations over both periods 1946-2000 and 1976-2000.

(10) Positive trends of extreme minimum temperatures were deduced at all reference stations from 1946-2000. In contrast, the trends of extreme maximum temperature were negative or weakly positive at most stations in the same period. Trends of mean extreme minimum temperature expressed a striking warming from 1976-2000 at all stations, while positive trends of extreme maximum temperature prevailed at only eight stations.

(11) For seasonal temperature trends over Libya, warming mostly occurred in summer and autumn in contrast to the global observations identifying warming mostly in winter and spring in both periods 1946-2000 and 1976-2000.

(12) The 1990s were the warmest decade over global and Libya, the 1998 was the warmest year over global, while 1999 was the warmest yeas over Libya in the 20th century.

(13) Most study stations are located in northern Libya and little information was available for southern parts which must be taken into account to investigate the spatial changes of temperature over Libya. Remarkably large spatial variations of temperature changes were observed from north to south over Libya.

(14) Positive trends of annual precipitation totals were observed from 1946-2000, while negative trends were computed at most stations from 1976-2000. Positive trends of annual precipitation intensity were elaborated in the long-observation period (1946-2000), while negative trends prevailed in the short-observation period (1976-2000) at most stations. Trends of winter and spring precipitation showed positive trends, while and trends of autumn precipitation were negative at most stations from 1946-2000. Remarkably large variations were seen among the different seasons over the period 1976 to 2000.

(15) Remarkable variations were observed in distribution of annual precipitation total changes over Libya. From 1946-2000, precipitation increased over northern Libya, while it decreased over southern Libya. From 1976-2000, the trends of annual precipitation total were negative over most Libya indicating decreasing precipitation at most stations.

(16) Negative trends prevailed for mean annual relative humidity at eight stations, while positive trends were shown at seven stations from 1946-2000. For the short observation period 1976-2000, positive trends were computed at most stations.

(17) Annual cloud amount totals decreased at most study stations over both periods 1946-2000 and 1976-2000.

(18) For all-Libya from 1951-2000, positive trends were identified for annual, minimum, autumn, summer, winter, maximum, and spring temperatures, while negative trends of extreme maximum temperature and mean annual temperature range were computed. From 1951-1975, decreasing trends were identified for mean annual, summer, minimum, autumn and maximum temperatures, while increasing trends were observed for winter and spring temperatures. From 1976-2000, strongly positive trends were observed for annual, minimum, summer and autumn temperatures, and positive trends were computed for winter, maximum and spring temperatures.

(19) From 1951-2000, weakly positive trends of 0.03, 0.03, 0.06 and 0.07 mm/decade prevailed for annual precipitation total over all-Libya, annual precipitation intensity, winter precipitation and spring precipitation, respectively. No trend was seen for autumn precipitation. Trend of annual precipitation over all-Libya was negative of -0.20 mm/decade. From 1976-2000, positive trend occur for winter precipitation at 0.17 mm/decade, while negative trends were computed for annual total, annual intensity, spring and autumn precipitation.

(20) A positive trend was identified for the annual mean relative humidity over all-Libya from 1951-2000, a positive trend was computed from 1976-2000, while a negative trend was seen from 1951-1975.

(21) Annual cloud amount totals decreased over all-Libya in both periods 1951-2000 and 1976-2000.

(22) Natural climate forcing probably increased during the first half of the 20th century, while since 1951, the changes observed are mostly due to human activities, and some changes are also reflection are natural variability.

(23) Correlation coefficient was significantly positive (0.27) between global annual temperature and sunspots number in the 20th century. The effect of sunspots number on temperature change was higher over the first half of the 20th century (1901-1950) than over the second one (1951-2000).

(24) There was no correlation between sunspots number and mean annual temperatures over Libya during the study period 1946-2000.

(25) The Pinatubo eruption was primarily responsible for the 0.8 °C drop in global average air temperature in 1992. Mean annual temperature in Libya is affected by the eruption of Mount Pinatubo (15°N-121°E) on 12 June 1991, the years 1992 and 1993 were the coldest in the 1990s.

(26) High variability of precipitation can partly be explained by changes in atmospheric circulation, which in turn alter the storm tracks and precipitation distribution.

(27) Correlation coefficient between North Atlantic Oscillation and global mean annual temperature was weakly positive (0.12) over the 20th century.

(28) Reversed relationship was seen between NAO index and temperatures in Libya.

(29) The relationship between NAO index and annual precipitation totals in Libya are positive in winter. The effect of NAO decreases eastward.

(30) El-Nino phenomenon is now widely recognized as the recurring cause of major natural perturbations to the climate system.

(31) There was no correlation between Southern Oscillation Index (SOI) and climate change over Libya (temperature and precipitation).

(32) Anthropogenic causes of climate change have increased significantly from the 19th century and have largely increased over the 20th century.

