

12927



Distr.: LIMITED

ECA/TNG/SRDC/ICE/XVI/7  
March 2001

Original: ENGLISH

**UNITED NATIONS  
ECONOMIC COMMISSION FOR AFRICA**

---

**Subregional Development Centre for North Africa (SRDC)**

Sixteenth Meeting of the Intergovernmental  
Committee of Experts of SRDC

Tangier, Morocco  
13-16 March 2001

**BEST PRACTICES FOR DROUGHT PREPAREDNESS  
AND MITIGATION AND WATER MANAGEMENT FOR  
INCREASED FOOD SECURITY IN NORTH AFRICA**

Document Prepared

By

**Mr. Siddig E. Ahmed, Consultant**

Deputy Director, Hydraulic Research Station  
Wad Medani, Sudan

*The views expressed in this document are those of the author and do not necessarily reflect those of the United Nations Economic Commission for Africa/ SRDC-NA.*

## TABLE OF CONTENTS

<b>Executive Summary</b>	1
<b>PART 1.</b>	
<b>Identification and Analysis of practices to combat drought in North Africa</b>	
<b>Chapter 1: Introduction</b>	3
1-1 Physical Features & Population	3
1-2 Climate	3
1-3 Agriculture and Land Use	3
1-4 Water Resources, and Water Withdrawals of North- Africa Sub-Region	4
1-4-1 Renewable Water Resources	4
1-4-2 Non-Renewable Groundwater	4
1-4-3 Non-Conventional Water Resources	5
1-4-4 Water Withdrawals	5
<b>Chapter 2: Characteristics of Drought in North Africa Sub-Region</b>	6
2-1 Rainfall in North Africa Sub-Region	6
2-2 Drought Characteristics and Impact on the Sub-Region	6
<b>Chapter 3: Practices to Prevent &amp; Combat Drought</b>	8
3-1 General	8
3-2 Water Harvesting	8
3-2-1 Contour Furrows	8
3-2-2 Microcatchment Water Harvesting	8
3-2-3 Bench Terraces	9
3-2-4 Water Spread embankments	9
3-2-5 Rainwater and Flood Harvesting	9
3-2-6 Hafirs	10
<b>Design Criteria</b>	10
3-3 Supplementary Irrigation in Rain-fed Area	11
3-4 Reforestation	12
3-5 Crop management Factors	12

3-6	Water Supply Management .....	13
3-7	Expansion of the Irrigated Areas .....	13
3-8	Improve the Productivity of Water Use .....	14
3-9	Using Saline Water for Irrigation .....	14
3-10	Strategies to Prevent & Mitigated he effects of Drought .....	15

## **PART II.**

### **Reutilization of Wastewater in North Africa: the present and future situation.**

<b>Chapter 1: Characteristics and Treatment Processes of wastewater .....</b>	<b>16</b>
1-1 Characteristics of Wastewater .....	16
1-1-1 Physical Characteristics .....	16
1-1-2 Chemical Characteristics .....	16
1-1-3 Biological Characteristics .....	18
1-2 Waste Water Treatment Processes .....	17
1-2-1 Pre-and Primary Treatment .....	18
1-2-2 Secondary Treatment .....	18
1-2-3 Tertiary Treatment .....	18
1-2-4 Physical –Chemical Treatment .....	19
1-2-5 Sludge Disposal .....	19
1-3 Nutritional Value of Wastewater and Quality Guideline of Wastewater Use in Agriculture.....	20
1-3-1 Advantages of Using wastewater .....	20
1-3-2 Nutrients .....	20
1-4 Appropriate Wastewater Treatment and Application Systems for Agriculture ..	21
1-4-1 Wastewater Treatment System .....	21
1-4-1-1 Conventional Primary and Secondary Treatments .....	21
1-4-1-2 Wastewater Stabilization Ponds .....	21
1-4-1-3 Disinfection .....	22
1-4-1-4 Storage Reservoirs .....	22
1-4-1-5 Tertiary Treatment .....	22
1-4-1-6 Sludge Treatment .....	23
1-4-2 Wastewater Application in Agriculture .....	23
1-4-2-1 Crop Selection .....	23
1-4-2-2 Wastewater Application .....	24
1-4-2-3 Human Exposure Control .....	24

<b>Chapter 2 : Present Situation For Wastewater Production and Re-Utilization in North Africa Sub-Region .....</b>	<b>26</b>
2-1 General .....	26
2-2 Current Situation of Wastewater in Countries of the Sub-Region .....	26
2-2-1 Algeria .....	26
2-2-2 Egypt .....	27
2-2-3 Libya .....	27
2-2-4 Mauritania .....	28
2-2-5 Morocco .....	28
2-2-6 Sudan .....	28
2-2-7 Tunisia .....	29
2-3 Re-use Wastewater in NASR for Agricultural Production .....	29
2-4 The Existing Treatment Processes Used in North Arica Sub-Region .....	32
<b>Chapter 3: Water Pollution .....</b>	<b>35</b>
3.1 Sources of Pollution .....	35
3.2 Situation of Water Pollution on the Sub-region .....	35
3-2-1 Algeria .....	36
3-2-2 Egypt .....	36
3-2-3 Libya .....	37
3-2-4 Mauritania .....	37
3-2-5 Morocco .....	37
3-2-6 Sudan .....	38
3-2-7 Tunisia .....	38
<b>Chapter 4 : Main Constraints to Re-Utilization of Recycled wastewater for Agriculture .....</b>	<b>40</b>
4-1 Environmental Constraints .....	40
4-1-1 Soil Hazards .....	40
4-1-2 Pollution of Groundwater .....	40
4-1-3 Eutrophication and Growth of Algae on Surface Water .....	40
4-1-4 Effects on Crops, Phytotoxicity Problem and Management .....	40
4-1-5 Human and Animal Health Problems .....	40
4-2 Social Constraints .....	40
4-3 Regulatory and Legal Constraints .....	41
4-4 Technical and Economic Constraints .....	41
4-5 Institutional Constraints .....	41

## **Chapter 5: Sub-Regional Plan of Action to Enhance the Use of recycled Waste Water for Irrigation ..... 42**

5-1	Objectives .....	42
5-2	The Action Plan .....	42
5-2-1	Preparation of Countries' Studies on Wastewater Potential and Reuse ...	42
5-2-2	Organization of a Sub-Regional Workshop on Wastewater Treatment ... and Reuse, Future Opportunities .....	43
5-2-3	Capacity Building in Integrated Water Resources Management .....	44
5-2-4	Community Participation .....	44

## **Chapter 6: Conclusions ..... 45**

### **ANNEXES**

<u>Sewerage system in Khartoum</u> .....	1
- A1: Khartoum Sewerage Network 000000000000..000..00	6
- A2: Soba Sewage Treatment Plant, General Plan 0000..000000..00	7
- A3: Soba Sewage Treatment Plant, Hydraulic Profile 00000000..000	8

#### **Part – I**

- No Figure

#### **Part – II**

- 1.1: Common Processes of Wastewater Treatments 00000000...000	9
- 1.2: Typical Flowsheet of an Activated Sludge Treatment Plant 0000000	10
- 1.3: Typical Flowsheet for Physical-Chemical Treatment 0000000.00..	11
- 1.4: Typical Flowsheet for Waste Sludge Disposal 00000000.0000..	12
- 2.1: Schematic Diagram for Wastewater Treatment 0000000000..000	13
- 2.2: Schematic Diagram of Wastewater Treatment in Garian City (Libya) o.	14

### List of Tables .....

#### **Part – I**

- Table 1.1: Total & Rural Population and Area of North Africa Sub-Region (1995-1998) .....	15
- Table 1.2: Total Cultivated Area and Total Agricultural Labor Force.....	16
- Table 1.3: Land Use (1998) (Area 1000 ha).....	16
- Table 1.4: Total Area, Yield & Production of Cereals and the Percentage of Self Sufficiency.....	17
- Table 1.5: Distribution of Renewable Water Resources of Na-Sub-Region Countries.....	17
- Table 1.6: Non-Conventional Water Resources in the Seven Countries of North Africa Sub-Region .....	18
- Table 2.7: Total Annual Rainfall .....	19
- Table 2.8 Rainfall Pattern & Drought Frequency* in North Africa Sub-Region.	32

- Table 3.1: Distribution of Traditional water Harvesting Systems in North Africa Sub-Region.....	33
- Table 3.2: Summary Chart of Main Water Harvesting Techniques.....	34
- Table 3.4: Worldwide Research Experiences.....	35
- Table 3.5: Worldwide Farmers Experiences.....	37

## Part – II

- Table 1.1: Wastewater Treatment Processes and Major Purposes.....	38
- Table 1.2: Sludge Treatment Processes and Their Major Purposes.....	38
- Table 1.4: Recommended Microbiological Quality Guidelines for Wastewater Use in Agriculture (WHO,1989).....	39
- Table 1.5: Expected Removal of Excreted Bacteria and Helminths in Various Wastewater Systems.....	40
- Table 1.6: Reported Effluent Quality for Several Series of Waste Stabilization Ponds, Each with a Retention Time of 25 Days.....	40
- Table 2.1: Predicted Wastewater by the Year 2020 at the North of Algeria.....	41
- Table 2.2: Accumulative Design Capacity of Wastewater Treatment Plants in Libya.....	41
- Table 2.3: Drinking Water Consumption in Mauritania.....	41
- Table 2.4: Re-use of Untreated Wastewater for Irrigation in Morocco.....	42
- Table 2.5: Sudan Water Requirements for Human Consumption.....	42
- Table 2.6: Plant of wastewater Treatment in Tunisia.....	43
- Table 2.7: Areas and Crop Grown in the Schemes of Elhadaba El Khadra and Elgawarisha in Libya Using Treated wastewater.....	43
- Table 2.8: Irrigated Areas Using Treated Wastewater in Tunisia as Per State...	44
- Table 5.1: Key Areas for Community Participation in Enhancing the Reuse of Treatment Wastewater.....	45

## Executive Summary

This study<sup>1</sup> was conducted within the framework of the recommendations of the seminar on "Water Management and irrigation" held in Cairo, from 9 to 12 October 1999 and which has been adopted by the 15<sup>th</sup> Intergovernmental Committee of Experts (ICE) of the NA-SRDC in March 2000.

The main purposes of the Study on Best Practices for Drought Preparedness and Water Management with Focus on Wastewater Re-Utilization in North Africa are: identification and analysis of best practices to prevent and combat drought in the sub-region, and to carry out a comprehensive analytical study on the present situation and prospects for wastewater production and reuse, water pollution, wastewater treatment existing network; and main constraints facing the reuse of recycled wastewater for agriculture. The study is also expected to come up with proposals for strategies with the aim to prevent and mitigate the effects of drought and suggestions for a sub-regional plan of action in view to fully utilize recycled wastewater primarily for irrigation during this century.

The study has been conducted into two parts but interrelated. *Part I* deals with the identification and analysis of practices to combat drought in North Africa, and *Part II* deals with the re-utilization of wastewater in North Africa sub-region.

*Part I* of the study is composed of three chapters. In *Chapters I and II* highlights are given on the physical features and populations; and characteristics of drought in the sub-region respectively. While *Chapter III* reviews and analyses the practices to prevent and combat drought, as well as proposing some strategies that might enhance the process of combating drought.

In North Africa Sub-region annual rainfall analysis shows the temporal and spatial high variability of rainfall. On the other hand, drought, in varying degrees of frequency and severity, is a common phenomenon in the sub-region. As such, the need to combat drought is very important for national development especially in water resources management and development. Many practices exist to combat drought. The study reviews and analyses these techniques. Such practices or techniques include: water harvesting and harnessing techniques, introduction of supplementary irrigation in rainfed agriculture, reforestation, crop managing factors, particularly the use of drought resistant cultivars, supply management, improve the productivity; and the use of saline water for irrigation. This part of the study proposes as well strategies for combating drought.

The objectives of these strategies are: to manage and combat drought as well as other associated on-set disasters through, inter alia, efficient allocation, redistribution, transfer,

---

<sup>1</sup> Prepared by Siddig Ahmed, Consultant



storage and efficient use of water resources, rainfall harvesting, and development of non-conventional water resources, develop long term water/balances/drought models with different scenarios including interventions like inter-basin water transfer, promote coordinated planning to combat drought through including, long term water allocation and conservation, and dissemination up to date guidance materials between the sub-region countries; and promote community participation and to raise public awareness in and about drought management.

The *second part* of the Study is composed of six chapters. *Chapter I* deals with the characteristics and treatment processes of wastewater. The characteristics of wastewater are broadly classified into physical (of the most importance are solids); chemical characteristics (organic carbon, BOD, COD, Nitrogen, Phosphorus, and PH); biological characteristics (Bacteria, Fungi, Algae, Protozoa, Rotifers and Crustaceans, and Viruses). Also this chapter gives a general review of the wastewater treatment processes, the nutritional value of wastewater and quantify guidelines of wastewater use in agriculture, as well as the appropriate methods for wastewater treatment and application. The latter one falls on: conventional primary and secondary treatment, wastewater stabilization ponds, disinfection, storage reservoirs, tertiary treatment, and sludge treatment.

*Chapter II* deals with the present situation for wastewater production and re-utilization in North Africa sub-region. The chapter gives statistical figures regarding the current and future quantities of wastewater; the number of treatment plants; and the methods used for wastewater treatment, based on the literature available. Most of the data used are old or incomplete. Also the chapter reviewed and analyzed the present re-use of wastewater for agricultural production in the seven countries of the sub-region.

Water pollution in the sub-region is covered by *Chapter III*. Sources of pollution can be from urban-wastewater, industrial wastewater, agricultural wastes and other pollutants. In Algeria shallow aquifers are subject to serious contamination from the surface water streams which act as drains to most of the sewage wastewater. In Egypt drainage water from agriculture is huge and may exceed 13 billion m<sup>3</sup>/year with the consequences on fresh water. In Libya the deterioration in water quality is mainly caused by excessive use to groundwater. In Mauritania, the Idni basin, located near the Atlantic ocean, authorities were obliged to close some of the operating wells in the basin because of sea water intrusion. In Morocco, eutrophication in some of its reservoirs was noticed because of the disposal of untreated wastewater (Kenitra and Masira dams on Um El rabei valley), also salt water intrusion prevails in most of the coastal areas. In Sudan data concerning water quality are rarely available, while in Tunisia, eutrophication can be noticed in Sidi Salim dam at Midjara and surface water salinity varies from 2000 ppm to 3000 ppm. Chapter IV highlights the main constraints facing the re-utilization of recycled wastewater for agriculture in the sub-region. These have been summarized as environmental constraints; social constraints; regulatory and legal constraints; technical and economical constraints; and institutional constraints.

*Chapters V and VI* are respectively covering the proposed sub-regional plan of action and the conclusions. The action plan is proposed to address: preparation of countries' studies on wastewater potential and reuse; organization of a sub-regional workshop on methods and techniques to enhance the reuse of wastewater on North Africa Sub-region; capacity building in integrated water resources management; and enhancing community participation.

## **PART I. Identification and Analysis of practices to combat drought in North Africa**

### **Chapter 1 : Introduction**

#### **1-1 Physical Features & Population**

The North Africa Sub-Region (NASR) extends from the Atlantic Ocean in the west to the Red Sea in the east and includes seven countries as follows : Algeria, Egypt, Libya, Mauritania, Morocco, Sudan, and Tunisia. The area of the sub-region is estimated at about 9.5 million km<sup>2</sup> which represents respectively 32%, 52% and 7% of the areas of Africa, near east region, and the world. Deserts have special importance in this sub-region landscape. The greatest desert in the world, the Sahara, extends from the Atlantic coast to the red sea. Besides desert territories which lack permanent rivers, large river system, such as the Nile, and Senegal river occur in the sub-region. In the deserts northern and eastern parts only sporadic water courses exist.

The populations of the sub-region are estimated at 164 millions persons as in 1998 estimates. Egypt is having the larger population (61 million) and Mauritania is having the lowest population. The population density in NASR ranges from 2 to 63 persons per km<sup>2</sup> with an average of 17 persons per km<sup>2</sup>. The annual population growth rate of the sub-region is estimated at 2.8%. Table 1.1 of Appendix I-1 summarizes the populations and areas of the sub-region as per country.

#### **1-2 Climate**

Because of the aridity prevailing in north Africa sub-region, many parts of it are very poor in their rainfall. The rainfall ranges from zero at the desert to some 1800 mm/year in the most southern Sudan. The climate varies from the Mediterranean along the whole northern and western coast of the sub-region, to desert and arid Savannah and equatorial when moving south wards.

#### **1-3 Agriculture and Land Use**

The area under cultivation of the sub-region is about 45.5 million hectares & 44.9 million hectares as in 1997 and 1998 respectively. The highest cultivated area is in Sudan, then followed by Morocco and Algeria. The agricultural labor force presents about 48% of the total labor force in the sub-region. The area of perennial crops is estimated at about 5 million hectares of which Tunisia alone occupied 46%. The rain-fed area of the sub-region is estimated at 28 million hectares, of which about 54% lies in Sudan. The irrigated area in the sub-region is about 5.5 million hectares, of which more than 47% is in Egypt. The uncultivated area is estimated at about 6.6 million hectares with approximately 50% of this area is in Algeria. The areas of forest & pastures are respectively about 78.7 million hectares and 113.6 million hectares with the largest portion in Sudan for forests; and Sudan & Algeria for pastures. The area of cereal crops in 1998 exceeded 23 million hectares. The %age of self

sufficiency varies from country to country with the lowest of 8.5% in Libya and its highest of 88.3% in Sudan.

Tables 1.2, 1.3 and 1.4 of Appendix I-1 show the contribution of agriculture to labor force; land use; and the production & productivity and %age of self sufficiency of the sub-region respectively.

#### **1-4 Water Resources, and Water Withdrawals Of North-Africa Sub-Region**

##### **1-4-1 Renewable Water Resources**

Due to the prevailing climatic conditions of the sub-region, water, whether from under ground or surface, is significantly very important. Based on water exchange characteristics, two concepts are often used in hydrology and water management to assess the water resources in the region, the static storage component and the renewable waters. The static storage conventionally includes freshwater with a period of complete renewal taking place over many years such as large lakes, groundwater (fossil water), etc.. Intensive use of this component unavoidably results in depleting the storage and has unfavorable consequences. It also disturbs the natural equilibrium established over centuries. Renewable water resources include water replenished yearly in the process of the water turnover of the earth. These are mainly runoff from rivers and groundwater recharges.

The quantitative characteristics of renewable water resources of a region can be determined by two approaches: by using meteorological data, or by using runoff observations. According to the meteorological data available the North Africa sub region can be classified as the driest part of Africa. While it covers 32% of the total area of Africa, its water resources are only about 4 % of the continent total renewable water resources. Further to this, large differences in water resources exist between its seven countries as shown in table 1.5 of Appendix I-1. The countries of the sub region have very limited water resources, and suffer severe water scarcity, with values per inhabitants varying between 146 and 4573 m<sup>3</sup>/year. Two countries ( Egypt and Mauritania) depend for over 90% on other countries for their renewable water resources.

##### **1-4-2 Non-Renewable Groundwater**

Some countries, that have few renewable water resources, overlie important non-renewable (fossil) groundwater basins, partly shared with neighboring countries. A country like Libya, by far the largest part of its total water withdrawal is fossil water. However, although groundwater reservoirs may allow storage of huge quantities of water accumulated during the pluvial periods of quaternary, its development cannot be considered sustainable in the long term, as the lack of present recharge would result in the slow depletion of the aquifers. Moreover, the increase of the cost of pumping, as well as the deterioration of the water quality in some areas may also make the abstraction of fossil water less attractive with time.

### 1-4-3 Non-Conventional Water Resources

Non conventional water resources includes, water from desalination and treated wastewater. The total use of desalinated water in north Africa sub-region is estimated at 202.8 million m<sup>3</sup>/year, of which Libya produced nearly 50% of this amount. Re-used wastewater was estimated at about 441 million m<sup>3</sup>/year, of which Egypt produced two third of this quantity and Libya produced the other third. Table 1.6 shows the annual non-conventional water resources for the various countries of North Africa sub-region.

### 1-4-4 Water Withdrawals

From table 1.4 of Appendix I-1, which shows the distribution of water withdrawal by country, between the three major sectors of water use: agriculture (irrigation and livestock), communities (domestic water supply) and industries, it can be seen that in some countries (Sudan, Mauritania and Morocco) more than 90% of the water withdrawal is directed to agriculture. In absolute terms, Algeria withdrawals was only 16% of its Annual Renewable Resources (ARR), Egypt withdrawals was 97% of its ARR, Libya withdrawals was 400 of its ARR, which means they overexploited their fossil water, Mauritania 14%, Morocco 37%, Sudan 55% and Tunisia use 68% of its ARR.

## **Chapter – 2: Characteristics of Drought in North Africa Sub-Region**

### **2-1 Rainfall in North Africa Sub-Region**

As mentioned early, the region is almost arid and the desert spans in all of the countries of the sub-region. However, rainfall occurs in the region and varies from few millimeters to more than 1800 mm. Most of the countries in the sub-region experience a wide range of tropical climates or Mediterranean climate, marked by a single rainy season with variable periods.

Rainfall in the region is mainly influenced by the seasonal relative movement of the sun and the associated winds movements. Various types of winds prevail in the sub-region and include; the south-west winds which blow across the Atlantic ocean, south-east winds which blow across the Pacific ocean, Northern, North-east, and the north-west winds.

Data for the seven countries of the sub-region were collected for the last ten years, from some of the existing rain gauge networks. The selection of these stations to a great extent, governed by the availability and the length of the rainfall record. For each station the annual rainfall records were available. The amount of rainfall received at any given station varies significantly from year to year. Tables 2.1 to 2.7 of Appendix I-2 show that the annual rainfall data for some of the various stations in each country of North Africa sub-region. The stations were selected to represent different parts of each country. The data collected were covering the period 1988-1998.

### **2-2 Drought Characteristics and Impact on the Sub-Region**

In north-Africa sub-region annual rainfall analysis shows the temporal and spatial high variability of rainfall. On the other hand, drought, in varying degrees of frequency and severity, is a common phenomenon in the sub-region. Besides the human toll, the economic and socio-economic drought-related costs are usually very high in terms of the lost production, misused inputs and the diversion of development resources. As such, the need to understand the characteristics and occurrence of droughts is very important for national development especially in water resources management and development. However, the causes of the below-normal rainfall which in turns causes drought are still not yet exactly known. But, recent research has revealed a frequency of solar sunspot activity and the temporal characteristics of Tele-connections especially the El-Nino Southern Oscillation (ENSO) and El-Nina phenomena.

El-Nino phenomenon results from the increase in sea temperature, which, due to unknown reasons, leads to the change of the moist wind direction. That is, instead of the moist wind blows in the land it blows on the sea and this is normally accompanied by severe droughts. El-Nina is the reverse of El-Nino and normally accompanied by floods.

The North Africa sub-region has been influenced by these phenomena, among others. And the result is that drought has been frequently witnessed. Since the last four decades rainfall started to decline in almost all the countries of the sub-region. During this period most records in the sub-region indicated a gradual decrease in the rainfall amounts. This could be attributed, besides the weather changes mentioned above, to changes in land use over vast stretches of the sub-region; such changes include deforestation and over grazing of farmland.

As a result of these decreasing in the amounts of rainfall, many demographic changes took place. For example in Sudan, most of the nomads in north Sudan deserted their traditional areas and move towards the Nile Valley or southwards. During the first half of the previous century the migration continued unnoticed. In recent years a rush was noticed especially from Western Sudan towards the east to the Nile Valley and moving south.

