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Geology, geomorphology and hydrology of the Wadi Gaza catchment, Gaza Strip, Palestine

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ABSTRACT

The geological, geomorphological and hydrological features along the course of the Wadi Gaza (Palestine) are discussed. The study confirms the existence of Pleistocene loess sediments along the Wadi. Wadi Gaza is characterized by meandering features along its course. The watershed of Wadi Gaza is estimated to cover more than 3500 km^2 of the Northern Negev Desert and the Hebron Mountains as well as the small catchment sub-area in the Gaza Strip itself. Storm water drains the hills and mountains of Hebron and the northern Negev desert, accumulates in the Beer-Sheva area, crosses the Gaza Strip and discharges into the Mediterranean Sea. In winter the Wadi Gaza brings about 20 million cubic meter of rainwater into the area.

Field investigations demonstrate the existence of loess sediments in the Wadi Gaza area, deposited during the dry periods that affected the area during the Pleistocene. The Digital Elevation Model (DEM) applied for the Gaza Strip confirmed the existence of three Kurkar ridges within the Gaza Strip. Arranged from west to east (i) Sheikh Ejlin Ridge extends up to the current coastline in the west, (ii) Al Montar Ridge occurs near the armistice line in the east and (iii) Bait Hanon Ridge of which a part is present to the northeast of the Gaza Strip and a part to the east of the armistice line (the intermediate part not being accessible for observation due to political reasons. It is considered as a security zone). All three ridges are running NE–SW, parallel to the Mediterranean coastline.

1. Introduction

The coastal zone of the Gaza Strip (Palestine) is 42 km long, and varies in width between 6 and 12 km, covering an area of 365 km^2. It consists of Pleistocene to Holocene sediments with alternating stratified calcareous sandstones (locally called Kurkar) and red brown layers (locally named as Hamra) (Gvirtzman and Reiss, 1965). The coastline of the Gaza Strip represents only a small section of a larger concave Quaternary sediment depositional system that extends from Alexandria (Egypt) at the west side on the Nile Delta, via Port Said, the Bardawil Lagoon, El Arish, Gaza, up to the Bay of Haifa (Israel) (Inman and Jenkins, 1984).

The topography of the coastal plain is determined by the exposure of aeolian Kurkar ridges presumably of different ages (Fig. 1). The ridges are separated by deep depressions (20–40 m above sea level) containing alluvial deposits. Picard (1943) noted that the Kurkar is mainly distributed in the western half of the coastal plain, forming ridges parallel to the coast. Neev et al. (1987) recorded three onshore Kurkar ridges parallel to the coastal line, while the Gaza Environmental Profile (1994) mapped five scattered ridges on the Gaza Strip. Anan and Zaineldeen (2008) mapped just two ridges within the Gaza Strip running NE–SW, parallel to the Mediterranean coastline with the possibility of a third one. Their Sheikh Ejlin Ridge extends up to the current coastline in the west while the Al Montar Ridge runs near the armistice line in the east. From observations of cross-bedding within these aeolian Kurkar ridges, Zaineldeen (2010) noticed a change in palaeowind direction during deposition of the Kurkar layers from westerly to southwesterly at the Sheikh Ejlin Ridge and from northwesterly to southerly at Al Montar Ridge. Anan (2010) noted the three ridges in the Gaza Strip and identified the sedimentary sequence exposed in these ridges (Kurkar and Hamra) as Gaza Formation.

Wadi Gaza (Fig. 1) is the largest Wadi in the Gaza Strip, crossing the Strip from East to West south of Gaza City for about 9 km. It extends into the armistice border for about 95 km where it collects water from a big catchment area (3600 km^2) in the Hebron Mountains and the Northern Negev.

Wadi Gaza occupies a key position in the geology and geomorphology of the area, but studies of its geological characteristics and its geomorphological and hydrological features are lacking. Therefore the aim of the present work was to: (1) study the geomorphology of the Gaza Strip, (2) study geological characteristics, and geomorphological and hydrological features of Wadi Gaza, and (3) determine age relationship between the Kurkar ridges and Wadi Gaza.

