Current and Future Challenges of Water Resources Management in Jordan

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ABSTRACT

Over millenia, people of Jordan have been adapted to prevailing water scarcity and occasional recurrence of prolong drought. The people developed their own traditional methods of soil conservation and management of limited water resources such as contour cultivation, land ripping and land terracing. They also developed their innovative techniques of water harvesting and flood water storage in soil profile, especially in case of Nabatean traditions in Southern Jordan. The water harvesting techniques comprised detention, dispersion and diversion structures. Such traditional methods proved to be effective in balancing food demand-supply equation until 1940's when tremendous exodus of Palestinian Arabs took place from Palestine into Jordan. Massive migration of refugees to Jordan had placed sudden increase in demand for water and food in a country known to be very poor in such commodities. In addition, the country had to receive two more waves of refugees; first in 1967 after fall of the West Bank to Israeli occupation and second as Jordanian expatriates who fled Gulf States that followed Iraqi invasion of Kuwait in 1990. Sudden increase in population was about 10%in 1991. Such massive influxes of the people that was joined with currently high population annual growth rate of 2.5% caused continuous drop in per capita share of water resources. It reached current annual figure of 160 m^3. Subsequently, Jordan had to cope with these challenges by developing new water resources. They included exhaustive pumping of ground water, desalination of brackish water, reuse of reclaimed wastewater in productive agriculture and detention of any feasible amount of fresh runoff water behind dams that are mainly overlooking the Jordan Rift Valley. Although previous water challenge was volumetric in nature, recent assessment of supply-demand formula for fresh water indicates growing interest in new dimension of quality in nature. This paper analyzes causes and nature of problems associated with management of the limited water resources. It provides suggestions for proper crop assignment from the water resources like assessing water value on the basis of net economic return from unit of irrigation water. It also proposes alternatives for developing new water resources.

KEYWORDS: Soil, water quality, water scarcity, water resources development, water economics, virtual water.

HISTORICAL BACKGROUND:

For past several millennia, Jordan and neighboring countries of *Bilad Ash-Sham* has been plagued by persistent drought. They may be interrupted by sudden and intense rainstorms that usually take place during winter season. This has led to diversity of environmental problems that lead to soil degradation. Archeological evidences indicate that rise and fall of civilizations in this area might have been associated with maintenance and neglect of soil and water resources (Hillel, 1991).

Soil conservation and water management can be traced back to dawn of civilization. Researchers found signs of early water harvesting facilities believed to have been structured over 9000 years ago in the Edom mountains in southern Jordan (Bruins et al., 1986). Ancient farmers of today's Jordan proved to share common understanding of scope of soil conservation with their modern counterparts. They had wide management perspective that encompassed more than mere physical works for erosion control. Their monumental achievements comprised integral approach to

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soil, water and farm management. All physical soil conservation practices contributed towards targets of improving and maintaining soil fertility, soil-water-plant relationships and, attainment of sustainable and productive agriculture.

Necessity for water was not to irrigate small fields but rather to provide continuous supply of potable water for domestic consumptions. It was a driving force to establish authentic facilities for water harvesting and management. Figure 1 shows deflection dam and gravity canal in ancient site of Jawa where an urban settlement was located in north east of Jordan. Its site can be dated to 3200 BC (Helms, 1981). Structurally, entire water scheme at Jawa is a matter of earth and stone. Low soil infiltration rate makes it ideal fill for gravity dams. One of water systems in Jawa consists of a canal leading water from deflection area past a series of irrigable fields to a sluice gate where some flows into an underground cistern. Main canal continues to another sluice gate where it divides to serve town’s drinking water containers then passes through a secede area of fields.

Sometime before 300 BC, Nabataean Arabs were skillful in hydraulic technology. They made efficient use of scarce desert water resources. Oleson (1986) surveyed water structures in Humayma (Avara). It was one of major Nabataean centers in southern desert of Jordan. He found sixty one sites. Some of them contained several different types of hydraulic structures. His survey demonstrated existence of fifty one cisterns, six terraces, stone piles, two wadi barriers, four slides, and single aqueduct. Bedouins today make use of earth and stone wadi barriers to slow process of soil erosion and to foster the infiltration of runoff water into their fields during winter season.

The Nabataean wadi barrier differs from modern examples in being constructed of large boulders rather than of earth or small stones**.** Clearing and terracing of slopes was used by the Nabataeans. The technique aims to improve and to protect arable land on such terrains. In addition, the terraces help to hold back the water that run off the slopes following rainfall and thus increase moisture storage in soil profile. Although modern structures have undergone slight modifications, they remain representative prototypes of ancient technology.

WATER RESOURCES OF JORDAN:

Aftermath first Arab-Israeli war in 1948, Jordan had to receive a huge influx of Palestinian refugees who fled their country empty handed. In addition, Jordan was target of two more waves of refugees; first in 1967 following fall of West Bank to the Israeli occupation and second as Jordanian expatriates fled Gulf States after Iraqi invasion of Kuwait in 1990. Sudden increase in population occurred by about 10% in 1991. Such massive influxes of refugees were joined with high population annual growth rates. The rates were 3.3% during the period 1994-1999, 2.8% for the period of 2000-2003 and 2.5% in Nov 2004 according to recent general census that was carried out by State Department of Statistics. They caused continuous drop in per capita share of the water resources to reach current annual figure of 160 m^3.

Many researchers claimed that the Middle East faces a desperate situation with regard to future water use. Few provided detailed analyses to show why this can be the case. Beaumont (2002) reported that nature of economies of the countries in the region changes together with rapid population growth. New water policies are required to recognize growing significance of service sector of the economy. Commercial/industrial/irrigation systems as main wealth providers in the 21st Century must be considered. Latest analysis of available water resources indicated that most of the Middle East countries will be able to meet water needs of their citizens up to 2025 without too much difficulty. To achieve former objective, reallocation of some irrigation water to other uses will be necessary. Beaumont (2002) also indicated that Jordan, Oman and Tunisia will experience major problems of water supply. Only Jordan can approach a crisis situation. Bielsa and Duarte (2001) constructed and applied a model for allocation of water between two competing sectors, namely irrigation and industry. The model was built to developing a constrained maximization process. It takes into account environmental, institutional and actual priority of the water rights. It was applied to study specific water systems in North Eastern Spain. Resulting solution can be useful as a guide for potential bargains between water users.

