Chapter 20

Coastal Aquifer Basin

INVENTORY OF
SHARED WATER RESOURCES IN WESTERN ASIA (ONLINE VERSION)

german cooperation
DEUTSCHE ZUSAMMENARBEIT

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

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Coastal Aquifer Basin

EXECUTIVE SUMMARY

The Coastal Aquifer Basin stretches along the eastern Mediterranean coast from the northern Sinai Peninsula in Egypt, via the Palestinian Gaza Strip into Israel. It consists of mostly consolidated alluvium increasing in thickness towards the sea. Groundwater originates from the recharge areas inland and generally flows towards the sea where it discharges.

Most of the abstraction in the basin originates from Israel (around 66% of total abstraction), while the Gaza Strip is responsible for 23% and Egypt has the lowest abstraction at about 11%. Both Egypt and Israel have invested in alternative water supply options for the coastal areas through inter-basin transfer and the use of non-conventional water resources. The Gaza Strip does not have access to alternative water resources and depends almost entirely on the Coastal Aquifer Basin for its water supply. However, as the aquifer in the Gaza Strip is severely threatened by over-abstraction and pollution, desalination is currently being explored as a major alternative source of water supply.

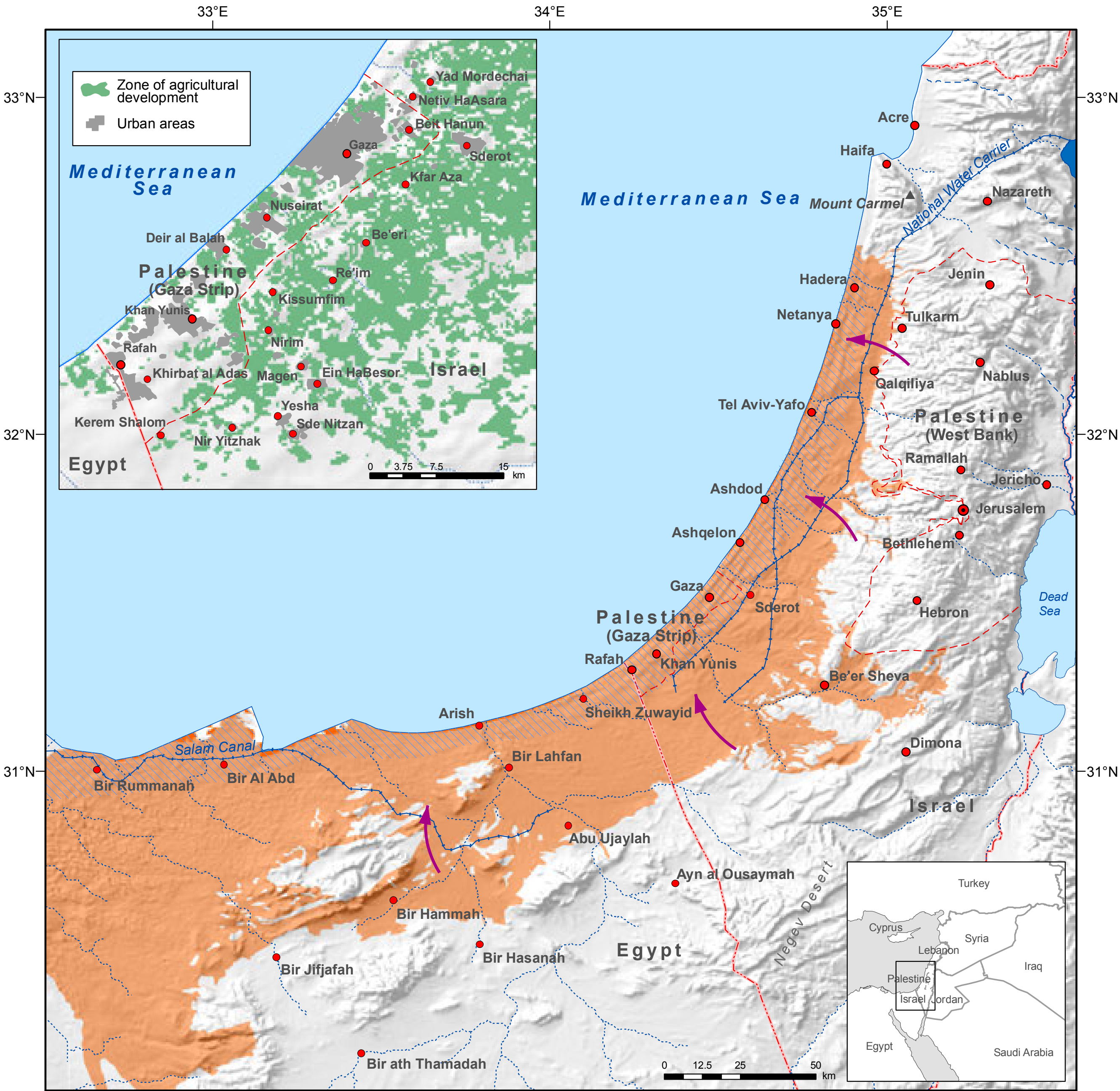
Pollution from untreated sewage, agricultural return flows and seawater intrusions coupled with continued over-abstraction, has led to increased salinization of the aquifer. As a result, water use has been greatly impaired, particularly in the Gaza Strip.

There are no formal or informal agreements for the optimization of use or protection of the aquifer. Political constraints currently make riparian cooperation over water resources in the Coastal Aquifer Basin unlikely, particularly between Israel and Palestine.

BASIN FACTS

RIPARIAN COUNTRIES	Egypt, Israel, Palestine
ALTERNATIVE NAMES	-
RENEWABILITY	Medium to high (20 - >100 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Moderate
ROCK TYPE	Porous
AQUIFER TYPE	Mostly unconfined
EXTENT	18,370 km^2
AGE	Cenozoic (Pleistocene-Holocene)
LITHOLOGY	Clastic series of sandstone, dune sand, gravel and conglomerate
THICKNESS	60-140 m
AVERAGE ANNUAL ABSTRACTION	Egypt: 70-80 MCM Gaza: 150-180 MCM Israel: 400-480 MCM
STORAGE	..
WATER QUALITY	Fresh to brackish
WATER USE	Domestic and agricultural
AGREEMENTS	Israel-Palestine (PLO) 1993 - Oslo I 1995 - Oslo II
SUSTAINABILITY	Over-abstraction resulting in a lowering of the water table and seawater intrusion; pollution from sewage, agricultural runoff

OVERVIEW MAP



Coastal Aquifer Basin

- Capital
- Selected city, town
- International boundary
- Armistice Demarcation Line
- River
- Intermittent river, wadi
- Canal, irrigation tunnel
- Approximate outcrop extent of the aquifer formation
- Approximate extent of productive area
- General direction of groundwater flow

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Inventory of Shared Water Resources in Western Asia

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Introduction

LOCATION

The Coastal Aquifer Basin stretches along the Mediterranean coast from the foot of Mount Carmel in Israel, through the Palestinian Gaza Strip into the Sinai Peninsula in Egypt (see Overview Map). The Mediterranean coastline forms the natural western and northern boundaries of this aquifer. Inland, the aquifer thins out to the east and south.

The Coastal Aquifer is comparatively shallow, renewable and mainly unconfined. The basin's productive zone forms a narrow strip along the coast, with groundwater generally flowing from the hinterland towards the sea. Direct transboundary dynamics and interlinkages exist mainly in the central section of the aquifer, where the Gaza Strip is located in a groundwater flow position downstream of Israel and where lateral effects across the political borders may occur.[1] While providing general information on the Coastal Aquifer Basin as a whole wherever possible, this Inventory focuses on the section that lies in the Gaza Strip and nearby areas in Egypt and Israel.

AREA

In an all-inclusive approach, based on the overall extent of the aquiferous Pleistocene-Holocene deposits, the Coastal Aquifer Basin covers a total area of 18,370 km^2, of which around 71% lies in Egypt, 27% in Israel and 2% in Palestine, mainly in the Gaza Strip (see Overview Map).[2]

The majority of the literature on the Coastal Aquifer Basin focuses on the aquifer in Gaza and Israel, extending only marginally into Egypt. Therefore, estimates from the literature on the basin area are usually lower than in this Inventory.

From a transboundary perspective, a small sub-section is most relevant, comprising the Gaza Strip and adjacent areas in Egypt and Israel, whereby the hinterland is of particular importance. A more refined delineation of the shared aquifer section would require specific groundwater dynamics and flow pattern studies in this area, which were not available for this Inventory. Area estimates for the shared aquifer section are therefore not included.