Studies carried out by AOAD, show that the potential evaporation is far greater than rainfall. Annual evaporation varies from 3000 mm to some 1700 mm, while on the other hand rainfall varies from zero to some 1800 mm/year. This means that over most of the year there are water deficiencies. Frequency analysis of rainfall has been carried out as shown in Tables 2.1 to 2.7 of Appendix I-2 for some of the various stations in the sub-region. Then regression analysis has been conducted to find the rainfall frequency relationship.

Two stations for each country were selected to show the pattern of rainfall with probabilities of 50% and 80%. The stations were selected to present the highest annual average and the lowest annual average. Table 2.8 shows the rainfall pattern and the frequency of drought, taking the average annual as a reference. It can be seen that the drought frequency varies from four to eight years out of the period in concern, which is 11 years. The drought pattern in Tunisia is the lowest compared to other countries, Where in Morocco it is the highest (6 – 8 years).

A study by Gilali and Gabaly (1997), shows that Al Maghreb Al Arabi suffered from drought episodes (Tunisia 1987 – 1989, Morocco 1979 – 1984, and 1991 - 1993). Rainfall decreases by a rate of 40mm/year in Morocco. However, Tangier estimated the decrease rate of 100 mm in a period of 40 years., whereas Ifran station estimated the decrease rate of about 400 mm in 30 years period. The same study shows the following statistics:

- Drought occurs on average once every 8 years.
- 116 drought events occurred during the period 1000 – 1984.
- Drought distribution in the aforementioned period is as follows:
  - 7 drought episodes, the period of each was 3 years.
  - 3 drought episodes, the period of each was 4 years.
  - 4 drought episodes, the period of each was 5 years.
  - 3 drought episodes, the period of each was 6 years.
  - One drought episode, with a period of 7 days.

A study by Siddig E. (1998) has shown that the unreliability of rainfall in Sudan has its great impact on rain-fed crop production. Analysis of data for Gedaref area showed that 65% in the variation of productivity is referred to the variation in the amount of rainfall, together with the timing of rainfall and its suitability for the variable needs of crops during their growth.

Unreliability or inadequate amount of seasonal rainfall and prolonged dry seasons are manifestation of droughts. The persistent drought that has been witnessed in the last few decades, brought huge food shortages. Some parts in the sub-region, particularly Sudan, were hit by famine, affecting many of inhabitants who lost their agricultural and grazing lands. Several practices are used to combat drought. The details of them is going to be described in the following chapter.

## **Chapter – 3: Practices to Prevent & Combat Drought**

### **3-1 General**

There exists many practices for drought combat and/or prevention. Such practices many include among others: water harvesting techniques; supplementary irrigation in rain-fed areas; reforestation; crop managing factors, particularly using drought resistant cultivars; development of water resources (supply management); expansion of the irrigated areas, improve the productivity and the use of saline water for irrigation. The followings describe the practices to mitigate droughts.

### **3-2 Water Harvesting**

There are several techniques by which rainfall can be managed. These include: precipitation enhancement, reduction of evaporation from water resources, water conservation in soils, flood water harvesting, artificial recharge and rainwater harvesting.

#### **3-2-1 Contour Furrows**

This technique can play an important role in arid and semi arid regions. Since it can be used for increasing the productivity of crops and enhancing the growth of grazing bushes suitable for climatic and soil conditions. The contour furrows method is suitable and effective on heavy deep soil and on lands that have simple and not a complicated topography.

The contour levees can be made manually from earth or stones. Water depth in these furrows varies from 30 – 40 cm and the height of the contour ranges from 45 – 60 cm, or relatively big contour furrows where water depth varies from 60 – 80 cm. In the later case the contour height range from 100 – 150 cm. The width of the basin ranges from 80 – 200m and the distance between the basins depends on land slope and the difference in the water depth in the contour and the one next to it. Normally the contour heights are higher in heavy soils than in the higher ones. The length of the contour furrow depends also on the topography and it is preferable not to be lengthy. This is important in the provision of uniform distribution of rainfall runoff.

The contour furrow function, is mainly to store water and hence increases the quantity of water in filtrated in the soil through the increases of water retention time and hence an increase in the period of water used by crops to the water and hence reducing the impact of drought during the season. Normally the crops are sown at the beginning of the rainy season and the water flooding is designed to take place in most of the cases at the mid of the rainy seasons or closely at its end.

#### **3-2-2 Microcatchment Water Harvesting**

The Micro-catchment water harvesting method can take several shapes (triangle, square, rectangular, or semi-circle). It is normally used for harvesting water for a local catchment with an area ranges from 100-300 meters and this technique is suitable for trees. Water is collected in pits with depths of 30 to 50 cm and widths of 1-3 meters relatively small storage capacities that range between 0.5-4.0 m<sup>3</sup>. This method proved to be very suitable for

improving the growth of forest and grazed trees and some vegetables such as watermelon and tomatoes. The sowing process is practiced immediately after the beginning of storing water, particularly the trees.

### **3-2-3 Bench Terraces**

Bench terraces are suitable in hilly areas and it is very effective in preventing soil degradation. This is mainly done by reducing flow velocities of the runoff by constructing benches which function similarly as water falls. Depending on the purpose of the use of bench terraces, three categories can be distinguished:

- hilly bench terraces,
- simple bench terraces, and
- weak bench terraces

Hilly bench terraces are used in humid areas to eradicate or minimizing soil degradation. However, in arid and semi-arid areas, the simple flat bench terraces are commonly used so as to store the large amounts of water resulting from run-off. A small channel is normally dug below each bench to convey the excess water to a collecting canal which is set perpendicular to the contour lines. Long age bushes with strong roots can be grown to strengthen the levees of the benches. The width of the bench can be in the range of 6 to 20 meters, depending on the soil type, and the purpose from constructing the bench terraces. Construction of the benches started from the lower end of the hill and then going uphill. Such terraces are used in Sudan Morocco.

### **3-2-4 Water Spread embankments**

Water spread embankments or dams method is one of the practical methods for water harvesting and distribution of water resulted from run-off and spreading it to the possible large areas, which are suitable for use in agricultural purposes. The other purpose is also to direct or divert water to suitable areas for agriculture investment or developing lands for natural grazing. The water is diverted or spread through the construction of small earth dams across the wadis. The structure of a water spread embankment composes of the following :

- main dam
- side earth embankment
- a canal for conveying water
- pipes to distribute water
- stone pitching
- a canal for draining excess water

### **3-2-5 Rainwater and Flood Harvesting**

In some of the countries in the sub-region the potential of water harvesting is tremendous. Harvesting rainwater can provide water for regions where other sources are too distant or too costly. Rainwater harvesting is particularly suitable to supply water for small villages, schools, households, livestock and wild life. Water harvesting by water spreaders, pits, contour furrows and borders and contour strip ploughing are most promising runoff agricultural techniques. Some of these techniques can be used in range-lands to increase



forage production of these areas on which most of the feed of the livestock of the sub-region depends. The advantages of the water harvesting include:

- Easy spread of water and low cost of constructions
- Simplicity in operating and maintaining the structures
- Possibility of selecting one of the several available techniques to fit the prevailing conditions of the area under concern.
- Minimization of soil degradation by water.
- Leaching of saline soils, hence making soils suitable for growing crops by reducing the total dissolved solids(TDS).

Some of the various water harvesting techniques are described hereunder:

### **3-2-6 Hafirs**

In all of the North Africa sub-region countries, rainfall is limited and seasonal as already seen on the previous chapter. The availability of water and continuity of its supply during the long dry season depend on the collection and storage capacities of surface water reservoir as well as ground water abstraction.

The idea of hafirs came first from natural depression, collecting water during wet season, to be used for a period of time after rainy season. The first promotion was the enlargement and shaping of the natural depression by hand to increase the storage capacity. When earth moving machines were introduced, and then was start of construction of proper hafir with engineering provisions in limited capacities of about 5000 m<sup>3</sup>. The hafir can be defined as the water impoundment collecting water during rainy season to be used in period of water shortage.

Due to the different prevailing conditions, source of water, type of soil and other natural conditions. There are many types of hafirs. The main types are given below :

- 1- Self-catchment Hafir.
- 2- Jebel catchment Hafir.
- 3- Stream fed Hafir.
- 4- Lined Hafir
- 5- Overground storage Hafir.

### **Design Criteria**

The main criteria of the design is the availability of both water and impervious soil. The design of hafir in most cases, is made according to the natural features and conditions. Every site require detail investigations as follow:

#### *(One) Site Selection*

First a reconnaissance survey is made for site selection.

*(Two) Soil Test*

Number of test pits are dug by hand or auger to determine the type and depth of soil. Samples are taken every 50 cms and checked by field test for classification of soil showing type, colour and moisture content.

*(Three) Topographical Survey*

An area of 2 to 6 kilometers square is topographically surveyed including the test pits, water resource of the site whether it's stream or self catchment. The Survey should show, topography around, e.g. Jebel (hill), goz (sand dunes), direction of flow water marks to certain contour and sections of stream.

*(Four) Hydraulic Calculation*

Collecting data for calculation of the total budget of the hafir resources. Some of data is collected by questionnaire of the local inhabitants, regarding duration and intensity of rainfall, number of streams, their floods number, duration, and height. On the other hand sections of stream, and water marks are taken.

*(Five) Technical Report*

This report should include background information about the traditional water resource, the number of people, and animals, rate of growth, the rate of consumption, and future projection.

Summary of these practices and their use are as shown in Tables 3.1, and 3.2 of Appendix I-3.

**3-3 Supplementary Irrigation in Rain-fed Area**

Rain-fed agriculture occupies about 62% of the cropped area in the sub-region. Some of the cereal crops, which constitute the main food crop, are mainly grown by rain form rain-fed agriculture. Recent researches on supplementary irrigation for pilot areas in some of the sub-region countries, e.g. Sudan, have demonstrated that the present yield of sorghum in areas of 350 to 400 annual rainfalls, which is about 0.4 Ton/hectare, can be increased to about 4 Ton/hectare by the application of supplement irrigation. This means that the productivity of the water unit added as a result from applying supplementary irrigation is about 10 times that of the rainwater. Water harvesting is one of the techniques that can be used for providing water for supplementary irrigation. Other techniques include provision of groundwater through digging wells, and conveying surface water by means of canals or pipes. Factors affecting the technical decision to use supplementary irrigation can be summarized as follows:

- Type of soils and their capacities of storing water.
- Land topography, particularly its slope and its direction.
- Winds and temperatures.
- The maximum annual rainfall and its maximum intensity.
- Vegetative cover and its density.

When examining the common properties of the North Africa sub-region, the following can be identified:

- Prevalence of the aridity phenomenon in most of the year.
- Spatial and temporal low rainfall.
- Prevalence of thunderstorm rains.
- High temperatures in most of the year.
- High rates of evapo-transpiration.
- Dry and strong winds.
- Low vegetative cover density and the impact of that on the run-off.
- Domination of dry and poor soils which have their constraints on the production of crops.
- Spread of sand dunes.

Normally in marginal areas where rainfall is less than 250 mm/year, it is hard to obtain a sustainable production except under supplementary irrigation. However, if winter rainfall exceeded 100 mm/year and summer rain in the vicinity of 150mm/year, supplementary irrigation can be applied.

### **3-4 Reforestation**

Forests intercept rain by simply holding rain drops on the leaves of trees. The process first starts in the upper part of foliage, once these parts were saturated, droplets drip downward, until the whole tree is saturated. Some water flows down the stem. If the rain lasted long enough then water drips to the ground below. Interception is known to regulate the down-flow of the rain to the ground in such a way to prevent floods. These in addition to other forest influences like soil erosion were realized long time ago and strict laws that conserve forests were passed by some of the sub-region countries' governments. Unfortunately these laws seem to have been relaxed. Tree felling for charcoal, mechanized farming and timber in addition to uncontrolled forest fires reduced the forest stand, particularly when examining the case of Sudan.

The forests affect noticeably the air mass. The evaporation from forests saturated with intercepted rain is assumed to be more efficient than from saturated ground surface. Therefore, forests in the path of air help the air to retain some of the moisture of the air lost in rain to the surface, that is on top of other influences of forests in this way, they do not only enrich boundary layer moisture, but also degrade sensible heat by this evaporation in the boundary layer too and this is very important in the process of rainfall.

Reforestation is expected to be a key element in the rainfall process and an important factor to combat desert encroachment. If this is done on a wide scale in the sub-region and the neighboring countries, rainfall can be kept at least to the present rate of fall.

### **3-5 Crop management Factors**

These factors include: high yield and drought resistant cultivars, planting dates, crop rotation and using fertilizers. Taking sorghum as an example, several improved sorghum varieties have been released by the Agricultural research stations in the sub-region. However,

the adoption of these cultivars by farmers in rain-fed sector is minimal. They insist on growing their traditional local varieties, which are long maturing and with low harvest indices. The importance of early planting of crops on the yield potential in the rain-fed sector is well known. However, farmers tend to plant late in order to economize on cost of weeding. In Sudan for example, research recommended that rotation in the rain-fed sector be to plant 50% of the area with sorghum, 25% with sesame and leave the remainder of the area as a fallow

However, farmers do not adopt this recommendation because of some practical reasons: scarcity of rain during early season, which hinder the planting of sesame, and lack of sesame cultivars, which are drought tolerant. The coincidence of planting the two crops, sorghum and sesame on equal areas makes harvesting of the former crop difficult and costly. Therefore farmers tend to plant most of the area with sorghum year after year, a practice which results in lowering the yields. Introduction of supplementary irrigation in the cropping system will permit initiation of the crops at the optimum planting date. Field demonstrations are needed to prove that: introduction of cultivars with short stalk, early maturity, high yielding and drought tolerant, optimum planting date, and crop rotation will promote harvest indices. Also more research in this area is needed.

### **3-6 Water Supply Management**

Water supply management has been an important feature of the allocation and management of water since the beginning of the twentieth century. This is still an option for some of the various sub-region countries, to increase their storage capacity by building dams. The degree to which those countries can mobilize additional water by the supply management practice is limited both by their capacity to mobilize the complex of resources needed to store, distribute and effectively utilize water in the difficult environment and the substantial economic investment needed.

On the other hand, ground water occurs under a vast portion of almost all of the countries of the sub-region. It is largely controlled by the geological formations and to some extent by the presence of a recharging. Further development in this regard is needed.

### **3-7 Expansion of the Irrigated Areas**

Extensive potential areas for irrigation exist in the seven countries of the sub-region as shown in Table 3.3. Irrigation is now of fundamental importance in the sub-region. The potential which can be irrigated in the sub-region is estimated at about 3.2 million ha, with the highest unirrigated area in Egypt (37%), then Sudan (26%), and Morocco (12%). Therefore still there is an opportunity for expanding the irrigated area in the sub-region.

**Table 3.3: Irrigation Potential in the Various Countries of  
North Africa Sub-Region**

Country	Year	Irrigation Potential (1000 ha)	% age Irrigated	Available for Irrigation
Algeria	1992	730	76.1	174
Egypt	1993	4435	73.2	1188
Libya	1990	750	62.7	280
Mauritania	1994	170	28.9	121
Morocco	1989	1653	76.1	395
Sudan	1995	2784	69.9	838
Tunisia	1991	563	68.4	178
NA-Sub-region		12085		3174

### 3-8 Improve the Productivity of Water Use

Initial attempts of water resources efficient management focused on technical conservancy measures (improved end-use efficiency). The objective is to increase the available amount of water by getting more use out of the same amount, through more efficient irrigation, more efficient appliances, and improving leaking distribution systems. In order for efficiency measures to be implemented, economic incentives, preferably market based have to come to the fore. Perverted water subsidy structures are criticized; instead the correct pricing of water has been suggested. Logically following from the focus on economic incentives, a whole new level of efficiency measures have cropped up.

Instead of discussing just how one should get out of existing finite water resources, the issue of putting these resources to their best economic use has come to fore. Central to this allocative efficiency reasoning is the fact that agriculture on average demands the greatest part of the water resources, while in many times only generate a much smaller fraction of the economic output. Another contradictory factor is that many believe water, a production factor, is free, non-marketable natural resources where water values are based on cost recovery only.

### 3-9 Using Saline Water for Irrigation

Irrigated agriculture is not only the main source, but rather the only sources of crop production in many arid areas. In order to maintain permanent, sustainable agriculture in these areas, it is inevitable to use the available poor-quality water for irrigation. However, to achieve this objective, great efforts are needed to overcome the saline water related problems or otherwise cope with them. Several regions in the world have practiced using saline water in agricultural production for long continuous periods. El Gabaly mentioned that the farmers in north Africa have utilized ground water containing dissolved solids up to 7000 ppm for the irrigation of sandy soils for more than 2000 years ago without causing much salinization. Tables 3.4 and 3.5 of Appendix I-3 shows some of world wide research and farmers experiences.

### 3-10 Strategies to Prevent & Mitigated the Effects of Drought

The objectives of the strategies are as follow:

- Manage and combat drought as well as other associated on set disasters through, interalia, efficient allocation, redistribution, transfer, storage and efficient use of water resources, rainfall harvesting, and development of non-conventional water resources.
- Develop long term water balances/drought models with different scenarios including interventions like inter-basin water transfer.
- Promote coordinated planning to combat drought through including, long term water allocation and conservation measures and also rehabilitative actions on catchment management.
- Propose methodologies for emergency measurements, develop data-base, and disseminate up-to-date guidance materials between the sub-region countries.
- Promote community participation and to raise public awareness in and about drought management.

The key strategic principles for drought combat and/or mitigation in North Africa sub-region are:

- Encouraging the use of water harvesting techniques and construction of dams for harnessing the floodwater.
- Increasing the efficiency of water use in agriculture.
- Developing of non-conventional water resources.
- Development of measures for catchment areas management.
- Promoting of community participation and raising of public awareness.
- Establishing of database and updating information on water resources.
- Enhancing the cooperation between the countries of the sub-region.
- Creating a favorable environment for the private sector to invest in water development, of particular agriculture.
- Encouraging research directed to development of low cost water harvesting techniques and other measures to combat drought.
- Developing appropriate institutions and/or make reforms for the existing ones, since they are fundamental requirements for sustainable water resources.

## **PART II: Reutilization of Wastewater in North Africa: the present and future situation**

### **Chapter -1: Characteristics and Treatment Processes of wastewater**

#### **1-1 Characteristics of Wastewater**

The characteristics of wastewater are broadly classified into physical, chemical, and biological according to the type of measurement test that has to be performed. The analyses range from the very specific quantitative tests usually applied for chemicals to the broad group tests applied to biological classes.

##### **1-1-1 Physical Characteristics**

The many properties of water which appeal to the natural senses are termed the physical characteristics. The most important physical characteristic of wastewater is its solids content as it affects the esthetics, clarity, and color of water. Other physical parameters are temperature and odors which are largely the result of baseline levels for that geographical area and are not commonly altered in a wastewater treatment plant.

**Solids:** The total solid in a water sample is the residue on evaporation of the sample at 103-105°C. Any low-boiling compounds in the water will be lost during this test. The total solids are composed of matter, which is settleable, in suspension, or in solution. Analytical tests are performed to separate out the fraction of the total solids, which lie in each area.

##### **1-1-2 Chemical Characteristics**

The chemical characteristics of wastewater can adversely affect the environment in many different ways. Soluble organics can deplete oxygen levels in streams, and give taste and odor to water supplies. Toxic materials can affect food chains as well as public health. Nutrients can cause eutrophication of lakes. Although some chemical tests are specific, many determined broad classifications due to the variety of compounds found in wastewater.

**Organic matter:** The principal categories of biodegradable organic matter in wastewater are proteins, carbohydrates, and lipids.

*Biochemical oxygen demand (BOD)* is used commonly as an indirect measure of organic matter. The BOD of a wastewater is related to the quantity of oxygen which must be supplied to the wastewater either by aerators during secondary treatment or by natural aeration of the receiving water.

In order to overcome some of the shortcomings of the BOD test, a chemical oxygen demand (COD) is performed by relaxing a sample of the wastewater with potassium dichromate for 2-3 hours and measuring the change in concentration of dichromate.

**Nitrogen:** Both nitrogen and phosphorus are receiving increased attention because their compounds promote unwanted growth of algae and aquatic plants.

**Phosphorus:** Phosphorus enters the wastewater through human wastes, primarily urine and through phosphate compounds used as builders in detergent formulations.

**Gases:** Of all the gases present in water, oxygen is the most important. Dissolved oxygen is necessary for the respiration of aerobic microorganisms and other life forms.

### 1-1-3 Biological Characteristics

The microorganisms of importance are as follows:

**Bacteria:** Bacteria are single-cell microorganisms in which organic matter diffuses into the cell and is consumed as food. If food and nutrients are in excess, the bacteria will multiply rapidly until the food source has been depleted.

**Fungi:** Fungi are important in water purification because like bacteria they metabolize dissolved organic matter. Fungi are non-photosynthetic and can grow in low moisture areas and in low pH solutions where bacteria could not survive.

**Algae:** Algae differ from bacteria and fungi in their ability to carry out photosyntheses, generating oxygen during their growth. Algae are classified by the color of pigment which they contain, the common fresh-water ones being green, motile green yellow green to golden brown, and blue-green.

**Protozoa:** Protozoa are the only members of the animal group within the protista kingdom, and are found in all types of surface waters and soils. They vary greatly in size, ranging from sizes comparable to bacteria up to several hundred times as large.

**Rotifers and crustaceans:** Rotifers are aerobic multicellular animals which feed primarily upon bacteria.

**Viruses:** Viruses are small parasitic particles that are not cellular in that they have no nucleus, cell membrane, or cell wall. They multiply only within living cells and are totally inert outside of living cells.

### 1-2 Waste Water Treatment Processes

The main objectives of conventional wastewater treatment processes are reduction of biochemical oxygen demand, suspended solids, and pathogenic organisms. In addition, it may be necessary to remove nutrients, toxic components, nonbiodegradable compounds, and dissolved solids. Since most contaminants are present in low concentrations, the treatment processes must be able to function effectively with dilute streams.

Many operations are used to purify water before discharge to the environment. A partial listing of these operations and their purposes is given in Table 1-1 of Appendix II-1. These operations will be discussed briefly to show where they fit into an overall treatment plant.

Conventional wastewater treatment processes are often classified as pretreatment, primary treatment, secondary treatment, tertiary treatment, and sludge disposal. Many of the



common operations are shown in Fig. 1.1 of Appendix II-1 under several broad classifications. The wastewater enters at the left side of the figure and passes through the operations needed to achieve the desired water quality.

### 1-2-1 Pre- and Primary Treatment

Pretreatment processes are used to screen out coarse solids, to reduce the size of solids, to separate floating oils and to equalize fluctuations in flow or concentration through short-term storage. Primary treatment usually refers to the removal of suspended solids by settling or floating.

Sedimentation is currently the most widely used primary treatment operation. In a sedimentation unit, solid particles are allowed to settle to the bottom of a tank under quiescent conditions. Chemicals may be added in primary treatment to neutralize the steam or to improve the removal of small suspended solid particles. Primary reduction of solids reduces oxygen requirements in a subsequent biological step and also reduces the solids loading to the secondary sedimentation tank.

### 1-2-2 Secondary Treatment

Secondary treatment generally involves a biological process to remove organic matter through biochemical oxidation. The particular biological process selected depends upon such factors as quantity of wastewater, biodegradability of waster, and availability of land. Activated sludge reactors and trickling filters are the most commonly used biological processes.