With respect to the water resources of Jordan, the country depends mainly on rainfall water. It is closely associated with geographic and physiographic features of the country. Land of Jordan is characterized by western hilly area overlooking the Jordan Rift Valley (JRV) to the west and the desert to the east. Such physiographic classification is associated with distinctive rainfall patterns of maximum and minimum values pertaining to the north western hilly area and the south eastern desert, respectively (Figure 2). Yield of water from watersheds (Figure 3) and groundwater basins (Figure 4) largely depends on rainfall distribution.

The JRV can be classified into two major sections; Jordan Valley (JV) to north of Dead Sea and Southern Rift Valley (SRV) to south of the Dead Sea. The JV is about 110 km long and ranges between 4 to 9 km wide. Yarmouk and Zarqa rivers and nine major wadis cut through Eastern Escarpments and enter the JV to end in the Jordan River. The Yarmouk River is a tributary of the Jordan River and is major source of fresh water in the JV. The River base flow dropped drastically to a record figure of 2 $m^3 s^{-1}$ in April 2001. Subsequently, Jordan requested from Syria to increase the former figure to 3 $m^3 s^{-1}$ by releasing extra water from dams in upper reaches of the River watershed. In addition, the Zarqa River flow to the JV is received primarily from King Talal Reservoir (KTR) releases. A large portion is reclaimed wastewater (RWW) that originates from Khirbit Es-Samra Wastewater Treatment Plant (KTP) which serves Amman-Zarqa metropolitan area. Table 1 demonstrates Dams overlooking the JV and their respective storage capacities.

The SRV stretches southward (220 km land distance) to the Gulf of Aqaba. Area of entire Wadi basin including both sides of the Wadi is about 2136 km^2 of which 156 km^2 lie between southern tip of the Dead Sea and altitude of 300 m below sea level (BSL). The latter area was formerly inundated by the Dead Sea water resulting very saline soil. Not all the Wadi floor lies below sea level. Altitude of the wadi floor increases from zero at sea level in Aqaba to 288 m ASL in Jebel Khraij and to 355 m ASL at close-by Jebel El-Reesha that is located 5 km to north east of Jebel Khraij. To the north of these two sites, altitude of the Wadi floor starts to decrease gradually to reach its lowest point at the Dead Sea level of 408 m BSL. Table 2 demonstrates annual discharge from major Wadis ending in the JRV. The SRV is more than twice longer than the JV but total surface water is about 28% of the water reaching the JV. This is mainly due to the dry climatic conditions prevailing in the southern part of the country.

IRRIGATED AGRICULTURE IN THE JORDAN RIFT VALLEY:

The JV is Jordan's premier agricultural production area. Mild winter provides the Valley with great potential as a natural greenhouse for the production of high-value off-season fruits and vegetables. The agriculture in the Valley covers a wide variety of crops, from horticultural crops such as citrus, banana and vegetables to field crops such as alfalfa and wheat. Irrigable land in the JV totals 36,000 ha of which approximately 31,000 ha are currently equipped with pressurized irrigation networks. At present, there are about 8,000 farm units in the JV and about 1,500 farm units in the SRV. Each farm unit ranged in size between 3 and 4 ha, with overall average of about 3.6 ha. The JV Authority Law No. 19 of 1980 placed limits on farm ownership. Lands were redistributed accordingly. Following the redistribution, 65% of the farm units have areas of 3 to 4 ha, 21% have areas of 4 to 5 ha and 14% have areas of more than 5 ha. About 48% of the ownership consist of one farm unit, 27% consist of two farm units and 25% consist of 3 or more farm units.

The major irrigable land in the SRV comprises eight distinctive sites of 11,360 ha of which 4,700 ha are currently under irrigation. However, if a second stage expansion is warranted then an additional 1,600 ha will be irrigated.

Wadi Araba irrigable area is vast. Its area under cultivation is limited due to limited quantity and poor quality of available water. Development plans for irrigated agriculture are based on exploitation of deep aquifer water. The Dead Sea area is narrow and has negligible potential for agricultural development. Tourism is the focus for developments in this zone.

The water resources in the JV are limited compared to land availability. Table 3 shows that volume of irrigation water has been very low. It never exceeded 150 MCM. It fluctuates annually due to rainfall fluctuation. Because of deficiency in water supply, the Government and farmers employ deep and shallow aquifer wells to meet their needs for additional quantities. Table 4 represents well water distribution in the JRV. In addition to water quantity limitations, water quality is a major constraint to maximize the production from the valley's irrigable area. Major source for fresh water in the Valley is King Abdulla Canal (KAC) which tunnels Yarmouk River water before ending in the Jordan River. The KAC conveys water from north to south to irrigate soils at low elevation to west. Table 5 presents results of chemical analyses for KAC water samples that were collected periodically after leaving the tunnel point. The Table indicates that all water samples had total dissolved solids exceeding 650 mg/l of which more than 50% were in the form of carbonates. Because of predominance of carbonate geochemistry of the water, carbonate and bicarbonate anions represent more than 65% of total negative charge of dissolved salts. The relatively high water salinity can be attributed to decreasing base flow of the Yarmouk River with time. It was result of several factors. Main factor is development of irrigation projects in upper reaches of the River watershed. Increases of nitrate concentration, coli and fecal bacterial counts can easily be observed in that water. Another factor is drought persistence in recent period. The deteriorated water quality of the Yarmouk River water poses a serious threat to use of drinking water purposes.

