ESCWA UNEP BGR (MEW)

Distr.
LIMITED
E/ESCWA/ENR/2000/WG.3/15
13 November 2000
ORIGINAL: ENGLISH

ECONOMIC AND SOCIAL COMMISSION FOR WESTERN ASIA

Expert Group Meeting on Implications of Groundwater Rehabilitation
for Water Resources Protection and Conservation
Beirut, 14–17 November 2000

IMPLICATIONS OF GROUNDWATER REHABILITATION IN THE ESCWA REGION

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Abstract

Increases in population growth will contribute to increasing pressures on groundwater resources also increase. More than 1.5 billion people worldwide depend on groundwater for drinking and agricultural usage. Groundwater is now being over-abstracted especially in arid regions of the world. The result is falling water levels and declining well yields, more expensive supplies development, land subsidence, the intrusion of salt water into freshwater supplies and ecological damage such as the drying out of wetlands.

The major quality constraint of groundwater use in the ESCWA countries is its naturally high salinity in wide parts of the region. In addition to these natural groundwater salinity problems, the groundwater quality is threatened in many areas by man-made pollution.

Pollution sources in different parts of the world and the ESCWA region in particular may result from infiltration of domestic sewage from unsewered sanitation, leaking sewers or sewage oxidation lagoons with severe contamination of water supply wells or springs. Additionally, residues of fertilizers and pesticides in irrigation return flow may endanger drinking water quality. Over-exploitation of fresh water aquifers can result in intrusion of brackish water contained in parts of the exploited aquifer or in underlying or overlying aquifers with regard to organic components and traces of heavy metals.

Solid waste disposals are, an important source of subsurface contaminant load. However, industries accidentally spill or release their effluents into the ground or into surface water causing pollution that runs deep underground.

The result is a serious deterioration of groundwater quality. It is always extremely difficult and very costly to clean up a polluted aquifer. It is therefore urgent that we protect the groundwater supplies with diligence, and whenever possible to rehabilitate it using different techniques.

I. INTRODUCTION

Groundwater is the main source of water supply for some of ESCWA countries. The magnitude of contribution of groundwater in the total supply varies not only from one country to another but also from sector to sector within the same country. Several major urban centers are completely dependent on groundwater, even in the GCC countries, where desalination utilization is extensive; groundwater sources are relied upon for mixing with desalinated water, as well as for irrigation purposes. A similar picture, of varying degrees of reliance on groundwater also emerges for the irrigation sector in the remaining member states. Furthermore, in terms of annual replenishment, groundwater aquifers receive and store the bulk of the annual runoff in countries of the Arabian Peninsula and Jordan.

Although groundwater is a subsurface resource, it is as vulnerable to pollution and contamination as waters in rivers and streams. Groundwater aquifers are often polluted with wastewater from urban centers, industries wastes and irrigation return flow. Groundwater quality may also deteriorate as a result of over-pumping from aquifers in coastal areas, which triggers seawater intrusion into the freshwater aquifers. On the other hand, groundwater pollution processes can go on for many years undetected. In many cases the cost for rehabilitation of the polluted aquifer may become very expensive.

Groundwater quality deterioration is of increasing concern all over the world. The major quality degradation indicators include, among others: (1) increased salinity, due to salt water intrusion or to a net accumulation of salts due to irrigation return flow; (2) pollution from nitrogenous wastes, especially agricultural and human-made; (3) contamination from agro-chemicals, such as pesticides, pathogens, toxic and heavy metals, etc.

In the Western Asia region where water is scarce, groundwater pollution has resulted in reducing the availability of supplies. Over the last few decades, cases of groundwater pollution in the region have been reported around some major urban centers and irrigation regions. Salinity increase of groundwater in coastal aquifers is also common in the region. Besides, cases of rising water table of shallow aquifers in some urban centers, has resulted in adverse environmental and health consequences.

Given the importance of groundwater as a vital water supply sources and the degree of contamination taking place in the shallow aquifers of the ESCWA region, it becomes imperative that member state enhance their capacity on groundwater remedial techniques and protection of their groundwater sources. In order to promote these concepts, this study will briefly review the groundwater situation in the region, the sources of groundwater pollution and mean to reduce or rehabilitate groundwater aquifer to improve water management and sustainable development as called for by Dublin recommend low.

II. WATER RESOURCES STATUS IN THE ESCWA REGION

The region covered by the ESCWA member countries is about 4.75 million square kilometers, and 97.7 per cent of this area is classified as arid and semi arid. Water is a valuable resource and its development and management require considerable investment. Climatic conditions, availability of water resources, socio–economic conditions, national borders, conflicts of interest and politics play an important role in hindering development in many countries of the region. Water resource issues are probably more significant in this region than in any other part of the world because of water scarcity and mismanagement practices. When available the projected water requirements for all purposes are compared with the available surface and groundwater resources. Serious questions arise concerning the long-term economic and environmental sustainability of existing water resource development and water usage patterns. Under existing patterns of water usage the prevailing water scarcity condition, it is unlikely that the expansion of irrigated agriculture can proceed without water shortage problems especially in the domestic sector. In regard to the water availability, the ESCWA region can be classified into three groups depending on the climatic, hydrological and geological regimes.

The first group consists of countries situated in arid zones, such as Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates. In this Arabian Peninsula subregion, surface-water resources are limited and usually occur as irregular, sporadic and unpredictable flood events. Groundwater and non-conventional water resources of desalinated water are the major components of the water supply in the subregion and supplement by reuse of treated wastewater and flood runoff for the irrigation sector.

The second group countries are situated in semi arid zones and include, Palestine and some parts of Jordan and Yemen. These countries have better natural water potential than that in-group I, but they experience severe water shortage from the natural water resources. Surface water from rainfall supplement groundwater sources to meet all requirements.

The third group countries are situated in relatively semi-arid zones and include Egypt, Iraq, Lebanon and the Syrian Arab Republic. This region has major rivers with adequate supply of water. The most important water resource problem of this group is that a substantial percentage of their surface water is shared among themselves and with neighboring countries. Surface water is the main water sources and groundwater represents the supplementary source. The water resources of group III are adequate only for the coming decade and only if these countries conserve, develop and manage these resources properly.

Expensive non-conventional water resources are being produced in desalination plants to meet the increasing water demands in the region, particularly in the Gulf Cooperation Council (GCC) member States.

The water resources from convention and non-convention resources for the ESCWA region are shown in table (1). The groundwater sources are shown in table (2) and figure (1).

