**GLOBALIZATION AND WATER RESOURCES MANAGEMENT:
THE CHANGING VALUE OF WATER**

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WHAT SCIENCE CAN CONTRIBUTE FOR FUTURE COOPERATION IN THE MIDDLE EAST: THE JORDAN RIVER

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ABSTRACT: The rise of the salinity is one of the most conspicuous phenomena that affects the water quality in the Middle East. Future exploitation and management of the water resources under these conditions will require deep understanding of the sources and mechanisms of contamination. The Jordan River located between Lake Tiberias and the Dead Sea has become a foul flow of saline water and effluents. This paper deals with the implications of the results of an ongoing research project that includes scientists from Israel, Jordan, and Palestinian Authority. The study reveals three principle zones of different salinity. We employ different diagnostic hydrological and geochemical fingerprinting tracers for elucidating the sources of the salinity. We show that groundwater discharge is an important component that affects the quality and quantity of the Jordan River. The impact of the groundwater component adds addition constraints for future management of the water resources in the Jordan River. We conclude that scientific information is vital for any future water management, particularly in the complex hydrological system of the Middle East.
KEY TERMS: Jordan River, salinity, Peace Treaty, geochemistry and isotopes.

INTRODUCTION

Water is one of the most valuable natural resources in the Middle East. The combination of population growth, economic and agriculture development, and arid climate with insufficient precipitation results in over exploitation of the water resources in the region. The continued stress leads to rapid degradation of the quality of fresh water resources owing to salinisation and contamination processes (e.g., Vengosh & Rosenthal, 1994; Salameh, 1996). The lack of sufficient water combined with rapid water quality deterioration presents a serious challenge to the people in the region. In order to be able to manage and share the water resources in conditions of accelerating degradation, it is crucial to understand the origin and mechanisms of the contamination process.

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The salinity that threatens the fresh water resources is derived from different sources, both natural and anthropogenic. In general, over- exploitation of fresh aquifers results in a rapid decrease of water level, which then triggers lateral and under flow of saline waters from adjacent aquifers. Consequently, the overexploited aquifer become saline due to mixing with saline waters (e.g., Vengosh & Rosenthal, 1994; Salameh, 1996; Vengosh et al., 1999; Marie & Vengosh, 2001). In addition, human activity produces low- quality fluids that enter the aquifer and further degrade water quality. These fluids include those derived from sewage, wastewater irrigation, landfills, and agricultural return flows. The superposition of natural and anthropogenic contaminants that affect water quality provides a scientific challenge and requires unconventional interpretations for the origin of the salinity.

The Jordan River is the largest river in the region (Fig. 1). It originates from three sources, the Dan, Banyas, and Hasbani springs and flows through the Upper Jordan River into Lake Tiberias (210m bsl). The Lower Jordan River starts at Alumot, downstream from Lake Tiberias, and ends at the Dead Sea in the south (410m bsl). The river symbolizes the history of the region. Starting with the Israelites crossing the river and continuing with the Prophets, Elijah, Elisha, John the Baptist and Jesus Christ all crossed the river in their lifetimes. At present, the lower Jordan River serves as an international border between Israel and Jordan.

The quality and quantities of water delivered by the Lower Jordan River have been extremely degraded during the last several decades. Since the implementation of water supply projects in Israel, Jordan, and Syria, no fresh surface water flows into the river except for negligible springs and rare flood events. As a result, the available water sources are limited to artificial deviation of saline springs from Lake Tiberias ("the Saline Diversion"), natural flows from adjacent saline springs, dumping and leakage of solid and liquid wastes, effluents from fish ponds, and agricultural return flows from adjacent fields. The total discharge of the river into the Dead Sea in the past was about 1200 MCM/year (Klein, 1998; Salik, 1988, Dalin, 1982, Sofer, 1994). The amount has now declined to a mere 100-200 MCM/year (Tahal, 2000).

The river is a resource shared by all peoples in the region. As such, it received a great deal of attention in the peace treaty between Israel and Jordan (October, 1994). Based on the agreements between the two countries and the desire to develop the regional environment, changes in the operation of the river and its surroundings are expected to take place in the near future. According to the water balance calculation of Al-Weshah (2000), the total discharge of the river into the Dead Sea is 175 MCM/year. If peace treaty allocations are included, the discharge will be reduced to only 60 MCM/year.