In the activated sludge process, wastewater is fed to an aerated tank where microorganisms consume organic wastes for maintenance and for generation of new cells. The resulting microbial floc (activated sludge) is settled in a sedimentation vessel called a clarifier or thickener. A portion of the thickened biomass is usually recycled to the reactor to improve performance through higher cell concentrations. Trickling filters are beds packed with rocks, plastic structures, or other media. Microbial films grow on the surface of the packing. Excess biological growth washes off the packing and is removed in a clarifier.

A typical flowsheet of an activated sludge treatment plant is shown in Fig. 1.2 of Appendix II-1. The plant includes primary sedimentation for removal of solids and chlorination to reduce the pathogen content of the effluent water.

### 1-2-3 Tertiary Treatment

Many effluent standards require tertiary or advanced wastewater treatment to remove particular contaminants or to prepare the water for reuse. Some common tertiary operations are removal of phosphorus compounds by coagulation with chemicals, removal of nitrogen compounds by ammonia stripping with air or by nitrification-denitrification in biological reactors, removal of residual organic and color compounds by adsorption on activated carbon, and removal of dissolved solids by membrane processes (reverse osmosis and electrodialysis). The effluent water is often treated with chlorine or ozone to destroy pathogenic organisms before discharge into the receiving waters.

The entering wastewater is first treated in conventional primary and secondary processes to remove most of the settleable solids and soluble organics. The tertiary treatment steps are phosphate removal by granular bed filtration, residual organic removal by activated carbon removal and disinfection by chlorine. The sewage sludges are incinerated, the spent granular carbon is regenerated thermally for reuse and the lime sludge is recalcined and reused.

#### 1-2-4 Physical-Chemical Treatment

Physical-chemical treatment processes are alternatives to the biological processes. In a physical-chemical plant, the main processes are chemical coagulation, carbon adsorption, and filtration. Suspended solids and phosphates are precipitated together in a sedimentation vessel after addition of suitable chemical, such as alum, ferric chloride, or lime. Adsorption on granular activated carbon extracts the remaining soluble organics and filtration is used to remove residual suspended solids. The granular carbon column may serve the dual function of adsorbing organics and filtering out solids. Physical-chemical treatment is usually applied to wastes containing toxic or nonbiodegradable compounds that are not amenable to biological processes. Typical physical-chemical flowsheets are shown in Fig. 1.3 of Appendix II-1.

#### 1-2-5 Sludge Disposal

Wastewater treatment processes generate significant quantities of sludge from suspended solids in the feed, biomass generated by biological operations, and precipitates from added chemicals. Some common sludge disposal operations and their functions are listed in Table 1.2 of Appendix II-1. Selection of a treatment sequence for sludges depends upon the nature of the sludge, environmental factors, and ultimate disposal options.

Concentration operations, such as gravity or flotation thickeners, increase the solids concentration and achieve a significant reduction in sludge volume. Stabilization operations, such as anaerobic digestion, convert sludges into a less offensive form in terms of odor, degradability, and pathogen content.

Figure 1.4 of Appendix II-1 shows a typical flowsheet for waste sludge disposal. Sludge conditioning by chemicals or heat improves rates of dewatering. In dewatering operations, the water content of sludges is reduced to a level where they can be handled as damp solids. Vacuum filtration, centrifugation, and sand beds are the most common dewatering methods. Thermal processes, such as heat drying and incineration, are used to either dry the sludge or to oxidize its organic content. Residual sludge and ash from sludge treatment processes must be disposed of in the ocean or on land. Some of the options for ultimate disposal on land are landfill, land reclamation, and crop fertilization.

Design of a wastewater treatment process for industrial or domestic wastes depends upon many factors, such as characteristics of the wastewater, required effluent quality, availability of land, and options for sludge disposal. In addition to capital and operating costs, stability, reliability, and flexibility are important considerations when selecting a process from the various alternatives.

### 1-3 Nutritional Value of Wastewater and Quality Guideline of Wastewater Use in Agriculture

#### 1-3-1 Advantages of Using wastewater

Reusing wastewater, rather than disposing of it, may help improve the environment by:

- Avoiding discharge to surface waters, thereby preventing anaerobic condition in rivers and eutrophication of lakes and reservoirs. Conserving water resources will benefit such uses as water supply and recreation.
- swing groundwater resources in areas where over-use is causing water-level depletion and salt intrusion.
- Helping to control dust storms and desertification in arid zones through irrigation and fertilizing tree belts. It also control environmental degradation caused by the demand for fuel-wood.
- Improving urban conditions and recreational activities by irrigating and fertilizing green spaces such as gardens, parks and sports facilities.

Worldwide application of wastewater to cultivated land has been practiced both as land treatment system and as an irrigation scheme for more than three centuries. The two approaches, however, should not be considered equal in terms of concept, engineering design and final objectives. While land treatment involves using the soil surface, the soil matrix and plants for treating wastewater to a certain level, wastewater irrigation can provide water nutrients and organic matter to crops.

#### 1-3-2 Nutrients

The suspended, colloidal and dissolved solids present in wastewater contain macro- and micronutrients, which are essential for crop nutrition. However, the nutrient content of the wastewater may exceed the plant needs and besides being potential source for underground water pollution, may cause problems related to excessive vegetative growth delayed or uneven maturity, or reduced quality of the irrigated crops.

Nutrients in wastewater occurring in quantities important to agriculture and landscape management include nitrogen (N), phosphorus (P) and occasionally potassium (K). Other macro and micronutrients may also be present. In addition, the organic matter in the wastewater beside its long-term effect on the soil fertility can also contribute to the soil stability and structure.

The concentration of N and P in the secondary treated wastewater may vary substantially depending on the source of the primary wastewater and the treatment process. From conventional treatment plants the N and P concentration are usually high than with the aerated lagoons and oxidation ponds. In general, N and P are reduced during treatment but K remains approximately at levels found in untreated wastewater.

The amounts of N, P and K applied per hectare with 1000 mm irrigation by a typical wastewater are given in Table 1.3.

**Table 1.3: Amounts of Some Nutrients in Wastewater**

Item	N	P	K
Nutrient Concentration (g/m <sup>3</sup> )	40	10	30
By 10,000 m <sup>3</sup> /ha in kg/ha	400	100	300

Evidently the load by nutrients depends on the overall amount of water applied. It is assumed that for high nutrient efficiency, irrigation should be based on crop water requirements. Such fertilizer application rates supply all or more of the N normally required by a number of agriculture crops and much of the P and K. In this respect, careful consideration should be given to each crop separately for estimating eventual supplementary fertilizer requirements.

In some cases some nutrients in wastewater may be in excess of that required for balanced crop growth and may potentially stimulate excessive growth of the vegetative parts of the crops rather than the flowers and seed. This may be a problem for crops as sunflower, cotton and some fruits. In case of excess nutrients an appropriate cropping and/or mixing of the wastewater with fresh water to reduce the nutrient application are some of the methods which can be suggested to solve the problem.

The quality guidelines can be seen in Appendix II-1, Table 1.4.

## **1-4 Appropriate Wastewater Treatment and Application Systems for Agriculture**

### **1-4-1 Wastewater Treatment System**

The following treatment systems are considered in terms of their appropriateness for wastewater used in irrigation.

#### ***1-4-1-1 Conventional Primary and Secondary Treatments***

Raw wastewaters contain  $10^7$ – $10^9$  faecal coliforms/100 ml; it is clear from Tables 1.4 and 1.5 of Appendix II-1 that conventional systems (plain sedimentation, biofiltration, aerated lagoons, activated sludge and oxidation ditches) can not produce an effluent that complies with the new guidelines for bacterial quality (<1000 faecal coliforms/100 ml).

#### ***1-4-1-2 Wastewater Stabilization Ponds***

This is usually the preferred treatment in warm climates whenever land is available at a reasonable cost. Ponds in series of anaerobic, facultative and maturation units, with an overall average hydraulic detention time of 10-50 days (depending on temperature) can produce effluent that meets the proposed guidelines for both bacterial and helminthic quality. Free-living nematode larval stages in stabilization ponds effluent is of no public health significance because they are not pathogenic to humans.

Table 1.6 of Appendix II-1 indicates the success with which pond series can meet the proposed guidelines in terms of faecal coliforms and nematode eggs. Stabilization ponds also have the following advantages:

- Lower construction, operation and maintenance costs than other treatment system;
- No energy expenditure;
- A high ability to absorb organic and hydraulic loads; and
- The ability to treat a wide variety of industrial and agricultural wastes.

#### ***1-4-1-3 Disinfection***

Disinfecting wastewater, usually by adding chlorine, has never been completed successfully because of difficulties in maintaining a uniform and predictable level of disinfecting efficiency. Effluents from well-operated conventional treatment systems treated with 10-15 mg/l of chlorine (depending on the concentration of organics) and a contact time of 30-60 minutes will reduce excreted bacteria considerably but will have no success removing helminths and protozoa.

**Because of complex operation and maintenance, high cost and lack of consistency, disinfected water is not recommended for developing countries. If more reliable treatment systems, such as stabilization ponds, can provide effluent that meets the proposed guidelines, there is no need for disinfection.**

#### ***1-4-1-4 Storage Reservoirs***

Since irrigation demand is usually concentrated in the dry season, wastewater can be stored in large reservoirs to further treat it-especially for bacteria and helminth reduction. Such storage reservoirs are used in Mexico and Israel. There are insufficient field data on their performance to formulate a rational design process at present, but pathogen removal will clearly be strengthened by dividing them into compartments connected in series. The greater the number of compartments and the longer the minimum retention time, the more efficiently the pathogen removal. An appropriate recommendation might be a minimum hydraulic detention time of 10 days during the irrigation season, assuming only two log<sub>10</sub> unit reductions of both faecal coliforms and helminth eggs. Thus, the effluent being discharged into the reservoir should contain no more than 100 helminth eggs/l, and if it is to be used for unrestricted irrigation, not more than 100 000 faecal coliforms/100 ml during the irrigation season.

#### ***1.4.1.5 Tertiary Treatment***

Tertiary treatment systems were originally developed to improve the quality of secondary treatment systems (activated sludge or trickling filters). Mechanisms designed to improve physicochemical quality (rapid sand filtration, nitrification, denitrification, carbon absorption) have little or no effect on excreted bacteria, but some (such as filtration) may remove helminths. Further research is needed to provide reliable design data. These systems, however, are usually complicated and expensive, and their use in developing countries to produce suitable effluent for crop irrigation is not recommended.

### 1-4-1-6 Sludge Treatment

The sludge from the settling units of some wastewater treatment systems shows high pathogen concentrations, including helminth eggs, which may remain viable for up to a year. No treatment is required, however, if the water is applied by subsurface injection or placed in trenches prior to the start of the growing season. The following treatment methods may be considered for other methods of land application:

- Storage of 6-12 months at ambient temperatures in a hot climate.
- Anaerobic digestion plants operating at temperatures lower than mesophilic temperatures show parasite egg removals of 90-95 percent, but only 30-40 percent of *ascaris*. Batch thermophilic digestion at 50°C for 13 days will inactivate all pathogens. Batch digestion is required to avoid pathogen short-circuiting.
- Co-composting sludges with domestic solid waste or some other organic bulking agent (such as wood chips) for 30 days at 55-60°C, and further maturation for 2-4 months at ambient temperatures will produce a stable, pathogen-free compost. Wastewater used for aquaculture (macrophyte or fish culture) should meet the proposed guideline quality for trematode eggs per litre and faecal coliforms per 100 ml which can be achieved by a properly designed stabilization pond system.

## 1.4.2 Wastewater Application in Agriculture

### 1.4.2.1 Crop Selection

Crops can be grouped into two broad categories according to the exposed groups and the degree to which health protection measures are required:

**Category A** – Protection required for consumers, agricultural workers and the general public includes crops likely to be eaten uncooked, spary-irrigated fruits, sports fields, public parks and lawns.

**Category B** – Protection required for agricultural workers only. Crop restrictions include irrigating cereal crops, industrial crops (e.g. cotton, sisal, etc.) food crops for canning, fodder crops, pastures and trees. Some vegetable crops may fall into this category if they are not eaten raw (potatoes) or if they grown well above the ground (chilies, tomatoes and green beans). It is necessary to ensure that crop contamination is not caused by sprinkler irrigation or by falling on the ground, and that contamination of kitchens from such crops before cooking is not a health risk.

To keep crops restricted to Category B requires:

- A law abiding society or strong law enforcement;
- A public body to control waste allocation;
- An irrigation project with a strong central management
- Adequate demand for the crops allowed under crop restrictions, and a reasonable price for them; and
- Little market pressure in favour of excluded crops (Category A).

Crop restriction in aquaculture is not as straightforward as it is for agriculture because most cultured aquatic macrophytes and fish are eaten raw in some areas. A good approach would be to enforce the practice of growing fish, such as tilapia, in wastewater ponds to produce fishmeal for animal feed or to feed to high-value fish such as catfish and snakeheads, or to crustaceans such as shrimp and crayfish.

#### *1-4-2-2 Wastewater Application*

Land can be irrigated by:

- Flooding or border irrigation, wetting almost all the land surface;
- Furrows, wetting only part of the ground surface;
- Sprinkler, in which the soil and crops are wetted in much the same way as by rainfall;
- Sub-surface irrigation, in which the surface is wetted little, if at all, but the subsoil is saturated; and
- Localized (trickle, drip or bubbler) irrigation, in which water is applied to each individual plant at an adjustable rate.

#### *1.4.2.3 Human Exposure Control*

The people most susceptible to potential risks from reusing wastewater in agriculture are:

- Agricultural fieldworkers and their families;
- Crop handlers;
- Consumers of crops, meat and milk originating from wastewater-irrigated fields; and
- Those living near the affected field.

There are several means of eliminating or minimizing exposure, depending on the target group. Agricultural fieldworkers and their families, and crop handlers can be protected by:

- Footwear to reduce hookworm infection;
- Gloves (mainly for crop handlers);
- Health education;
- Personal hygiene;
- Immunizing against typhoid and hepatitis A;
- Regular chemotherapy – mainly for intense nematode infections – in children and control of anemia;
- Providing adequate medical facilities to treat diarrhoeal diseases.

Consumers can be protected by:

- Cooking vegetables and meat and boiling milk;
- Maintaining high standards of personal and food hygiene;
- Health education campaign;
- Meat inspection (where there is risk of tapeworm infections);
- Ceasing wastewater irrigation at least two weeks before cattle are allowed to graze (where there are risks of bovine *cysticercosis*);
- Ceasing fruit tree irrigation two weeks before picking; and
- Warning notices on the edges of the fields.

There is no epidemiological evidence that the aerosols from sprinkler irrigation schemes cause significant pathogen contamination risks to people living near the wastewater-irrigated fields. However, to allow for a reasonable safety margin and to minimize odour, there should be a minimum distance of 50-100 m between houses and roads and sprinkler systems.

For aquaculture, the groups at potential risks are:

- Aquacultural pondworkers;
- Fish and macrophyte handlers;
- Fish and macrophyte consumers; and
- Those living near the wastewater-fertilized ponds.

The risks are higher since many people will belong simultaneously to more than one of the groups.

Basic protective measures include:

#### Pondworkers

- wastewater treatment and snail control;
- using rubber boots or high-body waders if pond is shallow and the practice is accepted by pondworkers; and
- regular chemotherapy in endemic areas.

#### Local residents

- information on which ponds receive excreta or wastewater;
- warning notices and, if possible, fences around the ponds; and
- adequate water supply and sanitation facilities
- to avoid using the pond for bathing and defecation

#### Produce handlers

- wearing gloves; and
- a high level of personal hygiene.



## **Chapter – 2: Present Situation for Wastewater Production and Re-Utilization in North Africa Sub-Region**

### **2.1 General**

In North Africa Sub-Region, water related issues are more prominent than ever before and the Sub-region stands at the start of a major natural resources crisis. The freshwater of the sub-region is in a precarious situation since the end of the twentieth century. Many people are facing chronic water shortages and many are living under frequent threat of flood and drought. Several water resources of the sub-region are threatened by pollution in one way or another.

Socio-economic development of the sub-region has historically been associated with its water resources. Population distribution is closely patterned after the water resources distribution – along the water courses and in the region of relatively high rainfall. Traditionally agriculture is by far the main consumer of water. But due to the rapid urbanization witnessed in the recent decades, domestic water consumption is increasing rapidly. So is the consumption for industry and hydropower generation.

Domestic water consumption for the major cities dwellers in NA-sub-region, is increasing at unprecedented rates due to explosive growth in urban population. This resulted in tremendous amounts of waste water. International trends show that wastewater reclamation and reuse have become a significant element in water resources management, rather than one of wastewater disposal options.

Wastewater reclamation and reuse has emerged not only as a realistic option for new sources of water to meet shortage and cover increasing water needs in North Africa sub-region countries, but also to meet wastewater disposal regulations in the countries of the sub-region aimed at protecting the environment and public health. In addition, from the environmental point, reclamation and re-use of treated municipal wastewater for irrigation could be, beside an efficient use of scarce water resources, probably the most safe, easy and useful disposal approach. This chapter main objective is to give an outlook of the present situation and prospects for wastewater production and re-utilization in the countries of North Africa sub-region.

### **2.2 Current Situation of Wastewater in Countries of the Sub-Region**

#### **2.2.1 Algeria**

The percentage of population who have been served through a sewage network has been increased from 52.4% to 63.7% during the years 1987-1995. This increase differed between urban and rural, in 1995 it reached 96.1% in urban, where it was only 28.4% in the rural area.

Daily drinking and industrial water consumption is estimated at 356 thousand m<sup>3</sup> which is equivalent to 1.3 billion m<sup>3</sup>/year. Normally 80% of the used water is disposed,

hence an amount of 600 million m<sup>3</sup>/year could be obtained as waste water. This amount can irrigate an area of 70 thousand hectares.

In Algeria, there exists 51 plants to treat the sewage waste water, particularly of the urban and pre-urban. However, many of these plants were not working. Theoretically the treated water has to be 22% of the total waste water, but in reality it was hardly exceeding 4%. There also exists about 435 decantation pools in 404 municipalities which are distributed over 31 states in the country.

In a recent study carried out by Taibi Rasheed (1999), the expected wastewater volume by the year 2020 in Northern Algeria will be estimated at 0.978 billion m<sup>3</sup>/year. Table 2.1 of Appendix II-2 shows the volume of waste water as by basin.

The amount, which is estimated at about one billion m<sup>3</sup>/year, can be stored in dams or can be used directly for irrigating small or medium plots. Normally the larger amounts of this sewage water were produced in cities, where it is very difficult to be reused.

### 2-2-2 Egypt

Sewage waste water in Egypt was estimated at 2.5 billion m<sup>3</sup>/year and expected to reach 5.5 billion m<sup>3</sup> by the year 2025. This latter quantity represents 10% of Egypt annual share from the Nile Agreement between Egypt and Sudan. The State has already started establishing treatment plant, so as to reuse the treated water directly for agriculture, or discharge it on water courses without causing harmful impact to the environment. Because of the growing water scarcity in Egypt, they endorse a strategy among which is the increase of water use efficiency through a set of different measures that include: Improvement of main irrigation network, increasing the on-farm efficiency, obtain the maximum benefit from any drop of water, and reuse of waste water in a safe environment. The Egyptian ministry of public works and water resources plan to use the sewage treated water to reclaim about 90 thousand hectares.

One of the very important existing projects for wastewater treatment is in Great Cairo. A plant in Zaneen area (capacity 330 thousands m<sup>3</sup>/day) and Abu Rawash (1.5 million m<sup>3</sup>/day) and Aljebel Alasfar. The quantity of reused waste water was estimated at 1.7 billion m<sup>3</sup>/year, and expected to reach 2.4 billion m<sup>3</sup>/year by the year 2010.

### 2-2-3 Libya

The techniques for waste water treatment in Jamahiria were used since early sixties, by installing the first plant in Tubruk in the 1963, followed by constructing an appreciable number of plants to achieve two main purposes that include:

1. Protecting the environment and eliminating or minimizing the negative impact of the polluted water to public health and natural resources.
2. Providing a water source (non-conventional) which suffices part of water required for agricultural purpose as well as providing support to the available water resources, which is subjected to excessive use.

During the last three decades, Libya has witnessed an increase in its population, together with an increase in their income. This required the construction of an intensive

infrastructure that includes: water supply system for the provision of drinking water, the systems for collecting and treating waste water, which are spreading over more than 50 cities and villages. The capacity of the waste water treatment plants has increased from about 31 thousand m<sup>3</sup>/day in 1970 to about 446 thousand m<sup>3</sup>/day as can be seen in Table 2.2 of Appendix II-2.

#### 2-2-4 Mauritania

Data concerning produced, treated or re-used wastewater in Mauritania are not available. Also data concerning the existing drinking water use per capita are not available. However based on WHO specifications, 50 litres per capita per day, the drinking water consumptions are predicted and shown in Table 2.3 of Appendix II-2. The prediction has been based on 1998 population estimates of 2.9 million and annual demographic growth rate of 3%.

It is clear from Table 2.3 of Appendix II-2, that the consumed drinking water in 25 years from now will be around 100 million m<sup>3</sup>/year. Taking the % urban of the year 1998 (54%) the drinking water for urban will be about 55 million m<sup>3</sup> and about 40 million m<sup>3</sup>/year may be produced as wastewater.

#### 2-2-5 Morocco

During the last two decades, the increase in the annual demographic growth rate had lead to a considerable increase in water consumption per capita. Studies have shown that between 1990 and 2020, the available water per capital will be reduced to 51%, that is from 833 m<sup>3</sup>/h/year in 1990 to 441 m<sup>3</sup>/h/year in 2020. Also the irrigated areas will be reduced from 33.8 hectare/1000 persons in 1990 to 29.3 hectare/1000 persons in 2020. Thus water resources will be the most important factor that hinders the future agricultural production.

Re-use of wastewater for agricultural purposes has been practiced in Morocco for decades. The quantity of wastewater has increased from 48 million m<sup>3</sup> in 1960 to some 370 million m<sup>3</sup> in 1990. This quantity is expected to reach about 900 million m<sup>3</sup> by the year 2020. The main factors that lead to the increase of the wastewater can be summarized as follows:

- An increase in the urban growth by 4.4% per annum
- An increase in the domestic water supply per capita from 58 to 116 litre/day during the period 1972-1992
- An increase in water supply coverage from 53% to 79% during the period 1972-1992.

It is worth to mention that the untreated wastewater had been used in Morocco since a long time ago in agriculture. In 1992, about 60 million m<sup>3</sup> of untreated wastewater had been used to irrigate about seven thousands hectares in areas adjacent to some cities as shown in Table 2.4 of Appendix II-2.

#### 2-2-6 Sudan

Appropriate disposal of excreta, waste water and solid wastes is of fundamental importance for the maintenance of acceptable levels of public health in both rural and urban settlements. In the Sudan, the two most common excreta disposal systems are the pit latrines

and septic tanks. Pit latrines, made up by digging a well reaching the ground water table, are the cheapest and simplest small-scale on-site disposal systems. Depending on household size, a pit latrine can provide a good service for 15 to 25 years before getting full and replaced by a new pit. Because of their advantages, pit latrines are the most popular excreta disposal systems in the Sudan. In the septic tank system, the excreta is separated from the waste water in the septic tank while the effluent is passed to a well connected to the ground water table. The septic tank system is relatively expensive and used by the affluent only.