TABLE 1. RENEWABLE AND NON-CONVENTIONAL WATER RESOURCES

	Conventional water resources [a/b/c]			Non-conventional water resources			
Country/Area	Surface water	Ground water recharge	Ground water use	Desalination	Wastewater & Drainage reuse	Water consumption	Utilization %
Bahrain	0.2	100	258	75	17.5 (3)*	310	309
Egypt	55500	4100	4850	6.6	4920 (3800)	65760	102
Iraq	70370	2000	513	7.4	1500	49100	78
Jordan	350	277	486	2.5	61	760	121
Kuwait	0.1	160	405	388	30	701	439
Lebanon	2500	600	240	1.7	2	1225	40
Oman	918	550	1644	51	23	1721	117
Qatar	1.4	85	185	131	28	298	345
Saudi Arabia	2230	3850	14430	795	131 (24)	16300	268
Syria	16375	5100	3500	2	1447 (1270)	9810	46
U.A.E.	185	130	900	455	108	1223	388
W. bank & Gaza Strip	30	185	200	0.5	2	440	205
Yemen	2250	1400	2200	9	52	2900	779
Total	150710	18738	29811	1925	8322	150548	

Source: Completed by ESCWA Secretariat from country paper prepared at EGM and international sources 1995, 1996, 1997, and 1999.

a/ The flow of the Tigris and Euphrates rivers can be reduced by upstream abstraction in Turkey.

b/ ACSAD paper submitted to the 2nd Symposium on Water resources development and Uses in the Arab World, Kuwait, 8-10 March 1997.

c/ Consolidated Arab Economic Report 1997.

* Drainage water reuse

TABLE 2. GROUND WATER DEPENDENCY IN THE REGION IN MCM

Country/Area	Renewable water Resources					Ground water use (MCM)
	Surface water (MCM)	Ground water (MCM)	Total (MCM)	Ground water Dependency (%)	Total Renewable & Non-conv. Res., (MCM)	
Bahrain	0.2	100	100.2	99.80	196	258
Egypt	55500	4100	59600	6.88	68,327	4850
Iraq	70370*	2000	72370	2.76	73877	513
Jordan	350	277	627	44.18	691	486
Kuwait	0.1	160	160.1	99.94	578	405
Lebanon	2500	600	3100	19.35	3104	240
Oman	918	550	1468	37.47	1542	1644
Qatar	30	185	215	86.05	218	200
Saudi Arabia	1.4	85	86.4	98.38	245	185
Syria	2230	3850	6080	63.32	7030	14430
UAE	16375*	5100	21475	23.75	24194	3500
Palestine Auth.	185	130	315	41.27	878	900
Yemen	2250	1400	3650	38.36	3711	2200
Total, BCM	150.71	18.54	169.25	10.95	184590	29811

Source: Papers presented at the EGM on Non-conventional Water Resources on the Application of Appropriate Technology for the Management of Groundwater Resources in the ESCWA Region. October 27-30, Manama, Bahrain 1997.

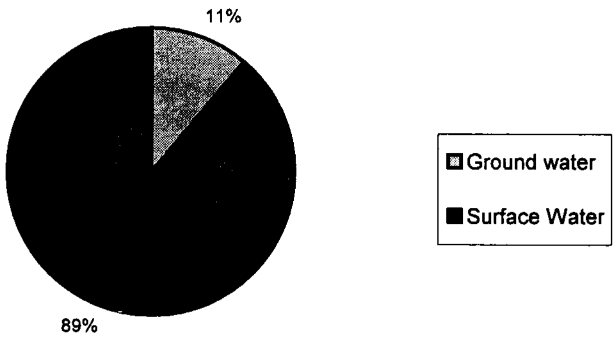
The contribution of groundwater to the total annual renewable water resources (i.e. ground water recharge) is about 11 % at the region level. At country levels, however, the contribution of groundwater can be much more significant. Table (2) shows that this contribution (or groundwater dependency ration) varies from nearly 100 % in Kuwait to less than 3 % in Iraq. Where as the contribution of groundwater to total annual renewable and non-conventional water resources are about 16 %.

The annual per capita water availability from renewable water sources for countries with relatively abundant surface water such as Egypt, Iraq and the Syrian Arab Republic, was estimated at 995,2960 and 1438 cubic meters, respectively in 1997. In those countries with extremely arid climates, the ranges were from 89 in Kuwait, to 615 cubic meters per year in Oman. The average regional per capita availability of renewable water resources in the ESCWA region is expected to decrease to 426cubic meters by the year 2015 and to 324 cubic meters in the year 2025, which is below the water poverty level as shown in table (3).

The largest user of water in the region is agriculture. However, rapid urbanization and improvement of the quality of life in terms of health, sanitation and social services, have resulted in a sharp increase in water demand for municipal purposes. When combined with industrial and agricultural uses, high demand for water has caused an imbalance between water availability and water required for socio-economic development.

The regional pattern of groundwater quality is related to climatic, morphological, geological and hypnological conditions of the ESCWA region. Groundwater with low salinity extends over wide parts of the western mountain ranges, the Mediterranean-type sub-humid climate and over the highlands and the western escarpment in Yemen.

Figure (1) Water Resources in percentage


Total renewable Water Resources

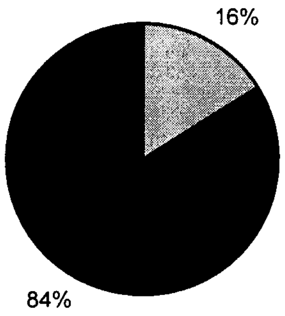

Total Renewable & Non-conventional water resources

TABLE 3. SUFFICIENCY OF RENEWABLE WATER RESOURCES IN THE ESCWA REGION

	Renewable water resources (mcm)			Annual water per capita** (m)^3			Sustainability indicator*** (%)		
Country/ Area	Surface water	Ground water	Total	1997	2015	2025	1997	2000	2025
Bahrain	0.2	100	100.2	137	131	99	309	349	608
Egypt	55,500	4,100	59,600	925	698	658	110	115	145
Iraq	70370	2000	72370	2,963	1,832	1,359	68	88	118
Jordan	475	277	752	168	78	70	101	168	235
Kuwait	0.1	160	160.1	89	62	57	438	500	874
Lebanon	2,500	600	3,100	995	437	341	40	53	124
Oman	918	550	1,468	613	403	309	117	103	169
Qatar	1.4	85	86.4	98	70	60	345	580	943
Saudi Arabia	2,230	3,850	6,080	311	182	150	268	292	398
Syrian Arab Republic	16,375*	5,100	21,475	1,438	948	609	46	80	110
U.A.E.	185	130	315	137	103	67	388	692	1,015
W. Bank & Gaza Strip	30	185	215	-	-	-	205	230	600
Republic of Yemen	2250	1,400	3,650	303	165	114	79	72	97
Total	**152,335**	**18.5**	**169,372**	-	-	-	-	-	-

Source: Papers presented at the EGM on Non-conventional Water Resources on the Application of Appropriate Technology for the Management of Groundwater Resources in the ESCWA Region. October 27-30, Manama, Bahrain 1997.