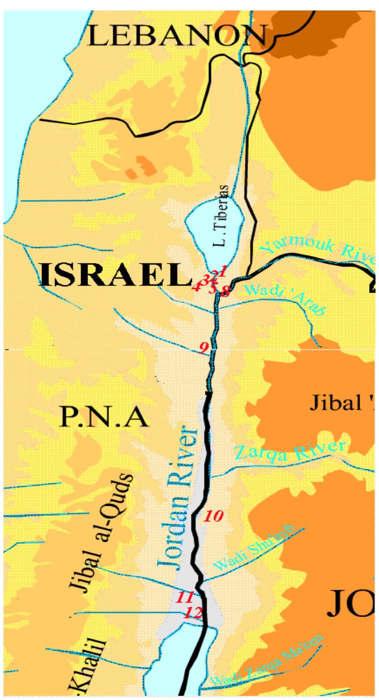

Figure 1: Location map of the Jordan River and major tributaries.

WATER ASPECTS OF THE JORDAN-ISRAEL PEACE TREATY

The peace treaty between Israel and Jordan (October, 1994) contains several elements that are related to water (Annex II, Water Related Matters). These components deal with the distribution of water between Israel and Jordan as well as some parameters related to preservation and even improvement of the water quality in the Jordan River. The agreement concerning current water allocation states that Israel will use an annual amount 25 MCM from the Yarmouk River and the rest of the flow will be diverted to King Abdulla Canal in Jordan (instead of natural flow to the Jordan River). During winter time Israel is allowed to pump additional 20 MCM from the Yarmouk River and store the water in Lake Tiberias (Sea of Galilee). In return, during summer Israel will transferred 20 MCM from Lake Tibeias to Jordan. In addition, Israel is required to supply Jordan additional 10 MCM a year from lake Tiberias as long as the desalination facility is not operational. During high floods events Israel is allowed to use the excess flood water that is not useable by Jordan. Israel is entitled to maintain its current uses of the Jordan River water below its confluence with the Yarmouk (i.e., the saline water of the Jordan River). Jordan is entitled to use an annual quantity equivalent to that of Israel. The amount of these consumption's is not outlined in the treaty.

The second aspect of the treaty concerns future operation. Israel is to search for financial support to establish desalination plant for desalination of the saline springs that are now diverted into Jordan River (about 20 MCM/year). Jordan is entitled to an annual quantity of 10 MCM of desalinated water. In addition, Israel and Jordan will cooperate in finding sources for the supply an additional quantity of 50 MCM of drinkable standards to Jordan.

The third aspect of the treaty is protection of the quality of the Jordan and Yarmouk rivers. In addition to monitoring the quality, both Israel and Jordan will each prohibit disposal of untreated municipal and industrial wastewater into the course of the Yarmouk or the Jordan rivers. The implementation of this prohibition was expected to be completed within three years from the entry into force of the Peace Treaty (1994). It should be emphasised that currently (2001) untreated wastewaters are still flowing into the Jordan and Yarmouk rivers and hence this aspect of the treaty has never been implemented.

The fourth aspect of the treaty is dealing with groundwater in the Arava valley. The pumping wells that were drilled by Israel and are located within the Jordanian territory will transferred to Jordan's sovereignty. Israel is allowed to continue to use and pump these well however. Israel also is allowed to increase the abstraction rate of these wells up to 10 MCM/year.

REVEALING THE SOURCES OF THE SALINITY IN THE JORDAN RIVER

An integrated research project of Israeli, Jordanian, and Palestinian scientists currently investigates the origin of the salinity of the Jordan River between the Sea of Galilee and the Dead Sea (Shavit et al., 2001; Vengosh et al., 2001). The project is funded by the US-AID (the Middle East Research Cooperation project, MERC). The objectives of the study are to trace the impact of different saline sources on the salt budget of the river and to establish a hydrological model of the Jordan River. The study shows large variations in the salinity and water composition along the flow of the river and identifies three regimes along the river: the upper (20 km), central (20-50 km), and the southern (50-100 km) sections.

The salinity of the initial flow of the river is extremely high due to artificial discharge of saline water that is diverted from the saline springs that flow to the western shore of the Sea of Galilee. The saline water is mixed with sewage effluents and is discharged (20 MCM/year) to the river. On the other hand, natural freshwater flow from the Sea of Galilee and Yarmouk River is tapped. Hence at the upper part of the Jordan River the quality of the water is very low. Along the first 20 km of flow the salinity decreases (from 2800 to 1500 mgCl/l) and the chemical and isotopic compositions are changing. By integrating hydrological, geochemical and isotopic data we show that surface inflows can not be the sources of this significant modification. Mass-balance calculation shows that integration of all of the surface inflows can not explain the increase in discharge volume along the flow. Similarly, the chemical and isotopic modifications of the Jordan River are not consistent with those of the surface inflows. Consequently, we argue that the external source of water is subsurface discharge of groundwater. Based on these results we identified local groundwater with chemical composition that is consistent with our model. The saline groundwater is located within the upper Jordan Valley and is derived from both natural and anthropogenic (e.g., fishpond effluents, irrigation) sources.