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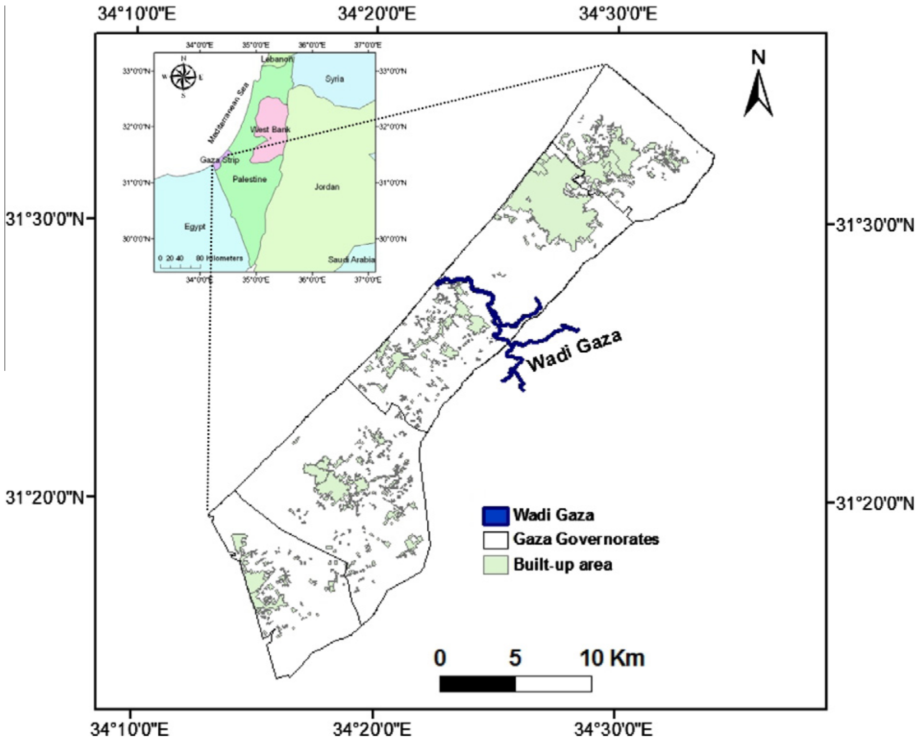

Fig. 1. Location map of the Gaza Strip (Palestine).

2. Methods

The methodology of the study depended mainly on field observations. An ArcGIS program as well as satellite images have been used, while areas of interest have been located with a GPS.

Groundwater flow simulations using the three-dimensional numerical model MODFLOW (Harbaugh and McDonald, 1996) allowed to evaluate the groundwater flow direction. The commercial pre- and post-processor software program Visual MODFLOW was used to conduct the modeling. MODFLOW numerically evaluates the partial differential equations for groundwater flow (McDonald and Harbaugh, 1988).

$$K_h \frac{\partial^2 h}{\partial x^2} + K_h \frac{\partial^2 h}{\partial y^2} + K_v \frac{\partial^2 h}{\partial z^2} - W = S_s \frac{\partial h}{\partial t}$$

where K_h represents the horizontal hydraulic conductivity, K_v the vertical hydraulic conductivity, h the hydraulic head, S_s the specific storage coefficient, W the source/sink term, t the time and x, y, z the space coordinates.

The interface of visual MODFLOW is divided into three modules. The Input Module provides users with the ability to create a graphical three-dimensional representation of the area under study. The modeler can assign values directly to the area of study and the software creates the appropriate files. The Run Module allows the user to alter specific parameters and options, such as the solver package, recharge and rewetting applications, and tolerances for convergence. The Output Module enables the user to display all modeling and calibration results. Although Visual MODFLOW graphically represents the area of study, the input and output files are translated and processed by MODFLOW version 2000 (Harbaugh et al., 2000).

3. Geology of the Wadi Gaza

The course of the Wadi Gaza is characterized by a 1–2 m thick gravelly horizon, consisting of poorly sorted sediments (Fig. 2). It is composed of pebbles, cobbles, gravel and some boulders in a sandy and clayey matrix. The clasts are mainly calcareous, but flints are also common. These gravels were eroded from the high mountains to the east where the Wadi originates. This gravel horizon underlies the loess sediments and was formed during the pluvial period that affected the area during the Pleistocene.