IRRIGATED AGRICULTURE IN HIGHLAND:

The area of irrigated agriculture in the highland and desert is estimated at 42,000 ha. All water is extracted from the aquifers of variable depths and quality. Table 6 lists major aquifers in the country and their respective water use in the year 1998. The Table shows that 2283 wells produced 483 MCM of water with annual pumping ranged between 16% (Sarhan and Hammad wells) and 235% (Jafr wells) of safe yield. Contrary to mandate of the JV Authority, no governmental institution has supervisory and managerial authority over groundwater extraction and subsequent irrigation water management in the high land and desert areas. In early stage of ground water mining, Water Authority of the Ministry of Water and Irrigation supervised well licensing and annual pumping of the water. Farmers are left without any restrictions and extension services on their approaches towards water management in relation to soil type, climatic condition and crop selection. Complete absence of any governmental role in the irrigated agriculture in the highland and desert areas exists. Pumping of the groundwater for irrigation accelerated at destructive pace in the 80s of the past century. It resulted in extensive over pumping from the aquifers of vital significance to drinking purposes especially at Dhuleil and Azraq Aquifers. The result was substantial depletion of all Aquifers and deterioration in their quality, especially increasing salinity and chloridity of their waters (Abu-Sharar and Rimawi, 1993).

ECONOMICS OF AGRICULTURAL PRODUCTION:

Agricultural sector in Jordan consumes more than 65%

of the total available water supply, where municipal, industrial and rural sectors consumption were 28.9%, 4.7% and 1.4%, respectively (MWI, 2000). Although the agriculture sector consumes more than 65% of the country's water resources, contribution of agriculture to gross national production was less than 2.25% in the year 2001 (DOS, 2001). In order to maintain an effective balance in the water supply and demand, importation of food grains and energy must be increased. Current imports of virtual water, according to estimates of Ministry of Water and Irrigation (MWI), is about 6.0 billion cubic meters per year. This is approximately seven times Jordan's annual water budget and 10 times Jordan's renewable water supply (El-Naser, 1999). The total agricultural production from the JV in 1998 was about 390,000 tons of vegetables, 192,000 tons of fruits including about 160,000 tons of citrus, and 20,000 tons of field crops. Unfortunately, not all crops were feasible in terms of net return from unit of land or water, because of water scarcity and competition of other sectors for water. Examples of net return from unit volume of irrigation water (m^3) is demonstrated in Tables 7 and 8 for protected and open field agriculture in the JV, respectively (Abu-Sharar and Battikhi, 2002). Unit price of irrigation water was considered as 0.021 US$ m^{-3}. Such low price contributes little to total production cost. Therefore, farmers do not bother on optimizing water use efficiency. As cost of water in other sectors can be as high as 1.41 US$ m^{-3}, feasibility analysis of crop production was made on basis of net return ($) from unit volume ($m^3$) of irrigation water. Table 7 indicates a wide range in the net profit from the unit of irrigation water under plastic house condition. It ranges from a net loss of 1.49 US$ m^{-3} for tomato production in spring season for Southern JV area to a net profit of 11.41 US$ m^{-3} for strawberry production in Autumn season for Middle JV. Such big rise in the net profit can be explained by exploitation of relative advantage for fruit and vegetable production off traditional European season. In fact, most of the straw berry production is destined for export to selected European markets. To the contrary, open field products do not have the former off-season relative advantage. Subsequently, most vegetables and fruits are produced for local market. Net profit from unit volume of irrigation water was relatively low (Table 8) with green bean recognizing maximum profit of 4.01 US$ m^{-3} in the autumn season for Middle JV.

Citrus and banana consumes about 47% of the irrigation water in the JRV. Analysis for the net return from unit volume of irrigation water (Abu-Sharar and Battikhi, 2002) indicated a relatively low net profit from these two crops. Maximum value was 0.65 US$ m^{-3} for banana production in SRV and was 0.21 US$ m^{-3} for citrus production in Northern JV. In fact, both crops face serious challenges by corresponding imports from countries with abundance of water. Concept of virtual water must be introduced in future management of the Jordan's limited water resources. Local production of high-water consuming crops must be substituted by importation of these crops from water-rich countries. A model has to be developed based on virtual water trade as a tool for optimizing water resources management (Van Hofwegen, 2004).

Concerning the highland and desert, Abu-Sharar and Battikhi (2002) carried out calculations for plastic house agricultural production. The unit price of irrigation water was considered as 0.11 US$ m^{-3} due to high cost of ground water extraction when compared to the cost of surface water supply in the JV. Maximum net profit was recognized for cucumber production in Irbid District (7.62 US$ m^{-3}). Plastic house production is limited to early spring season. No production is carried out during the cold winter season as the plastic houses require additional heating. They also may suffer from wind mechanical damages. Results showed that lowest net profit was associated with green bean production. Net loss was of 2.08 US$ m^{-3}. This is opposite to respective values that were recognized from the production in the open fields in the JRV. Such comparison indicated particular sensitivity of making decision concerning crop selection, growing season, production technology and production area. For such complexity most farmers fail to recognize net profit from their agricultural activities. Those who reach tangible profit are mainly farmers with university education and marketing skills. In the open field agriculture in the Highland, maximum recognized net profit in the case of onion production in Irbid District was 1.69 US$ m^{-3}. The latter value was less than half respective figure in the Middle JRV for the autumn season (3.97 US$ m^{-3}). Unfortunately, most of the irrigated area in the highland is utilized for open field production.

WATER MANAGEMENT OPTIONS:

Irrigated agriculture in Jordan is characterized by the following:

1) Substantial consumption of water by the agricultural sector. The consumption reaches about 65% of the Nation's water resources. It has low direct input into national economy. It is less than 5% of gross domestic production.

2) In many agricultural cases, there has been actual waste of the water resources when expressed as net return from unit volume of irrigation water.

3) Low distribution efficiency of drinking water. This can be attributed to illegal water uses and water losses from network.

Based on these premises, alternative management policies must take into account the following:

1) Demand for drinking water should occupy top priority over any other water use. Irrigated agriculture must be evaluated on the bases of alternative opportunity that is provided when water is allocated to other sectoral usages, especially domestic one (Hagen, 1994).

