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# JOINT MANAGEMENT OF SHARED AQUIFER SYSTEMS



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**Ahmed R. Khater**
Director, Research Institute for Groundwater,
National Water Research Center,
Ministry of Water Resources and Irrigation, Egypt.

## ABSTRACT

The region covered by the ESCWA member countries is home to about 2.5% of the world's population and have some 0.4% of the world's annual renewable water resources. About 97.7% of the region is classified as arid and semi arid desert land. Scarcity of water associated with large geographical and seasonal variations and increasing competition for water among consuming sectors are major constraints in the region. About 80 % of the region's annual renewable water resources are provided by river flows generated outside the region, and the major aquifers in the region are shared between two or more countries. Thus, joint management for sustainable development of shared water resources is of considerable importance. Groundwater abstraction from renewable and non-renewable aquifers is the main source of water in 61% of the member countries. Shared aquifers, especially non-renewable ones, contribute significantly to current water demand in these countries. Competition over shared aquifers in the region is likely to develop and could trigger tensions, especially with the absence of cooperation mechanisms to jointly manage these shared aquifers. Therefore, it is in the interest of the countries in the region to enhance cooperation regarding joint management of shared aquifers. This paper discusses the multi-disciplinary and multi-dimensional nature of joint management of shared aquifer systems. The discussion comprises technical, legal, institutional, socio-economic and environmental issues associated with the management of shared aquifers, which extend across two or more national constitutions. On the other hand, it presents overview of the Egyptian experience in the management of shared groundwater in the Nubian aquifer system.

## 1. INTRODUCTION

The region covered by the ESCWA member countries (Bahrain, Egypt, Iraq, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, Syria, United Arab Emirates and Yemen) is about 4.75 million square kilometers, of which about 97.7% is classified as arid and semi arid desert land (Fig.1). The region is home to about 168 million people, about 2.5% of the world's population. Annual renewable water resources in the region average about 169 billion cubic meters (BCM). This is equivalent to some 0.4% of the world's annual renewable water resources. Competition over shared aquifers in the region, which is likely to develop, could trigger tensions, especially when no cooperation mechanisms exist to jointly manage these shared aquifers.

Most ESCWA countries are experiencing rapid population growth and have high dependency ratios. Because of the extreme aridity of much of the region, the population is distributed very unevenly among countries and within them. It is the relative availability of water that determines population distribution and density. Scarcity of water associated with large geographical and seasonal variations and increasing competition for water among consuming sectors are major constraints in the region. In many countries, all available water resources, which can be used for economic purposes, have already been developed or are in the process of development.

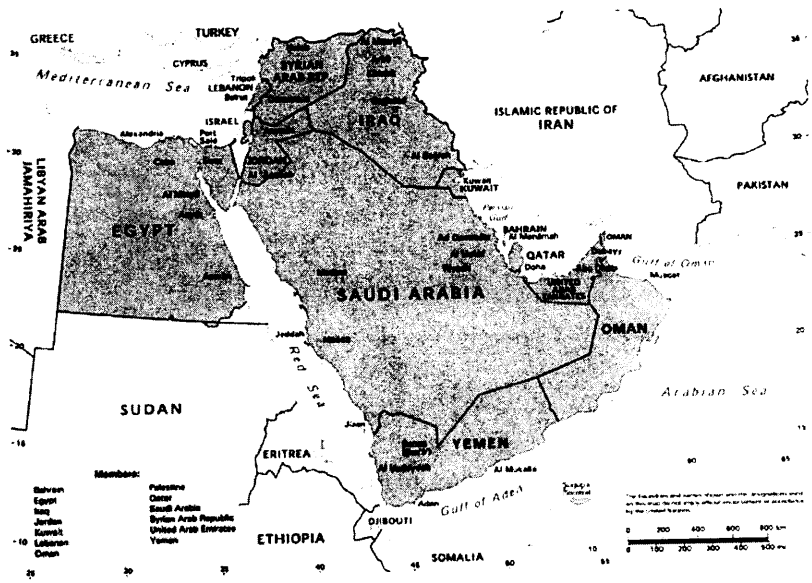


**Fig. (1) Location Map of the ESCWA region.**

The annual renewable groundwater recharge in the ESCWA countries is about 18.5 BCM, representing some 11% of the region's total annual renewable resources. Considerable groundwater mining is taking place in the region, since the present groundwater abstraction exceeds the annual recharge by 60%. Furthermore, the actual contribution of groundwater to the total water demand in the region is more than 16%. This is at the region level, however, for countries with little or no surface water, groundwater abstraction from renewable and non-renewable aquifers are the main source of water in the Gulf countries, Jordan and Yemen.