* The flow of rivers can be reduces by upstream abstraction;

** Water barrier index. Renewable resources/population;

*** Sustainability indicator. Water use/renewable resource. Future sustainability is based on 2000 and 2025 water demand programs (10-20% indicate better management practices while more than 4% mismanagement).

\- Indicates data not available.

The groundwater salinity (TDS) in most areas of the Syrian steppe and the Arabian Peninsula is range from 1000 to several thousand mg/l TDS. Low hydraulic gradients and related long residence time is contributing groundwater salinity as well.

The groundwater with relatively low salinity is found some areas of ESCWA with relatively high rainfall contain, however, fossil groundwater in sandstone aquifers; fresh water lenses sustained by present-day recharge along major wadi systems have low salinity. The main processes, which control the groundwater quality in ESCWA, are: the present and prevailing infiltration-recharge the mechanism, human activities, irrigation, solid and liquid waste disposal, groundwater abstraction; to meeting water requirement the dynamic equilibrium of and Seawater intrusion process in coastal areas.

In the ESCWA region groundwater quantity and quality is being threatened by the various development activities and mismanagement practices. Groundwater over-exploitation has been taking place from excessive and uncontrolled pumping, and is common features observed in many regional basins such as those in Jordan, GCC countries, the Syrian Arab Republic and Yemen. Groundwater quality is deteriorating as a result of seawater intrusion into the aquifers underlying the coastal plains in Bahrain, Oman, Qatar, the United Arab Emirates and Yemen. All these factors have resulted in a progressive reduction in available groundwater resources in the ESCWA region, to the extent that sustainable agricultural development may be hindered in the future.

III. GROUNDWATER POLLUTION

A. SOURCES OF WATER QUALITY DETERIORATION

It has been repeatedly observed that one of the most critical issues in the region is the accelerated decline of water quality, which has a direct effect on the quantity of water available for specific uses. As the quality of water deteriorates, its scope of uses diminished, thereby reducing supplies and intensifying shortages in the ESCWA region (E/ESCWA/ENR/1995/14). Resources degradation in the region can be attributed to a number of causes, the most important among them are:

(a) An increase in the discharge of untreated or inadequately treated domestic and industrial water;

(b) Discharge from agro-processing plants and a high level of agrochemicals in drainage water;

(c) Discharge of hazardous and toxic industrial wastes;

(d) Saline agricultural drainage from large-scale irrigation;

(e) Overdraft of groundwater, causing depletion and eventually water quality deterioration.

B. SOURCES OF WATER POLLUTION

Population increase, with its urbanization, has resulted in a dramatic rise in urban dwellers in most countries of the region. This, in most instances, was not accompanied by the necessary increase in domestic and urban wastewater treatment facilities. In fact the old practice of discharging wastewater into surface waters has continued in a number of major cities of the region. Intensive irrigation area expansion of the salinity of groundwater affecting its further use for irrigation. Additionally, residues of fertilizers and pesticides in irrigation return flow can endanger drinking water quality.

The rise of industry and the rapid industrialization that took place in the region in the last three decades of this century have increased the demand for fresh water, but the poor control exercised on industrial water discharge and the type of technologies used have resulted in serious water pollution.

Infiltration of domestic sewage from unsewered sanitation, leaking sewers or sewage oxidation lagoons is creating different degree of contamination of water supply springs, in particular, through increase counts of bacteria and viruses and elevated nitrogen compounds.

Irrigation without proper drainage, at insufficient or excessive amounts, the use of poor quality irrigation water, and the dissolution of surface and soil salts can cause soil and groundwater salinization.

Over-exploitation of fresh water aquifers along coastal zone has resulted in intrusion of brackish water contained in parts of the exploited aquifer or in underlying or overlying aquifers. Particular hazards of intrusion of brackish or saline water into exploited fresh water aquifers have to be expected:

Irrigation with surface water is a major cause of soil and groundwater salinization. Where salt content in the soil is high due to insufficient natural leaching, such as in semi-arid areas, salt content in irrigation return water can be relatively high. Solid waste disposals represent another important source of subsurface contaminant load.

C. CLASSIFICATION OF POLLUTION SOURCES

Water pollution sources can generally be classified into four major sources in relation to their way of disposal. They are as follows:

(1) *Point Source pollution*

The problems caused will depend on the nature of the pollutant; they can make water unsuitable for use as a source of drinking water; they can make it unsuitable for certain production processes or present a potential health hazard to the user of the water or to the consumer of water exposed products.

(2) *Diffuse source pollution*

The problems associated with diffuse pollution are much the same as for point source pollution, the crucial difference lying in the choice of tools for tackling the pollution source.

(3) *Accidental pollution*

The impact on the environment and on the potential uses of the polluted water body is much the same as for point source pollution, but with the potential for more dramatic effects leading to catastrophic results.

(4) *Acidification*

It can affect groundwater via the soil. Impacts could also be conceptually divided into two broad categories, short-term and long-term. Short-term environmental and social impacts, for example, can be represented by the impact of human interventions in a region for the construction of a specific project. Long-term impacts, on the other hand, are more pronounced. Some examples are presented below.

Figure (2) shows pollution sources resulting from different utilization sectors. Table (4) elaborates the classification of pollution sources.

TABLE 4. CLASSIFICATION OF POLLUTION SOURCES

Category	Sources
1. Sources Designed to discharge Substances	• Septic tanks and Cesspools • Injection Wells • Land Application
2. Sources Designed to Store, Treat and/or Dispose Substances	• Land fills • Open Dumps • Residential Disposal • Surface Impoundments • Mine Wastes • Material Stockpiles • Graveyards • Animal Burials • Above-Ground Storage Tanks • Underground Storage Tanks • Containers • Open Incineration and Detonation Sites • Radioactive-Waste-Disposal Sites

TABLE 4 (*continued*)

Category	Sources
3. Sources Designed to Retain Substances During Transport	• Pipelines • Material Transport and Transfer
4. Sources Discharging Substances as a Consequence of Other Planned Activities	• Irrigation • Pesticide Application • Fertilizer application • Farm Animal Wastes • Salt Application for Highway Deicing • Home Water Softeners • Urban Runoff • Percolation of Atmospheric Pollutants • Mine Drainage
5. Sources Providing a Conduit for Contaminated Water Enter Aquifers	• Production Wells • Monitoring Wells and Exploration Borings • Construction Excavations
6. Naturally Occurring Sources Created and/or Exacerbated by Human Activities	• Groundwater-Surface water interaction • Natural Leaching • Salt water Intrusion

D. IMPACTS OF GROUNDWATER POLLUTION

(1) *Impact on the environment*

Impacts can be categorized as primary caused directly by inputs, and secondary caused by outputs such as flow regulation. Impacts can be due to point source and diffuse sources pollution making water unsuitable for drinking and health hazard potential.