2) Capacity of JV to absorb most of the RWW in productive agriculture without adverse environmental impacts is questionable. Therefore, releasing RWW into the JV must not exceed safe absorption capacity of that ecosystem (Abu-Sharar, et al., 2003). In this regard, one-third of the valley's water consumption may be provided from the wastewater treatment plants in Irbid (North), Amman-Zarka (Middle) and Salt (South) areas. Surplus RWW must be employed in irrigating forage crops and fruit trees of known tolerance to salinity stress, particularly olives and pistachio. The crops may, preferably, be cultivated in the highland area that receives more than 200 mm annual rainfall. Such volume of rain would provide sufficient water quantities for leaching excessive salts that accumulate in top soil layers during dry summer season. In addition, drip irrigation system must be avoided wherever is possible since conservative application of RWW would aggravate the problem of salt accumulation in the top soil layer.

3) Usage of the RWW in the JV must run in parallel with the alternative irrigation with fresh water. The alternative irrigation can be practiced seasonally during given crop growing season. It can also be practiced annually every other year. Management of irrigation waters of dual quality must be subject to further field investigation. Moreover, preference must be given to irrigate the Northern JV with the RWW. Such arrangement would ensure optimum usage of the high rainfall for salt leaching of the surface soil layes. In this context, two pipe lines must be established independently to convey fresh, RWW and other saline waters to the entire JV. Such arrangement is relatively sophisticated and remotely accessible. Its application is an inevitable measure to be undertaken, especially to maintain high land productivity and healthy environmental profile in the JV.

4) Usage of the RWW must take into consideration enrichment with macro- and micro-nutrients. Subsequently, irrigation scheduling and volumes of the delivered RWW in each irrigation cycle must be based on phenotypic crop nutrient requirement, soil physical and chemical properties.

5) Alternative to direct employment of the RWW in

irrigation, effluent from the KTP can be purified by making use of large water head between the KTP (174 m ASL) and JV floor at Deir Alla (300 m BSL). Such water head can be employed directly in reverse osmosis facilities that will be established at some points along the Zarqa River that runs down to the Jordan River. Produced water will be of high quality and adequately suitable for non-restricted agriculture and conservative irrigation. The reverse osmosis technology has been proved feasible by many farmers in the JV even for the production of high water consuming crops like banana (JICA, 1995).

6) Pumping of the groundwater in the highland must be reduced to estimated annual safe yield of about 290 MCM. In this regard, Azraq Aquifer is the most depleted by over pumping. The depletion approaches 230% of the annual safe yield. The Azraq wet land area has long been a desert depression oasis in the north east of the country. It receives extensive amounts of runoff water which results in very rich ecosystem in terms of biodiversity. The over pumping has caused a catastrophic impact on plant and animal life in that area. Rehabilitation of that oasis can only be initiated by reducing well water pumping, especially for agriculture. Table 6 shows that water pumping for irrigation constitutes 112% of the safe yield. Unfortunately, most of irrigated farms in that area have been proven unsuccessful and do not have any advantage over other irrigated areas. If substantial cut in volume of the irrigation water is adopted then real progress can be achieved on several levels as follows: a) rehabilitation of the Oasis itself, b) improving drinking water quality and c) improving the RWW quality as a result of the improvement of the drinking water quality. More recently, the Ministry of Water and Irrigation has become authoritative of well closure and imprisonment of well owners in cases of illegal or over pumping of the groundwater. In this regard, the Ministry usually issues a license of annual pumping not to exceed 50,000 m^3 for farm irrigation. This amount of water is sufficient to irrigate about 10 ha. On the other hand, pumping water for domestic consumption requires a certain official permission subject to per m^3 fee. In many cases, well owners have demonstrated resistance to such regulations, especially to fix water meters on main well-intake pipes for monitoring purposes.

7) Encouraging contracted (market-oriented) agriculture to replace haphazard practice which is prime reason for low farmers' income. In this regard, the unit price of irrigation water of 0.7 US$ m^{-3} (0.5 Jordan Dinar m^{-3}) may be taken as threshold value below which agricultural production will not become feasible. Concept of contracted agriculture would ensure minimum net return to the farmers. The Government can generate funds to help upgrade the irrigation water sector and can also maximize use efficiency of irrigation water. Both components will have positive impact on saving portion of the irrigation water for the drinking purposes.

Above regulatory measures can suffice increasing demand for the fresh water in coming short period. Long term and genuine solution must be sought. This can take one or more of the following:

1) Importation of Water:

Preliminary studies were conducted to assess possibilities for importing water to Jordan. A study was completed in 1983 to import 160 MCM / year from Euphrates River in Iraq to supply northern part of the country. Another major water importing project is Turkish Peace pipeline. This project is intended to divert the water of Ceyhan and Seyhan Rivers in south Turkey to supply Jordan and other Gulf Cooperation Council countries with water. Major concern with regard to importing water is political uncertainty that is encountered in such multi-national projects. Other options were developed and studied as the diversion of Euphrates River to Jordan (Howard Humphrey, 1986) and pipe line diversion of 150 MCM annually from the Litani River water to Amman for the domestic consumption. Estimated cost of the later option was 0.68 US$ m^{-3} (GTZ, 1998).

The option of diverting part of the Euphrates River water to Jordan through north eastern Badia was postponed due to remarkable changes in water quantities of the Euphrates River. Building Ataturk dam played a crucial role in re-thinking of this option. Hussein and Jayousi (1999) reported that the most feasible and attracted option is the peace pipeline as demonstrated by the 1998 study of GTZ.

2) Transporting Disi Aquifer Water:

The Disi Aquifer is fossil water. It is located in south eastern desert of the country. It is estimated that the aquifer can provide major urban centers by about 100 MCM of excellent quality water for a century long. Construction costs are estimated at $600 million, with a cubic meter operating cost of $0.18. Most drinking water resources are undergoing deterioration in major quality parameters. The Disi Aquifer water will furnish the country with water of most needed quality. In addition, this project has a major advantage of providing a pipe line extending along country's south-east transect. It can be utilized wholly or in-part to transport future desalted sea water from the Gulf of Aqaba (JICA, 2001).

3) Sea Water Desalination:

Today, average price of desalinated sea water is about one-tenth of what was twenty years ago. It dropped dramatically from $5.5 per m^3 in 1979 to $0.55 per m^3 in 1999. Desalination plants producing several million gallons per day are commercially available. They are already used for domestic and industrial purposes in Saudi Arabia, United Arab Emirates and Kuwait. Total desalination plants capacity in Arab countries in 1997 was estimated at $11.6x10^6$ m^3/day (IDA, 1997). Two thirds of the world installed capacity of desalination plants exist in the Arab countries. It is expected that this number will be doubled in year 2020. Gulf Cooperation Council countries will become potential customers for this technology.