The ESCWA region is actually a region of shared water resources. This manifested by the facts that about 80 % of the region's annual renewable water resources are provided by river flows from outside the region and many of the major aquifers in the region are shared between two or more countries. Shared aquifers, especially non-renewable ones, contribute significantly to current demand in many countries. Meanwhile, it is postulated that future water deficit in the region will have to be met largely from non-renewable groundwater in shared aquifers.

Therefore, joint sound management and sustainable development of shared water resources are of considerable importance. In contrast to the management of shared river basins, for which several international treaties, conventions and agreements exist, there is very limited experience worldwide for shared aquifer systems. Competition over shared aquifers in the region, which is likely to develop, could trigger tensions, especially when no cooperation mechanisms exist to jointly manage these shared aquifers. Accordingly, development of such cooperation mechanisms is of paramount importance to the region's sustainable development.

In this paper, the multi-disciplinary and multi-dimensional nature of joint management of shared aquifer systems will be discussed. On the other hand, overview of the Egyptian experience in the management of shared groundwater in the Nubian aquifer system will be presented.

## 2. WATER RESOURCES MANAGEMENT

### 2.1 General Principles

Actions, both physical and administrative, that lead to the beneficial use of water resources are known as "water resources development". Over the last three decades, we have witnessed an evolution in the water resources development thinking. It was formerly narrowly defined as "economic" development; environmental and social impacts were not directly addressed. Today water resources development is defined as encompassing economic, environmental and social factors.

Any discussion of water resources development begins with reference to conflict over a scarce and important resource, which is some way, must be resolved. The solution process normally yields various plans that expand on future objectives and projections for each of the water uses of the nation and its people, the summation of which far exceeds the available resources. The process by which the difference between supply and demand is brought into balance by investment in new supplies and/or technologies for reducing demand and by making rather hard choices as to which uses will be encouraged and which discouraged is known as "water resources planning".

At the national level, planning for water resources development is considered successful if it enables decision makers to make the correct decision on the next water investment. Decisions made in the past determined the pattern of development today. Similarly, decisions made today will set the pattern of future development. If the economic, social and environmental setting remains unchanged or could be predicted with precision, a fixed plan could be prepared setting out a development schedule for many years to come. But social preference changes and so the value of

goods and services relative to each other and today's rationale for development may be out of phase with priorities a decade from now.

Water resources management integrates by definition all aspects and functions related to water. It can be considered as the process including all activities of planning, design, construction and operation of water resources systems. The process involves modification of the hydrologic cycle to regulate the natural water supply to better meet human needs.

## 2.2 Management and Sustainable Development

Sustainable development is generally a function of the availability of the natural resource base over time. Planning for water resources utilization is a must to ensure the sustainability of present and future actions. It is a continuous/dynamic process that depends on various inputs. The primary input is the water policy accompanied by clear objectives. A set of scenarios is considered, evaluation of which is generally made against pre-identified criteria. Finally, come the actions needed to implement the policy, which are also known as strategies.

Planning is the process of thinking through *various possible actions* before a decision to act is made. Planning is a *dynamic* process.

A Policy is a description of goals/objectives in broad terms (e.g. food security).

Policy Objectives is a more concrete specification of a policy (e.g. increase in grain production though horizontal expansion of cultivated area and better genetic processes, etc.).

A Criterion is a quantification of an objective.

A Scenario is a description of socio-economic developments that are outside the influence of the plan (e.g. increase in population, bringing water to people or people to water, feasible developmental sectors based on culture, food security, food consumption).

A Strategy is a course of action to reach the policy objectives set for the development of water resources. It would consist of (groups) of measures (technical and/or non-technical) or programs with a common policy objective or a combination of objectives.

A Plan describes the strategy chosen by the decision-maker for the development of the water resources and policy objectives on which the strategy is based.

Water use policies are generally based on prevailing issues and driving forces such as:

1) Rapid population growth, rapid urbanization, internal immigration and uneven settlement patterns.2) Aridity and continuous decline of per capita water share. 3) Decline in food share and increasing dependence on imported food. 4) Environment degradation, including depletion of natural resources. 5) Inefficient water use, including irrational use of fossil groundwater, poor water recycling practices, poor irrigation systems and practices. 6) Deteriorating rural environment.