Accidental pollution could lead to catastrophic results. Groundwater quality and over exploitation can lead to crop damage, land subsidence and seawater intrusion.

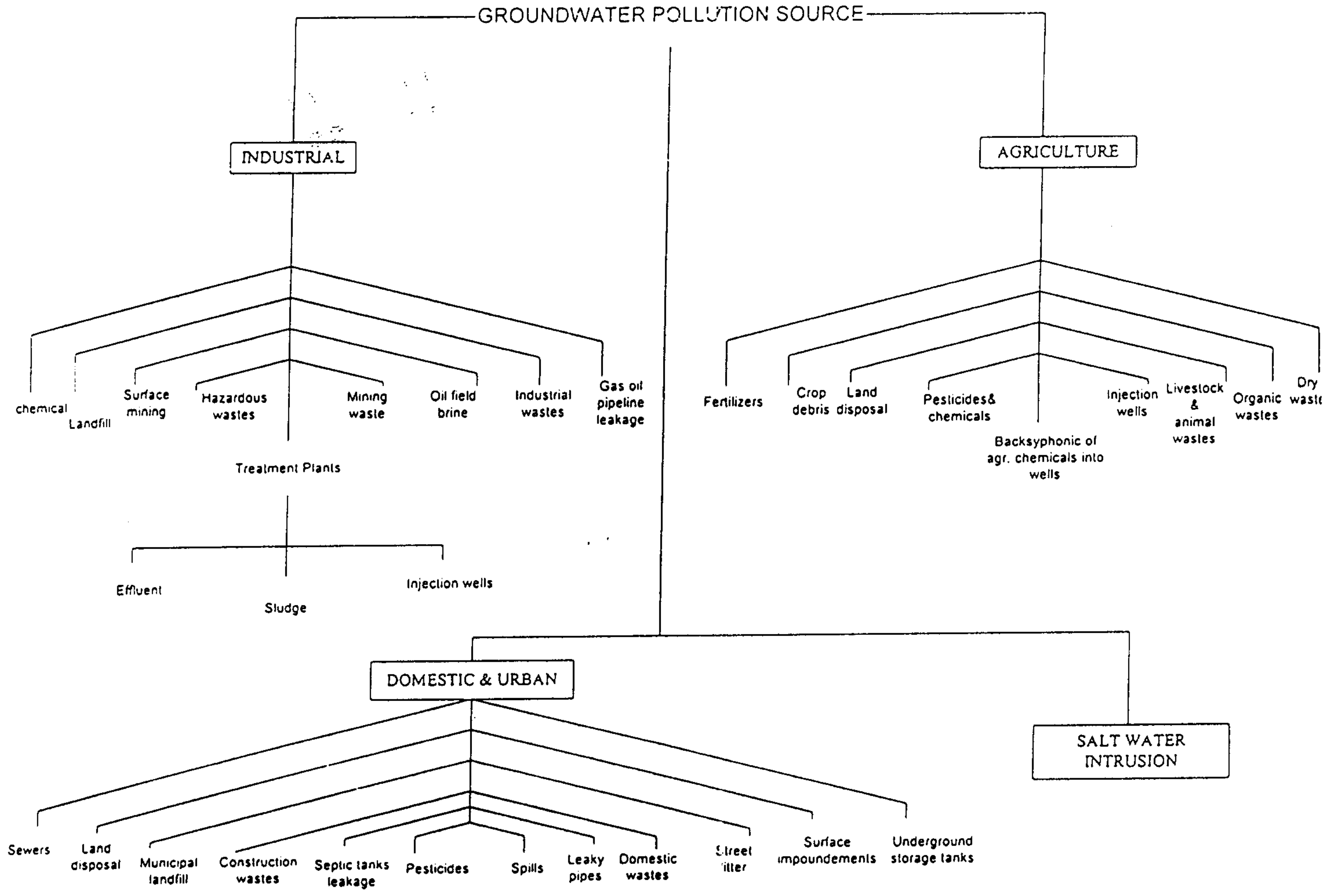
(2) *Impact on human health*

Water resources development is closely linked to water-related diseases. Infections can be caused by water-borne or water-carried agents. Under natural conditions the agents causing these diseases are produced by the seasonal variation of water availability and by limited contacts between human and water. Thus diseases spread by water development projects may either due to chemical contamination such as radio-active material, Arsenic, Manganese, Lead etc.. or due to biological contamination that contribute to the spread of vectors, viruses, parasites and bacteria.. The symptoms of these two distinct types of contaminants can be easily noticed. Symptoms due to chemical poisoning may include mental confusions; dementia, mental retardation in babies, etc. and their long-term exposure could lead to cancer. On the other hand, the spread of biological contaminants could lead to uncontrollable emergence of outbreaks especially in the context of developing countries; and the symptoms include diarrhea, gastro-intestinal manifestations, and fever, etc. Consequently, the absence of proper waste water collection systems, and the persistence of open channels or pools of wastewater that seeps contaminated water to the ground contribute to polluting the groundwater and creating a health hazard.

(3) *Socio-economic impact*

Socio-economic development in the ESCWA region is dependent on the availability of adequate water resources. The most accessible sources have already been developed to meet the rising water demand. The cost of water resources development and groundwater conservation is rapidly increasing. Hence, understanding the social, economic and institutional dimensions essential for effective groundwater management from the early use of springs and seeps to the wholesale abstraction of deep aquifers and the injection of hazardous wastes is crucial. A failure to identify and articulate the public interest in groundwater until it is too late, and groundwater resources are depleted and degraded beyond physical or economic recovery can be observed.

Figure 2. Groundwater Pollution Sources



As the reliability of water supplies declines, risks for users dependent on it increase. From small investment decisions by poor farmers regarding the purchase of fertilizer or seeds to major investments by companies or governments, economic returns depend on whether or not water is available when needed. In many areas, the assurance provided by groundwater is a key foundation for socio-economic development.