In addition to conventional desalination of the sea water by distillation, reverse osmosis is a newly emerging competitive technology. Three major new water developments have been accomplished in the World. The reverse osmosis technology is used in Tampa Bay, Florida (34 MCM per year at $ 0.55 m^{-3}), Trinidad (40 MCM per year at US$ 0.7 m^{-3}) and Cyprus (14 MCM per year at $0.82 m^{-3}). Prices include capital recovery, interest operations and maintenance (Center for Middle East Peace & Economic Cooperation, 1999).

In respect to Jordan, desalination of the seawater is most promising alternative. Two main water sources can be desalted; Red Sea and brackish groundwater in some basins, particularly Hisban-Kafrein in the southern JV. The desalination may start first with brackish groundwater for several reasons. They include reducing cost of desalted water transportation to major cities and building human capacities. Volume of the brackish water base flow in the Hisban-Kafrein area is 50 MCM per year. The cost of desalination is estimated at $0.35 per m3. Moreover, preliminary studies showed that by the year 2010 more than 20 MCM/year can be developed in Central JV. This figure may reach 70 MCM/year by year 2040 (JICA, 1995). However, major source for the desalination will be the Red Sea water in Aqaba (Hussein and Al-Jayyousi, 1999). The desalination of sea water must be given a "national priority". National water carrier may be suggested for conveying water from south to north. An additional advantage of such proposal is improvement of the drinking water quality. It has been under ongoing deterioration due to anthropogenic pollution and the groundwater over pumping. Reclamation of domestic water quality will, subsequently be reflected on the improvement of the RWW quality.

Figure 1: Ancient deflection dam in the historic site of Jawa to North East of Jordan.

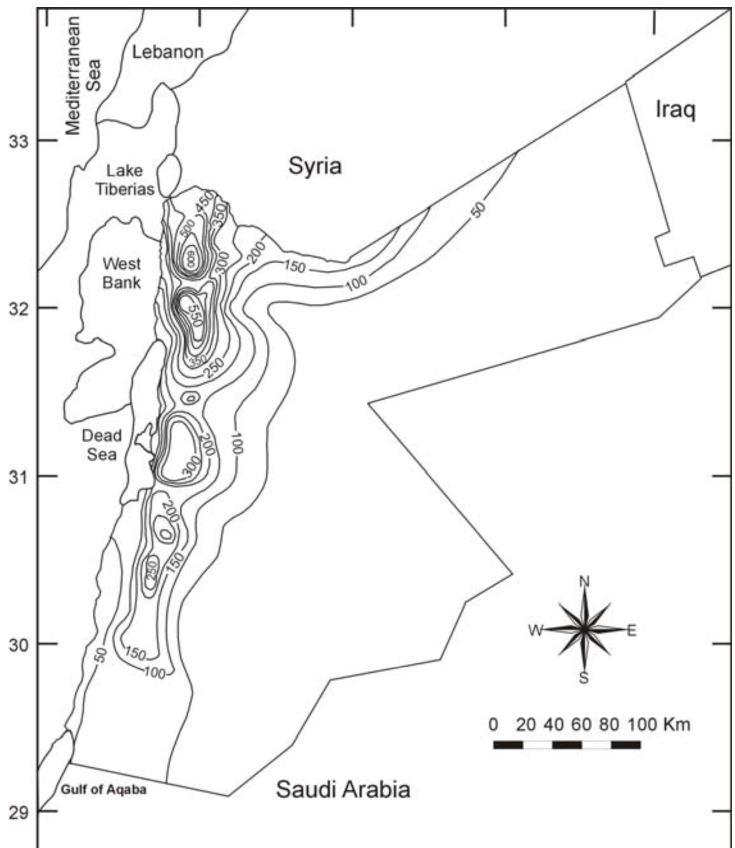

Figure 2: Rainfall distribution over Jordan.

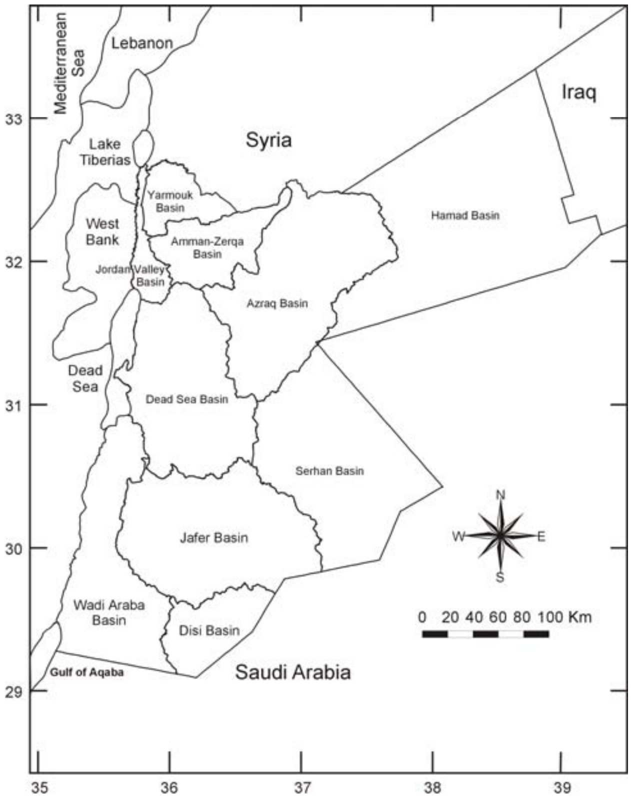

Figure 3: Watersheds of Jordan.