Table 1. Geographic features of the Coastal Aquifer Basin

	EGYPT	PALESTINE	ISRAEL	TOTAL
Length (km)	200	40	150	390
Width (km)	40-130	7-12	12-45	7-130
Area (km^2)[a]	12,950	365 (Gaza Strip) 49 (West Bank)[c]	5,006	18,365
Population	395,000[b]	1,644,000[d]	3,816,000[e]	5,628,000
Population density (inhab./km^2)	31	4,504[f]	762	307

Source: Compiled by ESCWA-BGR.
(a) The basin outline in Israel and Gaza is based on Bartov, 1994.
(b) The population estimate for the area of the basin situated in Egypt is based on CAPMAS, 2012.
(c) According to the 1948 boundary, the map shows that the outcrop of the aquifer in the West Bank is 49 km^2 (Messerschmid, 2011).
(d) Projection for 2012 by PWA, 2012. The last population census in Gaza was carried out in 2007 and published by PCBS, 2012. It states a population of 1,416,966. The population estimate for the area of the basin situated in Israel is based on Central Bureau of Statistics in Israel, 2006; Central Bureau of Statistics in Israel, 2010.
(e) The population estimate for the area of the basin situated in Israel is based on Central Bureau of Statistics in Israel, 2006; Central Bureau of Statistics in Israel, 2010.
(f) Only the population in the Gaza Strip is included in the count based on data availability.

CLIMATE

Annual precipitation diminishes from north to south, with approximately 600 mm in central Israel and less than 50 mm in Egypt. Precipitation levels also gradually decline away from the coast. The Gaza Strip receives 200-400 mm/yr, with a mean value of 302-345 mm/yr.[3]

POPULATION

The total population in the Coastal Aquifer Basin is estimated at about 5.6 million, with about 3.8 million inhabitants in the Israeli part of the basin and 1.6 million in the Gaza Strip. The Egyptian part of the basin which is mostly made up of desert comprises 395,000 people. Population density in the Coastal Aquifer Basin varies immensely, with density rates in the Gaza Strip 145 times higher than in Egypt and nearly six times higher than in Israel (Table 1).

OTHER AQUIFERS IN THE AREA

The basin is surrounded by and partly in contact with deeper carbonate aquifers, such as the Eocene (Negev and Gaza) and the Cretaceous Mountain Aquifer (Mount Carmel, West Bank, Negev and part of Sinai. See Chap.19, Western Aquifer Basin).

While the hydraulic connections with the aquifers can be locally important, they are assumed to be insignificant at an overall, regional scale, particularly from the perspective of shared water resources. They are therefore not further explored in this Inventory.

An exception is the hydraulic connection with Eocene formations near Palestine (Gaza), which allows for lateral groundwater inflow into the Gaza Strip.

INFORMATION SOURCES

This chapter focuses on the parts of the Coastal Aquifer Basin that are located in Palestine (Gaza) and Israel and draws on data published in scientific studies, official government documents and organization reports as listed in the bibliography. Certain data was obtained directly through this Inventory's Country Consultation process.[4] Very little information was available for the part of the aquifer located in the Sinai Peninsula, and West Bank.

Agricultural fields near Tel Aviv, Israel, 2011. Source: Janie Easterman.

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

The Coastal Aquifer Basin is a shallow, mostly consolidated, alluvial aquifer system with soil, dune, sand or loess alluvial as a cover. It dips and drains towards the sea (Figure 1).[5]
The Pleistocene formations of the marine Kurkar A and continental Kurkar B are at an average depth of 50 m and 100 m respectively.

STRATIGRAPHY

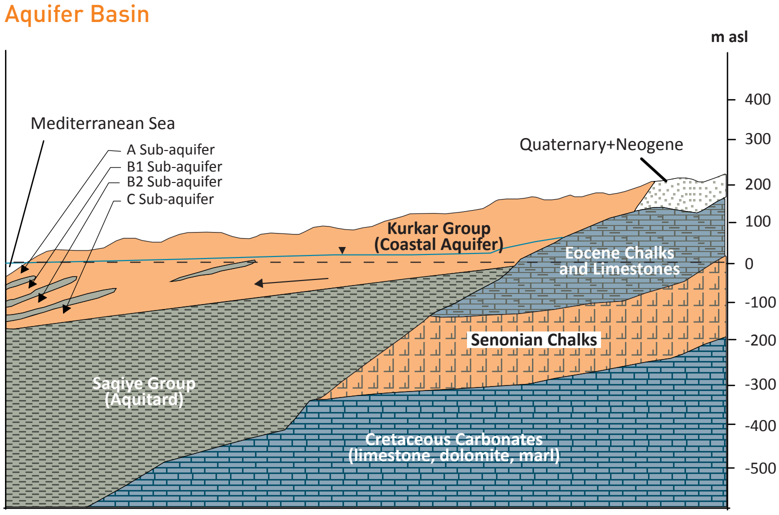
The aquifer formations are of Pleistocene and Holocene age, consisting of clastic series such as sandstone, dune sand, gravel and conglomerate with some top cover of loess and a marly bottom. Intermediate loamy and clayey "red bed" intercalations in the aquifer belong to the marine Kurkar A and continental Kurkar B Group.[6] They extend 2-5 km inland and divide the aquifer into four sub-aquifers, referred to as A, B1, B2 and C (Figure 1). Further inland, the clay layers thin out and the entire aquifer column forms one connected aquifer system.[7] The Pleistocene is mostly underlain by impermeable Neogene strata (Saqiye Group), but locally also by the Eocene, as is the case near the Gaza Strip (Table 2).

The lithology of the part of the aquifer basin situated in the Sinai Peninsula comprises coastal dunes and bars, fluviatile wadi deposits, calcarenites and shallow marine sands. The aquifer is considered to be more productive along the Sinai coast than further inland in Egypt[8] and the Kurkar A is often the most productive formation.[9] Locally, the main aquifer formations of the continental alluvial (gravel, sandstone and clay) Kurkar B and the marine Kurkar A sandstone are overlain by Holocene sand dunes.[10]

AQUIFER THICKNESS

Total aquifer thickness varies between 60 and 140 m. The aquifer thins out as it extends inland from the coast. The mostly unsaturated Holocene cover is typically less than 10 m thick, while the Kurkar B is 30-70 m thick. The Kurkar A is made up of 30-40 m thick sandstones, less than 10 m thick conglomerates and less than 10 m thick marls (Table 2). However, along the coast of the Sinai Peninsula, the aquifer's freshwater zone is limited to a thin layer of 2-5 m of saturated thickness.

Figure 1. Schematic hydrogeological cross-section of the Coastal Aquifer Basin



Source: Modified by ESCWA-BGR based on Greitzer,1967 in UNEP, 2009, p. 55.

Table 2. Lithostratigraphy of the Coastal Aquifer Basin

AGE	NAME	LITHOLOGY, ROCK FACIES	THICKNESS (m)[a]
Holocene	-	Sand and loess (dunes, soil alluvium)	0-10
Pleistocene	Kurkar B (continental)	Calcareous sandstone[b]	30-70
	Kurkar A (marine)	Shelly sandstone, with loamy, clayey "red beds"	30-40
		Conglomerates[c]	<10
		Marl	<10
Neogene	Saqiye	Shale, clay horizons	0-300
Eocene	Avedat	Limestone, evaporites	..

Source: Compiled by ESCWA-BGR based on Salem, 1963, p. 94-97; Gvirtzman, 2002, p. 63; CAMP and USAID, 2000; Vengosh et al., 2005, p. 4; HWE, 2010, p. 13; Mills and Shata, 1989, p. 789.
(a) HWE, 2010, p. 13-15.
(b) "Always cemented, very porous and friable", according to Salem, 1963, p. 94.
(c) Pliocene conglomerates and Mio-Pliocene dark grey marl (or marly shale) are not part of marine Kurkar A, according to Salem, 1963, p. 94.

AQUIFER TYPE

Near the coast, where intercalations with clay lenses occur, the upper sub-aquifer (A) is unconfined, whereas at deeper levels some confined parts (B and C) can be identified (Figure 1). Perched aquifers can also occur in the dune belts, but are only of very local importance.

Further inland, at a distance of 2-5 km from the coast, the clays thin out and the entire aquifer column forms one hydraulically connected, unconfined (phreatic) aquifer.[11]

AQUIFER PARAMETERS

Pump tests in 24 wells[12] in Gaza showed a transmissivity ranging between $2.0x10^{-3}$ and $6.9x10^{-2}$ m^2/s, with averages of $2.0x10^{-2}$-$2.3x10^{-2}$ m^2/s. Hydraulic conductivities range between 15 and 140 m/d, with averages of 50-60 m/d. Specific yields are estimated at 15%-30%.[13]

Sewage outflow on the Gaza coast, 2010. Source: Cara Flowers.