E. GROUNDWATER VULNERABILITY TO CONTAMINATION

Groundwater vulnerability refers to whether or not an underlying aquifer will become contaminated as a result of activities at the land surface. Groundwater vulnerability to contamination is defined as "the contaminants (resulting from non-point sources or really distributed point sources of pollution) to reach a specified position in the groundwater system".

Groundwater can be contaminated by localized releases from sources such as hazardous waste disposal sites, municipal landfills, surface impoundments, underground storage tanks, gas and oil pipelines, back-siphoning of agricultural chemicals into wells, and injection wells. Groundwater can also become contaminated by substances released at or near the soil surface in a more dispersed manner including pesticides, fertilizers, septic tank leachate, and contamination from other nonpoint sources. Pumpage-induced movement of contaminated shallow groundwater into deeper aquifers may be a significant consideration in some situations.

The groundwater pollution risk at a certain location depends on the combination of the vulnerability of groundwater to pollution, the type of pollutants, and to pollution load. The vulnerability depends on the local hydrogeological situation; while the pollution load depends mainly on the land use.

Key elements to consider in a vulnerability assessment for a particular application include the reference location (e.g., the water table or a specified position within the groundwater system), the degree of contaminant specificity, the contaminant pathways considered, and the time and spatial scales of the assessment. Groundwater contamination is likely to occur in areas having shallow water tables and sandy soils with high recharge rates.

Many methods for predicting groundwater vulnerability are based on analytical, statistical and empirical methods to describe the behavior o substances in the subsurface environment. The favored approach at the present is to produce maps of groundwater vulnerability to man-made pollution.

IV. GROUNDWATER REHABILITATION

Groundwater aquifers are important resources for meeting the water requirements in all sectors of the ESCWA region. The loss of this important resource due to contamination is common in many poses an environmental and health risks as well as diminishing needed water supply. Thus remediation strategy must be developed to address to conserve source rehabilitate the polluted groundwater aquifers and define measure to protect groundwater. The selection of rehabilitation methods depends on the contaminated media, contaminants, remediation objectives, current status, and location of polluted sites, time, and availability to complete the treatment, funding and technologies to be used. Remediation techniques (15) that can be applied to rehabilitate groundwater aquifer system are briefly discussed as follows:

A. IN SITU PHYSICAL/CHEMICAL TREATMENT

1. *In situ physical treatment*

(a) *Air Sparging*

It involves the injection of gas (usually air or oxygen) under pressure into well(s) installed within the saturated zone to volatize contaminants dissolved in groundwater, present as non-aqueous phase liquid, or sorbed to the soil matrix. Volatilized contaminants migrate upward and are removed upon reaching the

Valdese zone, typically through soil vapor extraction. Most applicable for volatile organic contaminants in relatively moderate to high permeability geologic materials.

(b) *Blast-Enhanced fracturing*

This technique used at sites with fractured bedrock formations to improve the rate and predictability of recovery of contaminated groundwater by creating "fracture trenches" or highly fractured areas through detonation of explosives in boreholes (shot holes). Blast-enhanced fracturing is distinguished from hydraulic or pneumatic fracturing in that the latter technologies do not involve explosives, are generally conducted in the overburden, and are performed within individual boreholes.

(c) *Directional Wells*

This techniques deal with drilling of a horizontal wells. Trenched or directly drilled wells installed at any non-vertical inclination for purposes of ground water monitoring or remediation. Especially useful when contaminant plume covers a large area and has linear geometry, or when surface obstructions are present. This technology can be used in the application of various remediation techniques such as groundwater and/or non-aqueous phase liquid extraction, air sparging, soil vapor extraction, in situ bioremediation, in situ flushing, permeable reactive barriers, hydraulic and pneumatic fracturing, etc.

(d) *Groundwater Recalculation Wells*

Encompasses in situ vacuum, vapor, or air stripping, in-well vapor stripping, in-well aeration, and vertical circulation wells. Creation of groundwater circulation "cell" through injection of air or inert gas into a zone of contaminated groundwater through center of double cased stripping well which is designed with upper and lower double screened intervals. Injection of air creates "airlift pumping system" due to density gradient, causing groundwater with entrained air bubbles to rise and partition volatile contaminants from dissolved to vapor phase. Water exits upper screen beneath a divider, where vapors are drawn off through annular spaces between well casings by vacuum pump, and groundwater reenters the contaminated zone, where it is again drawn into the stripping well. In this manner, groundwater is recirulated through the stripping well until remediation goals are met. Several commercial types of in-well vapor stripping exist which strive to make the general process most efficient, or to use the process to enhance bioremediation or metals fixation by taking advantage of the circulation cell development. Most applicable to volatile organic contaminants; modifications of the basic remedial process are proposed for application to semivolatile organic compounds, pesticides and inorganic. May be used in unconfined or confined aquifers; process has been applied to geologic materials of wide ranging permeability.

(e) *Hydraulic and Pneumatic Fracturing*

Techniques to create enhanced fracture networks to increase soil permeability to liquids and vapors and accelerate contaminant removal. Especially useful for vapor extraction, biodegradation and thermal treatments. Hydraulic fracturing involves injection of high pressure water into the bottom of a borehole to cut a notch; a slurry of water, sand and thick gel is pumped at high pressure into the borehole to propagate the fracture from the initial notch. The gel biodegrades, leaving a highly permeable sand-filled lens that may be up to 60 feet in diameter. Pneumatic fracturing involves injection of highly pressurized air into consolidated sediments to extend existing fractures and create a secondary fracture network. Most applicable for unconsolidated sediments or bedrock.

(f) *In Situ Flushing*

Also known as injection/recirculation or in situ soil washing. General injection or infiltration of a solution into a zone of contaminated soil/groundwater, followed by down gradient extraction of groundwater and elutriate (flushing solution mixed with the contaminants) and above ground treatment and/or re-injection. Solutions may consist of surfactants, cosolvents, acids, bases, solvents, or plain water. Any variety of configurations of injection wells, directional wells, trenches, infiltration galleries and extraction wells or collection trenches may be used to contact the flushing solution with the contaminated zone.

Excellent understanding of the hydrogeologic regime for potential projects is essential; best applied to moderate to high permeability soils. May be used for variety of organic contaminants, including non-aqueous phase liquid; may have application to some inorganic contaminants.

2. *In situ stabilization/solidification chemical treatment*

Also know as in situ fixation, or immobilization. Process of alteration of organic or inorganic contaminants to innocuous and/or immobile state by injection or infiltration of stabilizing agents into a zone of contaminated soil/groundwater. Contaminants are physically bound or enclosed within a stabilized mass 9solidification), or their mobility is reduced through chemical reaction (stabilization). Excellent understanding of the hydrogeologic regime for potential regime for potential projects is essential; best applied to moderate to high permeability soils; may be used for variety of organic and inorganic contaminants.