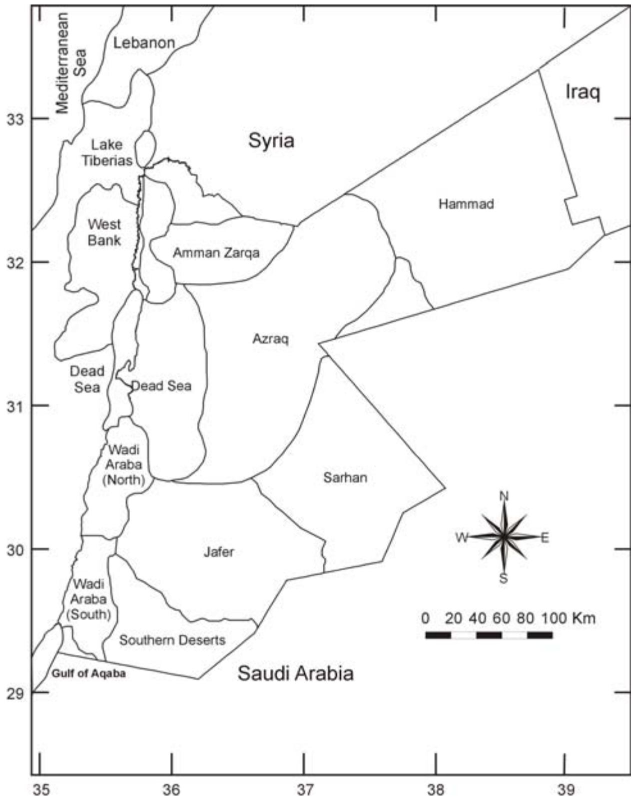

Figure 4: Ground water basins of Jordan.

Table 1: Dams overlooking the Jordan Valley and their respective storage capacities (MCM).

Dam Name	Storage Capacity
King Talal	75.00
Wadi Arab	16.90
Karama	55.00
Kafrein	8.45
Wadi Shueib	1.43
Sharhabeel	3.90
Total	160.68

* Source: Jordan Valley Authority. Personal Communication, 2004.

Table 2: Annual discharge (MCM) from major Wadis ending in the Jordan Valley and Southern Rift Valley.

River or Wadi Name	Discharge Volume
Jordan Valley	
Rivers:	
Yarmouk (at Maqarin)	240.3
Zarqa (at DeirAlla)	67.1
Wadis (listed from north to south):	
Wadi Arab	28.8
Wadi Ziglab	9.5
Wadi Jirim	11.2
Wadi Yabis	3.5
Wadi Kufrinja	6.1
Wadi Rajib	7.1
Wadi Shueib	7.9
Wadi Kafrein	14.3
Wadi Hisban	5.0
Southern Rift Valley	
Wadi Hasa	24.9
Wadi Ben Hammad	8.1
Wadi Karak	4.4
Wadi Fefa	3.3
Wadi Thraa	1.5
Wadi Khneizeera	1.5
Wadi Asaal	0.9
Total	44.6

* Source: Jordan Valley Authority. Personal Communication, 2004.

Table 3: Net water yield in the Jordan Valley (MCM) during the period of 1995-1999.

Calendar Year	Net Yield (MCM)	Irrigation use (MCM)	Sold water (MCM)	Water pumped to Amman (MCM)
1995	261	140	125	37
1996	247	143	128	38
1997	268	136	123	38
1998	264	150	142	37
1999	207	123	115	41

* Source : Jordan Valley Authority, Personal Communication.

Table 4: Well water distribution in the Jordan Valley and Southern Rift Valley and volumes of extracted water for the period of 1997-1999.

Location	Number(1)	Yield ($m^3\,hr^{-1}$)	Irrigated Area (ha)	Extracted Water (MCM)(2)	Water Consumption ($m^3\,ha^{-1}$)(3)
Northern JV	7	125	102	0.591	16,600
Karama	6	300	NA	0.669	NA
Wadi Shueib	2	75	160	0.250	15,630
Southern JV	63	2552	5191	10.393	15,23
Kafrein	58	2028	3951	7.300	15,39
Rama & Sweimeh	37	1480	2835	5.265	15,390
Total JV	173	6560	12239	24.467	-----
Southern Rift Valley	11	370	1300	0.649	4,570
Total	184	6930	13539	25116	-----

(1) 0nly 69% of the total number have official license. High salinity is a common problem in at least 173 wells in the JV. Water salinity usually exceeds 2000 mg/L.

(2) Annual safe yield in the JV and Southern Ghor wells is estimated at 21 and 3.5 MCM, respectively.

(3) Water consumption was calculated only for wells of known irrigated area.

* Source: Jordan valley Authority. Personal Communication.

Table 5 : Selected Chemical and biological properties of King Abdulla Canal water samples at tunnel intake from Yarmouk River on different dates of the years 1999 and 2000.