The policy should also consider all components of the environment. The dynamic interrelations among water resources system components impose an integrated approach on policy makers. Accordingly, a multidisciplinary approach has to be adopted in the policy formulation process. Because policies cover long-term horizons and have wide spatial coverage, many uncertainties can be expected. Therefore, uncertainty has to be explicitly considered in the policy formulation rather than just being ignored. Achievement of the policy objectives is not an easy task. Transparency of the policy formulation process and general public approval is key elements to achieve the policy objectives. Proper understanding and analysis of people perceptions is a major factor to ensure sustainable development.

## 3. MANAGEMENT OF SHARED AQUIFER SYSTEMS

Management of aquifer systems essentially aims at achieving certain goals through a set of decisions related to the operation of the system. Goals may be defined at different levels within the hierarchy of levels ranging from national ones, regional ones to those at the level of individual users. Goals can be achieved by different policies. Therefore, management essentially includes selection of the best policy. Selection of the best policy is normally made according to some criterion or a measure of the relative effectiveness with which the different alternative policies meet or approaching the specified goals. The function of decision variables, which measure the efficiency of the alternative policies, is known as the objective function. Meanwhile, the feasibility of a policy has to be checked so that it does not violate specified constraints.

In order to solve the management problem we must be able to predict the response of the aquifer system to any proposed operation policy, and obtain the modified states of the system (i.e. solving the forecasting problem of the system). This requires, among others, a good knowledge of the system configuration and its present state, which are the bases for predicting system response to future stresses (i.e. solving the system's identification problem). Thus, solving the management problem requires solving the forecasting problem of the system, and solving the system's identification problem is a prerequisite.

Similar to other natural resources, both groundwater and surface waters traverse national borders and political boundaries without opposition. Consequently, the actions of one state, in connection with an international river or groundwater aquifer, may deleteriously affect the quality or quantity of water in another state. Groundwater aquifers can span international boundaries or may be part of a greater hydrologic system linked with the surface or groundwater of neighboring states. Hence, shared aquifer systems are those contiguous aquifers that extend across national boundaries. Within a national context, most management issues can be addressed under the single national constitution. Obviously, this is not the case regarding the management of shared aquifers, which extend across two or more national constitutions, where national policies may have to be adjusted to achieve equitable distribution. Accordingly, frameworks for the management of shared aquifers should comprise hydrogeological, legal, institutional, socio-economic and environmental issues.

### 3.1 Hydrogeological Aspects

Sound management of groundwater resources clearly requires a through understanding of the hydrogeology of aquifers under consideration. Therefore, a unified and consistent knowledge base is a prerequisite for the management of shared aquifers. Modern methodology should be used for hydrogeological investigations of the shared aquifer resources, such as isotope hydrology studies, in a multi-disciplinary context of shared aquifers. Such knowledge should be developed within a conceptual model for the shared system. A consistent monitoring of the basic hydrologic parameters on the sharing boundaries should augment this model. Without such understanding one cannot estimate the resources of shared aquifers and assign resources between countries. One crucial concern is the approach that may be adopted for aquifer management that is whether or not the aquifer is recharged. In the case the aquifer receives recharge, the management strategy is based on abstracting a proportion of the average annual recharge. Such strategy can only be achieved through joint management among the countries sharing the resource. Sustainable development of such renewable aquifer can be explicitly formulated among those sharing the resources. On the other hand, shared aquifers with minor or no recharge are more difficult to manage, as yet there is little real consensus about how such resources should be developed. In this case, the management strategy is shaped according to the demand driving force. To ensure that each sharing country accepts the mutual impacts of groundwater development in the sharing countries, the amount and rate of abstraction by each country should be subject to multilateral agreements.

### 3.2 Legal and Institutional Aspects

In contrast to the management of shared river basins, for which several international treaties, conventions and agreements exist, there is very limited experience worldwide for shared aquifer systems. Until quite recently, the international legal regime regulating the use of international waters neglected the importance of groundwater resources. International groundwater law and treaty practice are only at a beginning stage. There are only few treaties and agreements that have provisions dealing with groundwater at various multinational levels. However, in those few cases, groundwater is considered when it is interconnected with a surface water body. Of particular significance in adapting to consider the hydrologic system as a whole and to acknowledge the integrated nature of surface and groundwater is the work of international organizations responsible for the codification of international customary law as it relates to transboundary waters. Most noteworthy of these organizations are the International Law Association and the International Law Commission, whose work is discussed below.