(a) *Permeable Reactive Barriers*

Encompasses passive barriers, passive treatment walls, treatment walls, or trenches. An in-ground trench is backfilled with reactive media to provide passive treatment of contaminated ground water passing through the trench. Treatment wall is placed at strategic location to intercept the contaminant plume and backfilled with media such as zero-valent iron, microorganisms, zeolite, activated carbon, peat, bentonite, limestone, saw dust, or other. The treatment processes, which occur within the treatment wall, are typically contaminant degradation, sorption or precipitation. Applicable to wide range of organic and inorganic contaminants; choice of media for treatment wall is based on specific contaminant. Hydrogeologic setting is critical to application; geologic materials must be relatively conductive and a relatively shallow aquitard must be present to provide a "basement" to the system. Ground-water flow should have a high degree of preference, and ground-water quality must support the desired reaction without imposing additional loading of the reactive media or creating undesirable by-products.

(b) *Thermal Enhancements*

Use of steam, heated water, or radio frequency (RF) or electrical resistance (alternating current or AC) heating to alter temperature-dependent properties of contaminants in situ to facilitate their mobilization, solubilization, and removal. Volatile and semivolatile where organic contaminant may be vaporized; vaporized components then rise to the vadose zone where they are removed by vacuum extraction and treated. Stream best applied to moderate to high permeability, clay-rich geologic materials as the clay will preferentially capture the RF or AC energy. Excellent understanding of hydrogeologic conditions essential for all applications. May be used for variety of organic contaminant and non-aqueous phase liquid; may have application to some inorganic contaminants.

3. *Biological treatment*

(a) *Bioslurping*

Use of vacuum-enhanced pumping to recover light, non-aqueous phase liquid (LNAPL) and initiate vadose zone remediation through bioventing. In bioventing, air is drawn through the impacted vadose zone via extraction wells equipped with low vacuums to promote biodegradation of organic compounds.

(b) *Intrinsic Bioremediation*

Natural, non-enhanced microbial degradation of organic constituents by which complex organic compounds are broken down to simpler, usually less toxic compounds through aerobic or anaerobic processes. For environmental application, documentation that current biodegradation rates are sufficient to control or degrade a contaminant plume or zone without creation of unacceptable risk to human health or the environment must be demonstrated.

(c) *Monitored Natural Attenuation*

Encompasses intrinsic bioremediation. Reliance on a variety of physical, chemical, or biological processes (within the context of a carefully controlled and monitored site cleanup approach) that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater.

(d) *Phytoremediation*

The general use of plants to remediate environmental media in situ. Includes rhizofiltration (absorption, concentration, and precipitation of heavy metals by plant roots), phytoextraction (extraction and accumulation of contaminants in harvestable plant tissues such as roots and shoots), phytotrans formation (degradation of complex organic molecules to simple molecules which are incorporated into plant tissues), phytostimulation or plant-assisted bioremediation (stimulation of microbial and fungal degradation by release of exudates/enzymes into the root zone), and phytostabilization (absorption and precipitation of contaminants, principally metals, by plants). May or may not involve periodic harvesting of plants, depending upon method utilization. Applicable to a wide range of organic and inorganic contaminants; most appropriate for sites where large volumes of groundwater with relatively low concentrations of contaminants must be remediated to strict standards. Most effective where groundwater is within ten feet of the groundwater surface, and soil contamination is within three feet of the ground surface.

4. *Electrokinetics*

An in situ process involving application of low intensity direct electrical current across electrode pairs implanted in the ground on each side of a contaminated area of soil, causing electro-osmosis and ion migration. Contaminants migrate toward respective electrodes depending upon their charge. Process may be enhanced through use of surfactants or reagents to increase contaminant removal rates at the electrodes. Process separates and extracts heavy metals, radionuclides, and organic contaminates from saturated or unsaturated soils, sledges, and sediments. Especially unique due to ability to work in low permeability soils as well as high permeability soils; applicable to a broad range or organic and inorganic contaminants.

B. GROUNDWATER FLOW MODELING

Groundwater flow modeling is based on mathematical and numerical relations using different techniques and approaches. These models are intended to simulate the groundwater flow, water recharge and saltwater concentration and dispersion.

The groundwater simulation models will help in:

(a) Comparing groundwater level field measurements with calculated groundwater level fluctuation;

(b) Predicting calculations with the calibrated model to develop concepts for groundwater extraction;

(c) Salt and contaminant flow transport.

Several groundwater simulation numerical models are available and existing such as flow models (saturated and unsaturated zones), multiphase flow and transport models, salt water intrusion (such as SUTRA and SWITCHA), solute transport (saturated and unsaturated zones) and MODFLOW, which delivers the full range of groundwater flow and containment transport modeling capabilities along with visualization and graphics. Modification and constant updating, the models must be observed to accommodate the various study area required. For example, MODFLOW added to the existing model new features such as:

- **MT3DMS**-MT3DMS gives the flexibility to run single or multi-species transport simulations. Includes new implicit solvers for dramatically improved run-times.

- **RT3D**-RT3D simulates natural attenuation processes including biodegradation and chemical speciation

- **Calibration Tools**-Improved calibration statistics and plotting features. Includes bubble plot of calibration residuals, scatter plots of calculated vs. observed data, residuals histogram and time-series plots

- **Import Data**-Import seasonal recharges boundary conditions directly from Visual HELP predictions, and import concentration-loading rates directly.

- **Export Graphics**- Export screen display to standard graphical formats such as Enhanced Windows Metafile (emf), AutoCAD (dxf) and ESRI Shape (shp) files.

Visual MODFLOW Add-On Packages:

- **WinPEST**-WinPEST is the original version of **PEST** for automated **P**arameter **Est**imation for conveniently estimating model parameter values and optimizing the model calibration results.

- **MT3D99**-MT3D99 is the most advanced version of MT3D99. It stimulates aerobic and anaerobic reactions between contaminants ***and*** takes full advantage of the new implicit solver

Most of the models are based on the finite difference or finite element schemes and can be adapted and modified to accommodate every case separately.