In the southern section of the Jordan River we trace the impact of water that is derived from water-rock interactions with Jurassic and Lower Cretaceous (Kurnob Group) rocks. The Zarka River is a good example of a base flow of these saline waters that enter the Jordan River. Further south, we have recorded a sharp increase of the salinity the occurs mainly during the late winter and spring months. The chemical and isotopic compositions of

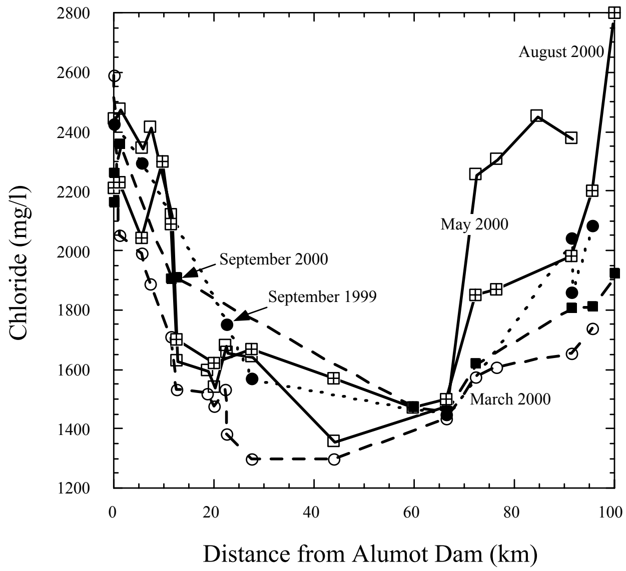

Figure 2. Chloride variations along the Jordan River between September 1999 and September 2000. Note the three major salinity zones along the flow of the Jordan River. Distance in km is referenced to y coordinate rather than actual river length from its beginning at Alumot Dam.

the saline Jordan River is consistent with saline groundwater that flow in the Lisan Formation, the sediment that make up the Jordan Valley. Based on the agreement of several geochemical and isotopic (boron and strontium) criteria we hypothesise that groundwater discharge into the Jordan Valley from both sides of the Rift valley is the source of local groundwater within the Jordan Valley. Large variations in permeability and extensive water-rock interactions result in significant chemical modification and salinization of local groundwater within the Jordan Valley. The local groundwater discharge to the Jordan River and control its salinity (up to 3000 mgCl/l).

IMPLICATIONS FOR FUTURE WATER MANAGEMENT

The Jordan River exhibits large variations in chemical and isotopic compositions along 100-km flow between the Sea of Galilee and the Dead Sea. We have demonstrated that these variations reflect continued rapid exchange with subsurface flows, in addition to surface inflows to the river. The impact of the groundwater component on the quality of the Jordan River adds additional constraint for future management of the river. For example, further utilisation of the Jordan River, in addition to the current use of about 60 MCM/year would reduce the overall discharge and increase the groundwater component that would further dominate the quality of the Jordan River.

According to the Peace Treaty between Israel and Jordan, both sides are committed to reducing and eventually eliminating the discharge of wastewaters and effluents to the river. Adequate treatment of the sewage effluents and discharge of the treated effluents to the river will defiantly improved the quality of the Jordan River by reducing the amounts of organic components and nutrients discharge. However, if the sewage effluents will be used for other applications, as usually they are, the lack of sewage discharge would reduce the dilution factor in the Jordan River. Moreover, as we expect that treated sewage effluents would be used for local agriculture within the Jordan valley, the irrigation would further increase the impact of local ground water on the quality of the Jordan River. Hence, the high salinity of local groundwater would further increase the salinity of the Jordan River.

In sum, a thorough understanding of the complex hydrology and mechanism of salt transport to the Jordan River will enable policy-makers to develop better tools for water management in the region. Moreover, the integration of different scientific tools shows that groundwater and surface water are connected, and as a result, any future exploitation of one resource will affect the other. The future development of irrigation in the Jordan Valley could also affect the groundwater flow, which in turn could increase the salinity level of the Jordan River. Thus, it is essential to understand the way in which these different uses of groundwater and surface water for economic development (e.g. irrigation) can affect the sustainability of water exploitation in the region, which could also affect the potential for future economic cooperation between Israel, Jordan, and the Palestinian Authority.

ACKNOWLEDGMENTS

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