- Work of the International Law Association

One of the earliest explicit recognitions of the interrelationship of surface and groundwater came in a statement of principles at the forty-eighth Conference of the International Law Association (ILA) in 1958. Under the title of "Agreed Principles of International Law," the comment to Principle One provided that although international law heretofore focused predominantly on surface water sources, it is essential to give due regard to all of the interdependent hydrological features of a drainage basin. Thereafter, in 1966, the ILA adopted the Helsinki Rules on the Uses of International Waters of International Rivers; the set of articles represented one of

the earliest attempts at codifying customary international law pertaining to transboundary water resources. Significantly, Article II of the Helsinki Rules defines an international drainage basin, the unit used to delineate the geographic scope considered under the Rules, as a transboundary geographic area defined by the extent of the watershed, "including surface and groundwater".

The Association later adopted the Seoul Groundwater Rules at the 1986. Seoul Conference of the ILA expanding the Helsinki Rules as they relate to transboundary groundwater resources. Paragraph Three of Article Two, entitled "Hydraulic Interdependence," provides that under the laws and duties of international law, states contemporaneous with a drainage basin must consider the interdependence of "groundwater and other waters, including any interconnections between aquifers". The inclusion of groundwater within the definition of drainage basin, and the obligation to give due regard to international groundwater resources, thus affirms the premise that groundwater is subject to contemporary international water law.

- Work of the International Law Commission

In 1991, the United Nation's International Law Commission (ILC) adopted the Draft Articles on the Non-Navigational Uses of International Watercourses. The ILC Draft Articles constitute a framework agreement intended to assist nations in developing watercourse agreements as well as in solving disputes over international water resources in the absence of existing agreements.

Article Two of the ILC Draft Articles defines "watercourses," the unit used to describe the geographic extent considered in the Articles, as "a system of surface and underground waters constituting by virtue of their physical relationship a unitary whole". In recognizing that the two sources of water constitute a part of a unitary whole, by virtue of the physical interrelationship, the ILC acknowledged the fact that groundwater is governed by international water law. Moreover, as the ILC Draft Articles are based on state practice, existing international agreements, and other potential sources of international law, they are regarded as obligatory and operative insofar as they codify current customary international law.

- Work of Other International Organizations

In reviewing drafts and recommendations pertaining to international water law, there appears to be widespread acceptance and recognition among international organizations that international watercourse systems must be considered and treated as a unitary whole. Moreover, it becomes more apparent within the legal community, as well as among the many international bodies regulating water resources, that attempting to isolate one aspect of the hydrologic cycle, when considering modern water issues, is an exercise in futility. A few representative examples of such drafts and recommendations are briefly discussed below.

The United Nations Economic Commission for Europe (ECE), in a 1986 report on groundwater legislation in the ECE region, concluded that "the interrelationships between surface and groundwater are various, frequently pervasive and of great practical significance". The ECE Report endorsed the principle that greater efficiency in use, storage and conservation, as well as improved overall administration of water resources could be achieved through an integrated approach in the management of

surface and groundwater resources. In addition, the ECE Charter on Ground-Water Management asserts that groundwater protection policies should be included within the rubric of comprehensive environmental protection strategies since groundwater pollution is inevitably interrelated and interconnected not only to other water resources, but also to the environment as a whole.

The Bellagio Draft Treaty, which developed out of the United States-Mexican dispute over the surface and groundwater of the Colorado River, provides another example of an international instrument, which considers groundwater within the unitary whole of the hydrologic cycle. The Draft Treaty was developed: (1) to be used as a blueprint for treaties regulating international groundwater resources, (2) to facilitate cooperation, and (3) to achieve optimum utilization of the resource. The preamble to the Draft Treaty provides that the "conjunctive use of surface and groundwater" resources is the foremost means of achieving rational and efficient water use while simultaneously safeguarding those resources for the future. Significantly, comment three discusses the definition of "conjunctive use" and explains that the phrase is rooted in the hydrologic interrelationship and interdependence between surface and groundwater, which further emphasizes the reciprocal effect one has on the other.

Accordingly, in the absence of institutional arrangement for shared aquifer systems, countries sharing one or more aquifers are encouraged to forge international cooperation in the management of such groundwater basins by establishing commissions or other frameworks, through an appropriate bi- or multi-lateral legal instruments. Such frameworks can be derived from international treaties and agreements or as well as local legislations and practices. Harmonized legislation can play an effective role in achieving inter-governmental cooperation. Current trends in national legislations for the management of aquifer systems suggest that harmonization could take place with respect to: status of groundwater ownership, regulation of drilling and abstraction including groundwater mining, protection and pollution control measures, and user participation in decision making.