Selected list of available groundwater flow models:

3DFEMFAT – 3-D Finite Element Model of Flow and Transport through Saturated-Unsaturated Media

AQUA3D –3D Groundwater Flow and Contaminant Transport Model

AQUIFEM-N -Finite Element Aquifer Flow Model

AT123D –Analytical Groundwater Transport Model for Long-term Pollutant Fate and Migration

BIOF&T2-D/3-D – Biodegradation, Flow and Transport in the Saturated/Unsaturated Zones

BIOPLUME III-Transport of Dissolved Hydrocarbons Under the Influence of Oxygen-Limited Biodegradation

BIOSLUPR-Multiphase Hydrocarbon Vacuum Enhanced Recovery (Bioslurping) and Transport

FEEFLOW-Finite Element Subsurface Flow System

Filter Drain –Design of Side Drains, Bottom Drains, and Underdrains
FLONET/TRANS –2-D Cross-Sectional Steady-State Groundwater Flow and Transport Model

FLOWPART II –2-D Groundwater Flow, Remediation, and Wellhead Protection Model

GFLOW 2000 –Analytic Element Model with Conjunctive Surface Water and Groundwater FLOW and a MODFLOW Model Extract Feature.
GMS-Groundwater Modeling System-Sophisticated Groundwater Modeling Environment for MODFLOW, MODPATH, MT3D, RT3D, FEMWATER, SEAM3D, SEEP2D, PEST, UTCHEM, and UCODE

Groundwater Vitas – Advanced Model Design and Analysis for MODFLOW, MODPATH, MT3D, PEST,B and UCODE

HST3D –3-d Heat and Solute Transport Model

KYSPILL – Unique groundwater Pollution Forecasting System

MARS 2-D/3-D – groundwater Multiphase Area Remediation Simulation Model

Micro-Fem -Finite-Element Program for Multiple –Aquifer Steady-State and Transient Groundwater Flow modeling

MOC –Computer Model of 2-D Solute Transport and Dispersion in Groundwater

MOCDENSE –Two-constituent Solute Transport Model for Groundwater having Variable Density

ModelGIS –Interface Linking Groundwater Models to ARC/INFO

MODFLOW –Three –Dimensional Finite Difference Ground-water Flow Model

MODFLOW-SURFACT –MODFLOW-Based Groundwater Flow and Contaminant Transport Model

SLAEM/MILAEM –Analytic Element Models-model regional groundwater flow in systems of confined aquifers, unconfined aquifers and leaky aquifers
SUTRA –2-D Saturated/Unsaturated transport Model

TWODAN -2-D Analytic groundwater Flow Model for Windows

VAM2D –2-D Variably-Saturated Groundwater Analysis Model

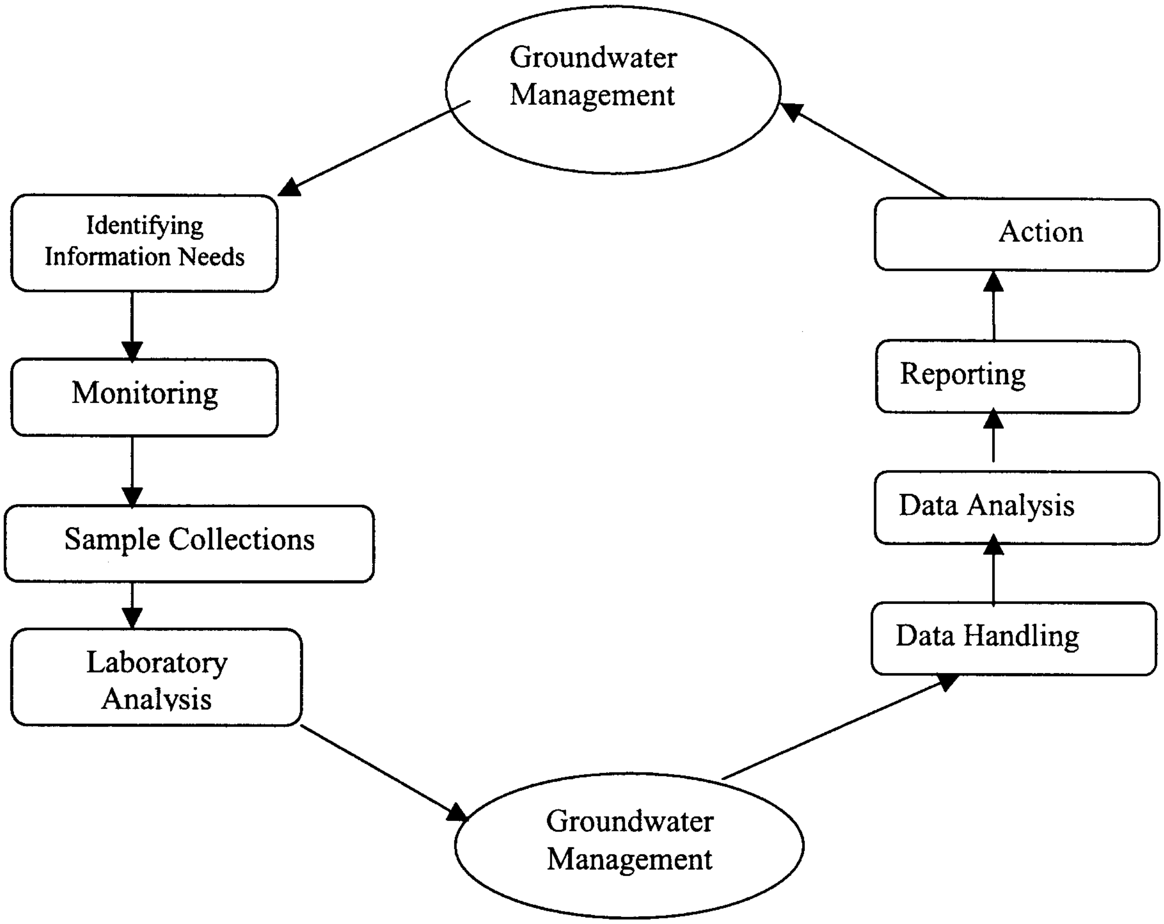
WinFlow – Analytical Steady State and Transient Groundwater Flow Model

V. GROUNDWATER POLLUTION CONTROL AND MANAGEMENT

The aim of groundwater management is ensure the sustainability of the resources and environment through periodic evaluation and monitoring processes.

Long-term effective management of available groundwater resources requires attention to two major potential problems: depletion and pollution. The former results from excessive abstraction and use of the resource, i.e., abstraction at rates, which exceed replenishment, whether this is natural or man-made. Where this occurs it is recognized as a serious problem, and strict control on abstractions is the key to restoring and maintaining sustainability of resource use. Pollution of groundwater results from a "point" and "non-point" sources, respectively. Pollution sources can be as industrial and domestic sewerage outfalls discharging directly into underground aquifers. Other pollution sources include not only the runoff from croplands where pesticides and fertilizers are employed; but also the overland runoff from such "point" sources as animal feedlots, the leakage from such other "point" sources as waste dumps and, in general, containers of dangerous liquids; and the disposal underground of effluents from such "point" sources as industrial plants and rural households.