Two note worthy observations need to be pointed out here concerning waste water and particularly sanitation in the Sudan. The first one is the almost complete absence of sewage treatment and disposal facilities on large scale. The only facility available in the country is in Khartoum which serves an insignificant number of the city dwellers. The second one, which is probably a corollary of the first is that each household makes its own arrangement for sanitation facility (most probably a pit-latrine). Surprisingly enough, private provision of household sanitation proved a success. Household sanitation coverage in urban area is 74% while it is 50% in rural areas (1993 census). These figures compare very favorably with developing world coverage which were 72% and 49% for urban and rural areas respectively in 1990.

WHO standard for human water consumption is set at a minimum of 50 litres per capita per day. In 1993, the water consumption level in Sudan is considered to be 26.5 litres/person/day. The National Comprehensive Strategy of the country set a value of 160 litres/h/day on average for urban and 75 litres/h/day for the rural uses. For the projection of domestic water demand, it is assumed that Sudan will reach the WHO by the end of this year (2000) and this figure will be increased steadily to reach 120 litres/h/day (average of urban and rural) by the year 2025. Table 2.5 of Appendix II-2 shows the water requirements for human consumption.

Examining Table 2.5 of Appendix II-2, the waste water is expected to be more than 1.5 billion m<sup>3</sup>/year. Plans have to be prepared to get use of that considerable amount of water.

#### **2-2-7 Tunisia**

In Tunisia, the treated wastewater was estimated at 130 million m<sup>3</sup>/year. There exists about 54 plants for the treatment of wastewater. These plants location and their capacities are shown in Table 2.6 of Appendix II-2. In the year 2001, the treated wastewater will be about 152 million m<sup>3</sup>/year and the plants will be increased to 75 for the treatment of wastewater; and to 83 plants by the year 2006 and the expected treated wastewater will be around 180 million m<sup>3</sup>/year. More than 50% of the wastewater is produced at the capital of the Country.

#### **2-3 Re-Use of Wastewater in NASR for Agricultural Production**

Re-use of municipal wastewater is not a new concept. With the increase in water demand as population grows and the standard of living is going up, wastewater reuse in North Africa countries is getting an increasing role in the planning and development of additional water supplies. This is particularly important for the sub-region countries, since they have low rainfall, mostly seasonal and with erratic distribution. Use of wastewater for beneficial purposes such as irrigation has been practiced, although without control, in many countries of the sub-region.

**In Algeria** the use of wastewater for irrigation has been practiced since 1980, but because of the malfunctioning of the wastewater treatment plants, the irrigated areas are comparatively small with the produced wastewater. In Karma and Wahran an area of only five hectares was irrigated using wastewater simply treated in lagoons. In Marais, west of the Capital an area of 10 hectares of pulses had been irrigated. However in Constantine state an area of 2500 hectares had been irrigated using wastewater, because of water scarcity in this State. However still the reuse of wastewater for agricultural production in Algeria is still not legally recognized.

Since 1900, sewage water has been used **in Egypt** to cultivate orchards in a sandy soil area at ElO Gabal El-Asfar willage, near Cairo. The area gradually increased to about 2500 hectares. The effluent was refined to get rid of suspended matter before use to prevent as much human infection as possible.

In 1979, an agreement was signed between the authorities of the Egyptian Academy for Science and Technology and the general organization of Sanitary drainage for Greater Cairo, to carry out a comparative study at Abou Rawash on three types of sewage water for cultivating the desert on the borders of El-Giza Governate. Three types of sewage water were to be used: crude, semi-crude and totally reclaimed water.

Research on using water for irrigation in Egypt has shown the followings:

- There is no marked variations in soil texture after prolonged-up to 10 years – liquid sewage application; the soil was still sandy. The changes in soil texture from sandy to loamy sand only occurred in the top soils that were exposed to sewage water for up to 40 years.
- The % of  $\text{CaCO}_3$  decreased.
- Prolonged use of sewage water markedly increased organic matter content, which accumulated more in the top 25 cm, sharply decreasing with depth. After 70 years of sewage water application, the average organic matter content on the weighed volume basis through the profile did not exceed 1.33%.
- Applying sewage for up to 5 years led to decreased CEC (Cation Exchange Capacity) in the top layer, from 8.4 to 5.92 meq/100 g, due to washing out most amorphous and jelly materials from the virgin sandy soils. After that, CEC values gradually increased with sewage water use, reaching 16.82 meq/100 g with the accumulation of fine particles and organic matter.
- Using sewage water to irrigate navel orange groves through the year, increased growth density, average shoot lengths, leaf number per shoot, leaf area, fruit weight, peel thickness and fruit yield per tree. However, fruit juice content was slightly affected.
- The results showed that Fe, Mn, Zn, Cu, Cd, Co, Ni and Pb tended to accumulate to different degrees in the leaves, peels, and juice of navel oranges with prolonged sewage water use. Generally the leaves contained the highest level, followed by the peel; juice had the lowest level. With all the sewage water treatments

(10,20,30, 40 and 60 years) the level of both Fe and Cu in leaves was considered safe, while Mn levels proved deficient.

Finally, Abu Zeid have shown that water that could be saved either for rehabilitation programmes or from reusing agricultural drainage water or sewage treated wastewater could help Egypt satisfying a considerable part of its future medium-range water needs. However, caution should be taken when setting up programmes for the reuse of wastewater. The short or long term impacts of such programmes on soil properties and crop production should be carefully assessed.

**In Lybia**, the treated wastewater has been used for the production of fodders and the sludge has been used as a natural fertilizer. Also the treated wastewater is used to irrigate public parks as well as in some cases for the purpose of constructing roads. To use the wastewater optimally, some irrigation schemes around Tripoli (Elhadaba El Khadra Scheme), and Bengazi (Elgawarisha Shceme) can be considered as the largest schemes in the country irrigated with treated wastewater. Table 2.7 of Appendix II-2 shows the area and crops grown in these two schemes. The potential of treated wastewater in Lybia can irrigate an area of 30 to 40 thousands hectares.

**In Morocco** some research on using treated wastewater for agricultural production in Rabat, Ourzazat, and Agadir was carried out. The results of these research can be summarized as follows:

- An increase in Tomato production in Rabat area. The production per ha was 75 tons/ha when using treated waste water, where it was only 53.4 Tons/ha when using normal irrigation water.
- An increase in the productivity in some of the crops (Sorghum, Wheat, Tomato, and beans) by 70% in Ouarzazate area.
- The treated wastewater provided 40 to 95% of Nitrogen and 55 to 100% of phosphorus for the crops nutrients needs.

**Agriculture in Tunisia** faces acute problems of water quantity and quality caused by limited conventional water resources and projected future needs. Using wastewater is now an essential component of any policy of integrated water resource management. Such policy allows optimal water use and savings on organic and mineral fertilizers, while preserving or improving soil fertility, preventing surface or groundwater pollution and protecting the environment.

The authorities in Tunisia have decided to systemize the reuse of wastewater after being treated. However the present wastewater treatment plants provide only secondary treatments, with an evident lack of disinfecting equipment. Thus the agricultural reuses allowed are only restrictive irrigations (fodder crops, olive, trees and cotton). The more attractive irrigations (Public parks, sports fields, green spaces, and vegetable crops ...etc.) will not be allowed until efficient, reliable and cost effective disinfection techniques are available. The irrigated area using treated waste water was estimated at 6600 hectares. The distribution of this areas is shown in Table 2.8 of Appendix II-2.

## 2-4 The Existing Treatment Processes Used in North Africa Sub-Region

There exist several treatment processes in use at the North Africa Sub-region. The following quantify the treatment process in some countries of the sub-region:

1/ **Activated sludge:** The use of this method is so simple. The characteristics of the method are:

Retention time:	6-10 hours
BOD5:	0.8-2 kg/m <sup>3</sup>

2/ **Stabilization Ponds:** Also this method is simple and efficient.

Retention time:	30-60 days
Pond depths vary from	0.9 – 1.5 m and
BOD5 varies from	50-100 kg/hectare.

**Libya:** The technique used for wastewater treatment in Libya includes: Trickling Filters (TF), and Activated sludge (AS) methods. In the main wastewater treatment plants, secondary sedimentation and chlorination are used.

Figures 2.1 and 2.2 represent schematic diagrams for two main plants for wastewater treatment in Tripoli and Gerian respectively. According to the information available the followings can be noticed:

- The TF methods, their use is limited only to those plants which have been installed in the early 60s, while the AS technique is used in almost all of the available plants in the country.
- The design capacities of the different plants vary from 150 m<sup>3</sup>/day to 110,000 m<sup>3</sup>/day.
- When designing those plants, particular consideration was taken to use the treated wastewater for irrigation.
- The techniques used guarantee a very high % (may reach 99%) removal of the organic matter subjected to biological decomposition (BOD), when operated under suitable conditions.

**Morocco:** Wastewater treatment plants are available in most of the big cities in Morocco. The methods used for treating wastewater are AS, TF, and Stabilization ponds. Table 2.9 shows the no. of plants for the various methods or techniques used in Morocco.

**Table 2.9: Systems and No. of Plants for Waste Water Treatment in Morocco**

System	No. of Plants	
	Operating	Malfunctioning
Activated Sludge	13	5
Trickling Filters	5	6
Drying	-	3
Stabilization Ponds	10	4
Sedimentation-Digestion	2	13

**Tunisia:** Secondary treatment is usually practiced in Tunisia using the following techniques:

- Activated sludge
- Oxidation ditch
- Stabilization ponds
- Aerated lagoons
- Trickling filter.

Table 2.10 Summarizes the various techniques used for treating wastewater in the various countries of the subregion.

**Table 2.10: Wastewater Treatment Techniques Used in NASR**

Technique	Algeria	Egypt	Libya	Mauritania	Morocco	Sudan	Tunisia
1. Activated Sludge	X	N.A.	X	N.A.	X	N.A.	X
2. Stabilization Ponds	X	N.A.	X	-	X	-	X
3. Aerated Lagoons	-	N.A.	X	-	X	-	X
4. Trickling Filters	-	-	X	-	X	-	X
5. Oxidation Ditch	-	-	-	-	-	-	X
6. Chlorination	-	-	X	-	-	-	-

### **Cost of Treatment Waste Sewage**

Information regarding the cost of treated wastewater for the various countries of the sub-region are not available. However some relevant information for a country at least similar in culture to the countries of the sub-region were found in literature. This country is Bahrain.

The cost of treating sewage effluent, including chlorination, is about 0.4 US \$ per m<sup>3</sup>. When azonation is introduced, the cost will nearly double to 0.8 US\$ per m<sup>3</sup>. However, the cost rises fast when chemical treatment is added or reverse osmosis is used. In the first case, the cost will be between 0.18 US\$/m<sup>3</sup>, and the second about 0.56 US \$/m<sup>3</sup>. The latter is still low compared with the present international cost of desalinized water, which is more than 0.75 US \$/m<sup>3</sup>.



Appendix II-2-A shows the sewerage system of Khartoum (Sudan). This can represent a base for determining the cost of one unit of treating wastewater e.g. one cubic meter of treated wastewater. The cost may include the followings:

- Capital cost (pumps installation, construction of ponds, construction of the irrigation canals, ..etc.)
- Running cost (operation and maintenance).

## Chapter – 3 : Water Pollution

### 3-1 Sources of Pollution

Generally speaking, humans have been exposed to hazardous substances dating back to prehistoric times when they inhaled noxious gases from volcanoes and in cave dwellings. Pollution problems started in the industrial sector with the production of dyes and other organic chemicals developed from the different types of industry. Later, the variety of chemicals and chemical wastes increased drastically, particularly the wastes from petroleum refinery.

Sources of water pollution can be found all over the place. However, intensive agricultural, in particular, contributes to groundwater pollution with pesticides and, above all, nitrates from nitrogen fertilizers, for example. Municipal and industrial wastewater can also contribute to water pollution by impurities that include organic and non-organic chemicals, heavy metal compounds, salts, etc.. other sources of pollution included: landfills, wastewater disposal injection wells, septic systems, land application, and surface impoundments.

All wastewater productions affect, in some way or another, the normal life of a river or a lake or reservoir. When the effect is sufficient to render the river unacceptable for its 'best usage' it is said to be polluted. Best usage means the use of water for drinking, bathing, fishing and so forth.

Rivers and lakes can assimilate a certain amount of waste before reaching a polluted state, however pollution in any form causes a nuisance.

Inorganic salts are present in most wastewater as well as in nature itself. They can cause water to become hard and make a river more undesirable for certain agricultural and other usage. Acids and alkalis make stream unsuitable not only for recreational uses but also for propagation of fish and other aquatic life. Organic matter can exhaust the oxygen from rivers and lead to unpleasant tastes, odors, and to septic conditions. Fish and most aquatic life are stifled by lack of oxygen.

These are some important water quality parameters of concern when attempting wastewater treatment for recycling or reuse. However, the overall chemical composition of water can be adjusted by dilution or selective treatment.

### 3-2 Situation of Water Pollution on the Sub-region

Problems associated with water pollution in the countries of the sub-region were recent. The water pollution problems emerged as by products to the relatively highly accelerated urban, industrial and agricultural development. Programmes in the sub-region for water quality conservation were unable to match the rapid development of water resources of the sub-region. The problems of water pollution appeared on the surface as a subsequent of the recent drought episodes that occurred in the sub-region. This led to a serious decrease in the amounts of surface and groundwater with an adverse impact on water quality. The main causes of water pollution in the sub-region can be referred to the disposal of the followings into natural water resources:

- Urban wastewater
- Industrial wastewater
- Agricultural wastes;
- Others.

### 3-2-1 Algeria

In Algeria shallow aquifers in the country are subject to serious contamination from the surface water streams which act as drains to most of the sewage wastewater. Another sources of pollution to groundwater is from infiltration of irrigation water which is rich in nitrates derived from fertilizers. Examples are found in Mitidja plain in southern Algeria, and Sidi Bel Abbas and Saida, where the nitrate exceeds 50 mg/l. Scanty information on water pollution is available, due mainly to inadequate monitoring network.

### 3-2-2 Egypt

Drainage water from agriculture in Egypt is huge and may exceed 13 billion m<sup>3</sup>/year. This drainage water flows into drains running through canal tail-escapes. Analysis of data collected since 1977 (Abu Zeid 1988) for the drainage water revealed the followings:

- About 80% of the drainage water discharged into the sea had a salinity below
- Actual concentrations vary between 400 and 500 ppm.
- The highest salt concentrations were found in the western part of the Delta and locally in the eastern part, mainly because of soil salinity, and the lowest figures were found in the central part.
- Drainage water salinity increases from the southern to the north part of the delta, due to variation in soil texture and sea water intrusion. The salinity of most drains south contours (3) and (8) (mid delta) reaches 1500 ppm. In northern delta areas, it may exceed 3000 ppm.
- The quality of drainage water varies throughout the year at every location. Concentrations reach their maximum values in January and February because of the closure period when irrigation releases are at a minimum; and during June, July and August (peak water requirement period), when evaporation and evapo-transpiration are at a peak. Such concentrations are minimal during March, April and May, due to weather conditions for the period (1980 – 86) are given in Table 3.1.

*Table 3.1: Quality of Wastewater in Egypt*

Salinity (ppm)	Discharge (billion m <sup>3</sup> )	%Discharge/ Total Discharge	Cumulative Discharge %
1000 or less	1.859	14	14
1000 – 1500	4.862	36	50
1500 - 2000	2.584	19	69
2000 – 3000	0.801	6	75
3000 or more	3.528	25	100

The general criteria used by the ministry of public works and water resources (MPWWR) for reusing drainage water are as follows:

- Less than 700 ppm: used directly for irrigation
- 700 – 1500 ppm: mixed with canal water at a ratio of 1:1
- 1500 – 3000 ppm: mixed with canal water at a ratio of 1:2 or 1:3
- more than 3000 ppm: not yet used for irrigation

In general it can be said that water quantity of the Nile reach between the high Aswan Dam is reasonably good. However, in the Delta area the Nile water is semi-stagnant because of the dense algae growth. Also this water are polluted with organic compounds resulted from the discharge of untreated wastewater. Algae growth in the Delta areas lead to complicated problems, among which is the blocking of the irrigation canals.

### 3-2-3 Libya

In Libya excessive groundwater use has been witnessed which lead to continuous decline in groundwater table. Also sea water is intruding inland at a rate of 0.5 to 3km/year in Djefara plain. This lead to the increase in salinity from 1000 ppm to about 7000 ppm.

In Jabal al-Akhdar region, the groundwater aquifer is continuously subject to seawater intrusion and the salinity varies from 300 ppm to 600 ppm.

Pollution from wastewater was not reported and the quality of the treated wastewater is very reasonable as can be seen from Table 3.2.

*Table 3.2: Treated Wastewater Quality in Libya*

Parameter	Maximum limit	
	Secondary treatment	Tertiary treatment
BOD <sub>5</sub>	15	10
Suspended solids	20	10
Ammonia	5	

### 3-2-4 Mauritania

Water, particularly groundwater is exploited sporadically and without adequate management, especially the aquifers adjacent to the coastline of the country. In Idni basin which is located near the Atlantic ocean, is used to supply domestic water for the capital Nouakchott. Authorities were obliged to close some of the operating wells in the basin because of sea water intrusion.

### 3-2-5 Morocco

Eutrophication in some of the reservoirs was noticed because of the disposal of untreated wastewater (Kenitra and Masira dams on Um El rabei valley). Salt water intrusion prevails in most of the coastal areas. Considerable contamination of shallow wells takes place, due to infiltration of irrigation water in which the nitrate content exceeds 50 ppm.

### 3-2-7 Sudan

Data concerning water quality in Sudan are rarely available. Even the available data are found in scattered institutions. The main concern, is the data on sediment concentrations and quantities. This is because of the problems created by the sediment carried by water during the flood seasons of the rivers originating from the Ethiopian plateau, particularly the irrigation difficulties and frequent interruptions in the hydropower supply. Sediment concentration may reach 30000 ppm. Data on surface water quality are limited to the White Nile and the Blue Nile at Khartoum.

The groundwater in Sudan, does not constitute a major water resources, as compared to the prevailing surface water, except in remote areas away from the Nile river and its tributaries. Therefore, little attention has been given to the groundwater problems.

### 3-2-7 Tunisia

Eutrophication can be noticed on Sidi Salim dam at Midjarada. Surface water salinity varies from 2000 ppm to 3000 ppm. The eutrophication phenomenon is mainly a result of disposing untreated wastewater on surface water. Accordingly Tunisian authorities set standards for discharging the wastewater as shown in Table 3.3.

The groundwater salinity varies between 500 ppm and 1500 ppm in the shallow aquifers, and between 1500 ppm and 8000 ppm in the deep aquifers. As a result of excessive water use, the groundwater levels decline in localized areas. Also salt water intrusion in some coastal areas at the north and east of the country are noticed. Salinization and alkalization of the irrigated lands have been observed in the Gayrawan plain and other places in Tunisia.

**Table 3.3: Tunisian Wastewater Discharge Standards**

Parameter	Limits (not greater than)Mg/l
<b>PH</b>	8.5<pH<6.5
BOD%	30
COD	90
Suspended solids	30
Chlorine	600
Florin	3
Cl <sub>2</sub> O	0.05
<b>Sulfate</b>	500
Sulfur	0.1
Nitrates	50
Nitrites	0.5
Nitrogen	1.0
Cadmium	0.005
Aluminum	5.0
Chrome	0.1
Copper	0.5
Iron	1.0
Manganesec	0.5
Magnesium	200
Potassium	50
Sodium	300
Mercury	0.001
Nickel	0.2
Silver	0.05
Lead	0.1
Tin	2.0
Selenium	0.05
Cyanide	0.05
Cobalt	0.1
Barium	0.5
Arsenic	0.05
Zinc	5.0

Source: El atairi, R. and Elgharbi, N. 1999. Reuse of Wastewater in Agricultural Production. Tunisia country report prepared for AOAD

## **Chapter – 4: Main Constraints to Re-Utilization of Recycled wastewater for Agriculture**

### **4-1 Environmental Constraints**

Though treated wastewater is of beneficial for agriculture however, there are some principal environmental hazards associated with wastewater. These hazards are as follows:

#### **4-1-1 Soil Hazards**

The main soil problems that can be encountered from using wastewater in irrigation may include: Salinization; Alkalinity and water permeability; Accumulation of potentially elements; and Accumulation of nutrients

#### **4-1-2 Pollution of Groundwater**

Although effects on groundwater are under certain conditions more important than effects on soil, the farmers take no sufficient care. Pollution of groundwater with constituents present in wastewater is very common. However, some management aspects need to be followed by farmers to reduce such an impact.

#### **4-1-3 Eutrophication and Growth of Algae on Surface Water**

This is mainly occurred if untreated wastewater or badly treated wastewater are disposed on lakes of the dams, because of N and P available in the wastewater. Under such conditions, blooming of green algae is very common and the problems associated, particularly clogging of modern irrigation systems, is difficult to overcome. The latter is one of the main concerns for the farmers.

#### **4-1-4 Effects on Crops, Phytotoxicity Problem and Management**

Besides the overall effect of certain characteristics of wastewater to the irrigated crops like salinity, the wastewater potentially may create plant toxicity due to high concentration of certain elements like B and some heavy metals. Necrotic spots on the leaves recognize the symptoms of B toxicity in sensitive crops.

#### **4-1-5 Human and Animal Health Problems**

Using of bad quality treated wastewater will jeopardy the health of human and animals as well. Protection measures as discussed in chapter 1 for the different disciplines have to be highly considered.

### **4-2 Social Constraints**

Wastewater, as a resource, is often not utilized by many of the communities, or even considered for reuse, for many reasons that include:

- Lack of information about its benefits
- Fear of health risk involved
- Cultural bias;

- Lack of a method for comprehensive economic analysis of reuse projects;
- Poor experience with wastewater reuse where it has been practiced under uncontrolled conditions.

#### **4-3 Regulatory and Legal Constraints**

Public health and environment are the main concerns in reuse projects. In this respect quality guidelines as well as requirements for treatment, sampling and monitoring are essential in each country. In a number of countries, strict control measures are imposed on reuse. In this way farmers are obliged to act within the framework of these regulations in order to safeguard public health and the environment. However, how well the farmers respect the regulations is questionable. Strong monitoring is essential. Moreover, legal authorization to enforce compliance with the regulations might be needed.

However in most of the countries of the sub-region the water sector laws fragmentation is evident. Overall review of law that adopt to the changing conditions in the water sector foster a greater public involvement and deal with externalities, dispute and third-party effects, are essential for better management of water resources and of particular the management of wastewater.

#### **4-4 Technical and Economic Constraints**

In Algeria 70% of the treated wastewater plants are not functioning. This is a clear indication that there is a lack of know how and hence the lack of the well trained personnel for operating and maintaining these facilities to function properly. Besides, the treated wastewater need large investments for the construction of dams to store this water.

In most of the countries of the sub-region, the treatment plants are at far distances from the lands suitable for irrigation. This also needs investment to transfer the treated water to where it is needed. The followings can also be considered as important factors:

- Mismatch between the peak requirements of crops and the volumes of treated wastewater, thus leading to a greater part of this water being unused.
- Impurities associated with the treated wastewater which cause damages to the irrigation systems.
- Lack of untrained skills and farmers.