(33) A strong relationship between CO_2 concentrations and global warming was observed in the 20th century, correlation coefficient was significantly positive at 0.78. Correlation coefficient between methane and global mean annual temperature from 1901-1994 was positive and significant (0.75).

(34) Total concentration of CO_2 has increased in Libya from 1950-2000. The largest contributor to CO_2 emissions is fossil fuel consumption. Correlation coefficient between CO_2 and temperature trends in Libya was significantly positive.

(35) Patterns of landuse and urban heat islands can play a small role of climate change in settlement centers located in northern Libya.

(36) Libya is vulnerable to climate change because of prevailing arid and semi-arid climates, recurrent droughts, and inequitable land distribution. High precipitation variabilities and intensities may cause severe moisture stress on cultivated crops.

(37) Increasing temperature derives also soil erosion and wind speed, which in turn increase amount of Saharan dust causing health and economic problems. Gibli wind has drastically effects on Libya.

(38) Crop productions and food security, water resources, human health, population settlement and biodiversity can be affected by climate change over Libya. But the effects depend on its magnitude and the rate with which climate change occurs.

(39) As high precipitation variabilities, wheat and barely crops in Libya experience to greatly changes from year to year in their productions and harvest areas.

(40) Climate change may increase the vulnerability of livestock due to shortage of water resources, increased salinity, and loss of grazing sites.

(41) Changing temperature and precipitation regimes cause change in the water budget. As a result, irrigation and flood control system, water storage, and hydroelectric installations as well as for a production systems are seriously affected.

(42) Sandstorms over northwestern Libya dating 29.03.2002 for 12 hours with a speed of 70 km/hour affected human health through charging the air with 387 microgram/m^3 pollutions, the safe level according to WHO is 120 micrigram/m^3/day.

(43) In Libya, population and urbanization increased sharply in the second have of the 20th century, it generated impacts on natural resources and the environment (water resources and soils) which are very vulnerable to climate change.

(44) Loss of biodiversity is a consequence of climate change at the local and global level, recurrent drought might decrease the ability of trees to resist pests, several kinds of animals and plants disappeared.

(45) Among the important consequences resulting from climate change in arid and semi-arid lands, ranks desertification which is diminution or destruction of the biological potential of land, and can lead ultimately to desert-like conditions.

(46) Jifara Plain, located in northwestern Libya, has experienced to desertification, soil was degraded, vegetation cover disappeared and groundwater wells were getting dry in many areas.

(47) Soil degradation is the main aspect of desertification in Jifara Plain; the most dominant soil-degradation process is wind and water erosion.

(48) Vegetation destruction takes place in Jifara Plain through overgrazing and over-cultivation, both activities being driven by the needs of growing population.

(49) The scarcity of water was aggravated by water level declines and deterioration of water quality. Water level declined over 1 m/year in some parts and total dissolved solids increased exceeding 9,000 mg/liter in the last four decades in Jifara Plain. Water deficit in Jifara Plain was six times from groundwater safe use.

(50) In northwestern Libya, 33,500 ha have been affected by sand dunes movements. In northern Jifara Plain (758,026.2 ha), the area which covered by sands has increased from 430,154.6 ha in 1989 to 450,636.3 ha in 2001.

(51) Over 25 % of highly fertile lands have been consumed by the expansion of urban areas in Libya. The belt-up area of Tripoli increased from 8,011.4 ha in 1966 to 19,236 ha in 2000.

(52) Desertification of Jifara Plain was caused by: climate change which can accelerate desertification process through precipitation patterns and Gibli wind; landforms in Jifara Plain accelerate soil erosion followed by desertification; overgrazing and over-cultivation are being increasingly eroded due to the widening and excessive use of technical methods; Increasing of population alters the consumption patterns against the limited natural resources.

(53) The effect of desertification on Jifara Plain appears through reducing soil fertility and crops productivity, leading to long-term declines in agricultural yields, livestock yields, plant standing biomass, and plant biodiversity. It has also significant implications on livestock industry and the national economy. It accelerates migration from rural to urban settlement areas as the land cannot support the original inhabitants.

(54) In the absence of major shifts in policy, economic growth, energy prices, and consumer trends, global warming is expected to continue. The mean annual temperature of all-Libya will be increased about 1 °C from 2000-2050 based on the projection of trend from 1976-2000 corresponding with the global temperature trend projection. Precipitation at 10 stations represented a decrease based on 1976-2000 period, while two stations only declared increasing of precipitation in the first half of 21st century.

(55) Water deficit will be increased in response to the increasing of water demands for domestic, industrial and agricultural purposes. In Libya, as a whole, water demands will be increased from 5,579 mill. m^3 in 2000 to 8,965 mill. m^3 in 2025 followed by water deficit of 4,735 mill. $m^{3.}$ Approximately half of the deficit water in all Libya will be in Jifara Plain which is inhabited by more than 50 % of Libya’s total population.