### 3.3 Socio-Economic Aspects

Socio-economic issues applicable to the management of shared aquifer systems are the same as those for national aquifers, driven by national priorities. Growing water scarcity and lack of access to water form major constraints to socio-economic development. Shared aquifer systems, including the renewable and the non-renewable resources, are part of the social and cultural inheritance. Aquifer resources have strategic importance for socio-economic and agricultural development, improved welfare and public health, alleviation of poverty and improved food security. Groundwater resources form the principal water supply in urban agglomerations, and the only source for accessible and safe supply to the populations in many large rural areas. Growing pressure and lack of coordinated management of shared groundwater and related land resources can result in loss of water resources, productive land and life-supporting eco-systems. In the absence of joint management there is risk to impose high social and economic cost and incur loss of resources and benefits. On the other hand, joint management should lead to identification of mutual opportunities for development and investments for socio-economic development with poverty alleviation, based on efficient and equitable utilization of shared aquifer resources.

### 3.4 Environmental Aspects

Usually aquifer systems have ecosystems that are dependent totally or partly on patterns of natural discharge or recharge of related aquifers. Ecosystems conditions are shaped by hydrogeological and hydrochemical features of related aquifer systems. Discharge of shared aquifers into surface water bodies can be critical to the maintenance of biodiversity. Therefore, utilization of shared aquifers in competitive way without riparian coordination can damage dependent ecosystems. Excessive pumping or mining of shared aquifers can cause adverse environmental impacts and harm all sharing parties by causing costly drop of piezometric levels and possible water quality deterioration. Thus, growing dependence on shared groundwater with lack of joint management of the shared aquifers can result in loss of water resources, productive land and life-supporting ecosystems. In order to minimize environmental risk, and threats to terrestrial and freshwater ecosystems, operational Environmental Impact Assessment (EIA) procedures for protection and monitoring of shared aquifers should be developed and applied. The prerequisite for this action is the establishment of regional agreements and frameworks providing for institutional mechanisms, ensuring continuity and stability of cooperation in the shared aquifers.

## 4. THE NUBIAN AQUIFER SYSTEM: REGIONAL EXPERIENCE

### 4.1 Background

The Nubian Sandstone Aquifer System underlies an area in excess of two million square kilometers within the Eastern Sahara in North-East Africa. The area occupied by the aquifer extends over the national territories of East Libya, Egypt, Northeast Chad and North Sudan (Fig. 2).