Sand Sediments are composed of medium to coarse-grained sands with some fine pebbly layers showing cross and graded-bedding Wadi (Fig. 3). In addition, few sand dunes could also be observed within the course of the Wadi.

4. Loess and its properties

Loess in the Wadi Gaza is mostly uniform in composition, ranges in thickness from 5 to l0 m, and shows a layer of pebbles (Fig. 2). Vertical sections demonstrate that the aeolian loess accumulation was interrupted either by a flood period (the pebbly intercalation in the middle parts of the loess) or by periods of non-deposition of loess with vegetation covering the surface, thus causing formation of a thin bed of brown soil during accumulation of the upper loess bed (Fig. 4). El Khoudary and Anan (1985) documented a thin pebbly horizon within the loess sediments in the Wadi indicating a short pluvial period during the loess accumulation.

Loess sediments are widespread in the Negev area (Ginzburg and Yaalon, 1963); they are composed mostly of coarse silt grains (20–60 μm) deposited during the late Pleistocene (Bruins, 1976; Goldberg, 1986; Magaritz, 1986; Goodfriend and Magaritz, 1988; Zilberman, 1992; Enzel et al., 2008). Pye and Tsoar (1987) interpreted the Negev loess to have been deposited during the glacial periods of the late Pleistocene based on proximal and distal sources to the Negeve loess. In addition, the coarse silt grains cannot be transported over long distance. Since the Wadi Gaza loess of forms an integral part of Negev sediments, it is interpreted to be of Late Pleistocene age as well. Loess has been formed during dry weather conditions that affected the area during the Pleistocene.

Twelve loess samples from different locations along the Wadi have been analyzed by the hydrometer method (Table 1),

Fig. 2. Gravel horizon observed in the course of Wadi Gaza (coordinates for location: N 31 26 47.9, E 34 24 48.4).

Fig. 3. Graded bedding in sand sediments in Wadi Gaza (coordinates for location: N 31 25 57.2, E 34 24 55.9).

Fig. 4. Loess sediments showing layering with a thin bed of brown soil in between (coordinates for location: N 31 26 26.4, E 34 24 55.7). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

indicating an average composition of 19.9% clay, 39.2% silt and 40.6% sand. Clay, silt and sand ternary diagrams plot the samples as loam.

Table 1
Grain size composition and texture of 12 samples, determined by the hydrometer method.

Sample number	Clay (%)	Silt (%)	Sand (%)	Texture
# 1	18.5	44.0	37.5	Loam
# 2	18.5	40.0	41.5	Loam
# 3	22.5	40.0	37.5	Loam
# 4	14.5	34.4	51.1	Loam
# 5	13.7	39.1	47.2	Loam
# 6	26.1	43.6	30.3	Loam
# 7	25.6	43.2	30.2	Loam
# 8	21.2	32.7	46.1	Loam
# 9	17.6	40.4	42.0	Loam
# 10	16.6	41.1	42.3	Loam
# 11	24.8	34.6	40.6	Loam
# 12	20.9	37.4	41.7	Loam
Average	19.9	39.2	40.6	Loam

Wadi Gaza loess is characterized predominantly by coarse silt , not stratified, stable in steep walls, easily erodible, and pale yellow in color. It contains 20% of mud and calcium carbonate. These characteristics coincide with those described by Pecsi (1990). Pye (1995) defines loess simply as a clastic terrestrial sediment, composed predominantly of silt-sized particles, and formed essentially by accumulation of wind-blown dust.

The loess in the study region is concentrated near the northern border of the Negev, in the south of the Palestine country. Investigations in particular by Yaalon (1969) and Yaalon and Dan (1974) report a typical loess with silt particles derived by weathering from rocky regions in adjacent deserts.

5. Morphology and geomorphology of the Wadi Gaza area

The length of the Wadi Gaza from source to mouth is about 105 km of which the last 9 km is located in the Gaza Strip from the armistice line in the East to the Mediterranean coast in the West. The general elevation of the topography on both sides of the Wadi ranges from 20 to 40 m above sea level. The Wadi floor descends from 30 m above sea level at its eastern limits its mouth. Located in a transitional zone between the Mediterranean, Negev and Sinai regions, the area is characterized by a semi-arid climate.