(56) Libya cooperates with the United Nations and international organizations. It has signed and ratified a number of international and regional agreements which effectively established a policy framework for actions to mitigate climate change and combat desertification. Libya has implemented several laws and legislative acts, with a number of ancillary and supplementary rules to regulate.

(57) In Libya, two nature reserves and five national parks were established in several outstanding environmental regions, covering a substantial area of 134,000 hectares. Libya in interested in establishing of the Natural Protectorates in many parts of Jifara plain.

(58) Libya was ranked during the 1960s and 1970s as a world pioneer in the field of desertification combat. The first use of fixation with petroleum emulsion was in Libya 1961. 125,000 ha have been stabilized by this method, in 1971 oil derivatives has been used to fix sand dunes named internationally the Libyan method.

(59) Water development projects were also established including steps for the utilization of surface water; in addition to the construction of thousands of reservoirs and tanks. Sixteen major dams with an estimated annual storage capacity of 300 mill. m^3 were constructed and over 100 mill/m^3 are treated annually for agricultural purposes. The Great Man-Made River project alleviates the pressure on water resources in northern parts of Libya such as Jifara Plain.

8.2 Recommendations

Despite the current efforts and ongoing projects being undertaken in Libya in the field of climate change and desertification, urgent actions are needed to mitigate climate change and combat desertification in the future.

(1) Mitigation of climate change and desertification combat require well-integrated national, regional and international efforts. Developing countries need international support in these fields and substantial reductions of greenhouse gases in developed countries and adaptation strategies are crucial.

(2) Greenhouse gases can be reduced by improving energy efficiency using cleaner energy sources and technologies and promoting renewable energy in electricity generation using wind and solar energies.

(3) Sink actions of CO_2 can also be carried out through the increase of CO_2 absorption capacity including planting and maintaining suitable types of trees in city center and along the roads, as well as along the water drains. In addition planting forests using treated sewage water for their irrigation, which have high biomass as are also an important sink for carbon dioxide.

(4) The present number of meteorological stations in Libya is inadequate and must be improved and intensified especially in the southern parts of the country.

(5) Research projects of climate change and desertification and development strategies in Libya must be set up as soon as possible.

(6) Gathering all the institutions which work in climate change and desertification issues in order to avoid the quarrel in decisions. Supporting the scientific institutions and institutes in order to increase the role of researches, education, and training. Monitoring, analyzing and forecasting variation is of prime importance to climatologists as well as policy and decision makers.

(7) Adaptation could be impeded in many areas by anticipated rate of climate change, limited access to technical expertise and wider social and economic circumstances and policies. Impacts of climate change could seriously undermine efforts for reorientation the society towards sustainable development.

(8) Sustainable development strategies must include expected climate change. Subsequently, national environmental action plans and implementation must incorporate long-term changes and should put the welfare of people at the center of the development agenda. More cooperation between people and government is crucial to implement polices.

(9) Improving and well management of natural resources, especially soil and water, success will be achieved by the means of an effective and decisive management taking into account the social and economic circumstances of the inhabitants. Measures to combat desertification must ultimately be directed toward people, sustaining and improving their livelihoods.

(10) Expansion of safely cropped areas by introducing crops which are more resistant to extreme conditions and by improving methods of cultivation and water conservation. Priority has to given to the quality of agriculture productions which has to be improved, instead of cultivating more marginal lands. Modern technologies and approaches in agriculture and water resources management are very important to meet increasing demands and to alleviate the effects of climate change and desertification.

(11) Discharges from the groundwater aquifer in Jifara Plain should be properly managed and the rate of the sea water intrusion could also be reduced by investigation and new

management policies for optimal use of the freshwater in the aquifer. Improved irrigation methods, mechanization, fertilization, plant protection and the selection of crops that use water more efficiently are important for facing desertification.

(12) Conservation of animal and plant varieties will be a series issue, as some nature reserves and national parks become increasingly inappropriate from climate for the species they were meant to protect.

(13) Popular awareness of climate change and desertification is crucial to achieve the objectives and requirements of sustainable development. Citizens should be aware about the importance of natural resources and not be excusive in using them. Local knowledge should also be enlisted.

(14) The availability of information base is very important for putting policies and action plans to mitigate climate change and combat desertification.

Summary

The study was arranged to manifest its objectives through preceding it with an introduction. Particular attention was paid in the second part to detect the physical settings of the study area, together with an attempt to show the climatic characteristics in Libya. In the third part, observed temporal and spatial climate change in Libya was investigated through the trends of temperature, precipitation, relative humidity and cloud amount over the periods (1946-2000), (1946-1975), and (1976-2000), comparing the results with the global scales. The forth part detected the natural and human causes of climate change concentrating on the greenhouse effect. The potential impacts of climate change on Libya were examined in the fifth chapter. As a case study, desertification of Jifara Plain was studied in the sixth part. In the seventh chapter, projections and mitigations of climate change and desertification were discussed. Ultimately, the main results and recommendations of the study were summarized.