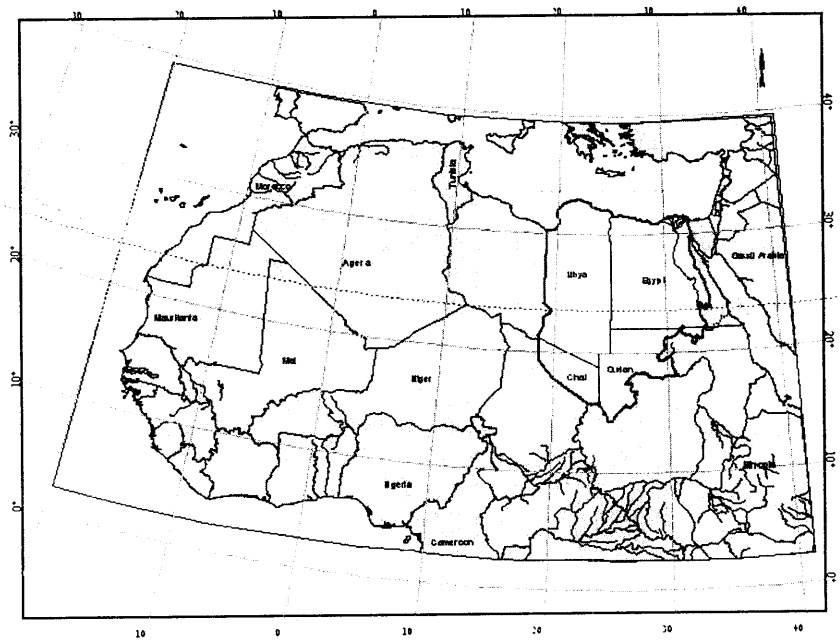


**Fig. (2) Location Map of the Nubian Sandstone Aquifer System.**

The Nubian Sandstone Aquifer System is composed of different water bearing strata that are differentiated into two systems, namely the Nubian Aquifer System (NAS) and the Post Nubian Aquifer System (PNAS). The NAS underlies almost all the area of Egypt, Eastern Libya, Northern Sudan and Northern Chad. The NAS comprises the Paleozoic and the Mesozoic deposits and overlies the Pre-Cambrian basement complex. The PNAS occurs to the north of the 26$^{th}$ parallel overlying the NAS in the North of the Western Desert of Egypt and North Eastern Libya. The PNAS comprises the Tertiary continental deposits in Libya and Egypt and the Tertiary carbonate rocks in Egypt. A low permeability layer belonging to the Upper Cretaceous and the lower Tertiary sediments separates the two systems.

Major recharge took place in the last pluvial period and at present no significant recharge has taken place, and the aquifer system is assumed to be depleting slowly through natural and artificial processes. The groundwater in storage in the Nubian Sandstone Aquifer is huge; it is estimated at 150,000 km$^3$. The flow directions of groundwater are from the south to the north and natural groundwater discharge take place into several depressions in the coastal areas of the Mediterranean Sea.

The development and management of such shared aquifer system requires large investment in exploration and investigation. During the past three decades, Egypt, Libya, and Sudan, have made separate attempts to develop the Nubian Sandstone Aquifer and the overlying arid lands. Each country has thus its specific experience. Sharing these experiences within a cooperation framework would be of vital importance to the sustainable development of the shared resource.

### 4.2 Evolution of Regional Cooperation

The mutual interest in regional cooperation in studying and developing the shared aquifer goes back to the early seventies. In 1972, UNESCO with the participation of Egypt, Libya and Sudan, sponsored in Cairo the first meeting for the preparation of a regional project to assess groundwater resources in the Nubian Sandstone Aquifer. A second meeting was held in 1974 and it was agreed to submit the proposed regional cooperation program to the UNDP for financial support. In 1977, a proposal entitled "Management of the major regional aquifer in North-East Africa and the Arabian peninsula" was presented at the United Nations Conference on Desertification (UNCOD) in Nairobi. In 1978, detailed proposal for North-East Africa was discussed in the first meeting of the consulting group on desertification.

In1980, the United Nations' Department for Technical Cooperation for Development (DTCD) provided from its regular budget a 3 years financial support to the coordination machinery of the "Transnational Project on the Major Regional Aquifer in North-East Africa" (INT-80-R44). The project coordination machinery then continued with funding from UNEP and UNDP until the end of February 1988 (INT-81-EO2 and RAB-82-OB). In June 1991, a meeting was held in Tripoli to review the progress achieved in the Transnational Project by the National Parties and donor organizations and to assess future cooperation requirements. During the Egyptian-Libyan Cooperation Council meeting in October 1992, the Joint Authority For the Study and Development of the Nubian Sandstone Aquifer has been established.

The Center for Environment and Development for the Arab Region and Europe (CEDARE), The Sahara and Sahel Observatory (SSO) and The International Fund for Agricultural Development (IFAD), among others joined forces to develop a

programme for the Development of the Nubian Sandstone Aquifer System. IFAD organized several meetings attended by CEDARE as well as representatives of Egypt, Libya and Sudan. In February 1994, IFAD organized a workshop, at the headquarters in Rome, with the objective of assisting the concerned countries to develop a strategy for the utilization of the Nubian Sandstone Aquifer System. IFAD also hosted the 1st Board of Directors meeting of the Joint Authority For the Study and Development of the Nubian Sandstone Aquifer attended by Egypt and Libya with the participation of Sudan as an observer.

After the success of the preparatory phase (April-October 1994), where a regional programme document was prepared, consisting of three phases: phase one is setting Base for a Sustainable Development Strategy, phase two Identification and Formulation of Development Projects and phase three Implementation of Development Projects. The Governing Board of IFAD approved funding of phase one of the Regional programme, in order to develop a Regional Strategy for the utilization of the Nubian sandstone Aquifer System. CEDARE has been selected as The Executing Agency of The Programme.

Sudan and Chad joined Egypt and Libya in the Joint Authority For the Study and Development of the Nubian Sandstone Aquifer in 1995 and 1999, respectively.

Phase one of the regional programme has been implemented during the period 1995-2000. Phase two of the programme has been implemented during the period 2000-2001 with funding from the Islamic Development Bank. The two phases of the regional programme have been successfully completed. The Joint Authority acted as the Regional Programme Steering Committee (RPSC). CEDARE, being the executing agency of the programme, provided continuous administrative backstopping throughout the two phases of the programme.