#### **4-5 Institutional Constraints**

In almost all the countries of the sub-region there exist a large number of public institutions responsible of water management. Coordination between these institutions in many cases is weak or may not exist. There is a lack of clear definition of responsibilities for each institution. This lead to situation whereby some functions are conducted by more than one institution while others may not be covered by the mandate of any institution. For example in Sudan, while several institutions may be involved in irrigation water distribution and use, no institution is responsible for water quality monitoring or environmental protection.



## **Chapter – 5: Sub-Regional Plan of Action to Enhance the Use of recycled Waste Water for Irrigation**

### **5-1 Objectives**

The objectives of the action plan are to:

- Prepare country reports on wastewater present and future situation in order to outline a systematic approach to plan for treatment and reuse of wastewater, so that authorities involved can make sound preliminary judgements about the local feasibility of reuse.
- Create awareness regarding the use of treated wastewater in agriculture in the countries of the sub-region.
- Provide education and training to improve human capacities in water resources management.
- Promote and strengthen hydraulic, hydro-meteorological information exchanges.

### **5-2 The Action Plan**

The sub-regional plan is proposed to address the followings :

- Preparation of countries' studies on wastewater potential and reuse.
- Organization of a sub-regional workshop on Methods and Techniques to enhance the reuse of wastewater on North Africa sub-region.
- Capacity building in integrated water resources management.
- Community participation

#### **5-2-1 Preparation of Countries' Studies on Wastewater Potential and Reuse**

The primary task of these studies, is to locate, study and quantify the potential sources of wastewater for reclamation and reuse and potential markets for this reclaimed water. Also it is important to identify institutional and legal constraints and also identify organized groups of people who may affect the overall implementation of the project. The country study is expected to cover the following issues:

- The current wastewater available and the available wastewater treatment plants.
- The potential demand for the treated wastewater and the available land for irrigation.
- The public health considerations associated with reuse and how these can be addressed.
- Assessment of the environmental impact of the reuse.
- Assessment of laws and/or regulations, institutions affecting reuse of treated wastewater.
- Identification of crops suitable to be irrigated by the treated wastewater.
- The present and projected future cost of fresh water and wastewater.

- The specific water quality requirements for each use in case that more than one water quality is required and/or adapted. Also what quality fluctuations can be tolerated
- Can the fluctuations in production of effluent and demand for irrigation best be met by storage and where such facilities could be located.
- What will be the best to the farmers to be connected to the delivery system and which incentives are anticipate?
- Will use of reclaimed water force the farmers existing already in the area to adopt the existing irrigation patterns and irrigation system?

Surely most of those questions mentioned above could be answered only with the appropriate authorities and the farmers. The outcome of these studies are:

- Set standards of wastewater quality through integrated set of measures including incentives to encourage its reuse for agriculture.
- Preparing proper national and sub-regional programmes for fostering the reuse of wastewater among farmers.
- Preparing a simple users' manual for the use of wastewater to be used by farmers.

National experts can prepare the Country's Studies. ECA can nominate two experts from each country to prepare such reports with terms of references as outlined above. A lump sum of 1000 US \$ has to be paid for each country report providing the reports have to fulfil the terms of reference.

#### **5-2-2 Organization of a Sub-Regional Workshop on Wastewater Treatment and Reuse, Future Opportunities**

The main objectives of this workshop are anticipated as follows:

- To bring together experts from North Africa sub-region, international experts and external support agencies to address specific topics related to the treatment and reuse of wastewater in the sub-region
- To discuss options for cooperative and institutional framework, and to come up with agreed upon sub-regional programmes for enhancing the reuse of treated wastewater.
- To enable participants to share experiences, and exchange information related to the development and reuse of wastewater for agricultural purposes in the sub-region and worldwide.

The sub-themes of the workshop can be as follows:

- The current situation of reuse of treated wastewater in North Africa sub-region.
- International and regional trends in the techniques used to treat wastewater.
- Appropriate irrigation techniques and criteria for crop selection for the optimum use of treated wastewater.

A 3-day Workshop can be organized by ECA. It can be held in Morocco, or Tunisia or Egypt. Each country in the Sub-region can be presented by a delegate of two members and have to represent their country study at the workshop. Experts from leading countries in reuse of treated wastewater from the sub-region or other countries can be invited to present key papers on each sub-theme. Organizations of relevance can also be invited.

The host country has to cover the cost of hotels and local transport during the period of the workshop. ECA has to pay the air tickets and pocket money. The expected total cost is estimated at 30,000 US \$.

### **5-2-3 Capacity Building in Integrated Water Resources Management**

The main issue here is to train skills in the field of all aspects of wastewater management. Since lack of skills and knowledge can cause failure in the implementation of the project. The training program has to include the following aspects:

- Promoting Environmental Education and Training in NASR Sub-region.
- Strengthening Water Pollution Control in NASR sub-region by establishing institutional arrangements for pollution control, promote networking in environmental pollution control, develop a data base and an early warning system for pollution control.
- Support member states in promoting the use of treated wastewater in agriculture.

### **5-2-4 Community Participation**

Reuse of wastewater in some countries of the sub-region (e.g Sudan) may present a new approach. Therefore, special care should be taken to provide information and education programmes for the users (farmers), because misuse of wastewater can lead to repugnance.

A well organized public information campaign should be planned as a means of making the public aware of the issue. Its primary objective will be to raise collective consciousness and to present wastewater reuse as a reliable substitution technique. It should also make the potential users aware of the facts related to wastewater reuse. Farmers and the public in general should be aware not only of benefits, which will result from reuse but also of environmental and health hazards connected with wastewater use. The information campaign should result in removal of cultural and psychological bias linked with wastewater.

Table 5.1 summarizes key areas where human community participation can be enhanced, as well as the objectives and means for implementation.

## Chapter – 6: Conclusions

This study have shown that many of the countries of North Africa sub-region are reaching the limit of their available water supplies. Also the sub-region is very vulnerable to high variation and unreliable rainfall, which lead sometimes to huge food gaps. Droughts in the sub-region are frequent and severe; and the mitigation of their pervasive effects will be a crucial element in food security, sustainable economic recovery and future development. As population increases, more people are at risk and the progressive exploitation and degradation may endanger the natural resources base, particularly by inserting more pressures to the water resources.

International indicators show that, water scarcity can prevail in countries where water uses exceed 40% of available water resources. Causes leading to this scarcity differ from real scarcity to hidden scarcity, that is, (i) all economically feasible water resources are exploited, and what remains is either technically or economically impossible to exploit; (ii) knowledge concerning the development of water resources is limited or absent; and (iii) water resources are available, but do not meet requirements (e.g polluted). Other indicators of water scarcity are the water scarcity indices, which show the levels of water stress.

Four levels of water stresses are identified:

- (1) Low water stress: countries using less than 10% of their available water resources, do not experience pressures on their water resources.
- (2) Moderate water stress: countries using between 10-20% of their available resources, water is becoming a factor which is limiting development.
- (3) Medium to high water stress: countries using between 20 –40%, of their available water resources, here careful management is needed to ensure sustainability of uses. Competition between sectors have to be solved.
- (4) High water stress: countries using more than 40% of their available water resources, indicates a position of scarcity. Here alternative sources of water have to be developed, and attention must be given to the management and demand styles.

*Part I* of this study has shown that all the countries of the sub-region, except Algeria, have far exceeded the 40% of their available water resources being used for various purposes. Under these conditions, alternative sources have to be developed, and urgent attention must be given to the intensive management to the resources and the demands made on it.

Part I has also shown that the sub-region is very vulnerable to high variation and unreliable rain. And agricultural drought occurs as insufficient water supply to cover crop or livestock requirements. This part of the study reviewed the practices to combat drought that include: water harvesting techniques, supplementary irrigation in rainfed areas, reforestation, crop management factors, water supply management, expansion of the irrigated areas, improve the productivity of water use and using saline water for irrigation. This part of the study ends up with proposing strategies that included: encouraging the use of water harvesting techniques, increasing the efficiency of water use in agriculture, developing the non-conventional water resources, development of measures for catchment areas management,

establishing a network of database and updating information on water resources, enhancing the cooperation between the countries of the sub-region, creating a favorable environment for the private sector to invest in water development; encouraging research, and developing appropriate institution and/or making reforms for the existing ones.

*Part II* of the study deals with the present and future re-utilization of wastewater in the sub-region. The following remarks can be concluded:

- There exists a marked indicative potential of wastewater productions in the countries of North Africa sub-region. The magnitudes of these productions vary from country to country. However, these productions whether the existing ones or the potential are not precisely quantified and characterized.
- Information regarding the existing network of waste water treatment are hardly available for all the countries of the sub-region.
- Information and data regarding the use of treated waste water also are not available in many of the countries of the sub-region, even for other countries of the sub-region which have, such information and data are not complete.
- There exist several constraints facing the reuse of wastewaters. These constraints can be categorized as those related to human, institutional, technical know-how, social, economic and environmental constraints.
- Wastewater has been reused for irrigation in the sub-region for sometime. However, the effects of reuse on public health and the environment, as well as socio-economic analysis of reuse, have not been sufficiently monitored.
- Standards and codes of practice for using treated effluent for irrigation have to be developed and established for each country.
- There is a need for training of skills in the areas of operating and maintaining wastewater treatment plants and training of farmers on the reuse of wastewater for irrigation.
- Laws and regulations, and institutions involve on water management, all need to be developed or amended to cope with the reuse of treated effluent.
- Raising public awareness and promoting health and education components should be included in reused projects.

A sub-regional plan of action to enhance the use of treated wastewater is proposed. The components of the action plan are:

- preparation of Countries' Studies on Wastewater Potential and Reuse
- Organization of a Sub-regional Workshop on Wastewater Treatment and Reuse, Future Opportunities.
- Capacity Building in Integrated Water Resources Management.

# ANNEXES

## **APPENDIX A**

### ***SEWERAGE SYSTEM IN KHARTOUM***

#### **A-1 Soba Sewage Treatment Plant**

The sewerage system in Khartoum consists of sewers gravity main, raising mains, pumping stations and sewage treatment plant at Soba. The sewer network of Khartoum is as shown in Fig. A-1. The system covers the design service area of 1175 ha, and the design service population of 72200 inhabitants.

The following flows relating to the design of the plant area are as follows:

- Design flow: 31429 m<sup>3</sup>/day (daily average)
- Domestic: 12620 m<sup>3</sup>/day
- Commercial and public facilities: 14300 m<sup>3</sup>/day
- Industrial: 4500 m<sup>3</sup>/day

#### **A-2 Capacity**

- Daily average sewage flow: 31429 m<sup>3</sup>/day
- Hourly maximum sewage flow: 2880 m<sup>3</sup>/hr

#### **A-3 Influent Sewage Quality**

- Biological Oxygen Demand (BOD<sub>5</sub>): 300 mg/l
- Suspended Solids (SS): 350 mg/l

#### **A-4 Effluent Quality**

- BOD<sub>5</sub>: 45mg/l
- SS: 75mg/l

## **A-5 Type of Treatment**

The waste stabilization pond process has been adopted for the Soba sewage treatment plant. The basic units required for this process are listed below:

- Pumping station
- Receiving well and screen
- Anaerobic pond
- Facultative pond
- Maturation pond

## **A-6 Process Description**

The major treatment processes which occur in waste stabilization ponds are:

- 1- reservoir effect, enabling ponds to absorb both organic and hydraulic shock loading
- 2- primary sedimentation, allowing settleable solids to sink to the benthal sludge layer.
- 3- treatment of the organic waste by aerobic bacterial oxidation (in the presence of oxygen) and anaerobic digestion (in the absence of oxygen).

## **A-7 Process Design**

The specifications performance requirements for the individual units are set out in the specification and the layout as shown in Table A-1, and Fig. A-2, and A-3.



**Table A-1: Capacity Calculation of the Sewage Treatment Plant of Soba at Khartoum (Sudan)**

Description	Items	Calculations of Capacity
Lift Pump Station	Design flow	Hourly max. $2,880 \text{ m}^3/\text{hr}$ $= 48.00 \text{ m}^3/\text{min}$
	Number of pumps	5 units (existing 2 pumps are for spare)
	Pumping capacity	$16.3 \text{ m}^3/\text{min}$ ... 3 (units) New $26.8 \text{ m}^3/\text{min}$ .. 2 (units) existing
	Pumping head	12.0 m
	Pump specification - New	Vertical mixed flow pump (installed at dry pit) 350 mm dia x $16.3 \text{ m}^3/\text{min}$ x 31.0 m x 132 kw x 3 units
	- Existing	Submersible pump (installed at wet pit) 600 mm dia x $26 \text{ m}^3/\text{min}$ x 20.0 m x 151 kw x 2 units
Screen	Type	Hand-ranking fine screen
	Angle of inclination	60 degree
	Spacing	20 mm
Anaerobic pond	Structural dimension	(W) 1.0 m x (h) 2.0 m x 2 units
	Design flow	Daily average: $31.420 \text{ m}^3/\text{day}$ $= 1,309 \text{ m}^3/\text{hr}$
	Influent quality	BOD 300 mg/l, SS 350 mg/l
	Influent BOD load	$31,420 \times 300 / 1000$ $= 9.426 \text{ kg/day}$
	Monthly average Lowest water temp	20 deg.C (22-23 deg.C.: Monthly average lowest atmospheric temp.)
	BOD load	$0.25 \text{ kg-BOD/m}^3/\text{day}$ .
	Required capacity	$9,426 / 0.25 = 37.700 \text{ m}^3$
	Water depth	3.0 m

	Required hydraulic surface	$37,700 / 3.0 = 12,566 \text{ sq.m}$
	Structural dimension	(1) 174 m x (w) 100 m x (h) 3.0 m x 4 (2 spares) units
	Effective capacity	$= 174 \times 100 \times 3 \times 2$ $= 104,400 \text{ m}^3 > 37,700 \text{ cu.m}$
	Effective hydraulic surface	$= 174 \times 100 \times 2$ $= 34,800 \text{ sq.m} > 12,566 \text{ sq.m}$
	Retention time	$104,000/31,420 = 3.30 \text{ days}$
	Removal rate of BOD	50%
	Removal rate of SS	70%
	Effluent quality	BOD : 150 mg/l SS : 105 mg/l
Facultative Lagoon	Design flow	Daily average : $31,420 \text{ m}^3/\text{day}$
	Influent quality	BOD : 150 mg/l
	Influent BOD load	$31,420 \times 150 / 1000$ $= 4,713 \text{ kg/day}$
	Monthly average lowest water temp.	80 deg.C
	Hydraulic surface load	$s = 20 \text{ T-60} = 20 \times 20 - 60$ $= 340 \text{ kg-BOD/ha/day}$
	Required hydraulic area	$A = 10 \times Li \times Q \times 1/s$ $= 10 \times 150 \times 31,420 \times 1/340$ $= 138,600 \text{ sq.m}$
	Effective water depth	1.20 m
	Structural dimension	(W) 240.0 m x (L) 785.0 m x (H) 1.20 m x 2 $= 376,800 \text{ sq.m} > 138,600 \text{ sq.m}$
	Effective capacity	$376.800 \times 1.20 \times 452,160 \text{ m}^3$

Maturation Pond	Retention time	452,160 / 31,420 = 14.4 days
	Design flow	Daily average: 31,420 m <sup>3</sup> /day
	Number of colifora in influent	2 x 10 <sup>7</sup> /100ml
	Monthly average lowest atmospheric temp.	22 deg.C
	Number of colifora in treated water	$Be = \frac{Bi}{1+KB(T)xt}$ $KB(T) = 2.6 \times 1.19^{(T-20)}$ $= 2.6 \times 1.19^{(22-20)}$ $= 3.68$ $Be = \frac{Bi}{(1+KB(T)xtan) \times (1+KB(T)xtfac) \times (1+KB(T)xtemt)}$ $tan = 2.0 \text{ days} \quad tfac = 12.0 \text{ days}$ $tmet = 3.0 \text{ days}$ $Be = \frac{2 \times 10^7}{(1+3.68 \times 2.0) \times (1+3.68 \times 12.0) \times (1+3.68 \times 3.0)}$ $= \frac{2 \times 10^7}{8.26 \times 45.16 \times 12.04} = 4,400 \text{ FC/100ml}$
	Structural dimension	Existing: W 240 m x L 220 m x H 1.2 m x 2 units
	Retention time	240 x 220 x 1.22 x 2 / 31,420 = 4.0 days