In order to carry through the objectives outlined above, the following methods and approaches were used: a simple linear regression analysis was computed to detect the trends of climatic parameters over time; a trend test based on a trend-to-noise-ratio was applied for detecting linear or non-linear trends; the non-parametric Mann-Kendall test for trend was used to reveal the behavior of the trends and their significance; PCA was applied to construct the all-Libya climatic parameters trends; aridity index after Walter-Lieth was shown for computing humid respectively arid months in Libya; correlation coefficient, (after Pearson) for detecting the teleconnection between sun spot numbers, NAOI, SOI, GHGs, and global warming, climate changes in Libya; aridity index, after De Martonne, to elaborate the trends of aridity in Jifara Plain; Geographical Information System and Remote Sensing techniques were applied to clarify the illustrations and to monitor desertification of Jifara Plain using the available satellite images MSS, TM, ETM+ and Shuttle Radar Topography Mission (SRTM). The results are explained by 88 tables, 96 figures and 10 photos.

Temporal and spatial temperature changes in Libya indicated remarkably different annual and seasonal trends over the long observation period 1946-2000 and the short observation periods 1946-1975 and 1976-2000. Trends of mean annual temperature were positive at all study stations except at one from 1946-2000, negative trends prevailed at most stations from 1946-1975, while strongly positive trends were computed at all study stations

from 1976-2000 corresponding with the global warming trend. Positive trends of mean minimum temperatures were observed at all reference stations from 1946-2000 and 1976-2000, while negative trends prevailed at most stations over the period 1946-1975. For mean maximum temperature, positive trends were shown from 1946-2000 and from 1976-2000 at most stations, while most trends were negative from 1946-1975. Minimum temperatures increased at nearly more than twice the rate of maximum temperatures at most stations. In respect of seasonal temperature, warming mostly occurred in summer and autumn in contrast to the global observations identifying warming mostly in winter and spring in both study periods.

Precipitation across Libya is characterized by scanty and sporadically totals, as well as high intensities and very high spatial and temporal variabilities. From 1946-2000, large inter-annual and intra-annual variabilities were observed. Positive trends of annual precipitation totals have been observed from 1946-2000, negative trends from 1976-2000 at most stations. Variabilities of seasonal precipitation over Libya are more strikingly experienced from 1976-2000 than from 1951-1975 indicating a growing magnitude of climate change in more recent times.

Negative trends of mean annual relative humidity were computed at eight stations, while positive trends prevailed at seven stations from 1946-2000. For the short observation period 1976-2000, positive trends were computed at most stations. Annual cloud amount totals decreased at most study stations in Libya over both long and short periods. Remarkably large spatial variations of climate changes were observed from north to south over Libya.

Causes of climate change were discussed showing high correlation between temperature increasing over Libya and CO_2 emissions; weakly positive correlation between precipitation and North Atlantic Oscillation index; negative correlation between temperature and sunspot numbers; negative correlation between precipitation over Libya and Southern Oscillation Index. The years 1992 and 1993 were shown as the coldest in the 1990s resulting from the eruption of Mount Pinatubo, 1991.

Libya is affected by climate change in many ways, in particular, crop production and food security, water resources, human health, population settlement and biodiversity. But the effects of climate change depend on its magnitude and the rate with which it occurs.

Jifara Plain, located in northwestern Libya, has been seriously exposed to desertification as a result of climate change, landforms, overgrazing, over-cultivation and population growth. Soils have been degraded, vegetation cover disappeared and the groundwater wells were getting dry in many parts. The effect of desertification on Jifara Plain appears through reducing soil fertility and crop productivity, leading to long-term declines in agricultural yields, livestock yields, plant standing biomass, and plant biodiversity. Desertification has also significant implications on livestock industry and the national economy. Desertification accelerates migration from rural and nomadic areas to urban areas as the land cannot support the original inhabitants.

In the absence of major shifts in policy, economic growth, energy prices, and consumer trends, climate change in Libya and desertification of Jifara Plain are expected to continue in the future.

Libya cooperated with United Nations and other international organizations. It has signed and ratified a number of international and regional agreements which effectively established a policy framework for actions to mitigate climate change and combat desertification. Libya has implemented several laws and legislative acts, with a number of ancillary and supplementary rules to regulate. Despite the current efforts and ongoing projects being undertaken in Libya in the field of climate change and desertification, urgent actions and projects are needed to mitigate climate change and combat desertification in the near future.

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