Figure 3. Groundwater Management Flowchart



The process of monitoring and evaluation consists of a sequence of related activities which start with the identification of information needs and ends with the use of the information in developing actions and strategies (figure 3).

Monitoring can be defined as the "action of observing charges in a system through a systematic approach". The aim of monitoring is to provide information that can help in the protection of the resource from degradation.

(a) *Specific Purposes of Groundwater Monitoring*

Examples of specific purposes for which a groundwater-monitoring program is carried out may include one or more of the following:

(1) Determination of the depth to water table and hydrogeologic characteristics of the groundwater system;

(2) Determination of the direction of groundwater flow and movement (travel time) of pollutants;

(3) Evaluation of water balance components and exploitable reserves;

(4) Determination of contact with mineralized bodies of groundwater, especially the sea-fresh water interface in coastal aquifers;

(5) Calibration of groundwater models;
(6) Assessment of environmental impacts of water projects.

(b) *Advantages of Groundwater Monitoring*

Each purpose dictates a package of parameters/indicators and a scale of monitoring, including frequency and system design.

The main advantages of putting the monitoring of groundwater quality into a monitoring system framework are:

(1) It is cost-effective, as its construction and optimization aim at obtaining the desired information at minimum measurement efforts;

(2) It guarantees a regular reporting of the desired information to the target groups;

(3) It prevents changes in approach, which could seriously obscure information over time;

(4) It warrants sound and unbiased statistical testing of hypotheses, because these tests and hypotheses were formulated before data were available;

(5) The official procedures for the information flow and the regular reporting of important information give the system some status and a reason for existence, which may serve as protection against unreasonable budgetary cut downs.

Therefore, by monitoring, one can clearly obtain the knowledge of the areas where quality standards are not met, and/or knowledge of the areas where groundwater is deteriorating.

(c) *Principles for groundwater quality:*

(1) *High level of protection*

In the context of water management, this requires that the level of protection of human health, of water resources and of natural ecosystems should be ambitious, aiming at a high level of protection rather that set at the minimum acceptable level.

(2) *Precautionary principle*

So much of the science underlying our understanding of water systems and, in particular, of the impacts of pollution on human health and the health of the environment is incomplete. The precautionary principle therefore requires that policy should always be based on recognized scientific knowledge.

(3) *Preventive action*

It recognizes the difficulty and cost of reversing or rectifying damage. Once an aquifer is contaminated with pesticide residues, in certain cases, it will take decades to cleanse itself and, in the meantime, it may be unsuitable for use as a source of drinking water unless expensive treatment facilities are installed.

(4) *Damage to be rectified at source*

This principle follows logically from that of "preventive action", but applies once environment damage has been identified. Wherever possible, action should be taken to discontinue the damaging activity rather than seeking technical solutions to solve the problem "downstream".

(5) *Polluter pays principle*

This principle establishes that the cost of measures to prevent pollution should be borne by the potential polluter. It also establishes that, where damage occurs, the polluter is liable for the costs of any damage and it therefore acts as an incentive towards the effective control of pollution at the source.

(6) *Integration*

Considering that agricultural pollution and water abstraction for irrigation are currently major issues to be addressed in order to achieve the objectives of water policy, the integration of water policy concerns into the agricultural policy area is particularly essential.

(7) *The use of available scientific and technical data*

One should make use of the most accurate information on best available techniques and on the various processes involved in the prevention treatment.

(8) *Monitoring requirements*

Water management is not possible without reliable data upon which to base decisions. There is also scope for including more information on water quantity in the monitoring data, and in particular on the amount of water abstracted and used for various purposes.

(9) *Transparency, public participation and accountability*

The general public should have a right to know the results of monitoring of the environment and to have it presented to them in an understandable manner. They should have a right to be informed, about the policies adopted to protect groundwater. Groundwater aquifers do not always form such easily identifiable units and there is no obvious "natural" administrative unite for the management of their water resources. Moreover, their catchment areas do not always coincide with river basins. However, for most practical purposes, and given the importance of integrating the management of groundwater and surface waters, it would seem logical to incorporate them both, together with coastal water near river mouths, under the direct or coordinating control of a river basin authority.

VI. CONCLUSION

Groundwater resources may often be local in nature, but they have global significance in relation to poverty, health, economic development, and the environment. Threats to the groundwater resources can result from indiscriminant exploitation and its consequences along with human induced pollution are crucial.

A. ISSUES CONTRIBUTING TO THE GROUNDWATER DETERIORATION

1. The lack of groundwater monitoring and data availability.

2. The need for integrated approaches to groundwater management that include regulatory, economic, technical and other measures.

3. The importance of taking action despite gaps in information. Delaying action while further information is collected may result in irreversible damage to resources.

4. The need to involve communities in management of groundwater sources including the collection of groundwater information that can increase stakeholder understanding of management needs and options.

B. RECOMMENDATIONS

1. There is a need for improved assessment monitoring of groundwater condition sand their implications for key uses.

2. The profile of groundwater needs to be raised commensurate with its importance as a strategic resource.

3. Initiate management where problems are evident regardless of data limitations.

4. Increase investment in groundwater management capacity building, monitoring infrastructure, research and management projects.

5. Protect the groundwater aquifers from pollution and apply rehabilitation techniques when needed.

6. Stress on public awareness campaign, role of women, and the community participation towards preserving groundwater from pollution and depletion.

7. In urban areas, there is a pressing need to take more integrated approach to the management of groundwater and wastewater interactions and to the interaction between public and private systems.

8. Develop a strategic initiative that enhances awareness oriented toward decision makers and the public of the importance of groundwater resources, the significance of emerging problems and the practical responses available to address such problems.

9. The empowerment of people at the local level to manage their groundwater and water resources.

10. Develop a combination of technical, economic, social, and institutional approaches to management that reflect local conditions.

11. Technology transfer, Capacity building, and research development must take place to transfer this knowledge onto the practical field level of restoring and re-establishing old practices of water management.

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Helpful Internet Sites:

15-http://www.gwrtac.org/
The groundwater Remediation Technologies Analysis Center

16-http://worldwatercouncil.org/
World Water Council

17-http://www.wria.org/
World Resources Guide

18-http://www.unep.ch/
United Nations Environmental Programme

19-http://www.fao.org/
United nations Food and Agriculture Organization

20-http://www.who.org/
World Health Organization