Hydrogeology - Groundwater

RECHARGE

The Coastal Aquifer is a shallow, renewable aquifer and natural groundwater recharge varies annually and seasonally according to distribution of rainfall and other factors. In Israel, the long-term average natural recharge from rainfall was estimated at 247 MCM/yr.[14] In the Gaza Strip, rainfall recharge estimates range from 35 to 48 MCM/yr, depending on the methodology used and the base year or period (Table 3). It is likely that the dense building fabric and spread of impervious surfaces in the highly urbanized Gaza Strip has dramatically reduced

Table 3. **Estimates of groundwater recharge and flow components in the Gaza Strip**

FLOW TYPE	ESTIMATE (MCM/yr)	SOURCE	COMMENT
Recharge from rain	45	CAMP and USAID, 2000.	From schematic flow chart.
	35	Vengosh et al., 2005.	Base year and method not specified.
	48.2	HWE, 2010, p. 24.	Maximum value.
	41	Aish, 2004.	Groundwater model, estimate for 2000.
	43	Baalousha, 2005.	Cumulative rainfall departure method, long-term average.
	37	CAMP and USAID, 2000 in Baalousha, 2005, p. 890.	Based on land use recharge coefficient.
	40-45		Groundwater model.
	40	Moe et al., 2001.	Groundwater model.
Infiltration from wastewater effluents, network losses, wells, reservoirs, agricultural return flows	54.2	HWE, 2010.	-
	52	Moe et al., 2001.	Estimate for 1998, a drier than average year.
	41.4	Aish, 2004.	-
Lateral inflow from the hinterland	37	Moe et al., 2001.	-
	51.8	Aish, 2004.	Estimate for 2000.
	10-15	Al-Yaqubi, 2006.	-
	20	Al-Yaqubi, 2010.	-
Seawater intrusion	7 (1935) 46 (2003)	Qahman and Larabi, 2006.	Estimates for 1935 and 2003.
Discharge to sea	55 (1935) 10 (2003)	Qahman and Larabi, 2006.	Estimates for 1935 and 2003.
	4.2	Aish, 2004.	Estimates for 2000.
	2	Al-Yaqubi, 2010.	-
Recharge from Wadi Gaza	1.5-2	Al-Yaqubi, 2006.	-
Groundwater deficit	31	Moe et al., 2001.	Estimates for 1998, a drier than average year.
	16	Aish, 2004.	Estimates for 2000.
	42	PWA, 2007 in Hamdan et al., 2011.	Estimates for 2006.

Source: Compiled by ESCWA-BGR.

recharge rates. Historic in-situ rain infiltration may have been 20% higher than today.[15] In the large, arid Sinai Peninsula, erratic rainfall and episodic infiltration from storm runoff results in a natural recharge of less than 100 MCM/yr,[16] with an annual average of 70-85 MCM.[17] Based on the above, total direct recharge to the Coastal Aquifer Basin from rainfall lies in the range of 350-375 MCM/yr.

Other reports that focus on the section of the Coastal Aquifer Basin in Palestine (Gaza) and Israel refer to an estimated total sustainable yield of 360-420 MCM/yr, of which 15% (approx. 55 MCM) are available in the Gaza Strip.[18] The values include lateral subsurface inflow of groundwater from the interior into the Gaza Strip (see section on Flow regime below), and possibly also limited recharge from Wadi Gaza (Box 1).

In addition, artificial recharge occurs from recharge reservoirs, infiltration and injection of wastewater effluents and agricultural return flows. Water inflows can be significant in densely populated areas such as the Gaza Strip and have a negative impact on water quality. Estimated at 40-55 MCM/yr, artificial recharge in the Gaza Strip exceeds freshwater recharge from rain (Table 3). In Israel, artificial recharge was estimated at 177 MCM for the hydrological year 2006/2007.[19] A large part of the water used in coastal areas in Israel was either imported from other basins and aquifer systems, or originated from desalination activities along the coast. Water from different sources also contributes to groundwater recharge.

FLOW REGIME

The Coastal Aquifer Basin is a shallow, renewable aquifer and groundwater flows vary annually and seasonally in quantity depending on distribution of rainfall, abstractions and other factors. The general flow in the Coastal Aquifer Basin follows the dip of the aquifer towards the coast. The western boundary of the aquifer follows the coastline where both outflows of freshwater to the sea and inflows (intrusion) of seawater occur. Heavy abstraction has led to local diversion of groundwater flow and disturbed the flow balance along the coast.

In the Gaza Strip, total annual aquifer outflow to the sea ranges between 2 and 10 MCM, while seawater intrusion has risen to 7-20 MCM/yr (Table 3).

BOX 1

Wadi Gaza Basin

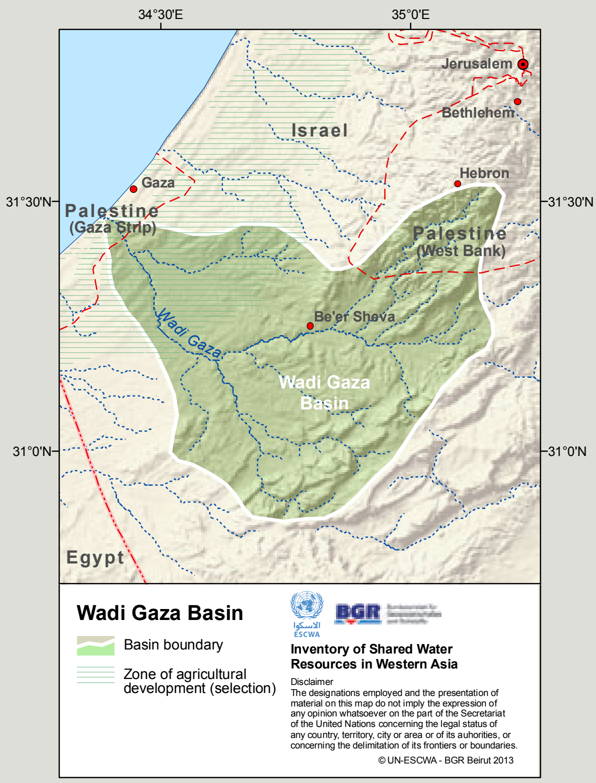
Known in Israel as the Besor River, Wadi Gaza originates from sources in the Hebron Mountains in the West Bank and the northern Negev in Israel, with Wadi Alshari'a and Wadi Shallala forming the main tributaries. The seasonal river flows westward from its source areas through the Negev Desert and into the Gaza Strip, where it feeds a small wetland at the wadi mouth and discharges into the Mediterranean Sea. Wadi Gaza has a total length of around 105 km and a catchment area of around 3,500 km^2.[a]

Wadi Gaza has a highly irregular flow pattern characteristic of seasonal rivers in arid to semi-arid climates with intense, short-lived storm floods. Most recently, torrential rains in January 2010 caused large-scale flooding along Wadi Gaza.[b] Overall discharge volumes may lie in the range of 5-30 MCM/yr,[c] with high inter-annual variability. In the past, Wadi Gaza flowed regularly for at least two months in winter.[d] Runoff in Wadi Gaza has changed over time due to the construction of dams and diversion schemes in Israel, which use almost all the river's water.[e] No data is available on historic recharge to the Coastal Aquifer Basin from Wadi Gaza. However, today it is estimated at less than 1.5-2 MCM/yr.[f]

Today, most of the water in the wadi depression in the Gaza Strip originates from the discharge of raw sewage, causing serious environmental problems and risks to public health.

(a) Laronne et al., 2004.
(b) IFRC-DREF Operation, 2010.
(c) Laronne et al., 2004, p. 9 mentions 5-10 MCM for the Besor Stream, Committee on Sustainable Water Supplies for the Middle East, 1999 mentions 15 MCM, MedWetCoast Project, 2001 quotes 20 MCM for 1994/1995, PWA, 2011b quotes 30 MCM.
(d) MedWetCoast Project, 2001, p. 18.
(e) PWA, 2011b, p. 17.
(f) Al-Yaqubi, 2006.

Figure 2. Wadi Gaza Basin



In Egypt and Israel, seawater intrusions amount to 2 MCM/yr[20] and 3 MCM/yr[21] respectively, but aquifer outflows are probably still greater than intrusions. In Israel, current aquifer outflows to the sea were estimated at 20-23 MCM/yr.[22]