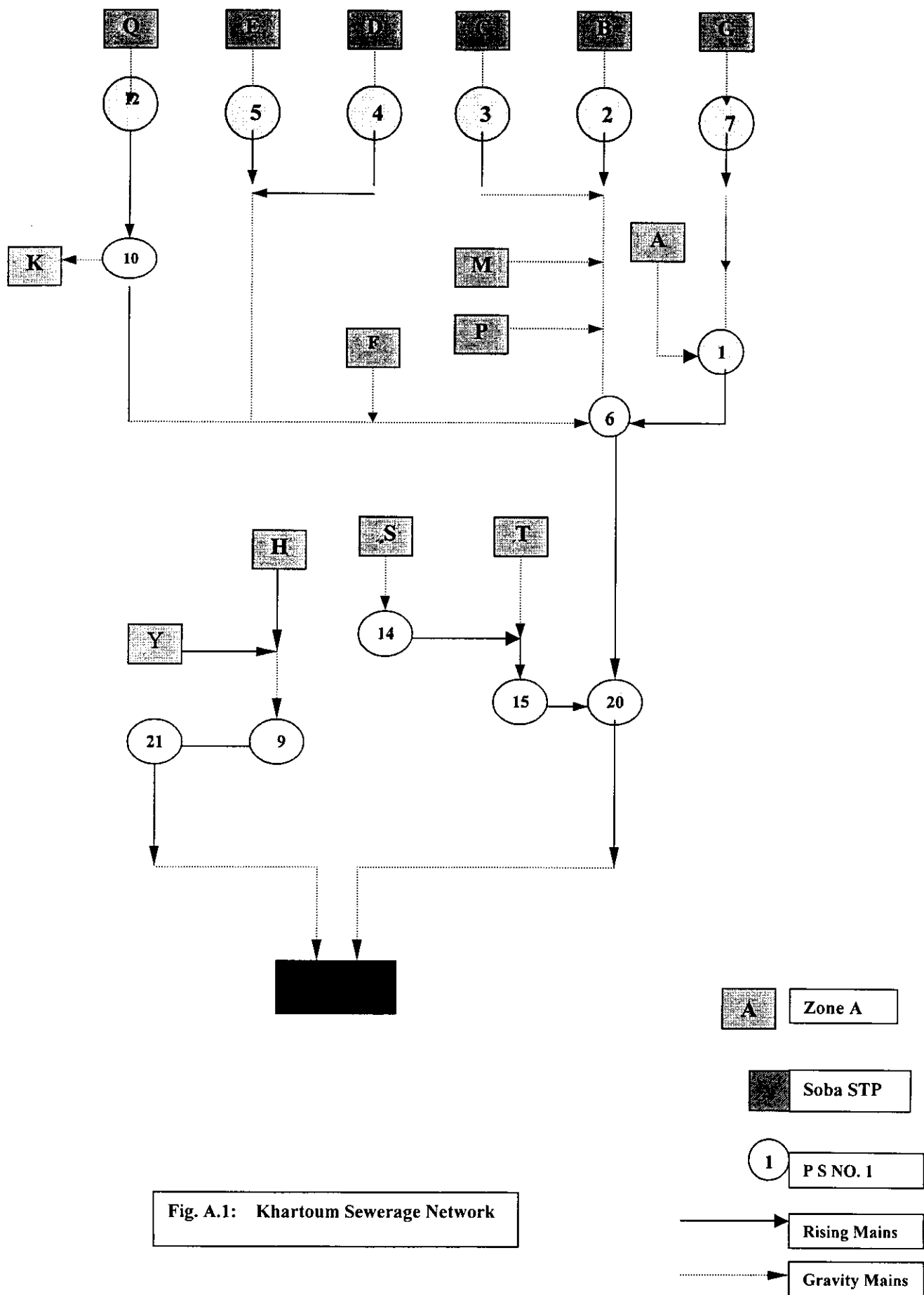


Fig. A.1: Khartoum Sewerage Network

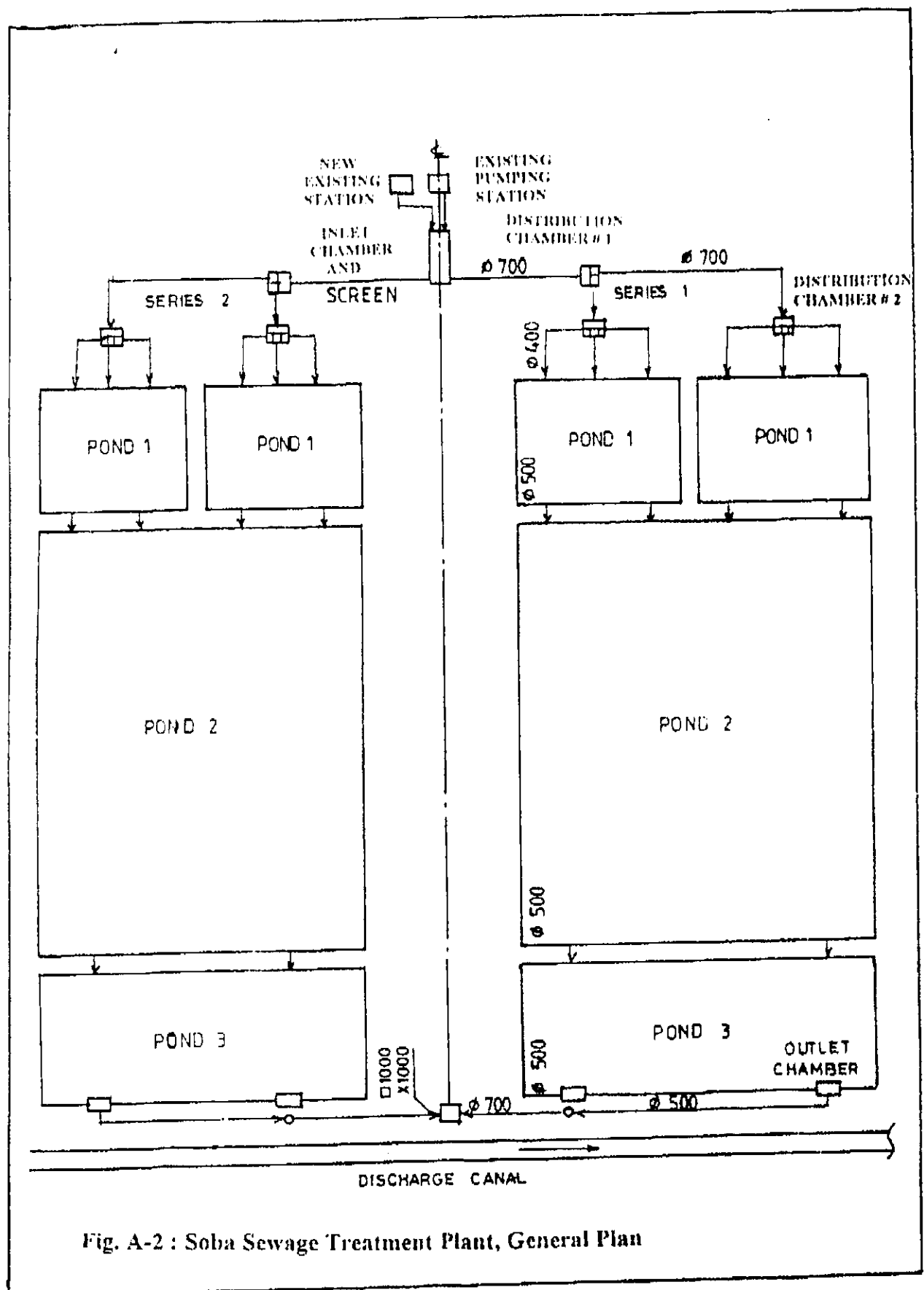


Fig. A-2 : Soba Sewage Treatment Plant, General Plan

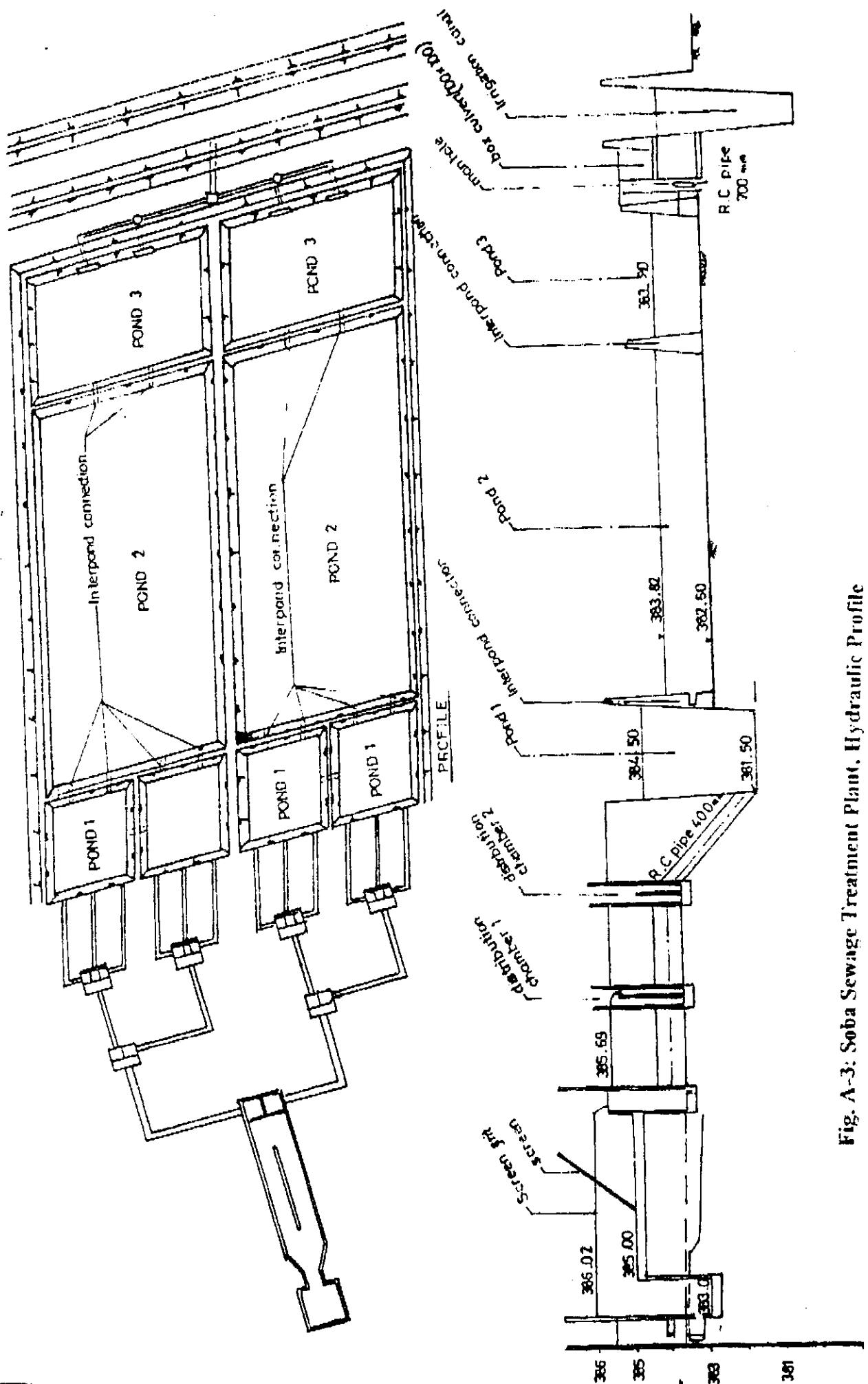
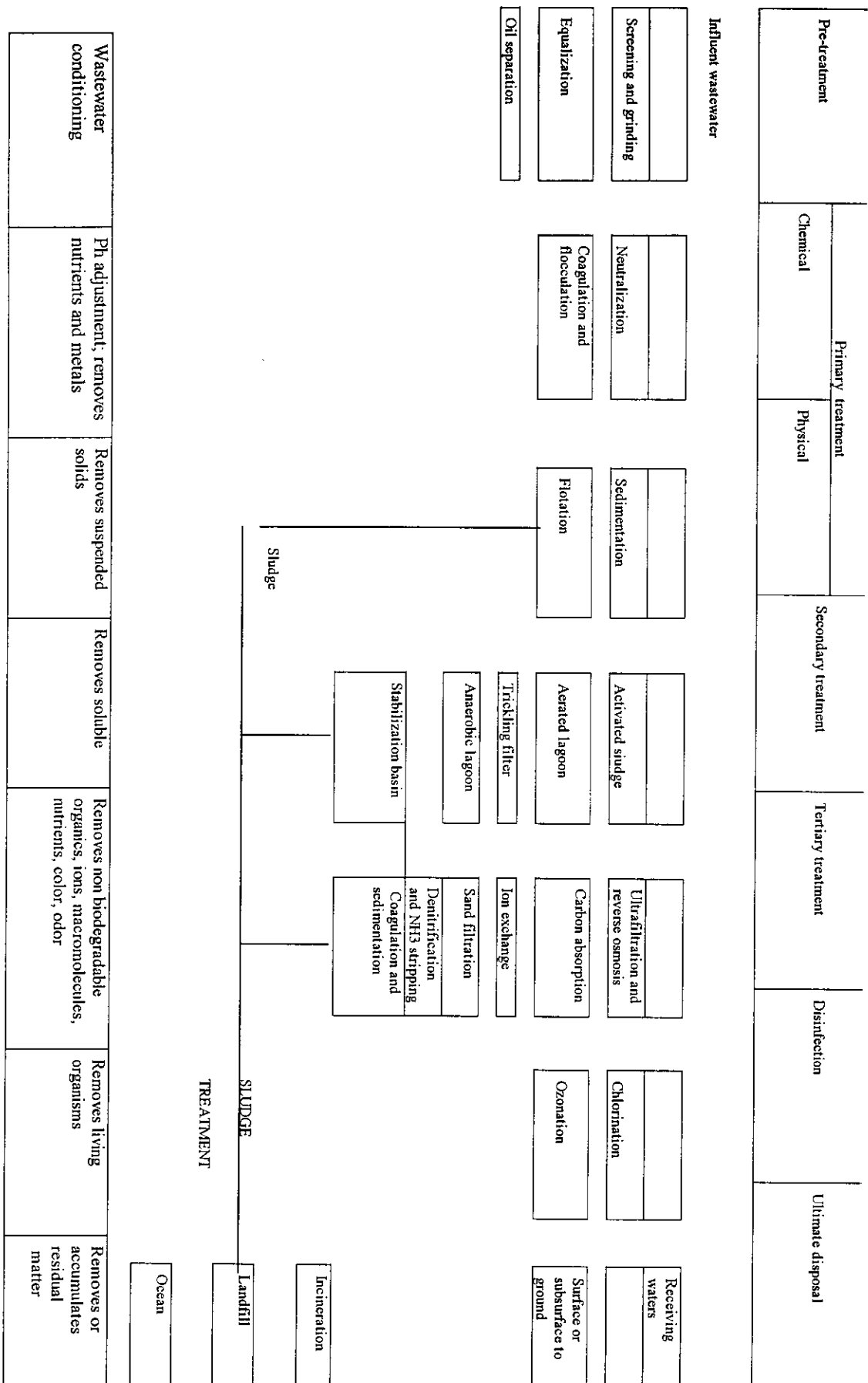


Fig. A-3: Soba Sewage Treatment Plant, Hydraulic Profile



## APPENDIX II-1

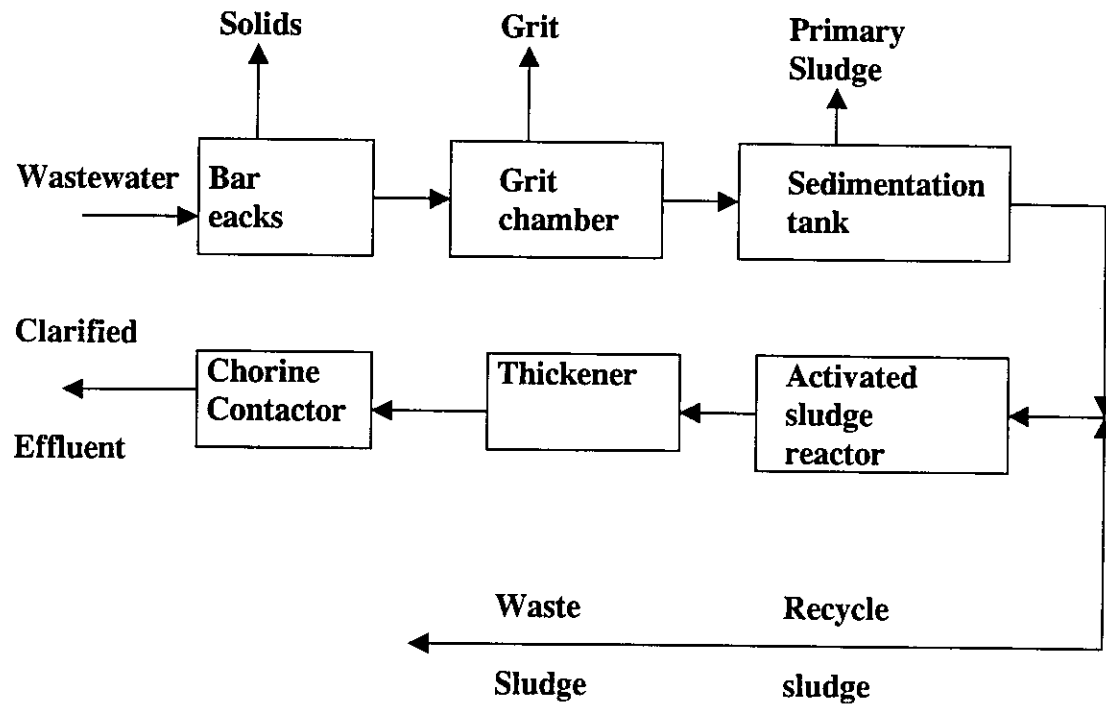
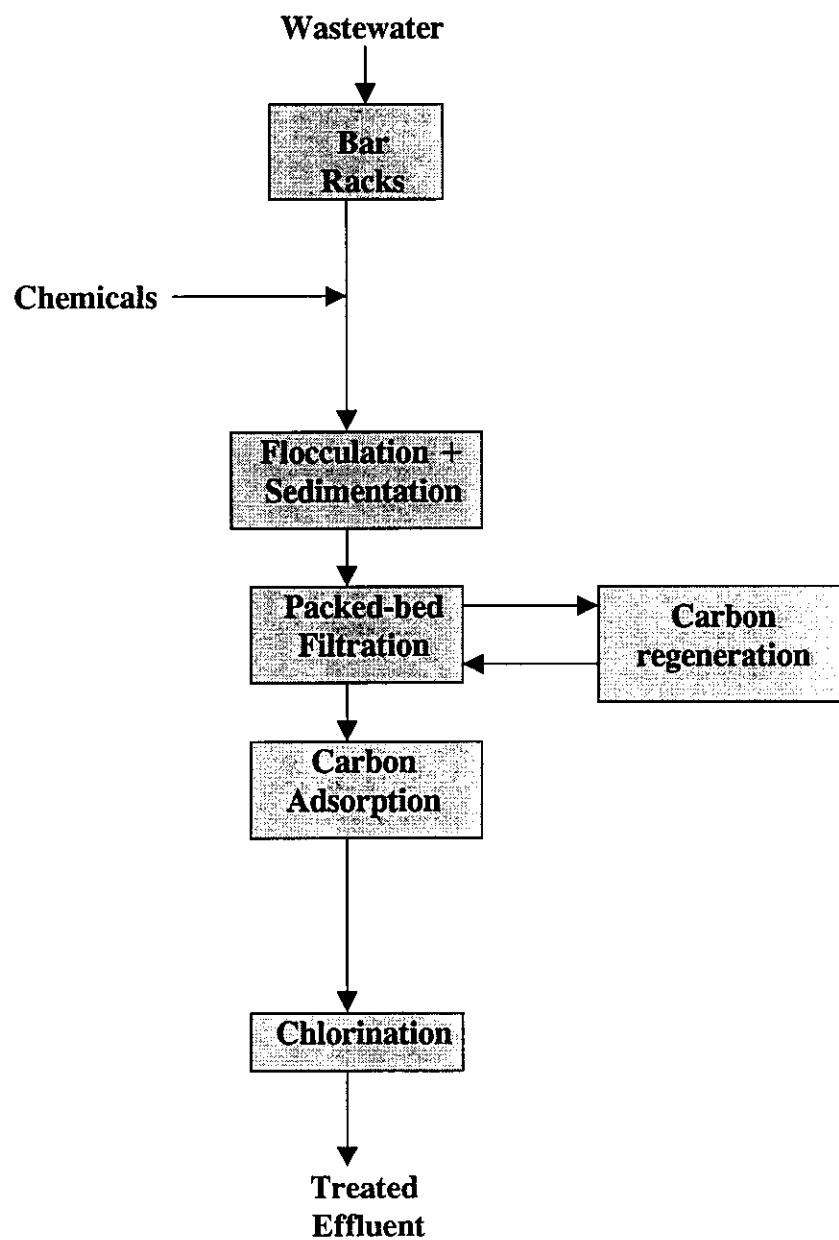
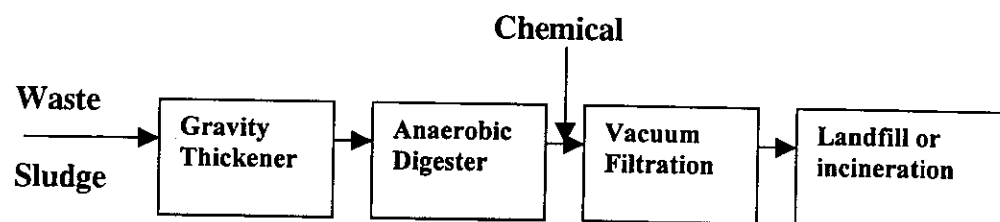


Figure 1.2: Typical Flowsheet of an Activated Sludge Treatment Plant



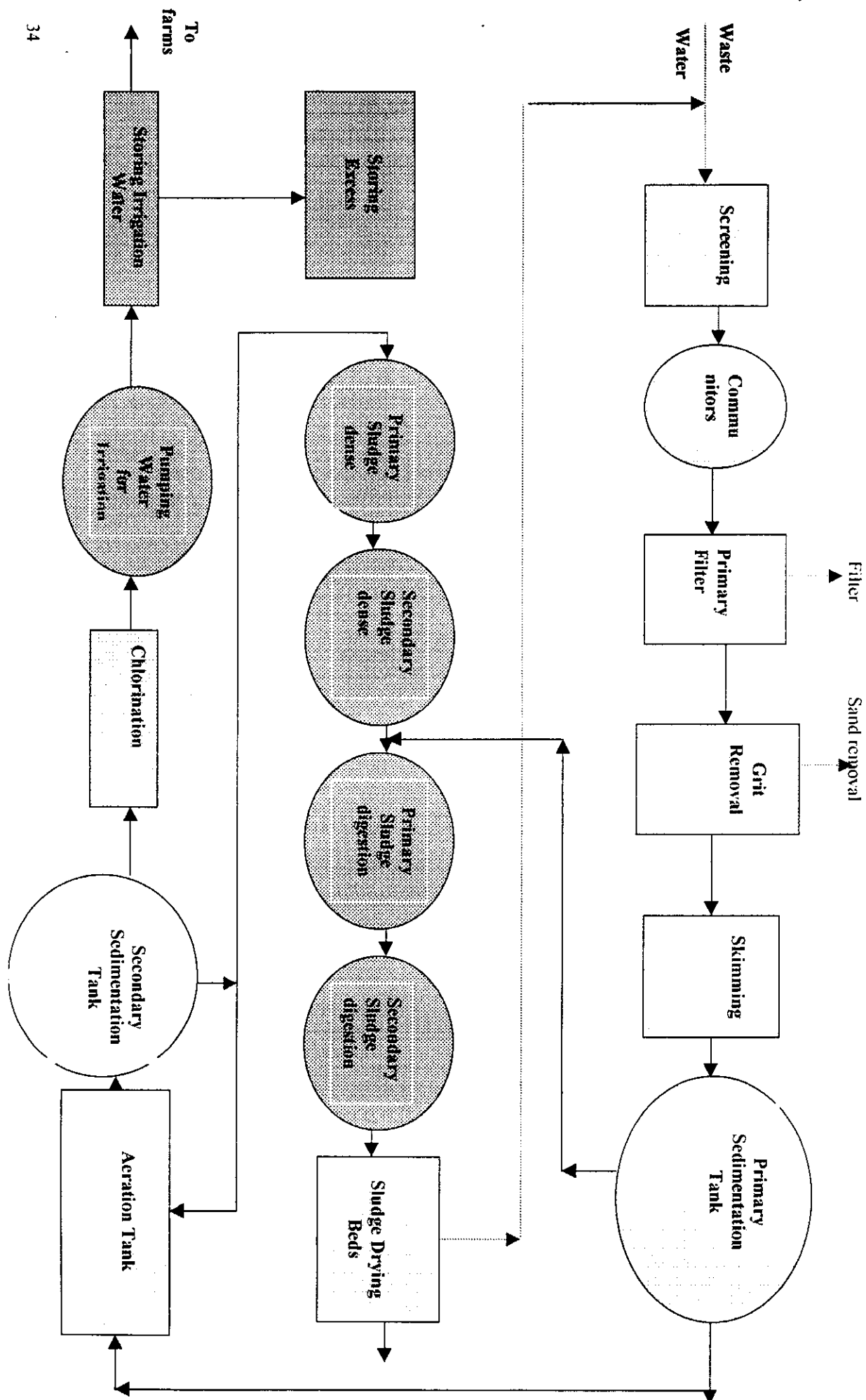


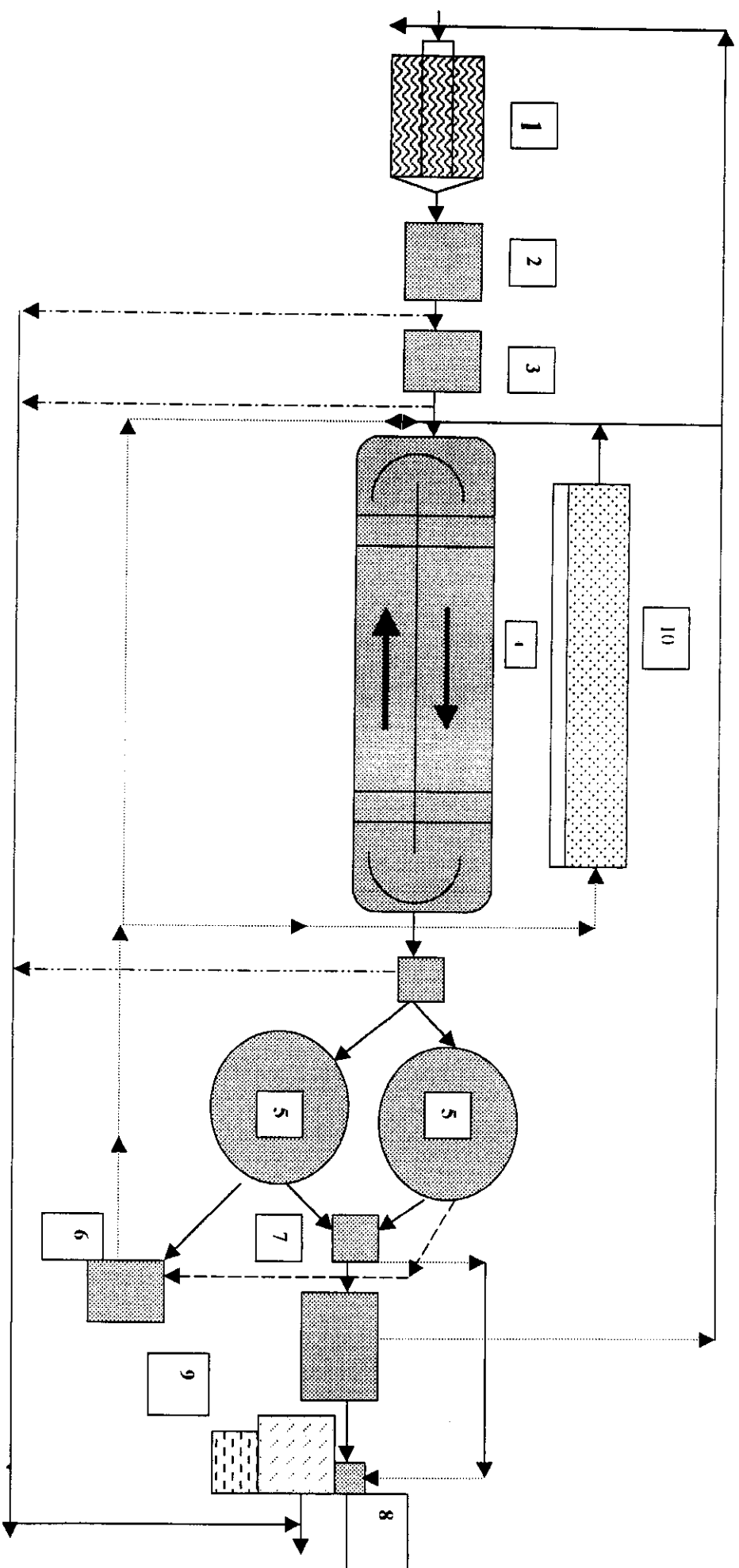
**Figure 1.3: Typical Flowsheet for Physical-Chemical Treatment**



**Figure 1.4: Typical Flowsheet for Waste Sludge Disposal**

Fig 2.1: Schematic Diagram for Wastewater Treatment





1. Pump Station
2. Screens
3. Grit Removal
4. Oxidation ditch
5. Sedimentation Tanks
6. Sludge Pump
7. Fine Filtration
8. Chlorination
9. Storage of Treelid wastewater
10. Sludge Drying Tanks

Fig 2.2: Schematic Diagram of Wastewater Treatment in Garian City (Libya)

## APPENDIX I - 1

**Table 1.1: Total & Rural Population and area of North Africa Sub-Region  
(1995 - 1998)**

Country	Population (1000 inhabitants)		year	Area (10 <sup>6</sup> km <sup>2</sup> )
	Rural	Total		
Algeria	13989	27794	1995	2.38
	14395	28566	1996	
	14496	28920	1997	
	14730	29272	1998	
Egypt	33374	59597	1995	1.00
	34027	59313	1996	
	34742	59440	1997	
	35472	60706	1998	
Libya	682	4405	1995	1.76
	682	4519	1996	
	682	4647	1997	
	717	4782	1998	
Mauritania	1139	2284	1995	1.03
	1145	2346	1996	
	1151	2421	1997	
	1156	2493	1998	
Morocco	12702	26386	1995	0.71
	12748	26848	1996	
	12786	27310	1997	
	12821	27775	1998	
Sudan	17332	26264	1995	2.50
	18396	27718	1996	
	18594	28466	1997	
	19031	29496	1998	
Tunisia	3469	8902	1995	0.16
	3544	9095	1996	
	3542	9243	1997	
	3572	9392	1998	
NA-Sub-Region	82596	155632	1995	9.54
	84937	158405	1996	
	85993	160447	1997	
	87499	163916	1998	