The width and depth of Wadi Gaza vary a lot. Being 40–60 m wide in its eastern and middle ranges, it becomes more than 400 m wide at its mouth in the West. The depth varies from 5 to 10 m in the East to 4–3 m in the West at the mouth.

According to Anan and Zaineldeen (2008), the Gaza Strip is characterized by the existence of two Kurkar ridges with a possible existence of a third one. The DEM generated by the ArcGIS program provides a detailed view of the topography of the Gaza Strip. It clearly demonstrates the existence of three ridges within the Gaza Strip (Fig. 5) arranged from west to east as follows: (1) Sheikh Ejlin Ridge extending up to the current coastline in the west, (2) Al Montar Ridge situated near to the armistice line in the east, and (3) Bait Hanon Ridge partly present in the northeastern Gaza Strip while the rest of the ridge continues east of the armistice line. All three ridges are running NE–SW, parallel to the Mediterranean coastline. Obviously the Wadi Gaza was created after the formation of these three ridges, crosscutting each of them.

Eight meanders form the most striking geomorphological features (Fig. 6) along the course of the Wadi within the Gaza Strip from the armistice line in the east to the coast in the west. El Khoudary and Anan (1985) consider the existing sand dunes to form obstacles forcing the Wadi to meander. Along the course of the Wadi, terraces can also be observed. These geomorphological features are believed to have been formed due to the lateral shifting of the meanders within the Wadi.

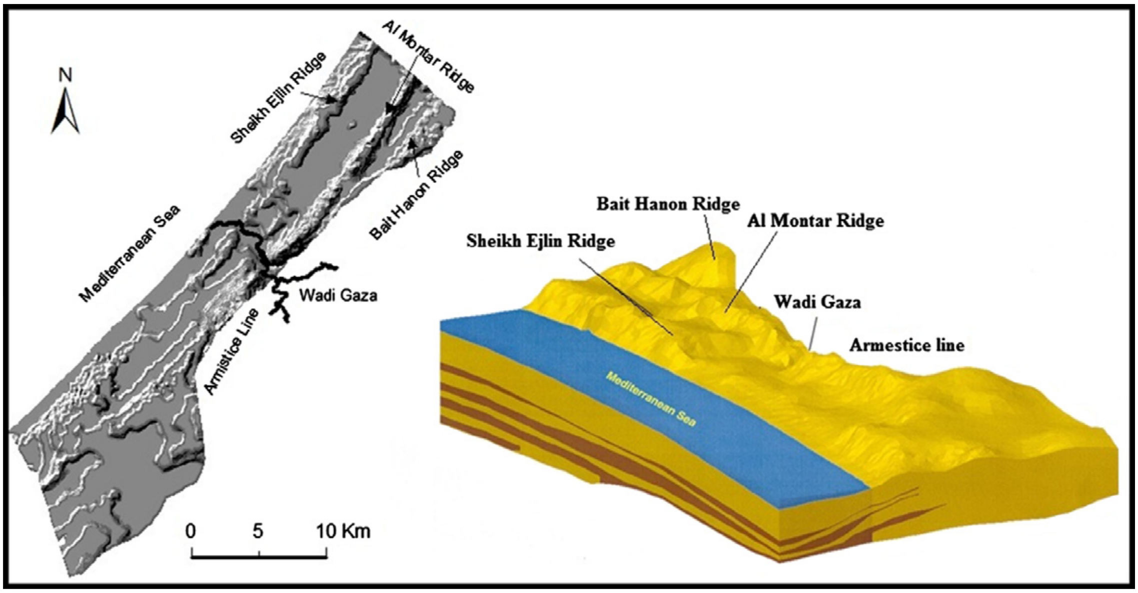

Fig. 5. Digital Elevation Model (DEM) and three-dimensional model for the Gaza Strip showing the existence of three ridges (Sheikh Ejlin, Bait Hanon, Al Montar ridges).