Date	EC	pH	Ca	Mg	Na	K	Cl	SO_4	CO_3	HCO_3	NO_3	Coli	Fecal
	dS/m		mg/l									mpn/100ml	
11-Jan-99	1.01	8.4	72.62	33.32	91.54	7.82	127.09	84.48	11.7	284.87	16.5	-	-
04-Feb-99	1.02	8.3	74.87	30.76	88.32	5.47	120.35	81.12	12.6	269.01	17	>1600	900
09-Mar-99	1.05	8.3	75.48	34.9	92.23	7.82	131	82.56	4.2	293.41	17.7	9000	108
01-Apr-99	1.03	8.3	74.26	33.32	93.84	8.21	120.7	82.56	15.9	281.82	14.3	>1600	2400
03-May-99	1.14	8.3	88.13	34.66	96.37	8.21	143.42	98.4	0	313.54	17.9	300	300
02-Jun-99	1.06	8.2	77.11	35.63	91.77	7.43	127.09	88.8	0	308.05	18.6	9000	800
03-Jul-99	1.01	8.3	74.46	32.59	84.64	7.04	121.77	82.56	23.7	248.88	13.2	>1600	1700
04-Aug-99	0.99	8.4	71.2	33.32	84.18	7.43	117.51	75.84	17.7	260.47	11.9	1100	700
04-Sep-99	0.98	8.3	69.36	33.32	81.19	7.04	120.35	77.76	7.8	270.84	7.05	5000	1700
02-Oct-99	1.01	8.4	75.07	34.05	83.49	7.43	120.7	81.6	9	279.99	10.4	5000	500
06-Nov-99	1.20	8.4	82.82	35.87	94.07	8.6	142.36	82.08	18	281.21	12.8	16000	3000
05-Dec-99	1.07	8.4	82.42	36.84	92	7.82	141.65	75.36	23.7	278.77	12.1	>16000	9000
03-Jan-00	1.00	8.4	79.36	32.71	79.58	7.04	119.28	82.56	11.4	278.16	15.1	9000	800
07-Feb-00	1.06	8.3	70.18	35.26	98.44	8.6	134.55	93.12	5.7	261.08	27.1	>16000	2200
01-Mar-00	1.00	8.4	67.12	33.32	97.29	8.99	123.9	86.88	11.4	260.47	20.2	16000	5000
04-Apr-00	0.96	8.4	64.67	33.44	83.26	7.43	112.54	80.16	22.5	240.34	16.7	>16000	1100
03-May-00	1.13	8.4	85.27	39.52	94.07	7.82	142	96.48	27.9	267.18	18.8	9000	500
04-Jun-00	1.06	8.3	82.42	38.55	80.27	7.43	137.74	92.16	17.1	273.89	13.1	3000	1700
05-Jul-00	1.05	8.1	74.66	38.43	84.18	7.04	133.13	89.76	18.3	248.27	10.3	>16000	900
02-Aug-00	1.04	8.2	74.66	35.99	84.64	7.04	134.19	89.28	13.8	265.35	7.74	2400	2400
03-Sep-00	0.96	8.2	70.99	34.78	75.67	4.3	119.99	83.04	15.3	250.1	6.9	2400	800
02-Oct-00	0.92	8.4	69.36	35.99	72.45	6.65	108.28	74.88	13.2	260.47	10.5	16000	3000
06-Nov-00	1.06	8.4	75.48	35.14	93.61	7.82	133.48	88.32	13.2	292.8	12.4	9000	700
04-Dec-00	1.07	8.5	74.26	38.06	90.85	8.6	140.94	89.28	14.4	287.31	14.9	>16000	9000
15-Jan-01	1.05	8.4	73.85	35.39	88.55	7.82	130.29	79.68	28.8	239.12	14.9	>16000	5000
04-Feb-01	0.96	8.3	65.48	32.47	89.47	7.82	112.54	77.28	15.6	268.4	16.3	>16000	>16000
12-Mar-01	1.19	8.3	73.44	38.67	92.92	7.82	133.13	86.88	25.2	280.6	12.2	16000	5000

* Source: The Water Authority-Directorate of Laboratories. Personal Communication.

Table 6: Ground water resources and their sectoral usage in Jordan for the year 1998.

Aquifer Basin	Safe Annual Extraction (MCM/Yr)	Sectoral usage of ground water											Extraction (% Safe Yield)
		Domestic		Industry		Agriculture		Nomads					
		Number of Yielding Wells	(MCM/Yr)	Number of Yielding Wells	(MCM/Yr)	Number of Yielding Wells	(MCM/Yr)	Number of Yielding Wells	(MCM/Yr)	Total Consumption (MCM/Yr)	Balance (MCM/Yr)	Total Number of Wells	
Yarmouk	40	37	23.49	2	0.17	111	30.77	3	0.37	54.80	-14.80	153	137
Side wadis	15	16	5.63	-	-	56	1.57	-	-	12.20	2.80	72	81
JV	21	23	7.57	5	1.07	189	29.39	-	-	38.02	-17	215	181
Amman-Zarqa	87.5	122	65.70	60	6.07	455	65.56	5	0.33	137.66	-50.16	642	157
Dead Sea	57	78	23.79	47	14.57	257	34.39	13	2.17	84.92	-27.92	395	149
Disi	125	14	9.65	-	4.27	51	50.18	6	1.1	65.20	59.80	71	52
Northern WA	3.5	-	-	11	3.16	9	0.41	4	0.20	3.77	-0.27	24	108
Southern WA	5.5	2	1.19	2	0.12	33	3.39	3	0.12	4.82	0.69	40	88
Jafr	9 18	21	6.94	19	6.59	92	9.44	8	0.31	23.27	-14.27	140	235 232
Azraq	24	32	28.093	3	0.29	451	26.86	12	0.54	55.79	-31.79	498	229
Sarhan	5	-	-	-	-	13	1.29	5	0.18	1.47	3.53	18	16
Hammad	8	3	0.78	-	-	2	0.10	10	0.43	1.30	6.70	15	16
TOTAL	418.5	348	172.83	149	36.31	1719	253.35	69	5.75	483.22	-82.69	2283	

* Source: Water Authority. Personal Communication. 2000

Table 7: Examples of production, water consumption and net yield profit for agricultural production under plastic houses in the Jordan Rift Valley.

Crop	District	Season	Yield (Ton/ha)	Irrigation Water (m^3/ha)	Production Cost (US $/ha)	*Price* * (US $/Ton)	Net Profit (US $/$m^3$)
Tomato	SJV	Spring	81.40	5057.10	19058.73	141.31	-1.49
Cucumber	SJV	Autumn	100.00	5457.10	25253.94	189.44	-1.15
Green Bean	SJV	Autumn	25.00	2414.30	16427.46	597.89	-0.62
Cucumber	MJV	Autumn	125.00	5200.00	25249.86	189.44	-0.30
Pepper	SJV	Autumn	50.00	6542.90	15845.77	341.79	0.18
Pepper	SG	Autumn	52.50	3514.30	15845.77	341.79	0.59
Tomato	NJV	Autumn	160.00	4742.90	19053.66	143.66	0.83
Tomato	SJV	Autumn	174.00	6242.90	19078.31	143.66	0.94
Tomato	MJV	Autumn	162.00	4400.00	19048.03	144.01	0.97
Green Bean	SG	Autumn	32.50	2100.00	16422.54	597.89	1.44
Cucumber	SG	Autumn	160.00	3300.00	25218.59	189.44	1.55
Pepper	MJV	Autumn	72.50	3785.70	15800.42	341.79	2.37
Tomato	SG	Autumn	230.00	5057.10	19058.73	143.66	2.76
Green Bean	NJV	Autumn	82.50	3457.10	15794.93	341.79	3.59
Cucumber	NJV	Autumn	160.00	2242.90	25201.13	229.23	5.11
Green Bean	MJV	Autumn	47.50	2300.00	16425.77	597.89	5.21
Green Bean	NJV	Autumn	57.50	2085.70	16422.25	597.89	8.61
Strawberry	MJV	Autumn	22.50	2085.70	18352.25	1873.24	11.41

NJV= Northern Jordan Valley, MJV=Middle Jordan Valley, SJV=Southern Jordan Valley and SG= Southern Ghor.