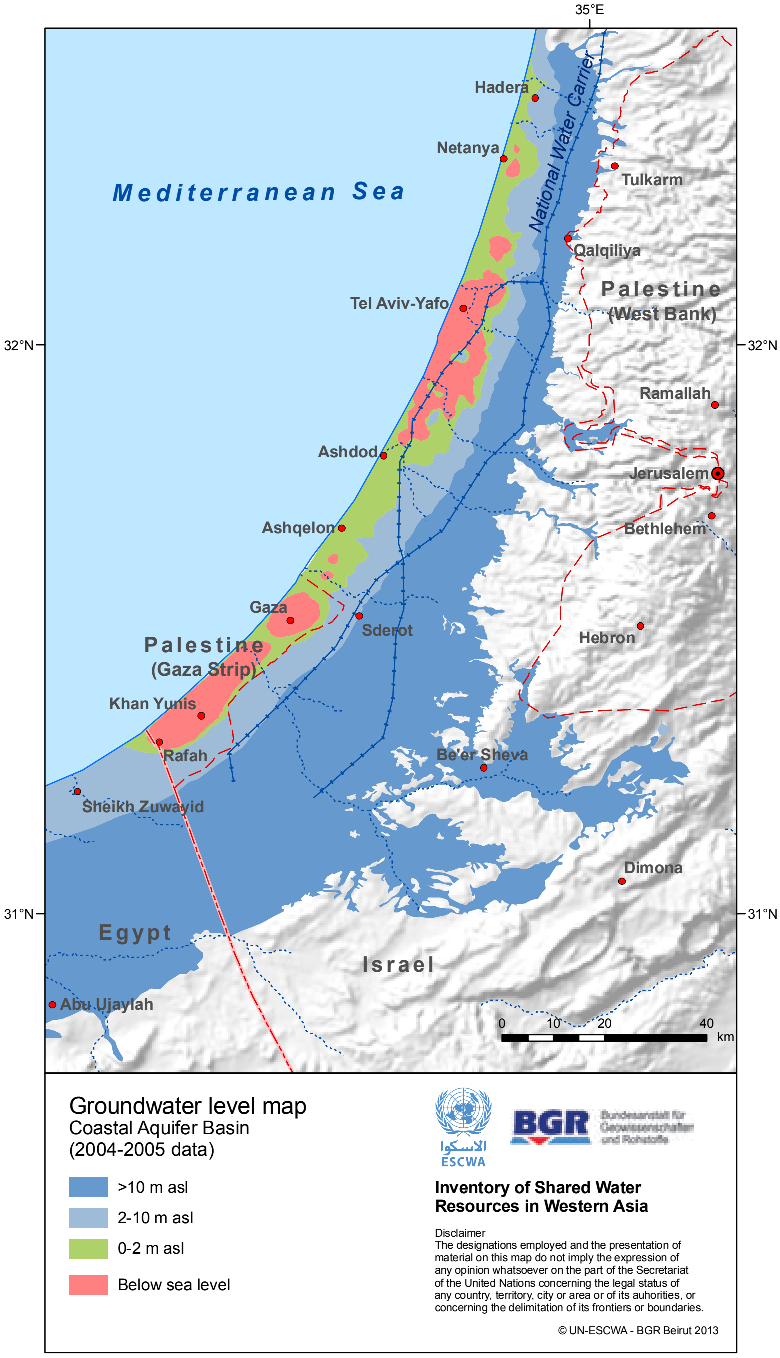
The southern foothills of Mount Carmel form the northern boundary of the Coastal Aquifer Basin, where lateral outflow into/from the shallow Carmel Coastal Aquifer may occur, depending on piezometric regimes of both aquifers. On the south-western edge of the Sinai Peninsula, the aquifer is bound by the highly productive intergranular aquifer that extends from the Nile Delta.[23] Possible flow linkages are mainly of local relevance, and are therefore not further explored in this Inventory.

The Gaza Strip lies downstream of Israel. Subsurface groundwater inflow from the interior in Israel forms an important component of the overall water balance of the Gaza Strip. In the south-eastern Gaza Strip, subsurface inflow from Israel originates from the salty Eocene Avedat Formation, contributing to natural salinization of the Coastal Aquifer.[24] Estimates for overall subsurface lateral inflow range from 10 to 52 MCM/yr (Table 3), presumably with a rising trend as over-abstraction in Gaza steepens the groundwater gradient towards the cones of depression. In recent years, Israel has drilled new wells to the north-east of the Gaza Strip.[25] However, no information could be found as to whether and to what extent pumping from the wells affects the lateral inflow and the water balance in the Gaza Strip.

Groundwater flow between Egypt and Gaza is assumed to be less than 5 MCM/yr.[26] The cones of depression caused by heavy groundwater abstraction in the southern Gaza Strip near Rafah and Khan Yunis extend across the south-western border of the Gaza Strip (Figure 3),[27] thus potentially accelerating groundwater inflow from Egypt. Flow from the Gaza Strip into Israel and from Israel to Egypt has not been reported, but is expected to be very limited.

Prior to the intensive development of the aquifer, groundwater in the Coastal Aquifer Basin was generally shallow and above sea level. Travelling away from the coast, water levels rose to over 20 m asl on the eastern edge of the aquifer and up to 50 m asl in the south-eastern corner of the basin near Be'er Sheva (Figure 3). Along the Sinai coast, water levels are less than 5 m asl,[28] with a depth to water of 15-30 m bgl. There are also some perched aquifers with water levels at 0-5 m bgl,[29] especially in the dune belts. Water levels have dropped considerably, however, as a result of over-abstraction (see section on groundwater use below).

Figure 3. Groundwater level map – Coastal Aquifer Basin



Source: Compiled by ESCWA-BGR based on HSI, 2006, p. 76; HWE, 2010, p. 43.

STORAGE

The Coastal Aquifer Basin is a shallow, renewable aquifer and storage estimates are rarely provided. Given that aquifer depletion from over-abstraction is partially compensated by intruding seawater, freshwater storage estimates depend on water quality and salinity criteria. Based on the World Health Organization drinking water standard for chloride (Cl^-) (<250mg/L), only 10% (450-600 MCM) of the aquifer below Gaza is considered freshwater storage.[30] The total storage volume of the part of the aquifer situated beneath Gaza would then be 4,500-6,000 MCM.[31] If a chloride concentration threshold of 500 mg/L is applied, freshwater storage increases to 1,400 MCM.[32] Across the Sinai Peninsula, recharge is limited and the total storage of brackish and saline groundwater was estimated at around 2,000 MCM,[33] including aquifers not directly linked to the Coastal Aquifer Basin.

DISCHARGE

No major springs discharge from the Coastal Aquifer Basin. Historically, almost all discharge flowed into the Mediterranean Sea through the subsurface, while water also evaporated from the large swamps in the Coastal Plain. Today, the wetlands have disappeared and sabkha conditions are only found in the northern Sinai Peninsula west of Arish. Discharge to the sea in the Gaza Strip has also been reduced from 55 MCM/yr in 1935[34] to less than 10 MCM/yr in 2003.[35] Today, seawater intrusion occurs in areas of high abstraction.

Small amounts of groundwater leak downward into deeper, underlying aquifers where direct contact exists (near Qalqiliya). Lateral discharge into the adjacent shallow Carmel Coastal Aquifer in the north may occur, but depends on the piezometric regimes of both aquifers.

WATER QUALITY

Rainwater recharge in the Coastal Aquifer Basin provides very freshwater with chloride concentrations below 200 mg/L. In the northern Negev in Israel and Sinai Peninsula, aquifer connections to saline groundwater pockets and deeper or adjacent salty aquifers cause chloride levels to rise above 1,000 mg/L. The south-eastern Gaza Strip also experiences lateral inflow of saline groundwater and upward leakage.[36] In addition, in the southern parts of the Coastal Plain in Israel and the Gaza Strip, salt levels have increased as a result of over-abstraction (Figure 6).

In the Sinai Peninsula, most of the groundwater in the littoral part of the Coastal Aquifer Basin remains brackish and saline with chloride levels at more than 2,000 mg/L. In the interior, in the shallow north and central Sinai aquifer, salinity ranges from 2,000 to 9,000 mg/L. A natural groundwater stratification of shallow, sweet water lenses[37] resting on a more saline groundwater body can be observed in the Sinai.[38]

EXPLOITABILITY

According to the standardized exclusion criteria used to assess exploitability in this Inventory,[39] the aquifer basin can be classified as theoretically exploitable across most of its extent, with the possible exception of the eastern, inland margin due to limited saturation and high salinities. More detailed studies of exploitability and productivity in this renewable and intensively developed aquifer basin are, however, available in the literature. In practice, the main productive zone of the aquifer is located in a small strip along the coast. High salinities, whether natural or as a result of over-abstraction, have hampered development of the aquifer in many parts of the basin.

Raw sewage flowing to the sea at Deir al Belah, 2009. Source: Olly Lambert.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

The shallow alluvial aquifer along the coast of Egypt and historic Palestine was easily accessible and the first wells in the area of the aquifer became operational in the late Ottoman period.

Egypt

There are about 1,800 wells in the Egyptian part of the aquifer basin, mainly situated in and around coastal cities in the Sinai Peninsula.[40] Annual abstraction from the alluvial aquifer in the north and central Sinai was estimated at 82.9 MCM in 2001, of which 72.3 MCM are abstracted in the coastal cities of Arish, Bir al Abd and Rafah.[41] Part of the abstractions are fresh and, for all of Sinai, 27.3 MCM/yr of brackish water (mostly 2,000-5,000 mg/L TDS) is abstracted.[42] An annual 1.2 MCM of brackish groundwater is desalinated in electro-dialysis plants at Arish[43] and in other Sinai cities.[44]

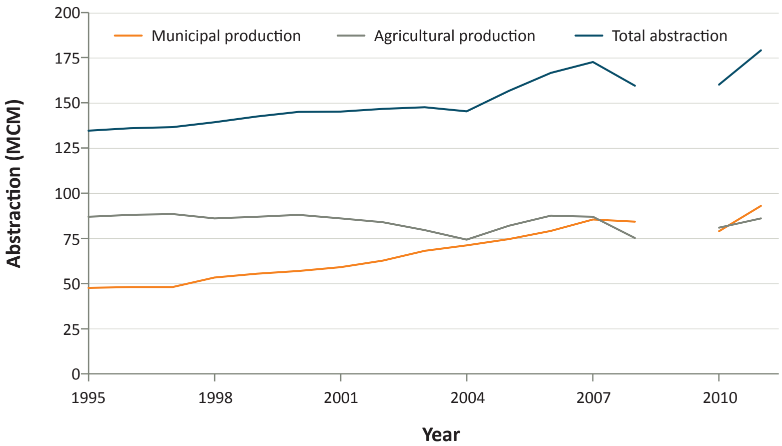
Although available data is incomplete, it appears that most groundwater abstractions in the Sinai Peninsula are used for domestic and industrial purposes (approx. 42 MCM/yr for each sector).[45]

Most of the large irrigation projects that are being developed in the region use water from outside the basin for agricultural development, with a pipeline from Port Said to Rafah providing 16.4 MCM/yr of water.[46] In addition, the partially completed Salam Canal[47] was designed to convey water from the Nile Basin to the Sinai Peninsula, mainly for irrigation purposes. In the long term, the projects aim to expand irrigated area in the Sinai Peninsula from the current 105,500 to 168,100 ha by 2017. However, water imports into the basin could also be used in the domestic sector, which would allow for a reduction in groundwater abstractions.