6. Climate of the Gaza Strip

The Wadi Gaza as well as the whole Gaza Strip area are located in the transitional zone between the temperate Mediterranean climate to the East and North and the arid desert climate of the Negev and Sinai to the East and South. As a result the Wadi Gaza area undergoes a characteristically semi-arid climate with a well-defined wet season starting in October and extending into April, and a dry season from May to September. Peak months of rainfall are December and January. The average daily mean temperature ranges from 25 °C in summer to 13 °C in winter, with an average daily maximum from 29 °C to 17 °C, and a minimum temperature range from 21 °C to 9 °C, in summer and winter respectively. The daily relative humidity fluctuates between 65% in daytime and 85% at night in summer and between 60% and 80% respectively in winter.

The mean annual rainfall in the Gaza Strip generally varies from 150 to 300 mm/yr. The average annual rainfall decreases to 50% from the north to the south of the Gaza Strip.

Fig. 6. One of the meanders along the course of the Wadi Gaza (coordinates for location: N 31 25 59.9, E 34 24 57.1).

7. Hydrogeology of the Wadi Gaza and the coastal aquifer

The coastal aquifer consists of one single sedimentary body. The post-Eocene marine clayey Saqiya Formation (Goldenberg, 1992) forms the bottom of the aquifer, covered by Pleistocene sedimentary deposits of alluvial sands, graded gravels, conglomerates, pebbles and mixed soils that constitute the regional hydrological system. Intercalated and randomly distributed clay deposits of marine origin compartmentalize the aquifer. Their thickness decreases to the east; basically they can be classified as aquitards. In the eastern plain the aquifer is semi-confined with an average thickness of 10 m clay, becoming phreatic 4 km from the sea. The regional groundwater flow is mainly westward towards the Mediterranean Sea (Fig. 7). The groundwater level ranges between 5 m below mean sea level to about 6 m above mean sea level. The aquifer is naturally recharged by precipitation, lateral flow from Israel and additional recharge occurs by irrigation return flow and from dune areas near the coast overlying the coastal aquifer itself and from the adjacent uphill area in the east zone. The maximum saturated thickness of the aquifer ranges from 120 m near the sea to a few meters near the eastern aquifer boundary located beyond the eastern Gaza border. Average natural groundwater heads decline sharply east of the Gaza Strip and then gradually decline towards the sea (Melloul and Collin, 1994).

The analysis of 15 ground water wells in the Wadi Gaza area shows high levels of chloride with an average concentration of 920 mg/l (exceeding the WHO standard of 250 mg/l), and nitrate concentrations averaging 84 mg/l which again is higher than the WHO standard (45 mg/l). The nitrate pollution in groundwater extends towards the western area of the Wadi. This result is very much in parallel with the fact that wastewater discharge starts from the middle of the Wadi westwards and that this area is also heavily populated. The high chloride concentrations are found at the middle of the Wadi where most of the existing wells in the area are located.

Environmentally, the Wadi Gaza water is not pure and eventually not good enough for human use or for irrigation. Untreated wastewater discharges in the Wadi and floods can occur during winter. The Wadi is polluted by the sewage collected from towns and refugee camps situated in the middle area of Gaza (Nusierat,