Source : AOAD 1999, Agricultural Statistics Yearbook

**Table 1.2: Total and cultivated Area and Total Agricultural Labor Force**

Country	Total area 1000 hectares	Cultivated 1000 ha		Total Labor Force		Agricultural Labor	
		1997	1998	1997	1998	1997	1998
Algeria	238174.0	8202	8215	5815	6012	1180	1200
Egypt	100160.0	3852	3260	17277	17588	9901	10059
Libya	175954.0	1403	1403	1224	1276	224	227
Mauritania	103070.0	207	182	712	728	342	350
Morocco	71085.0	9508	9518	8657	8758	3467	3507
Sudan	250000.0	17251	17251	6633	6873	4916	5094
Tunisia	16230.0	5079	5113	3008	3091	835	848
NA-Africa	954673	45502	44942	43326	44326	20865	21285
Near-east	3029020	-	-	-	-	-	-
region	1848600	-	-	-	-	-	-
World	13422300	-	-	-	-	-	-

Source : AOAD 1999, Agricultural Statistics Yearbook

**Table 1.3 : Land Use (1998) ( Area 1000 ha)**

Country	Perenni al corps Area	Seasonal Crops		Uncultivat ed Area	Forests Area	Pastures
		Rain-fed	Irrigated Rain-fed			
Algeria	512	4144	341	3245	3900	37387
Egypt	576	79	2605	-	-	-
Libya	421	363	619	-	754	12712
Mauritania	N.A	93	90	N.A	44	N.A
Morocco	758	6566	460	1733	9000	21000
Sudan	338	15142	1140	630	64360	39480
Tunisia	2192	1713	233	975	635	3065
NA-Su-region	4797	28100	5488	6583		

Source : AOAD 1999, Agricultural Statistics Yearbook

**Table 1.4 : Total Area, Yield & Production of Cereals and the %age of Self Sufficiency**

Country	Average (Period 91 – 1995)			1998			%of Self Sufficiency
	Area	Yield Kg/ha	Produc <sup>n</sup> (Metric Tons)	Area	Yield	Produc <sup>n</sup>	
<b>Algeria</b>	2554.5	868.69	2219.07	3575.2	846.21	3025.36	35.4
<b>Egypt</b>	2553.7	5780.29	14761.42	2629.28	6822.93	17939.39	68.5
<b>Libya</b>	5	668.97	241.05	180.23	1419.57	255.85	08.5
<b>Mauritania</b>	360.33	744.44	115.89	117.44	918.94	107.92	28.7
<b>Morocco</b>	155.62	1042.58	5334.38	5900.6	1125.22	6639.50	69.4
<b>Sudan</b>	5116.5	514.81	3712.82	9282.84	556.10	5162.20	88.3
<b>Tunisia</b>	7212.0	1043.11	1594.52	1446.2	1151.22	1664.90	48.1
	6						
	1528.6						
	2						
<b>NA-sub-region</b>	19481.33	1436.2	27979.15	23131.79	1504.2	34795.12	

Source : AOAD 1999, Agricultural Statistics Yearbook

**Table 1.5 : Distribution of Renewable water Resources of NA-Sub-Region Countries**

Country	Annual Renewable Resources BCM	Annual Withdrawals		Water Usage (%)		
		BCM*	As %of ARR	Agriculture	Domestic	Industry
Algeria	14.3	4.5	31	60	25	15
Egypt	58.0	56.5	97	88	7	5
Libya	0.7	2.8	400	75	15	10
Mauritania	11.4	1.6	14	92	6	2
Morocco	30.0	11.0	37	91	6	3
Sudan	30.5**	17.8	55	94	4	2
Tunisia	4.4	3.0	86	80	13	7
NA-Su-region	149.3	97.2	65			

\* BCM = Billion Cubic Meters

\*\* Including water to be reclaimed from swamps

Source : FAO 1997, Irrigation in the Near East Region in Figures

**Table 1.6: Non-Conventional Water Resources in the Seven Countries of North Africa Sub-Region**

Country	Desalinated Water		Re-used Treated Water		Total Non-Conventional Water
	Year	Million m <sup>3</sup> /year	Year	Million m <sup>3</sup> /year	
Algeria	1990	64.0	-	-	64.0
Egypt	1990	25.0	1993	200.0	225.0
Libya	1994	100.0	1990	110.0	170.0
Mauritania	1990	1.7	-	-	1.7
Morocco	1992	3.4	1995	60*	3.4
Sudan	1990	0.4	-	-	0.4
Tunisia	1990	8.3	-	81.5	89.8

- Untreated but re-used
- Source: Compiled from different sources



Tableau 2.7

**Total Annual Rainfall  
In the North Africa sub-region**

Total Annual Rainfall in Some Stations in Algeria					
<b>1. El Shalaf</b>		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	305.00	-23.67	4	2.50	40.00
1996	480.00	151.33	2	5.00	20.00
1997	527.00	198.33	1	10.00	10.00
1998	246.00	-82.67	7	1.43	70.00
	328.67				
<b>2. Tebessa</b>		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	407.00	43.00	3	3.67	27.27
1996	338.00	-26.00	7	1.57	63.64
1997	378.00	14.00	4	2.75	36.36
1998	339.00	-25.00	6	1.83	54.55
	364.00				
<b>3. Skikda</b>		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	630.00	-69.20	7	1.57	63.64
1996	760.00	60.80	3	3.67	27.27
1997	751.00	51.80	4	2.75	36.36
1998	855.00	155.80	2	5.50	18.18
	699.20				
Year	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	536.00	56.10	3	3.67	27.27
1996	619.00	139.10	1	11.00	9.09

1997	379.00	-100.90	9	1.22	81.82
1998	570.00	90.10	2	5.50	18.18
	479.90				

#### 5. Biskra

Year	Annual Rainfall (mm)	Deviation from the mean x - x	Order - m-	Return Year $Tr = n+1/m$	Frequency $Fr = 1 \times 100 / Tr$
1995	92.00	-253.75	7	1.29	77.78
1996	344.00	-1.75	3	3.00	33.33
1997	514.00	168.25	2	4.50	22.22
1998	91.00	-254.75	8	1.13	88.89
	345.75				

#### 6. Wahran

Year	Annual Rainfall (mm)	Deviation from the mean x - x	Order - m-	Return Year $Tr = n+1/m$	Frequency $Fr = 1 \times 100 / Tr$
1995	396.00	-114.80	3	3.67	27.27
1996	338.00	-172.80	5	2.20	45.45
1997	478.00	-32.80	1	11.00	9.09
1998	235.00	-275.80	9	1.22	81.82
	330.80				

#### 7. Ahrash Market

Year	Annual Rainfall (mm)	Deviation from the mean x - x	Order - m-	Return Year $Tr = n+1/m$	Frequency $Fr = 1 \times 100 / Tr$
1995	606.00	94.78	4	2.50	40.00
1996	621.00	109.78	3	3.33	30.00
1997	324.00	-187.22	9	1.11	90.00
1998	633.00	121.78	2	5.00	20.00
	511.22				

# Total Annual Rainfall For Some Stations in Egypt

1. Marsa Matrah		Deviation from the		Return Year	Frequency
Year	Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	106.10	-37.60	8	1.50	66.67
1996	137.70	-6.00	6	2.00	50.00
1997	39.80	-103.90	10	1.20	83.33
1998	6.10	-137.60	11	1.09	91.67
Average	143.68				
2. Alexandria		Deviation from the		Return Year	Frequency
Year	Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	127.60	-24.16	8	1.50	66.67
1996	199.40	47.64	3	4.00	25.00
1997	57.50	-94.26	9	1.33	75.00
1998	9.30	-142.46	11	1.09	91.67
Average	151.76				
3. Port Said		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	21.10	-41.19	9	1.22	81.82
1996	73.30	11.01	4	2.75	36.36
1997	44.90	-17.39	8	1.38	72.73
1998	1.80	-60.49	10	1.10	90.91
	62.29				
4. Arish		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	34.40	-39.40	8	1.38	72.73
1996	104.70	30.90	3	3.67	27.27
1997	39.50	-34.30	7	1.57	63.64
1998	1.60	-72.20	9	1.22	81.82
	73.77				

5. Cairo		Deviation from the		Return Year	Frequency
	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	7.70	-14.37	8	1.38	72.73
1996	23.90	1.83	3	3.67	27.27
1997	8.30	-13.77	7	1.57	63.64
1998	1.00	-21.07	10	1.10	90.91
	22.07				

### Total Annual Rainfall For Some Stations in Libya

		Deviation from the		Return Year	Frequency
1. Tripoli					
	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	226.70	-23.93	4	2.50	40.00
1996	180.90	-69.73	7	1.43	70.00
1997	148.70	-101.93	9	1.11	90.00
1998	199.50	-51.13	5	2.00	50.00
	250.63				
2. Al Khomous		Deviation from the		Return Year	Frequency
	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995					
1996					
1997					
1998					
	193.48				
3. Misirata		Deviation from the		Return Year	Frequency
	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995					

4. Fas		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	240.90	-158.20	11	1.09	91.67
1996	713.30	314.20	1	12.00	8.33
1997	494.20	95.10	3	4.00	25.00
1998	287.50	-111.60	9	1.33	75.00
	399.10				

5. Ifran		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	802.30	-59.00	5	2.40	41.67
1996	1777.10	915.80	1	12.00	8.33
1997	1115.90	254.60	2	6.00	16.67
1998	632.60	-228.70	10	1.20	83.33
	861.30				
6. Marrakech		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	287.80	66.00	4	3.00	33.33
1996	385.80	164.00	1	12.00	8.33
1997	367.80	146.00	2	6.00	16.67
1998	129.00	-92.80	9	1.33	75.00
	221.80				

7. Tanger		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	594.20	-120.40	7	1.71	58.33
1996	1661.30	946.70	1	12.00	8.33
1997	822.20	107.60	3	4.00	25.00

1998	446.10	-268.50	11	1.09	91.67
	714.60				
<b>8. Warrazat</b>					
		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	Tr = n+1/m	Fr = 1x100/Tr
1995	150.60	28.56	4	3.00	33.33
1996	107.50	-14.54	5	2.40	41.67
1997	68.60	-53.44	9	1.33	75.00
1998	62.50	-59.54	11	1.09	91.67
	122.04				

<b>9. Algardiedah</b>					
		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	Tr = n+1/m	Fr = 1x100/Tr
1995	324.90	-18.30	7	1.71	58.33
1996	778.80	435.60	1	12.00	8.33
1997	435.60	92.40	2	6.00	16.67
1998	80.50	-262.70	11	1.09	91.67
	343.20				

**Total Annual Rainfall For Some Station in Mauritania**

<b>1. Nouakchoot</b>					
		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	Tr = n+1/m	Fr = 1x100/Tr
1995	217.00	99.00	2	6.00	16.67
1996	181.00	63.00	4	3.00	33.33
1997	62.00	-56.00	8	1.50	66.67
1998	236.70	118.70	1	12.00	8.33
	118.00				

2. Alhoud Alshargi		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	Tr = n+1/m	Fr = 1x100/Tr
1995	312.00	95.00	3	4.00	25.00
1996	209.00	-8.00	5	2.40	41.67
1997	193.00	-24.00	7	1.71	58.33
1998	179.00	-38.00	8	1.50	66.67
	217.00				
3. Alhoud Algharbi		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	Tr = n+1/m	Fr = 1x100/Tr
1995	302.00	123.80	1	12.00	8.33
1996	126.00	-52.20	9	1.33	75.00
1997	295.00	116.80	2	6.00	16.67
1998	176.00	-2.20	7	1.71	58.33
	178.20				
4. Libarkna		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	Tr = n+1/m	Fr = 1x100/Tr
1995	281.00	113.40	3	4.00	25.00
1996	121.00	-46.60	8	1.50	66.67
1997	149.00	-18.60	5	2.40	41.67
1998	286.00	118.40	2	6.00	16.67
	167.60				

5. El traza		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	Tr = n+1/m	Fr = 1x100/Tr
1995	171.00	-125.50	5	2.40	41.67
1996	356.00	59.50	4	3.00	33.33
1997	164.00	-132.50	6	2.00	50.00
1998	138.00	-158.50	8	1.50	66.67
	296.50				

6. Atshieri		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x - x	Order - m-	Tr = n+1/m	Fr =1x100/Tr
1995	99.00	38.80	3	4.00	25.00
1996	25.00	-35.20	8	1.50	66.67
1997	56.00	-4.20	4	3.00	33.33
1998	39.00	-21.20	7	1.71	58.33
	60.20				

7. Kiedmagha		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x - x	Order - m-	Tr = n+1/m	Fr =1x100/Tr
1995	533.00	207.60	1	12.00	8.33
1996	389.00	63.60	5	2.40	41.67
1997	453.00	127.60	3	4.00	25.00
1998	493.00	167.60	2	6.00	16.67
	325.40				

8. Ediar		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x - x	Order - m-	Tr = n+1/m	Fr =1x100/Tr
1995	208.00	102.80	2	6.00	16.67
1996	18.00	-87.20	10	1.20	83.33
1997	55.00	-50.20	8	1.50	66.67
1998	140.00	34.80	4	3.00	33.33
	105.20				

Total Annual Rainfall for Some	Stations in Sudan				
1. Wad Medani		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x - x	Order - m-	Tr = n+1/m	Fr =1x100/Tr



1995	423.80	116.30	1	10.00	10.00
1996	302.30	-5.20	4	2.50	40.00
1997	239.80	-67.70	8	1.25	80.00
1998	381.30	73.80	2	5.00	20.00
	307.50				
<b>2. Sennar</b>					
Year	Annual Rainfall (mm)	Deviation from the mean x -x	Order - m-	Tr = n+1/m	Fr = 1x100/Tr
1995	677.80	210.52	1	11.00	9.09
1996					
1997	626.60	159.32	2	5.50	18.18
1998	352.00	-115.28	8	1.38	72.73
	467.28				
<b>3. Damazine</b>					
Year	Annual Rainfall (mm)	Deviation from the mean x -x	Order - m-	Tr = n+1/m	Fr = 1x100/Tr
1995	625.50	-34.86	8	1.50	66.67
1996	686.00	25.64	6	2.00	50.00
1997	695.50	35.14	5	2.40	41.67
1998	389.90	-270.46	11	1.09	91.67
	660.36				
<b>4. Kosti</b>					
Year	Annual Rainfall (mm)	Deviation from the mean x -x	Order - m-	Tr = n+1/m	Fr = 1x100/Tr
1995	272.70	-67.91	6	2.00	50.00
1996	371.50	30.89	5	2.40	41.67
1997	264.00	-76.61	8	1.50	66.67
1998	815.80	475.19	1	12.00	8.33
	340.61				
<b>5. Obeid</b>					
Year	Annual Rainfall (mm)	Deviation from the mean x -x	Order - m-	Tr = n+1/m	Fr = 1x100/Tr
1995	337.70	28.75	5	2.40	41.67
1996	351.30	42.35	3	4.00	25.00

1997	306.10	-2.85	7	1.71	58.33
1998	353.50	44.55	2	6.00	16.67
	308.95				
<b>6. Kadougli</b>					
Year	Annual Rainfall (mm)	Deviation from the mean x -x	Order - m-	Return Year $Tr = n+1/m$	Frequency $Fr = 1 \times 100 / Tr$
1995	991.30	375.00	1	12.00	8.33
1996	384.80	-231.50	11	1.09	91.67
1997	627.80	11.50	4	3.00	33.33
1998	501.10	-115.20	9	1.33	75.00
	616.30				
<b>7. Fashir</b>					
Year	Annual Rainfall (mm)	Deviation from the mean x -x	Order - m-	Return Year $Tr = n+1/m$	Frequency $Fr = 1 \times 100 / Tr$
1995	221.10	-13.60	4	3.00	33.33
1996	86.30	-148.40	11	1.09	91.67
1997	119.60	-115.10	9	1.33	75.00
1998	381.30	146.60	2	6.00	16.67
	234.70				
<b>8. Malakal</b>					
Year	Annual Rainfall (mm)	Deviation from the mean x -x	Order - m-	Return Year $Tr = n+1/m$	Frequency $Fr = 1 \times 100 / Tr$
1995	830.00	46.20	4	3.00	33.33
1996	661.30	-122.50	11	1.09	91.67
1997	788.70	4.90	7	1.71	58.33
1998	734.20	-49.60	9	1.33	75.00
	783.80				

<b>9. Juba</b>					
Year	Annual Rainfall (mm)	Deviation from the mean x -x	Order - m-	Return Year $Tr = n+1/m$	Frequency $Fr = 1 \times 100 / Tr$
1995	682.00	-271.00	10	1.20	83.33

1996	669.90	-283.10	11	1.09	91.67
1997	732.90	-220.10	9	1.33	75.00
1998	1309.80	356.80	1	12.00	8.33
	953.00				
<b>10. Gadaref</b>		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	530.00	-32.80	9	1.33	75.00
1996	558.00	-4.80	8	1.50	66.67
1997	589.00	26.20	3	4.00	25.00
1998	578.10	15.30	5	2.40	41.67
	562.80				

<b>11. Kassala</b>		Deviation from the		Return Year	Frequency
Year	Annual Rainfall (mm)	mean x -x	Order - m-	$Tr = n+1/m$	$Fr = 1 \times 100 / Tr$
1995	394.80	119.50	1	12.00	8.33
1996	384.80	109.50	2	6.00	16.67
1997	204.00	-71.30	9	1.33	75.00
1998	316.70	41.40	6	2.00	50.00
	275.30				

**Table 2.8: Rainfall Pattern & Drought Frequency\*  
in North Africa Sub-Region**

Country	Station	Annual Rainfall (mm)			Reliability of Rainfall (mm)		Drought Frequency (No. of years out of 11 years)
		Min	Max	Average	50%	80%	
Algeria	1. Skikda	513	855	669	657	583	4
	2. El Shalaf	212	527	329	285		6
Egypt	1. Alexandria	9	389	152	75	32	6
	2. Cairo	7	79	22	9	4	6
Libya	1. Tripoli	149	532	282	209	161	7
	2. Sirat	38	194	130	92	46	6
Mauritania	1. Kiedmagha	13	533	325	157	54	5
	2. Edrar	1.6	369	105	35	11	7
Morocco	1. Ifran	463	1777	861	736	586	8
	2. Warzazat	63	263	122	94	68	6
Sudan	1. Juba	669	1310	953	873	749	6
	2. Fashir	109	638	235	171	118	8
Tunisia	1. Tabaruka	662	1178	883	817	706	5
	2. Ramaza	64	104	80	81	67	4

\* Average Annual Rainfall is taken as a Reference

**Note:** It would have been preferable if potential evapo-transpiration annual averages are taken as reference instead. But due to lack of information this has not been done

**Table 3.1: Distribution of Traditional Water Harvesting Systems in North Africa Sub-region**

Name of System	Algeria	Egypt	Libya	Mauritania	Morocco	Sudan	Tunisia
Cisterns	?	X	X	-	X	-	X
Small dams	X	X	X	X	X	X	X
Hafirs	-	-	-	X	-	X	-
Tree trunks	-	-	-	-	-	X	-
Koroum/Ghadirs	-	X	-	-	X	X	-
Terraces / Masateh	X	-	X	-	X	-	X
Irrigation diversion dams	X	X	-	-	X	X	X
Water spreading dykes	X	X	-	X	X	X	-
Miskat	-	-	X	-	-	-	X
Artificial recharge	-	X	-	-	X	X	-
Check dams	-	-	X	-	-	-	X
Foggaras	X	X	X	-	X	-	X
Surface wells	X	X	X	X	X	X	X
Springs	X	X	X	X	X	-	X
Ghouas	X	X	X	-	-	-	X
Shadouf	X	X	-	X	X	X	-
Saquia / Naoura	-	X	-	-	X	X	X
Tambour	-	X	-	-	-	-	-
Bucket and pulleys	X	X	X	X	X	X	X
Wind mill	X	X	X	-	X	X	X
Hydraulic mill	-	-	-	X	X	-	-

Source: Collected from different sources, main sources: Rainfall

**Table 3.2 : Summary chart of main water harvesting techniques**

	Classification	Main uses	Description	Where Appropriate	Limitations
negarin microcatchments	microcatchment (short slope catchment) technique	trees & grass	Closed grid of diamond shapes or open-ended "v"s formed by small earth ridges, with infiltration pits	For tree planting in situations where land is uneven or only a few tree are planted	Not easily mechanised therefore limited to small scale. Not easy to cultivate between tree lines
contour bunds	microcatchment (short slope catchment) technique	trees & grass	Earth bunds on contour spaced at 5-10 metres apart with furrow upslope and cross-ties	For tree planting on a large scale especially when mechanized	Not suitable for uneven terrain
semi circular bunds	microcatchment (short slope catchment) technique	rangeland & fodder (also trees)	Semi-circular shaped earth bunds with tie on contour. In a series with bunds in staggered formation	Useful for grass reseeding, fodder or tree planting in degraded rangeland	Cannot be mechanized therefore limited to areas with available bund labour
contour ridges	microcatchment (short slope catchment) technique	crops	Small earth ridges on contour at 1.5m -3m apart with furrow upslope and cross-ties uncultivated catchment between ridges	For crop production in semi-arid areas especially where soil fertile and easy to work	Requires new technique of land preparation and planting, therefore may be problem with acceptance
trapezoidal bunds	external catchment (long slope catchment) technique	crops	Trapezoidal shaped earth bunds capturing runoff from external catchment and over-flowing around wingtip	Widely suitable (in a variety of designs) for crop production in arid and semi-arid areas	Labour-intensive and uneven depth of runoff within plot
contour stone bunds	external catchment (long slope catchment) technique	crops	Small stone bunds constructed on the contour at spacing of 1.5-3.5 metres apart slowing and filtering runoff	"versatile system for crop production in a wide variety of situations. Easily constructed by resource- poor farmers	Only possible where abundant loose stone available
permeable rock dams	floodwater farming technique	crops	Long low rock dams across valleys slowing and spreading floodwater as well as healing gullies	Suitable for situation where gently sloping valleys are becoming gullied and better water spreading is required	Very site-specific and needs considerable stone as well as provision of transport
water spreading bunds	floodwater farming technique	crops & rangeland	Earth bunds set at a gradient, with a "dogleg" shape, spreading diverted floodwater	For arid areas where water is diverted from watercourse onto crop or fodder block	Does not impound such water and maintenance begins in early stages after construction

Source: FAO 1991, (Grichley and Sievert)