Israel

Israel has over 1,500 wells in the Coastal Aquifer Basin with a total annual abstraction of 443 MCM in 2006/2007, of which about 45% (200 MCM) was used for agriculture and about 55% (243 MCM) for domestic and industrial purposes.[48] In 2009, Israel expanded its groundwater abstractions by roughly 10% with some 40 MCM/yr drawn from 35 new bore-holes in the area north-east of the Gaza Strip near Ashdod and Sderot.[49]

Figure 4. Groundwater abstractions from the Coastal Aquifer Basin in the Gaza Strip (1995-2011)



Source: Compiled by ESCWA-BGR based on PWA, 2012.

Israel imports significant quantities of water to the coastal region from various sources, including the Upper Jordan River (380 MCM/yr),[50] other aquifers such as the Western Aquifer Basin (402 MCM/yr),[51] and desalinated seawater, which is used in all sectors. Desalination projects are expected to provide 650 MCM/yr of Israel's water supply by 2020. Desalinated seawater is also used for irrigation in the Negev Desert.[52]

Palestine (Gaza Strip)

The development of the Coastal Aquifer in Gaza gained momentum in the early 1930s as a result of increased demands from a growing population and the intensification of irrigated agriculture.[53] By 1943, 76 wells had been drilled in the area that today comprises the Gaza Strip.[54] Abstraction rates have increased dramatically over the last 70 years due to high population growth and the drilling of numerous unlicensed agricultural wells.[55] This also includes abstractions by Israel through its settlements, present until 2005 in the Gaza Strip. At present, there are about 1,750 licensed agricultural wells and 217 licensed domestic wells. In addition, there are about 2,700 unlicensed but registered wells and an estimated 2,000 unregistered and unlicensed wells in the Gaza Strip, most of which are used for agricultural purposes. For the period 1995-2011 alone, total annual abstractions increased more than 30%, from around 135 MCM to nearly 180 MCM, mainly due to growing municipal demand (Figure 4).[56]

In 2010, the total agricultural area in the Gaza Strip covered around 10,191 ha, of which 7,524 ha were cultivated and 1,889 ha were under temporary fallow.[57] Fruit trees and vegetables were the dominant crops, covering around 40% and 26% of the agricultural lands respectively.

Unlike the other riparian countries, the Gaza Strip does not have access to water from other sources. Currently the only water transfer into the Gaza Strip is the 4-5 MCM/yr bought from the Israeli water company Mekorot.[58]

Impact on water levels

More than 95% of all wells in the Coastal Aquifer Basin abstract water from the Kurkar A aquifer unit. The water balance in the Coastal Aquifer Basin varies per year and also depends on location, rainfall and abstractions, but a continuous decline in water levels and seawater intrusion along the coast suggest that the three riparians generally abstract water at a rate higher than recharge and that the aquifer is being depleted. In the Gaza Strip, the deficit has been estimated at 16-42 MCM/yr (Table 3).

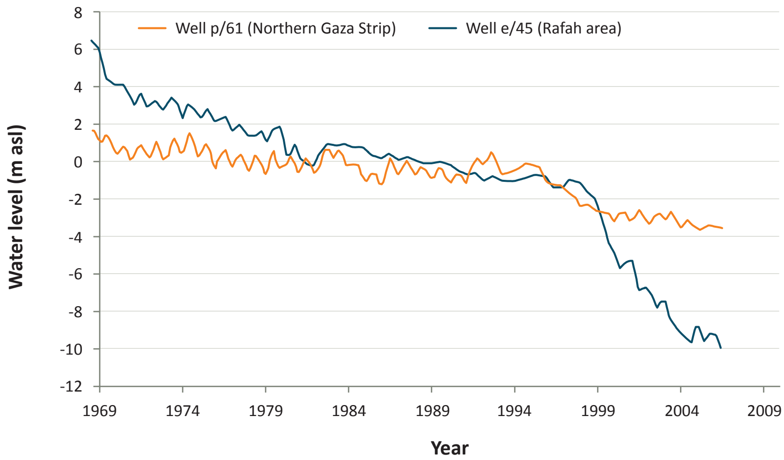
The deepest cones of depression are found near large population centres such as Arish and Rafah in Egypt, Tel Aviv-Yafo in Israel,[59] and most of the Gaza Strip (Figure 3). In the Egyptian town of Rafah, water levels have dropped by up to 5 m since 1984.[60] In Arish, water levels have dropped 2-6 m in the 30 years after 1962.[61] The shallow freshwater lenses are rapidly being depleted. Most dramatically, in the Gaza Strip water levels have been dropping at rates of up to 1 m/yr and water levels in many areas now lie near or below sea level. In the northern Gaza Strip, groundwater levels have dropped by about 5 m in the period 1969-2007, while a drop of over 15 m was observed in the Rafah area in the southern Gaza Strip, with a clear acceleration from 1998 onward (Figure 5). Locally, the decline of groundwater tables may reach more than 15 m bsl, and many shallow wells have dried up, especially in the southern part of the Gaza Strip, while other wells show a decrease in bore-hole yields.[62] This has led to seawater intrusion and an increase in brackish groundwater inflow from the east, south-east and from Sinai.[63]

Current trends include decreases in natural recharge due to urbanization and increases in mostly contaminated return flows from agriculture and sewage. Those conditions increase the long-term sustainability challenges with regard to water quantity and quality.

GROUNDWATER QUALITY ISSUES

Groundwater salinization has long been an issue of concern throughout the Coastal Aquifer Basin. Nowadays, anthropogenic pollution and over-abstraction have worsened salinization and affected groundwater quality in several respects. Four main factors contribute to the deterioration of groundwater in the basin:

Figure 5. Groundwater levels in two wells in the Gaza Strip



Source: Compiled by ESCWA-BGR based on PWA, 2012.

(1) **Seawater intrusion:** Seawater intrusion occurs in the vicinity of large cones of piezometric depression resulting from groundwater abstractions (Figure 3). In Gaza, two major cones/zones of depression exist, which have increased in size, extended towards each other and may soon join, thus providing conditions for seawater intrusion all along the coast. Currently, total seawater intrusion[64] still lies below natural lateral saline groundwater inflows, but already affects the overall quality of many drinking water wells, together with other sources of pollution. Israeli wells further inland are less prone to seawater intrusion, with a net outflow of 20-23 MCM/yr[65] of groundwater from the Coastal Aquifer Basin to the sea occurring in the Israeli part of the basin. In the Sinai Peninsula, groundwater levels have also dropped below sea level in the vicinity of major population centres like Arish and Rafah. Seawater intrusion is, however, partly prevented by the infiltration of wastewater and agricultural return flows, which creates local groundwater highs.[66]

(2) **Lateral Inflow of saline groundwater:** The water in the hinterland of the Coastal Aquifer Basin is generally more saline. In Israel, lateral hydraulic connections to older saline groundwater exist in the hinterland. As the salt front has moved from inland areas towards the coast, salinity has increased considerably over the past 70 years (Figure 6). In the Gaza Strip, inflow of natural brackish groundwater from the east and south-east is significant and affects most areas.[67] Israeli abstractions east of Gaza are likely to intercept part of the lateral groundwater inflow, but it is not clear to what extent it will affect salinity levels inside the Gaza Strip. In the Sinai Peninsula, it can be assumed that there are connections between the Coastal

Aquifer Basin and brackish/salty groundwater in the hinterland. Some upward leakage along fault lines from the more saline Lower Cretaceous Kurnub Sandstone Aquifer has been suggested.[68]

(3) **Upconing of deeper saline water:** This phenomenon, which is closely related to abstraction rates, occurs in the Sinai Peninsula, where thin freshwater lenses occur above saline layers within the same aquifer formation. In 1961, the TDS level in wells in this area was 2,000 mg/L. Over the following 20 years the level doubled and continues to rise. In Gaza, upconing occurs in the deeper wells that tap sub-units B and C as shown in Figure 1.[69]

(4) **Infiltration of sewage effluents and agricultural return flows:** As the unsaturated zone above the water table is permeable and just a few metres thick throughout the Coastal Aquifer Basin, it provides only limited protection from pollution.