The 7th Board of Director meeting of the Joint Authority For the Study and Development of the Nubian Sandstone Aquifer was held in Tripoli in September 2002 with the participation of the four countries sharing the aquifer system. In the meeting the four countries explored opportunities for future joint cooperation.

### 4.3 Scope of the Regional Programme

The Regional Programme has been developed and implemented with the overall objective of the formulation of a regional strategy for the sustainable utilization of the Nubian Sandstone Aquifer System. This is achieved through the following specific objectives: i) create an enabling environment for the formulation of a regional development strategy; ii) assist in the capacity-building of the national institutions in the concerned countries; iii) formulate a regional groundwater development strategy aimed at conflict-free development and management of groundwater from the Nubian Sandstone Aquifer System in each country in order to avoid any negative reciprocal externalities.

At the aim of enabling the environment for the development of a regional strategy for the utilization of the Nubian Sandstone Aquifer System, the following institutional arrangements were carried out:

- A Regional Programme Steering Committee (RPSC) was formed of the Joint Authority members. Its role was to review and approve the proposed Plan of Work

and Budget, and also to discuss any other issues related to the Programme and its regional setup. The RPSC met once a year or whenever necessary.

- A Regional Technical Review Committee (RTRC) was formed including representatives of the four countries sharing the aquifer, namely Egypt, Chad, Libya, and Sudan, CEDARE, IFAD, the Islamic Development Bank (IDB), UNESCO, ACSAD, Sahara & Sahel Observatory (OSS), and the Technical University of Berlin (TUB). Its role was to review, discuss and approve technical matters and issues related to Programme and its regional implementation. The RTRC met once a year or whenever necessary.
- The members of the Joint Authority and the Regional Programme Steering Committee (RPSC) in their first meeting appointed focal point Institutions and the National Coordinators.

In the process of the development of a regional strategy, data and information were obtained from the literature and previous studies, and data collected by the focal institutions in each country and/or by other local, regional and international organizations that carried out extensive research in the area. These were all assessed, verified and digitized. The verified data was reformated, harmorized and standerdized then stored in a unified form. This information includes: Geography, Geomorphology and Hydrography, Geology, Hydrogeological Units, The Aquifer Extent and Boundaries, The Aquifer Hydraulic Parameters, Aquifer Potentiometry, Groundwater Extraction, Aquifer Response to Extraction, Groundwater Quality, and Potential Groundwater Resources.

A simulation model of the Nubian Sandstone Aquifer System has also been developed within the Programme activities. The developed model is a regional model; it is therefore not intended to analyse the detailed response of the aquifer system on the local scale. The model is used to analyse the regional behaviour of the aquifer system, to simulate aggregated national development scenarios and predict the related aquifer response, to anticipate and evaluate the risk of deterioration of water quality in relation to water abstraction, to constitute the technical basis for a consultation mechanism between the countries, and to provide boundary conditions for local detailed models. Since the model and the related calibration and simulation data have been transferred to the four countries, the countries themselves in order to test other development scenarios and also to get acquainted with the use of the software should perform other regional and local simulation runs.

Within the objective of the capacity building of the National Institutions of the countries sharing the Nubian Sandstone Aquifer System, training courses were conducted in the fields of groundwater modeling and Geographic Information Systems as well as the installation and use of monitoring equipment. Introductive and advanced levels in those fields were provided to empower human skills to master the tools for the management of groundwater resources. Upon assessment of the needs of these Institutions hardware and software were purchased and provided.

### 4.4 Mechanism for Continued Regional Cooperation

In order to assure the sustainable development and the continued mechanism of regional cooperation for the shared management of the Nubian Sandstone Aquifer, it was deemed imperative to share the information, monitor the aquifer regionally, and exchange updated information on the behavior of the shared resource. Therefore, the

Programme had the National Coordinators of the four countries sign two agreements for the data sharing, monitoring and exchange of information.

Within the context of the first agreement the four countries will share the data that was consolidated throughout the implementation of the Programme and that was incorporated in the Regional Information System. Within the framework of the second agreement they will update the information by continuous monitoring of the aquifer and updating the Information System.

