Groundwater salinity in Jericho area, West Bank, Palestine

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ABSTRACT

The Jordan Valley is a fertile productive region, described as the food basket of Palestine. Groundwater originating from the Quaternary Aquifer System forms the main water resource in the Jordan Valley. However, the quality of this groundwater is threatened mainly by the high chloride concentration.

The most representative area of the Jordan Valley is Jericho area, which was chosen to be the study area. The Quaternary Aquifer System in the study area could be divided into an upper alluvial layer and a lower low-permeable Lisan layer, which crops out in the eastern part of the study area. In the study area, there are 63 production wells tapping the Alluvial Aquifer, 3 small springs and 6 observation wells. Hydrogeochemical investigation reveals that the water is generally earth alkaline with higher content of earth alkalis and prevailing chloride. The water type is mainly very-hard brackish MgNaCl, while some wells are extremely-hard brackish-salt NaMgCl or NaCl. Groundwater quality is deteriorating (increase in salinity) spatially towards the east and vertically with increasing depth (when nearing the Lisan Formation). As an indication of groundwater salinity, total dissolved solids show some variability with time over the last 21 years (1983-2004). In short-time scale, there are high seasonal and yearly fluctuations in regards to salinity, specifically, Cl⁻, SO₄²⁻, and NO₃⁻ contents.

Spring water from the Upper Cenomanian Aquifer (CaHCO₃) represents the fresh end member, while Rift Valley brines (RVB-CaNaCl) and Dead Sea brines (DSB-MgNaCl) represent the saline end members. The probable sources of salinity are: mixing with saline end members (RVB/DSB); dissolution of the minerals of the Lisan Formation (calcite, dolomite, gypsum and halite); and to some extent, agricultural effluent pollution.

INTRODUCTION

The Jordan Valley is a fertile productive region, which constitutes 52% of the total irrigated land in the West Bank. It is described as the food basket of Palestine where citrus, bananas, date palms, vegetables and field crops are grown all over the year. Groundwater originating from the Quaternary Aquifer System forms the main water resource in the Jordan Valley. However, the quality of this groundwater is threatened by the high chloride concentration and, to some extent, also to the elevated concentrations of sulphate and nitrate in some boreholes.

The Study Area

The most representative area of the Jordan Valley is Jericho area (Fig 1), which was chosen to be the study area. The study area (65 km²) is almost a flat area with a gentle decline of 1.5% towards the east. It is the lowest land on earth with ground levels ranging between 200 meter below sea level (mbsl) near the Jordan Rift fault, which is the site of contact between the Mountain Aquifer and the Quaternary Aquifer, in the west, and 400 mbsl near the Dead Sea
shores, in the east. In the study area, there are 63 production wells tapping the Alluvial Aquifer (4.5 Mm³/year), 3 small springs (~0.1 Mm³/year), and 6 observation wells. Depths of these wells range between 15 and 200 m. Depths of these wells range between 15 and 200 m. To the west and northwest, there are few deep wells and springs discharging the Mountain Aquifer. Almost all water from wells and springs is used for irrigation. To the west and northwest outside the study area, there are few deep wells and springs (23.3 Mm³/year) discharging the Mountain Aquifer. 26.5 Mm³/year (4.5 Mm³/year from alluvial wells and 22.0 Mm³/year from springs) is used for irrigation in the study area.

METHODOLOGY

Hydrochemical investigation was carried in the study area to determine the sources of groundwater salinity using several analysis and interpreting methods such as: spatial and vertical distribution of quality parameters combined with hydrogeological distribution; water type classification by Stuyfzand (1986); Piper and Durov diagrams; saturation index; chemical composition and ion ratios, scatter diagrams; Time Domain Electro-magnetic Method (TDEM) and graphs of time-series for chloride and nitrate.

RESULTS AND DISCUSSION

Hydrogeology and hydrodynamics

The Quaternary Aquifer System in the study area could be divided into: (1) Upper Alluvial Aquifer: mainly composed of lenticular pervious beds of gravels and sands and lowly-pervious beds of calcareous clays and marl. It is considered as a good local aquifer in terms of quantity and quality with thickness varying from 40 to 150 m. It covers an area of 40.5 km² (62%) in the western and central parts of the study area. There is higher percentage of coarse grained sand and gravel in the west, while towards the east the sediments turn to very fine grained sediments of marl and clay. The alluvial deposits decrease in thickness towards the east, until they
disappear where the lowly-permeable Lisan Formation crops out. Transfer from high to low
permeability explains the emerging of springs at the interface between the Alluvial Aquifer and
the Lisan Formation and backs the view of two aquifer layers. (2) Lower Pleistocene Lisan
Formation: mainly composed of thinly laminated marl with gypsum, conglomerate, chalk, thin
limestone, halite, poorly sorted gravel and pebbles. It is considered an aquifer/aquitard and
crops out over 24.5 km² (38%) in the eastern part of the study area with thickness over 200 m.