Table 3.4 Worldwide Research Experiences

Country	Type & Quality of Irrigation Water	Soil Characteristics	Tested Crops	Method of Irrigation	Gross Water Consumption m <sup>3</sup> /ha	Seasonal Rainfall (mm)	Drainage	Yield		Remarks
								Crop	Ton/ha	
U.S.A. Safford Experimental Station University of Arizona (1)	Groundwater ECw: 3.1-3.5 dS/m SAR: 14	-Clay loam -pH: 8.0 -ECe: 4.5-5.6	-Cotton -Barley -Sorghum -Sugarcane	Common Surface Irrigation	N.A.*	N.A.*	N.A.*	Cotton Barley Sorghum Sugarcane	1.258 4.117 7.820 56.000	The yields of the field experiments equal or exceed the Statewide average yield for the same crops.
<b>Jordan</b> Khaldia Experimental Station (2)	Groundwater ECw: 6.56-7.2 dS/m	-clay loam -pH: 7.5 -ECe: 5.4 dS/m	-Barley -Sugarcane -Onion	-Basin -Drip -Drip	1500-2000- 703-02 1179- 1533 1806-3764	111-156	Good Natural Drainage	Barley Sugarcane Onion (green)	4.49-6.00 53.3-68.0 6.83-14.49	Leaching requirement (LR) Treatments: 0%, 15% and 30% for sugarcane experiment.
<b>Syria</b> Deir Ez Zor Experimental Station (2)	Drainage water mixed with canal water ECw: 1.55-13.55 dS/m	-Clay loam -pH: 7.5 -ECe: 2.0 dS/m -CaCO <sub>3</sub> : 15-25%	-Barley -Alfalfa -Corn -Cotton	-Basin -Basin -Basin -Furrow	3,600-4,680 32,430- 42,105 6,055-8,000 9,455-12,291	83-110	Sub-surface Drainage	Barley (grain) Alfalfa (Dry matter) Corn (grain) Cotton	1.67-4.86 5.89-30.48 0.008-3.33 0.614-3.364	LR of 15% gave the highest yield of all crops compared to 0.0% and 30% LR for EC of water greater than 5 dS/m
<b>Tunisia</b> Sherfish Experimental Station (2)	-Drainage water mixed with relatively good water: ECw: 2.37-9.25	-Silty clay -pH: 7.7 -ECe: 2.0 dS/m	-Barley -Cotton	-Basin -Furrow	3880-4310 4427-5609	200-221	Sub-surface Drainage	Barley (grain) Cotton	4.302-4.557 2.39-2.43	No soil salinity hazard LR treatments: 0% and 15%

Table 3.4 (Continued)

Country	Type & Quality of Irrigation Water	Soil Characteristics	Tested Crops	Method of Irrigation	Gross Water Consumption <sup>1</sup> m <sup>3</sup> /ha	Seasonal Rainfall (mm)	Drainage	Yield		Remarks
								Crop	Ton/ha	
Saudi Arabia. Regional Centre For Animal Nutrition and Breeding Hofuf-Alhassa (3))	Drainage water mixed with artesian spring water. EC <sub>w</sub> : 2.5, 4.0, 6.0 and 8.0 dS/m	-Sandy loam -EC <sub>e</sub> : 2.5, 4.0, 6.0, 8.0 dS/m	-Barley	-Basin	About 7 mm/day	12	N.A.*	Barley for EC <sub>e</sub> : 2.5 dS/m 4.0 dS/m 6.0 dS/m 8.0 dS/m	4.34 3.87 3.29 3.29 (dry matter)	The experiments were conducted under the joint auspices of Leichtweis institute, technical University Braunschweig, Germany and Ministry of Agriculture, Saudi Arabia
<b>Qatar.</b> Rodi Al-Faras Experimental Farm (4)	Groundwater EC <sub>w</sub> : 6.56-7.2 dS/m	-clay loam -pH: 7.7-9 -CaCO <sub>3</sub> : 17-20% -EC <sub>e</sub> : 9-10 dS/m	-Tomato -Squash -Eggplant -Onion -Cauli-flower	-Furrow -Basin -Basin -Basin	10,000-12,000 5,000 9,000 12,000 7,000-8,000	115 (average)	Natural Drainage	Tomato Squash Eggplant Onion Cauliflower	65-80 35-40 50-55 40-50 20-22	Rainfall of the 1980/81 season was very low (43 mm)
<b>Qatar.</b> Wadi Al Araig Experimental Station (5)	Drainage water mixed with canal water EC <sub>w</sub> : 1.55-13.55 dS/m	-Coarse sand (Dune sand) -pH: 7.9-8.0 -CaCO <sub>3</sub> : 9-10% -EC <sub>e</sub> : 6.3-7.7 dS/m -Available moisture: 0.8-2.0%	-Alliaria -Rhodes grass -Tomato -Sugarbeet -Potato	-Sprinkler -Sprinkler -Drip -Sprinkler -Sprinkle	36,090 36,090 27,890 6,350 7,420	76 (average)	Sub-surface Drainage System	Alliaria Rhodes grass Tomato Sugarbeet Potato	98.4 (green matter) 97.2 (green matter) 107.5 39.9 25.8	-The figures represent the average of the results of the experiments conducted during period 1984-1987. -Tomato was grown on trellises and huge amount of water was used.
<b>Qatar.</b> Al Kilor Farm (6) (No. 695)	Groundwater EC <sub>w</sub> : 7.5 dS/m SAR: 16.2 EC <sub>e</sub> : 2.37-9.25 dS/m SAR: 23.6	-Calcareous clay -pH: 7.9 -EC <sub>e</sub> : 6.5-8.6 -Available moisture: 10.6-12.6%	-Wheat -Barley -Tomato -Red Onion -White " -Wheat -Barley	-Flat basin -Flat basin -Furrow -Furrow -Flat basin -Flat basin	6,650 6,490 10,130 14,390 14,390 6,690 5,900	124	Natural Drainage	-Wheat -Barley -Tomato -Red Onion -White " -Wheat -Barley	3.64 3.41 55.44 25.00 48.80 3.29 3.89	Leaching was effective in reducing the soil saturation extract (EC <sub>e</sub> ) from 8.60 dS/m to 6.56 dS/m (average values)

(1) Dart et al. (1984) (2) Abdelgawad et al. (1996) (3) Hussain (1981) (4) Dastane et al. (1981) (5) DAVR (1984-1987) (6) ACSAD and DAVR (1988)  
\*N/A= Data not available



Table 3.5 Worldwide Farmers Experiences

Country	Type & Quality of Irrigation Water	Soil Texture	Major Irrigated Crops	Cultivated Area (ha)	Method of Irrigation	Average Annual Rainfall (mm)	On-farm Drainage System	Yield (ton/ha) Or Yield Loss (%) Crop Ton/ha	Salinity & Waterlogging Problems	Remarks
Tunisia (1)	Groundwater (60.7%), Reservoirs (32.7%), Pumping in Wadis (4.6%), Treated waste water (2.0%), ECw: 2.3-6.3 dS/m	-Variable	-Vegetables -Wheat	303,000	Surface: 78%, Drip: 2.0%, Sprinkler: 18.2%	207 mm but almost half of the country receives less than 100 mm/year	1. limited Surface Drainage	N.A.*	Salinization is not yet a serious problem	
Tunisia (2)	Medjerda river ECw: 1.3-4.7 dS/m	Calcareous heavy clay (up to 35% lime content)	-Date palm -Sorghum -Barley -Alfalfa	N.A.*	Surface	Low rainfall	N.A.*	N.A.*	N.A.*	Rainfall just enough to leach the salts to a depth of 15 cm in the soil.
United States of America Pecos Valley of West Texas (3)	Groundwater ECw: up to 9.4 dS/m Average: 3.9 dS/m	Silt loam to Silty clay -pH: 7.5-8.3	-Cotton -Gram -Sorghum -Alfalfa	81,999	-Furrow	Less than 300 mm	Internal Good Drainage	Minimal Yield Losses		
	Groundwater ECw: 3-11.5 dS/m	Sand	-Cotton	N.A.*	Alternate furrow irrigation	N.A.*	N.A.*	0.84-1.61 tons/ha	N.A.*	Cotton was germinated with relatively low saline well water
South West Arizona (2)										
Egypt (3) (Northern Delta)	Drainage water ECw: 2-3 dS/m	-Sand, silt loam and clays -CaCO <sub>3</sub> : 2-20% -Very low Organic matter	-Clover -Rice -Wheat -Barley -Sugarbeet -Cotton	Over 10,000	Traditional surface irrigation	Scattered rain showers	Poor drainage	Yield reductions 25-30%	Waterlogging and salinization are serious problems	

Table 3.5 (Continued)

Country	Type & Quality of Irrigation Water	Soil Texture	Major Irrigated Crops	Cultivated Area (Ha)	Method of Irrigation	Average Annual Rainfall (mm)	On-farm Drainage System	Yield (ton/ha) Or Yield Loss (%) Crop Ton/ha	Salinity & Waterlogging Problems	Remarks
<b>Kuwait</b> (1)	Groundwater & treated wastewater ECw: 1.5-15.7 dS/m	Sand	-Alfalfa -Tomato	4,770	- Surface: 63.3 % -Drip: 24.1 % -Sprinkler: 12.6 %	176 mm	Not developed	Alfalfa: 100 tons/ha. Tomato: 40 tons/ha. (Open field) 200 tons/ha (greenhouse).	Secondary Salinization area = 4080 ha.	
<b>Bahrain (2)</b>	Groundwater & Treated wastewater ECw: 3-11.5 dS/m	Mostly of sandy texture	-Cotton	4,230	- Surface: 78.9 % -Drip: 17.0 % -Sprinkler: 4.1 %	70 mm	Drainage works for 44% of the cultivated Area	Alfalfa: 74.5 tons/ha Tomato: 11.7 tons/ha Date palm & Fruits: 7.5 tons/ha	Agricultural land suffers from water-logging and salinity	
<b>Qatar (1) &amp; (4)</b>	Groundwater (94.2% of irrigation water Treated wastewater (5.8%) ECw: 0.5-16 dS/m	Calcareous clay loam, calcareous sandy loam and coarse sand	-Green fodder -Vegetables -Date palm	8,825	Surface: 77.5 % Drip: 0.4 % Sprinkler: 14.0 % Bubble: 8.1 %	83 mm		-Green fodder: 77.9 tons/ha -Vegetables: 11.5 tons/ha -Fruits and datepalm: 4.2 tons/ha	Soil salinity problems, especially in the farms near the sea coast	17% of the farms are abandoned because of the high saline irrigation water.
<b>Israel (3)</b>	Groundwater ECw: 2-8 dS/m	Light to medium textured soils	Various crops	N.A.*	Mostly sprinkler and drip	Exceeds 200 mm in the arid region	Good drainage	N.A.*	-	Cotton is successfully grown commercially with saline groundwater of 5 dS/m in ECw and SAR of 26.

(1) FAO (1997) (2) Ayers and Westcot (1985) (3) Rhoades et al. (1992) (4) DAWR (1994)  
\*N.A. = Data not available

**Table 1.1: Wastewater Treatment Processes and Major Purposes**

<b>Operation</b>	<b>Purpose of Operation</b>
Bare screens and racks	Coarse solids removal
Comminutor	Grinding up of screening
Grit chamber	Grit and sand removal
Skimmer and grease trap	Floating liquid and solid removal
Equalization tank	Smoothing out flow and concentration
Neutralization	Neutralizing acids and bases
Sedimentation and flotation	Suspended solids removal
Activated sludge reactor, trickling filter, aerated lagoon	Biological removal of soluble organics
Activated carbon absorber	Soluble nonbiodegradable organics removal
Chemical coagulation	Precipitation of phosphates
Nitrification-denitrification	Biological removal of nitrates
Air stripping	Ammonia removal
Ion exchange	Charged species removal
Bed filtration	Fine solids removal
Reverse osmosis and electrodialysis	Dissolved solids removal
Chlorination and ozonation	Pathogenic organism destruction

Since many different combinations of these operations are possible, each situation must be evaluated to select the best combination.

**Table 1.2: Sludge Treatment Processes and Their Major Purposes**

<b>Operation</b>	<b>Purposes of Operation</b>
Thickening Gravity Flotation	Increase solids concentration and reduce volume
Stabilization Anaerobic digestion Aerobic digestion	Reduce sludge solids, pathogens and odor
Conditioning Chemical addition Heat treatment	Improve dewatering rate and solids capture
Dewatering Vacuum filtration Centrifugation Sand beds	Reduce volume and form a damp cake
Drying and oxidation Incineration Heat drying Wet air oxidation	Dry or oxidize sludge cake
Ultimate disposal Landfill Spreading on soil Lagoons Ocean	Utilize or dispose of sludge solids

Water quality criteria are essential foundation for successful implementation of any reclamation project. Microbiological water quality is most important when field workers as well as the public is exposed to reclaimed water directly or indirectly. Probably most of the North Africa sub-region countries don't have yet their national guidelines. In this regard the WHO guidelines can be proposed. Guidelines in concern with biological quality are shown in Table 1.4.

**Table 1.4: Recommended Microbiological Quality Guidelines for Wastewater Use in Agriculture (WHO, 1989)**

Category	Reuse Conditions	Exposed Group	Intestinal Nematodes (arithmetic mean no. of eggs per litre <sup>3</sup> )	Faecal coliform (geometric mean no. per 100 ml <sup>3</sup> )	Wastewater Treatment Expected to Achieve The Required Microbiological quality
<b>A</b>	Irrigation of crops likely to be eaten uncooked, sports fields, public parks	Workers, Consumers, Public	$\leq 1$	$< 1000$	A series of stabilisation ponds designed to achieve the microbiological quality indicated, or equivalent treatment
<b>B</b>	Irrigation of cereal crops, industrial crops, pasture and trees	Workers	$\leq 1$	No standard recommended	Retention in stabilisation ponds for 8-10 days or equivalent helminth and faecal coliform removal
<b>C</b>	Localised irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but not less than primary sedimentation

**Table 1.5: Expected Removal of Excreted Bacteria and Helminths in Various Wastewater Systems**

Treatment	Removal (log <sub>10</sub> ) units of			
	Bacteria	Helminths	Viruses	Cysts
Primary Sedimentation				
Plain	0-1	0-2	0-1	0-1
Chemically Assisted <sup>a</sup>	1-2	1-3 <sup>g</sup>	0-1	0-1
Activated sludge <sup>b</sup>	0-2	0-2	0-1	0-1
Biofiltration <sup>b</sup>	0-2	0-2	0-1	0-1
Aerated lagoon <sup>c</sup>	1-2	1-3 <sup>g</sup>	1-2	0-1
Oxidation ditch <sup>b</sup>	1-2	0-2	1-2	0-1
Disinfection <sup>d</sup>	2-6 <sup>g</sup>	0-1	0-4	0-3
Waste stabilization Ponds <sup>e</sup>	1-6 <sup>g</sup>	1-3 <sup>g</sup>	1-4	1-4
Effluent storage Reservoirs <sup>f</sup>	1-6 <sup>g</sup>	1-3 <sup>g</sup>	1-4	1-4

a. further research is needed to confirm performance

b. including secondary sedimentation

  Including settling pond

c. chlorination or ozonation

d. performance depends on number of pond in series and other environmental factors

e. performance depends on retention time, which varies with demand

f. with good design and proper operation, the recommended guidelines can be met

Source: FAO: Wastewater Reclamation and Use.

**Table 1.6: Reported Effluent Quality for Several Series of Waste Stabilization Ponds, Each with a Retention Time of 25 Days**

Pond System	No. Of Ponds in series	Effluent quality (FC/100 ml)*
Australia Melbourne	8-11	100
Brazil. Extrabes	5	30
France. Gogolin	3	100
Jordan. Amman	9	30
Peru. Lima	5	100
Tunisia. Tunis	4	200
*PC = faecal coliforms		

## APPENDIX II-2

**Table 2.1: Predicted Waste Water by the Year 2020 at the North of Algeria**

Item	Hydrographic Basin Amount in Million m <sup>3</sup> /year				Total Million m <sup>3</sup> /year
	Wahran	Shalaf	Algeria	Constantine	
Drinking Water Demand	610	610	1550	850	3620
Cities with population > 20,000	39	49	74	700	232
Water demand for cities > 20,000 citizens	272	288	649	435	1644
Volume of Waste Water	126	171	286	259	978

Source: Taibi Rasheed 1999: Reuse of Waste Water in Agricultural Production, Algerian Country Report, Prepared for AOAD

**Table 2.2: Accumulative Design Capacity of Waste Water Treatment Plants in Libya**

Year	Design Capacity (m <sup>3</sup> /day)
1970	32910
1975	66510
1980	90510
1985	223885
1990	372635
1995	391735
1998	446000

Abu Faid A.A, 1999: Reuse of Waste water in Agricultural Production in Great Jamahiria

**Table 2.3: Drinking Water Consumption in Mauritania**

Year	Population (Million inhabitants)	Water Consumption (million m <sup>3</sup> /year)	Expected Wastewater (million m <sup>3</sup> /year)
2000	2.64	48.2	38.6
2005	3.06	55.8	44.6
2010	3.55	64.8	51.8
2015	4.11	75.0	60.0
2020	4.77	87.1	69.7
2025	5.53	100.9	80.7

**Table 2.4: Re-use of Untreated Wastewater for Irrigation in Morocco**

City	Population (thousand)	Volume of Wastewater (million m <sup>3</sup> )	Irrigated Areas (ha)
Marrackesh	473	15.0	3000
Maknes	352	14.0	1500
Fas	530	21.0	800
Bin Salih	55	1.0	100
Bani Milal	110	2.6	300
Kharbieka	145	4.0	360
Wajda	-	-	470
Tatwan	-	-	70
Bin Jarir	-	-	35

Source: Gamali O., Kharfati A., 1999. Morocco Experience in the Field of Re-Use of Wastewater, a Country Report prepared for AOAD.

**Table 2.5: Sudan Water Requirements for Human Consumption**

Year	Water Requirements per Capita		Population (Millions)	Water Requirement (Billions)
	Litre/h/day	m <sup>3</sup> /h/year		
1993	26.5	9.7	24.9	0.242
1997	40.0	14.6	27.64	0.404
2000	50.0	18.25	29.85	0.545
2005	60.0	21.9	33.94	0.743
2010	75.0	27.4	38.58	1.057
2015	90.0	32.9	43.87	1.443
2020	105.0	38.3	49.87	1.910
2025	120.0	43.8	56.7	2.483



**Table 2.6: Plant of Wastewater Treatment in Tunisia**

<b>Plant</b>	<b>Capacity m<sup>3</sup>/day</b>	<b>Plant</b>	<b>Capacity m<sup>3</sup>/day</b>
Tunis-East	60000	Elministir/Elfrina	18240
Tunis-Shratana	43000	El gab a Elsugra	1450
Tunis-North	15750	Elwardaneen	1400
Galaat Elandalus	1500	Elsahleen	2560
Tunis-South	37500	Sbada-Lmta-Bohajar	1660
Tunis-Rads	700	Gosoor Elsaf	1500
El Hamamat 1	4208	Masakin	9700
El Hamamat 2	5146	El Mahdia	10220
Nabl 3	9585	Eljum	1250
Nabl 4	9585	El mahris	1335
Golybia	5542	Safax	24000
Solyman	2457	Elgayrawan	12000
Garnabalia	3235	Sidi Bozaid	3125
Manzel Bozalfa	2068	Elgasrain	15000
Benzerte	26600	Gafasa	3500
Manzel Borgaiba	11100	Gabix	17260
El Kaf	8500	Nafta	1335
Tabria	5500	Homat El soug	3500
Baja	14000	Dar Jarba 1	1100
Majaz El Bab	4500	Dar Jarba 2	480
Jandoba	8000	Sidi Mhriz	4400
Sidi Bo Ali	900	Sidi Saleem	1800
Sosa-North	14000	Taneet	256
Sosa-South	187000	Elsowayhil	1208
Makneen	6400	Lala Mariam	1724
Elministir/Dakila	3100	Karkees	1335
Elministir/Elgadeer	2000	Tatween	5340

**Table 2.7: Areas and Crop Grown in the Schemes of Elhadaba El Khadra and Elgawarisha in Libya Using Treated Wastewater**

Plant	Phase	Design Capacity m <sup>3</sup> /day	Irrigated Area (ha)	Cropping Pattern
Tripoli/Elhadaba Elkhadra	I	27000	2500	Vegetables, Fruits, Fodder
	II	110000	1500	Fodder
Bengazi/Elgawarisha	I	27000	360	Fodder
	II	27000	658	Fodder
	III	27000	1000	Fodder

**Table 2.8: Irrigated Areas Using Treated Wastewater in Tunisia as Per State**

State	Irrigation Zone	Equiped Area (ha)	Cropping Pattern	Irrigated Area (m)
Ariana	Sakra	600	-	450
Bin Arons	Borg Taweel Marnag	3200	Cereals & Fodders	2620
		1047	Fodders-Trees-Cereals	430
Nabl	Elmasadi Wad Sowayhel	120		120
		236		235
Sosa	Elzawia	205	Fodder	150
Elminstir	Elwardaneen Lamla	50	Fruits	50
		50	Fodders	50
Elgayrawan	Dura'Tmar	240	Fodders	240
Elgasrain	Wad Elsaid	100		100
Sfax	Elhajib	425	Fodders	425
Gafsa	Elagila	116	Cereals and Fruits	115
Madneen	Sidi Shamakh	26	Fodder	10
<b>Total</b>		<b>6615</b>		<b>5195</b>

Source: Elatiri R., and Elgarbi N., 1999. Re-use of Wastewater in Agriculture, a Country Report Prepared for AOAD.

**Table 5. 1: Key Areas for Community Participation in Enhancing the Reuse of Treated Wastewater**

<b>1- Public Awareness</b>	To enhance active public involvement and participation.	The public at large	Systematic popular campaigns, grass root education.
<b>2- Empowerment</b>	To enable the community to identify and assess its own needs and the means to realize them.	Water user communities and stakeholders	Education, establishment of water-user and stakeholder associations, lobbying groups and management participation
<b>3- Role of Women</b>	To make women play more active role in wastewater management and better to accommodate their water related needs.	Women in rural and urban communities.	Gender related campaigns, provision of basic education, and empowerment.
<b>4- Professional Awareness</b>	To make participatory approach an integral part of wastewater development and management.	Water sector professionals.	Professionals-community interactions, understand community needs and perceptions, establish and strengthen customer service and public relations department.

Bib# 12927 Status: Cataloging Complete

Created 30/08/02 12:15PM Operator: Semira

Updated 16/10/02 03:34PM Operator: Koru

000 01127cam 22002775 4500

043 \$aAFR

072 0 \$a14.01.01

072 0 \$a04.02.00

080 \$a338.1:556.18(61)

088 \$aECA/TNG/SRDC/ICE/XVI/7

110 2 \$aUnited Nations Economic Commission for Africa \$bSub-regional Development Centre for North Africa (SRDC)

245 10 \$aBest practices for drought preparedness and mitigation and water management for increased food security in North Africa / \$cUNECA. \$keCAP

260 \$aTangier, Morocco: \$bECA, \$c2001.

300 \$av, 92 p.: \$bill.

500 \$aIncludes bibliographical references.

650 0 \$aPoverty mitigation \$zAfrica, north

650 0 \$aWater management \$xFood security \$zAfrica, north

650 0 \$aAgricultural productivity \$zAfrica, north

651 4 \$aAfrica, North

653 0 \$aFood security

653 0 \$aPoverty and welfare

710 0 \$aUnited Nations \$bEconomic Commision for Africa

710 0 \$aUNECA

711 2 \$aSixteenth meeting of the Intergovernmental committee of experts of SRDC  
\$cTangier, Morocco \$d13-16 March 2001 \$nSixteenth

850 \$aECA

852 \$aECAL \$cCIRC \$9338.1:556.18(61) \$mB561