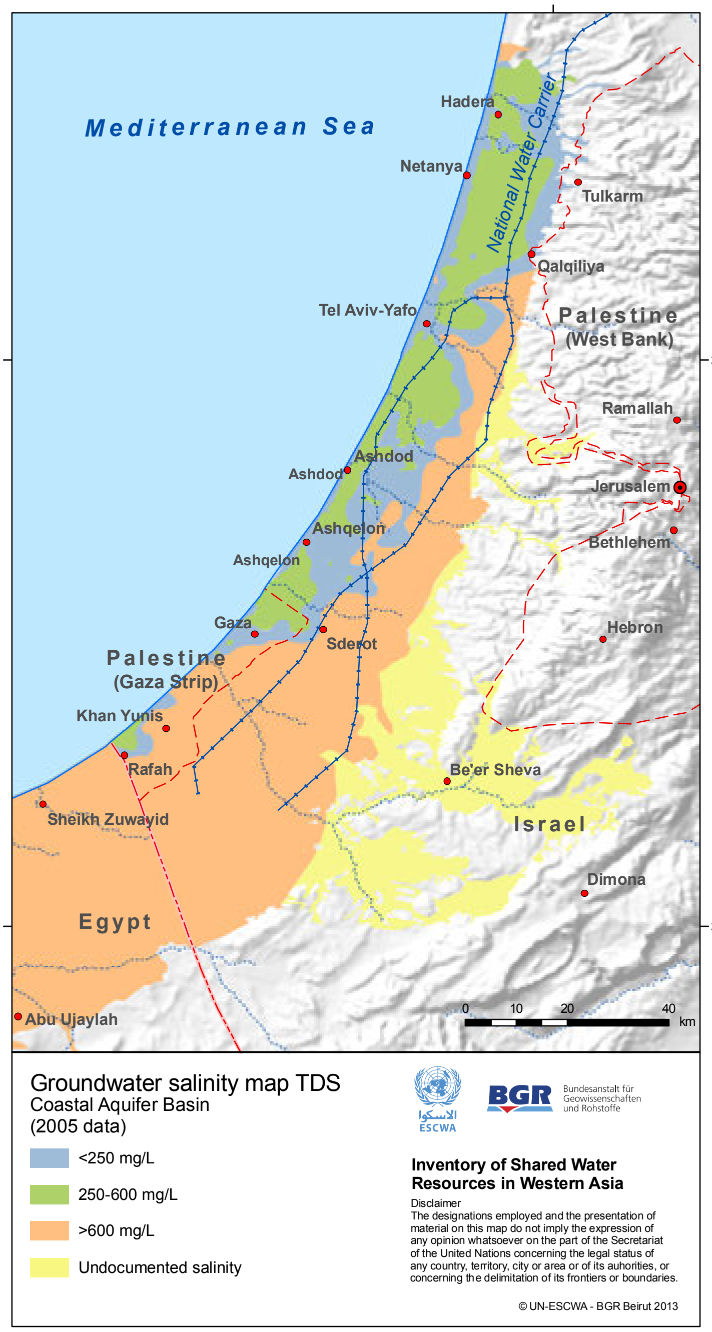
In the Egyptian part of the basin, public health has already been affected and diseases such as hepatitis, diarrhoea, dysentery, kidney diseases and blue baby syndrome have been reported in Arish and Rafah.[70] The completion of the Salam Canal and the implementation of related large-scale irrigation schemes are expected to trigger considerable population growth and an increase in economic activity, which may in turn exacerbate the pollution problem. In particular, return flows from large-scale irrigation may harm groundwater quality. Due to the relatively saline mix of Nile water with drainage return flows, leaching requirements will be substantial.[71]

In Israel, leachate from non-point urban pollution or industrial waste and agricultural return flows has infiltrated into the basin for decades, which has seriously affected groundwater quality and led to the relocation or abandoning of many wells. Furthermore, as much of the contamination is located in the unsaturated zone and migrates slowly downwards, current pollution has not yet fully impacted the aquifer.[72] Israel has started to address the contamination through the introduction of wastewater treatment plants and environmental legislation, and by cleaning up rivers and wadis.

The water quality situation is the worst in Gaza. Besides the lateral inflow of saline groundwater and seawater, the principle source of pollution is poorly treated or raw sewage (Table 3). About 78% of Gaza households are connected to a sewage network,[73] but as most treatment plants are currently not or only partly functional, only small amounts of sewage are be treated. As a result, wastewater is discharged into wastewater lagoons, wadis, open cesspits or directly into the Mediterranean Sea.[74] Agricultural fertilizers and leachate from solid waste disposal sites further contribute to the deterioration of groundwater quality.[75]

As a consequence, over 90% of the groundwater in Gaza is unfit for domestic use according to internationally accepted guidelines.[76] Chloride levels are mostly above the World Health Organization permissible maximum of 250 mg/L. In addition, high nitrate (NO_3^-) levels above 50 mg/L are found in many wells throughout the Gaza Strip,[77] while TDS values may reach up to 5,000 mg/L.[78] Given that the Gaza Strip covers a small surface area and has

Figure 6. Groundwater salinity map – Coastal Aquifer Basin



Source: Compiled by ESCWA-BGR based on HSI, 2006 (by-map); assumptions for Sinai based on Vengosh et al., 2005; Allam et al., 2002; Ministry of Water Resources and Irrigation in Egypt, 2005b; Mills and Shata, 1989.

a high population density, it is not an option to close or relocate wells as in Israel.

More than three quarters of the households in the Gaza Strip (83%) buy their water from unregulated private water vendors, who distribute water in tankers or jerry cans.[79] Poverty has forced many more people to drink water from private and agricultural wells that are polluted by agricultural runoff and wastewater seepage.[80] Water-borne diseases caused by the lack of clean drinking water are on the rise, including diarrhoea, hepatitis A, typhoid fever, paratyphoid, and gastro-enteritis. High salinities in drinking water are also a major cause of kidney problems. An estimated 26% of diseases in Gaza are water related, with children being among the most vulnerable.[81]

SUSTAINABILITY ISSUES

Continued over-abstraction forms a threat throughout the Coastal Aquifer Basin, with seawater intrusion and infiltration of agricultural runoff and untreated wastewater posing an ongoing threat to the future of the aquifer basin in Egypt, the Gaza Strip and Israel.

Overall, the sustainability of the Coastal Aquifer Basin is most threatened in the Gaza Strip, where high population growth and density drive sustained over-abstraction from the aquifer. The absence of alternative sources of water supply in the Gaza Strip further complicates the situation. Rainfall and lateral groundwater inflow constitute the main freshwater input to the Gaza water budget. Common estimates of total renewable freshwater resources suggest an annual availability of 50-80 MCM/yr.[82] This corresponds to an annual per capita availability of 31 m^3, which is less than a tenth of the threshold for severe water scarcity (500 m^3/yr).[83] Even under the theoretic assumption that the entire volume of rainfall would be available for human use and that high levels of fresh lateral groundwater inflow occurred, Gaza's renewable total freshwater resources would not exceed 160 MCM/yr.[84] This would correspond to an annual per capita availability of 100 m^3, which is a fifth of the threshold for severe water scarcity.

Projections to 2020 estimate that domestic water use in Gaza will rise to between 110[85] and 170 MCM/yr,[86] while agricultural water use will increase from 73.7 to 88 MCM/yr.[87] In view of the sustained population growth, per capita freshwater availability will further decline and the stress on the aquifer will rise. Already now, total groundwater abstractions are higher than the long-term sustainable yield, leading to accelerated aquifer depletion and salinization. Additionally, since 2009, Israel intercepts groundwater flow before it enters Gaza, which may increase water shortage there. All of the above has sparked growing concerns about the eventual collapse of the aquifer, which would make all of Gaza's groundwater unfit for domestic or agricultural use.

Domestic water use in the Sinai Peninsula and Israel is also projected to increase.[88] Given that the Coastal Aquifer Basin is already over-used, increasing demand can only be met by water imports or the introduction of non-conventional water sources, such as desalination.

Egypt and Israel perform large-scale water transfers into the Coastal Aquifer Basin, with varying impacts on the aquifer basin.

The Egyptian Government plans to convey about 2,800 MCM/yr to the Sinai Peninsula through the Salam Canal, but it is not clear whether this will lead to a reduction in groundwater abstractions from the shallow coastal aquifers. Israel transfers an annual 700-900 MCM of water to the Coastal Plain from the Jordan River Basin and the Western Aquifer Basin.