The Programme proposed a regional monitoring network, indicating representative sites that should be monitored, the parameters and the frequency of monitoring of these parameters. These included the yearly extraction in every extraction site, yearly measurement of the quality in each extraction site in addition to the water level measurements in specified locations, which should be recorded twice a year. The monitoring network was designed to provide as much spatial coverage as possible of the Nubian as well as the Post Nubian aquifers. The four countries sharing the resource, represented by their National Coordinators, adapted the regional network and agreed to continue the monitoring of the Aquifer through a mechanism specified in the two agreements. The regional monitoring network included existing locations as well as proposed ones to cover information gaps.

The Joint Authority as a permanent regional organization founded by the four countries sharing the Nubian Sandstone Aquifer System should be reinforced by both legislative and institutional mechanisms in order to enhance the cooperation among the countries sharing the Nubian Basins.

## 5. CONCLUDING REMARKS

Shared aquifers, especially non-renewable ones, contribute significantly to current demand in many countries. Meanwhile, it is postulated that future water deficit in the ESCWA region will have to be met largely from non-renewable groundwater in shared aquifers. Therfore, joint management for the sustainable development of shared water resources are of considerable importance. On the national level, most management issues can be addressed under the single national constitution. Obviously, this is not the case regarding the management of shared aquifers, which extend across two or more national constitutions. Accordingly, frameworks for the management of shared aquifers should comprise hydrogeological, legal, institutional, socio-economic and environmental issues. A unified and consistent knowledge base of the hydrogeological set-up is a prerequisite for the management of shared aquifers. Such knowledge should be developed within a conceptual model for the shared system. A consistent monitoring of the basic hydrologic parameters on the sharing boundaries should augment this model. Without such understanding the resources of shared aquifers cannot be estimated and assigned between countries. A management strategy is essentially shaped according to the demand driving forces. To ensure that each sharing country accepts the mutual impacts of groundwater development in the sharing countries, the amount and rate of abstraction by each country should be subject to multilateral agreements. There is very limited experience worldwide regarding the international legal and institutional regime regulating the use of shared aquifer systems. There are only few treaties and agreements that have provisions dealing with groundwater at various multinational levels. Of particular significance in this respect is the work of international organizations responsible for the codification

of international customary law as it relates to transboundary waters. Most noteworthy of these organizations are the International Law Association and the International Law Commission. Countries sharing aquifer systems are therefore encouraged to forge international cooperation in the management of such groundwater basins by establishing commissions or other frameworks, through an appropriate lateral legal instruments. Such frameworks can be derived from international treaties and agreement or as well as harmonized local legislations and practices. Harmonized legislation can play an effective role in achieving inter-governmental cooperation. Aquifer resources have strategic importance for socio-economic development. Socio-economic issues applicable to the management of shared aquifer systems are the same as those driven by national priorities for national aquifers. Growing pressure and lack of coordinated management of shared groundwater and related land resources can result in loss of water resources, productive land and life-supporting eco-systems. In the absence of joint management there is risk to impose high social and economic cost and incur loss of resources and benefits. On the other hand, joint management should lead to identification of mutual opportunities for development and investments for socio-economic development. Ecosystems conditions are dependent on and shaped by hydrogeological and hydrochemical features of related aquifer systems. Therefore, utilization of shared aquifers in competitive way without riparian coordination can damage dependent ecosystems. In order to minimize environmental risk, and threats to terrestrial and freshwater ecosystems, procedures for protection and monitoring of shared aquifers should be developed and applied. However, establishment of regional agreements and frameworks providing for institutional mechanisms, ensuring continuity and stability of cooperation in the shared aquifers is a prerequisite for this action.

The Nubian Sandstone Aquifer System, extending over the national territories of Egypt, Chad Libya, and Sudan, is one of the major shared aquifers worldwide. During the past three decades, the sharing countries have made separate attempts to develop the Nubian Sandstone Aquifer. Each country has thus its specific experience. Sharing these experiences within a cooperation framework is of vital importance to the sustainable development of the shared resource. The mutual interest in regional cooperation in studying and developing the shared aquifer goes back to the early seventies. A Regional Programme has been developed and implemented with the overall objective of the formulation of a regional strategy for the sustainable utilization of the Nubian Sandstone Aquifer System. This has been achieved through the Joint Authority For the Study and Development of the Nubian Sandstone Aquifer founded by the four countries sharing the aquifer system. The support of regional and international organizations is playing a major role in keeping the momentum for sustainable and continued mechanisms of regional cooperation for the shared management of the Nubian Sandstone aquifer system. Such achieved regional cooperation provides a successful example that could help in the development of similar cooperation programmes for the other shared aquifer systems in the region, which is of paramount importance to the region's sustainable development.

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