The main structural feature in the Jordan Valley is the south-north Jordan Rift Fault of Senonian
chalk and Upper Cretaceous limestone and dolomite. It represents the contact zone between
the Mountain and Quaternary Aquifers in the northwestern boundary, while it is considered a
hydrogeological barrier in the southwestern boundary. The Jordan Rift fault forms together with
other smaller faults important channels for groundwater movement from deep to shallow
aquifers feeding the main springs in the area, but also allowing Rift Valley brines to flow along
them to shallow aquifers.

The climate in the study area is arid where evaporation (2120 mm/year) exceeds precipitation
(166 mm/year) during the entire year. Groundwater budget calculations show that the total
groundwater recharge of the Alluvial Aquifer is around 6.2 Mm³/year including: infiltration from
wadis runoff (0.9 Mm³/year), irrigation return flow (5.2 Mm³/year), and lateral groundwater
inflow (0.1 Mm³/year). Groundwater in the Alluvial Aquifer is mostly discharged through
pumping wells (4.5 Mm³/year) and to some extent through springs (~0.1 Mm³/year); in addition
to leakage (~1.6 Mm³/year) from the Alluvial Aquifer to the Lisan Formation.

Water table elevations (WTE) are decreasing towards the east and southeast; they ranged from
310 mbsl in the west to 343 mbsl in the east in the year 2003. There is a decline of 10 to 15 m in
WTE over the last 34 years (1969-2003). Drawdowns are different from one well to another
depending on the location and abstraction rate. The highest drawdowns occur in the central
areas, which are used for agricultural purposes with high abstraction rates.

**Hydrogeochemistry**

Hydrochemical investigation reveals that the water is generally earth alkaline with
higher content of earth alkalis and prevailing chloride (Fig. 2). The water type is mainly very-
hard brackish MgNaCl, while some wells are extremely hard brackish-salt NaMgCl or NaCl,
especially in the east and at certain depth.

Groundwater salinity is increasing towards the east and with increasing depth.
Good quality water is associated with lithology of dominantly coarse grained
sediments of gravel and sand and mainly exists in the western part of the study area, and at
shallow to medium depth and close to the wadis and springs. Low quality water is associated

![Piper Diagram](image-url)
with lithology which is dominantly of very fine grained sediments of marl, clay and gypsum and mainly exists in the eastern part of the Jordan Valley where the Lisan Formation is outcropping and at a certain depth when nearing the Lisan Formation. It is also associated with areas under intensive agricultural activities.

TDS, indication of groundwater salinity, show a slight change (variability) over the last 21 years (long-time scale); however, in the short-time scale, there are high seasonal and yearly fluctuations in regards to salinity, specifically in Cl$^-$, SO$_4^{2-}$ and NO$_3^-$ contents. This occurs as a result of over-exploitation (pumping) of the Alluvial Aquifer for agricultural purposes, scarcity of rainfall and replenishing of groundwater, in addition to the effect of irrigation return flow of brackish water (agricultural pollution).

Spring water from the Upper Cenomanian Aquifer (CaHCO$_3$) represents the fresh end member, while Rift Valley brines (RVB-CaNaCl) and Dead Sea brines (DSB-MgNaCl) represent the saline end members. Water types in the Alluvial Aquifer are mixtures of the three end members. They vary from hard fresh CaMgHCO$_3$ or MgCaHCO$_3$ water in the west and northwest (undersaturated for all minerals), to very hard brackish MgNaCl or NaMgCl in the centre (oversaturated for calcite and dolomite and undersaturated but with higher Si values for gypsum and anhydrite). In the east, the water becomes extremely hard brackish-salt MgNaCl or NaCl (highly oversaturated with dolomite, relatively saturated with calcite, and undersaturated with gypsum and anhydrite, but with Si values higher than the rest of the wells). Hard fresh-brackish water (CaMgHCO$_3$) has TDS values < 1000 mg/l; very hard brackish water (MgNaCl) has TDS values between 1000 and 2000 mg/l, while extremely hard brackish-salt water (NaMgCl or NaCl) has TDS values > 2000 mg/l. Salinity profiles based on Time Domain Electromagnetic Method (TDEM) follow the same trend as profiles based on hydrochemical data with almost the same interfaces.

CONCLUSIONS

There is a consistency in results from analysis and interpretation of geological, hydrogeological, hydrochemical and geophysical data. There are three probable sources of groundwater salinity:

- Mixing with saline end members: Rift Valley brines and Dead Sea brines.
- Dissolution of the minerals of the Lisan Formation (calcite, dolomite, gypsum and halite).
- Agricultural effluent, and to a lesser extent, wastewater pollution.

REFERENCES


Other references cited in the PhD Thesis (Ref. 1).