Palestinians in the Gaza Strip currently cannot rely on such inter-basin transfers. Plans for the construction of a north-south Water Carrier from Israel into Gaza, or from Egypt into Gaza via the Salam Canal have not materialized due to budget constraints, Israeli sanctions and other political issues.[89]

Seawater desalination is considered an option to alleviate water stress and increase water supply in all three riparian areas. Israel plans to desalinate around 650 MCM/yr by 2020,[90] while Egypt plans to desalinate 1.8-3.7 MCM/yr.[91] Desalination in the Gaza Strip is currently still very limited but is expected to increase significantly in the coming years. In 2011, the European Union announced its support for the construction of a short-term low-volume desalination plant to supply 75,000 people in the Khan Yunis and Rafah Governorates.[92] The Union for the Mediterranean has also announced its support for a large desalination plant for Gaza with a capacity of 100 MCM/yr, but funding for this project has not been secured.[93] In the meantime, small-scale desalination, mainly of brackish water by private water vendors (around 40 plants, estimated production of around $7x10^{-1}$ MCM/yr) and at the household level (possibly up to 20,000 home plants) forms a temporary solution,[94] producing a total of around 4-5 MCM/yr.[95]

Agreements, Cooperation & Outlook

AGREEMENTS

Riparian cooperation on water resources management in the Coastal Aquifer Basin is inextricably linked to the Israeli-Palestinian conflict. There is no basin-wide agreement in place for the aquifer basin as a whole, which is shared between Egypt, Israel and Palestine.

However, Israel and the Palestine Liberation Organization (PLO) have signed two bilateral agreements regarding the use, protection and allocation of water resources in the Coastal Aquifer Basin. Officially referred to as the Declaration of Principles on Interim Self-Government Arrangements (DOP), the 1993 Oslo Accords between Israel and PLO were the result of extensive negotiations in the aftermath of the Madrid Conference.[96] The agreement dedicated a short paragraph to water, outlining principles of cooperation, joint management, water rights and equitable use.[97]

The Oslo Accords were followed in 1995 by the Israeli-Palestinian Interim Agreement on the West Bank and the Gaza Strip or Oslo II, which addressed the topic of water and sewage in Article 40 of the Protocol on Civil Affairs (Annex 3). The agreement was intended to cover the five-year period from 1995 to 1999. In addition to detailing other aspects of water resources management in the West Bank and Gaza Strip,[98] Oslo II stipulated a water transfer of 5 MCM/yr from Israel to the Gaza Strip.

Since then, final status negotiations and agreements have stalled and the various high-level multilateral summits and conferences[99] have not addressed joint management of the Coastal Aquifer Basin. Since the Israeli withdrawal from the Gaza Strip in 2005 and in light of ongoing political tension and violent conflict between Israel and Palestine, the Oslo agreement and other provisions regarding water supply, the building of infrastructure and data sharing have been neglected.

Recent official reports from Israel exclude the Gaza Strip from maps of the Coastal Aquifer Basin.[100] This may indicate that Israel no longer considers the aquifer shared, an argument which is also being developed in recent regional research.[101] Such a position would represent a clear shift away from the Oslo Accords,[102] as well as Israel's own long-standing practice[103] and considerable amounts of Israeli and international scientific literature, which consider the basin a shared water resource.[104]

COOPERATION

The three riparian countries do not cooperate over any aspect of water management or use. Israel exercised control over water resources in the Gaza Strip between 1967 and 2005 and applied Israeli water law in the territory. Palestinians in the Gaza Strip had to secure Israel's permission to build wells, networks, pumping stations and treatment plants. Today, major water and sewage projects still require Israeli de facto approval due to the restrictions on the importation of material to the Gaza Strip. Israel did not develop water infrastructure for the Palestinian population in the Gaza Strip and focused its attention on water supply development for Israeli settlements.

After the outbreak of the Second Intifada in September 2000, Israel destroyed thousands of Palestinian wells throughout the Gaza Strip.[105] When Israel withdrew from the Gaza Strip in 2005, it did not sign any cooperation agreements with the Palestinian Authority. Most of the water infrastructure left behind by the departing settlers was damaged before the Palestinian Water Authority (PWA) could establish control.

Since then, PWA has been negotiating an increase in the water transfer from Israel to the Gaza Strip. This would require the construction of a north-south water carrier in the Gaza Strip, which has been hampered by Israel's blockade of Gaza and the heavy restrictions on the import of construction materials. Other details of the water transfer, such as the type to be delivered (desalinated or blue water) and the cost, remain unclear.

There is no information on Egyptian plans to develop a strategy for shared water resources management with Israel or Palestine.

OUTLOOK

Political constraints currently make riparian cooperation over water resources in the Coastal Aquifer Basin unlikely, particularly between Israel and Palestine. Instead, the three riparians will probably continue implementing unilateral water management strategies for the foreseeable future.

Egypt continues to develop the northern Sinai Peninsula through the implementation of large-scale inter-basin water transfers.

Israel relies on seawater desalination and inter-basin transfer to supply water to the Coastal Plain[106] and has not addressed shared management of the Coastal Aquifer Basin. In the context of future negotiations towards a final status agreement, it has proposed land swap deals to compensate Palestinian loss of land in the West Bank as a result of settlement activity.[107] Under such a deal, Israel would maintain control over annexed land in the West Bank, while Palestine would receive territory along the south-eastern border of the Gaza Strip in exchange. However, groundwater in this region is mainly brackish or saline.

Palestinians in Gaza have little room to implement unilateral development of their water supply in a sustainable manner. In order to avert further degradation of the aquifer, Gaza would have to ban all agricultural groundwater abstractions. That is not a viable option under the current circumstances as Gaza's economy lacks alternatives to agriculture, and industrial production has sharply declined under the Israeli blockade. In addition, a further reduction of domestic supply, which already lies below minimum acceptable levels, is not feasible. Theoretically, there are four options available to Palestinians in the Gaza Strip:

- Water transfer from the West Bank.
- Increased water transfer from Israel.
- Transfer from Egypt through the Salam Canal.
- Seawater desalination.

In practice, PWA continues to seek an increase in water allocations from Israel. It is also working with international organizations, including the European Union and the Union for the Mediterranean, to finance and construct a number of desalination plants.

In conclusion, it is clear that closer riparian cooperation is needed to protect water resources in the Coastal Aquifer Basin from over-abstraction and pollution, particularly in the Gaza Strip. However, in the short term, such cooperation is unlikely to materialize, and the sustainability of the Coastal Aquifer Basin will remain at risk.

The Gaza coast, Palestine, 2009. Source: Stuart Reigeluth.