Products prices were taken from Bulletin for Prices of Agricultural Materials (1998)-Department of General Statistics. Amman.

* Source : Abu-Sharar and Battikhi (2002)

Table 8: Examples of production, water consumption and net yield profit for agricultural production from open fields in the Jordan Rift Valley.

Crop	District	Season	Yield (Ton/ha)	Irrigation Water (m^3/ha)	Production Cost (US $/ha)	Price * (US $/Ton)	Net Profit (US $/$m^3$)
Pepper	SG	Spring	20.00	7742.90	5226.20	230.52	-0.08
Cauliflower	SG	Autumn	37.50	3557.10	2593.75	71.83	0.03
Potato	MJV	Autumn	30.00	2557.10	5222.54	183.10	0.11
Pepper	SJV	Spring	25.00	5000.00	5210.99	230.52	0.11
Cauliflower	MJV	Autumn	35.00	1785.70	2564.79	83.10	0.20
Pepper	SG	Autumn	20.00	5514.30	5189.58	341.79	0.30
Cabbage	MJV	Autumn	35.00	3242.90	2249.01	95.77	0.34
Potato	MJV	Spring	40.00	2857.10	5227.61	161.27	0.42
Onion	SG	Autumn	30.00	5400.00	2478.31	166.90	0.46
Tomato	SG	Autumn	45.00	5985.70	3600.56	143.66	0.48
Potato	SG	Autumn	50.00	3757.10	5242.25	144.37	0.52
Watermelon	MJV	Spring	40.00	5214.30	5652.82	211.27	0.54
Potato	SJV	Autumn	60.00	4885.70	5260.85	144.37	0.69
Onion	SJV	Spring	50.00	4242.90	2478.31	109.15	0.70
Potato	SJV	Spring	50.00	3914.30	5244.93	161.27	0.72
Green Bean	NJV	Autumn	15.00	1528.60	2893.80	597.89	3.97
Green Bean	MJV	Autumn	15.00	1514.30	2893.80	597.89	4.01

NJV= Northern Jordan Valley, MJV=Middle Jordan Valley, SJV=Southern Jordan Valley and SG= Southern Ghor.
Farm gate prices were taken from Bulletin for Prices of Agricultural Materials (1998)-Department of General Statistics. Amman.

- Source : Abu-Sharar and Battikhi (2002).

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التحديات الراهنة والمستقبلية في إدارة موارد الأردن المائية

طالب أبو شرار*

ملخـص

عبر آلاف السنين، ضبط أبناء الأردن إيقاع حياتهم لينسجم مع ندرة مواردهم المائية الناجمة عن مناخ بلادهم الجاف فطوروا طرائقهم التقليدية لحفظ التربة وحصاد وإدارة مياه الأمطار كالزراعة الكونتورية وأساليب حفظ رطوبة التربة وإنشاء المصاطب على المنحدرات. تعتبر الشواهد النبطية في جنوبي الأردن مثالا على ما تقدم إذ يظهر بعضها تقنيات متقدمة لاقتناص وتوجيه وتوزيع مياه الأمطار وفق الكيفية المثلى آنذاك. لقد أثبتت تلك التقنيات نجاعتها في الموازنة الموضوعية بين وفرة المياه والطلب عليها لإنتاج الغذاء أو لغايات الشرب إلى أن حل العام 1948 الذي شهد هجرة بشرية مكثفة من فلسطين. لقد أدت تلك الهجرة القسرية إلى زيادة فجائية في الطلب على المياه في بلد يفتقر إليها ثم تفاقمت تلك الحاجة في أعقاب نزوحين كبيرين آخرين تليا الهزيمة العربية في العام 1967 وخسارة الضفة الغربية إلى الاحتلال الإسرائيلي ثم في العام 1991 إثر دخول القوات العراقية إلى الكويت وعودة المغتربين الأردنيين من بلدان الخليج. فبالإضافة إلى الزيادة السنوية الطبيعية المرتفعة في عدد السكان (2.5%)، ازداد سكان الأردن بنحو 10% نتيجة عودة مغتربي الخليج في العام 1991، الأمر الذي ترتب عليه نقص فجائي ملموس في حصة الفرد السنوية من الموارد المائية لتصل إلى 160 م^3 . لقد فرضت تلك التحديات السكانية المفاجئة (بسبب الهجرات) أو المتدرجة (بسبب الزيادة الطبيعية) على الأردن مهمة تطوير موارده وسياساته المائية لضمان أمنه المائي فشملت الضخ الجائر من مخزون مياهه الجوفية وتحلية الماء المسوس واستعمال مياه الصرف الصحي المستصلحة في الزراعة واعتماد أساليب الري بالتنقيط وإنشاء شبكة من السدود لاقتناص مياه الجريان السطحي خاصة تلك المتدفقة إلى وادي الأردن. وبالرغم من أن أزمة المياه ذات طبيعة كمية إلا أن البعد النوعي للمياه أصبح ذا وزن مقلق مع الاضطراد المستمر في تدهور نوعية معظم الموارد المائية. تحلل هذه الدراسة طبيعة وأسباب مشكلة شح المياه في الأردن وتقدم مقترحات علمية لإدارتها وتوزيعها خاصة في قطاع الزراعة، المستهلك الأكبر للمياه، مثل تخصيص مياه الري وفق العائد الاقتصادي منها كما تقدم مقترحات لتطوير موارد مائية جديدة.

الكلمات الدالة: تربة، نوعية مياه، ندرة مياه، تطوير موارد مياه، اقتصاديات مياه.

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