Notes

1. Groundwater in the shallow, renewable and narrow Coastal Aquifer Basin does not drain to one outlet but generally discharges to the sea along the entire length of the aquifer. Impacts of groundwater abstraction or other management measures are felt predominantly along groundwater flow lines, i.e. from the hinterland towards the coast. Lateral impacts, perpendicular to flow lines and in a south-west/north-east direction along the coast are probably limited in horizontal range.
2. All area figures from GIS calculations are based on the Overview Map. An area of 49 km^2 in the basin lies in the West Bank.
3. Qahman et al., 2011 gives a range of 302-333 mm/yr depending on method; Abu-Maila and Abu-Maila, 1991 estimates 306 mm/yr; Hallaq and Elaish, 2008 gives a range of 335-345 mm/yr.
4. Groundwater level data for selected wells.
5. As Figure 2 shows, the upper sub-aquifer (A) is unconfined, whereas at deeper levels, some confined sub-horizons (B and C) can be identified, especially near the coast. In the hinterland, all aquifer sub-units are connected.
6. The facies name "Kurkar" is used in Israel and Egypt. Israeli authors sometimes also apply it to the Gaza Strip.
7. HWE, 2010, p. 14.
8. Ministry of Water Resources and Irrigation in Egypt, 2001, p. 32.
9. HWE, 2010.
10. Sometimes the Holocene strata bear another shallow perched sub-aquifer unit, such as in Al Mawasi in the southern Gaza Strip.
11. HWE, 2010, p. 14.
12. CAMP and USAID, 2000 in HWE, 2010, p. 15, Table 3.1.
13. HWE, 2010, p. 15, Table 3.2.
14. Average for the period 1971-2007 (HSI, 2008, p. 108), partly accounting for an estimated 70-150 MCM/yr of loss in infiltration due to urbanization (Shamir and Carmon, 1999, p. 409).
15. On the one hand, approximately 20% of Gaza is covered with impervious surfaces or building fabric, which has reduced infiltration. On the other hand, irrigation return flows have increased with the intensification of agriculture in recent decades.
16. Ministry of Water Resources and Irrigation in Egypt, 2001, p. 33.
17. MWRI 2001 states that current annual abstractions of 83 MCM (of which 72 MCM takes place in coastal cities) are near the "limit" of the aquifer. Overall return flows are probably negligible due to the low population density.
18. The values are referred to in World Bank, 2009, p. 27 (total value and 15% share) and PWA, 2011b, p. 3 (55 MCM) but original sources are not given; Al-Yaqubi, 2006 estimates combined freshwater recharge in the Gaza Strip at 57-62 MCM/yr.
19. HSI, 2008. This includes 31 MCM from agricultural return flow.
20. Ministry of Water Resources and Irrigation in Egypt, 2001.
21. HSI, 2008, p. 107-110.
22. HSI, 2008, p. 107-110 calculated 23 MCM; Livshitz and Issar, 2010 state an outflow of 20 MCM.
23. BGS and MacDonald, 2010.
24. Vengosh et al., 2005; Weinthal et al., 2005.
25. In 2009, it was estimated that 40 MCM was abstracted from around 35 additional wells (Haaretz, 2009).
26. This assumption is based on water level maps and declines in water levels on both sides of the Rafah border between Egypt and Gaza (Geriesh et al., 2004, p. 44-45; Al-Yaqubi, 2010).
27. Simulated groundwater level maps for the Gaza Strip in HWE, 2010, p. 43-44 for different years in the period 2000-2008 show the expansion and deepening of the cones of depression in Gaza, especially in the south-western part. The simulated depression clearly extends into Egypt.
28. Allam et al., 2002, p. 21, Table 1.
29. Such as in the dune belt near Al Mawasi in the southern Gaza Strip, see HWE, 2010, p. 106.
30. Moe et al., 2001.
31. Al-Yaqubi, 2006 quotes total storage of 5,000 MCM.
32. Al-Yaqubi, 2006.
33. Allam et al., 2002, p. 22.
34. Qahman and Larabi, 2006. The value is close to later estimates of sustainable yield.
35. Qahman and Larabi, 2006 state 10 MCM for the year 2003. Aish, 2004 estimates 4.2 MCM.
36. The isotopic fingerprint of the brackish water in the south-eastern Gaza Strip is clearly different than that of Mediterranean seawater, including higher boron (B) levels, as shown by Vengosh et al., 2005, p. 18.
37. Pumped at only 2 MCM/yr (Allam et al., 2002, p. 20).
38. Ministry of Water Resources and Irrigation in Egypt, 2005a.
39. The following criteria are used to assess exploitability in this Inventory: drilling depth/depth to top of aquifer; groundwater level; and water quality/salinity. For more information on the approach, see 'Overview & Methodology: Groundwater' chapter. See Figure 3 for information on groundwater levels and Figure 6 for information on water quality. Drilling depth is not a limiting factor in this shallow aquifer.
40. Ministry of Water Resources and Irrigation in Egypt, 2001, p. 31.
41. Ibid.
42. Abou-Rayan et al., 2001, p. 5. This includes all coastal aquifers in Sinai, along the Mediterranean and Red Sea coasts with a total area of 20,000 km^2.
43. Ministry of Water Resources and Irrigation in Egypt, 2001, p. 34, Table 15.
44. Allam et al., 2002, p. 22.
45. Ministry of Water Resources and Irrigation in Egypt, 2005a.
46. The 158 km pipeline (700 mm diameter) was built in 1986 and provides water to Arish, Bir al Abd, Bir er Rumana, Rafah and Sheikh Zuwayid, with a total capacity of 45,000 m^3/d (Abou-Rayan et al., 2001; Ministry of Water Resources and Irrigation in Egypt, 2001).
47. Construction of the canal began in 1997 and brings water from the Damietta Branch of the Nile, under the Suez Canal to the Sinai Peninsula (Egypt Independent, 2012). It was designed to provide 4.45 BCM of Nile water mixed with agricultural drainage water in order to reclaim and cultivate 260,000 ha (Yehia and Sabae, 2011; Abou-Rayan et al., 2001). To date, it has reached a little further than the region of Bir al Abd (based on Google Earth observations) and 76,000 ha have been reclaimed (Ministry of Water Resources and Irrigation in Egypt,

2009). Upon completion, the Salam Canal is expected to stretch to Arish (Ministry of Water Resources and Irrigation in Egypt, 2005a).

48. HSI, 2008, p. 107-110.
49. This groundwater is brackish and needs to be desalinated before it can be used as drinking water, according to Haaretz, 2009, p. 1.
50. Gvirtzman, 2002, p. 35, Fig. 3.3. Israel transfers water out of the Jordan River Basin to the coastal region and the Negev Desert through the National Water Carrier, a 200 km conduit originates from Lake Tiberias (see Overview Map). See Chap. 6 for more information.
51. HSI, 2008, p. 221.
52. Yermiyahu et al., 2007.
53. G.S.I.H.Q. Palestine, 1943, p. 46-93; Messerschmid, 2008, p. 5.
54. G.S.I.H.Q. Palestine, 1943, p. 46-93.
55. PWA, 2011b, p. 3.
56. PWA, 2012. Another estimate from 2010 showed similar results, with about 4,600 wells abstracting around 80 MCM/yr for agricultural use and an additional 197 wells abstracting about 94.2 MCM/yr for domestic and industrial use, according to HWE, 2010, p. 42.
57. All figures in this paragraph from PCBS, 2011; World Bank, 2009, p. 31 estimates total irrigated area at 8,200 ha.
58. PWA, 2010, p. 9.
59. This has been a problem for decades. In 1958, water levels already reached 10 m bsl (Gvirtzman, 2002, p. 69).
60. Geriesh et al., 2004 predicted another two-metre drop.
61. Ghodeif and Geriesh, 2003, p. 192.
62. PWA, 2012.
63. Al-Yaqubi, 2010 estimates brackish groundwater inflow at 1-5 MCM.
64. Al-Yaqubi, 2010 estimated a rate of 20 MCM/yr.
65. HSI, 2008, p. 107-110 calculated 23 MCM; Livshitz and Issar, 2010 state an outflow of 20 MCM.
66. Ghodeif and Geriesh, 2003, p. 198.
67. Vengosh et al., 2005, p. 1-2.; Weinthal et al., 2005.
68. Mills and Shata, 1989, p. 801.
69. HWE, 2010, p. 1-3.
70. Ghodeif and Geriesh, 2003, p. 7; Allam et al., 2002, p. 20.
71. Ministry of Water Resources and Irrigation in Egypt, 2005a, p. 108.
72. HSI, 2008, p. 115.
73. PCBS, 2012.
74. World Bank, 2009, p. 30-31: an estimated 70,000-80,000 m^3 or 50% of total wastewater is discharged to the sea.
75. UNEP, 2009, p. 19, 82.
76. ECHO, 2010; PWA, 2011b.
77. PWA, 2011b, p. 5-7.
78. PWA, 2012; PWA, 2011b.
79. UNICEF and PHG, 2010, p. 15.
80. Ibid., p.26.
81. World Bank, 2009, p. 30; UNICEF, 2011 in PWA, 2011b.
82. Including aquifer recharge from rain and lateral inflow according to Table 3. Green water is not considered in this estimate.
83. According to Falkenmark, 1989.
84. This is based on an estimated total rainfall volume of 120 MCM/yr (around 330 mm) and lateral inflow of 40 MCM/yr.
85. PWA, 2010, p. 16.
86. PWA, 2012.
87. PWA, 2010, p. 17.
88. For Israel compare IWA, 2002; for Egypt/Sinai compare to Ministry of Water Resources and Irrigation in Egypt, 2001; Ministry of Water Resources and Irrigation in Egypt, 2005b.
89. PWA, 2012.
90. Dreizin et al., 2008.
91. Allam et al., 2002, p. 24.
92. EWASH, 2011.
93. UfM, 2011; PWA, 2011a.
94. World Bank, 2009, p. 28.
95. Estimate according to PWA, 2012.
96. The Madrid Conference, which was held in Spain in October 1991, was led by the United States of America and jointly sponsored by the Soviet Union. Its aim was to initiate a negotiated peace process involving Israel and Palestinians, as well as other Arab countries, including Jordan, Lebanon and Syria. The conference comprised negotiations on various issues, including shared water resources and is considered the catalyst for the later Oslo Accords (Hiro, 2003; MERIP, 2012).
97. Israel and the PLO, 1993, Annex III, partly focuses on cooperation in the field of water and mentions the joint establishment of a water development programme as a basis for cooperation on water management, water rights and the equitable use of joint water resources.
98. As outlined in Israel and the PLO, 1995; specific to the Gaza Strip and pursuant to Paragraph 25, Schedule 11 deals with the operation and management of water and wastewater infrastructure, the exchange of data on abstractions and water quality, the provision of additional water from Israel to Gaza, the protection of water systems and the establishment of technical sub-committees.
99. In Camp David (July 2000), water negotiations did not reach the level of specific technical discussions on allocations. At Annapolis (2008/09), only exploratory negotiations in the domain of water were initiated.
100. HSI, 2008 includes a map of the Coastal Aquifer Basin that delineates the aquifer up to the groundwater cell line at Nir 'Am north of the Gaza Strip.
101. FoEME, 2012.
102. JMCC, 1996 p.254, Oslo I.
103. Dating back to 1937, see also Messerschmid, 2008b p.14
104. E.g. in HSI 2005; HSI, 2006; HSI 2007; Gvirtzman, 1969; Gvirtzman, 2002; Vengosh et al., 2005; Vengosh et al., 2007.
105. UNEP, 2009.
106. "To finance these and other steps, the government has allocated NIS 12 billion over a five-year period", from 2009 to 2013 (Haaretz, 2008).
107. Rothem, 2008.

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