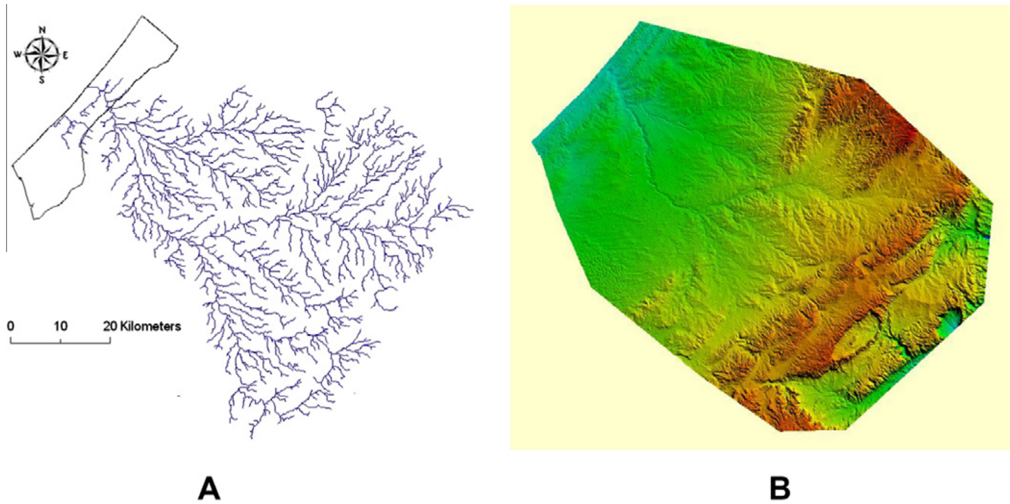

Fig. 7. Map of the Wadi Gaza drainage catchment area. (A) Upstream and downstream of the Gaza Strip and (B) satellite image of the same area.

Maghazi and Bureij camps). The Wadi is currently also polluted with illegally dumped solid wastes.

Flooding of the Wadi Gaza in wintertime is caused by intense rainfall and will transport large amounts of heavily polluted water into the marine environment. In January 2010, flooding of Wadi Gaza has forced more than 100 people from their homes and farms in Gaza after heavy rains hit the area. Flood waters reaching three meters height in some places cut off roads and washed away a bridge linking Gaza city to the southern Gaza Strip.

8. Groundwater modeling of the Wadi Gaza area

The Wadi Gaza aquifer is considered as an unconfined aquifer composed of seven layers of alternating finer and coarser unconsolidated sediments belonging to the Kurkar sandstone formation. The layers are sub-horizontal, with a small inclination towards the sea. The aquifer extends into areas far outside the chosen model domain that encloses an area of 7.0×3.0 km. The grid is chosen to be regular with a cell size of 50 m, and with 140 columns and 60 rows. In the east of the Gaza Strip, the model boundary can be described as a general head boundary, whereas in the west it is a zero constant head boundary; according to the water level contour map, there exist no flow boundaries in both north and south directions. The recharge was calculated with the WetSpass model (Aish et al., 2008). WetSpass has a flexible structure and is fully integrated within the GIS ArcView; it is based upon land use, soil type, some meteorological parameters (such as precipitation, potential evapotranspiration, temperature and wind speed), slope, groundwater depth, wind speed and potential evapotranspiration. The spatially distributed recharge output calculated by the WetSpass model allows to improve the prediction of the simulated groundwater level and the locations of discharge and recharge areas for steady state groundwater models. The groundwater extraction from agricultural and municipal wells was calculated according to Palestinian Water Authority measurements.

Hydraulic property values are assigned based on our hydrogeological investigation and previous studies (Gvirtzman et al., 1984; Melloul and Collin, 1994; Aish et al., 2008). The hydraulic conductivity is assumed to be constant for each layer. The horizontal hydraulic conductivity of the sandstone aquifer is 32 m/d, specific storage amounts to $2.2 \times 10^{-6}\ m^{-1}$, specific yield is 0.24 and total porosity amounts to 0.30. The horizontal hydraulic conductivity of the clay layer is 0.2 m/d, specific storage amounts to $3.1 \times 10^{-6}\ m^{-1}$, specific yield is 0.10 and total porosity amounts to 0.45. The vertical conductivity was set at 10% of the horizontal hydraulic conductivity. The measured ground water level was used as initial condition.

Ten available piezometers data were used for the calibration of the model. During calibration, differences between measured and calculated piezometric heads were minimized by trial and error adjustment of the hydraulic conductivities. Fig. 8 shows the comparison between calculated groundwater levels and average measured values with a correlation coefficient of 0.99 between the measured and simulated water levels. Other indicators of the goodness of fit are the root mean square error of 0.078 m and the mean absolute error of 0.059 m. Hence, all tests indicate a good correspondence between simulated and measured groundwater levels. The simulated groundwater flow direction is from ESE to WNW as shown in Fig 9, and is influenced by groundwater extraction in the Wadi Gaza area.

9. Human interferences and their relation with the geomorphology of the Wadi

Wadi Gaza is currently facing serious environmental problems that have to be solved urgently:

1. Uncontrolled disposal of domestic garbage (Fig. 10) and sewage into the Wadi from the cities located east to the armistice line and from the cities surrounding the Wadi.

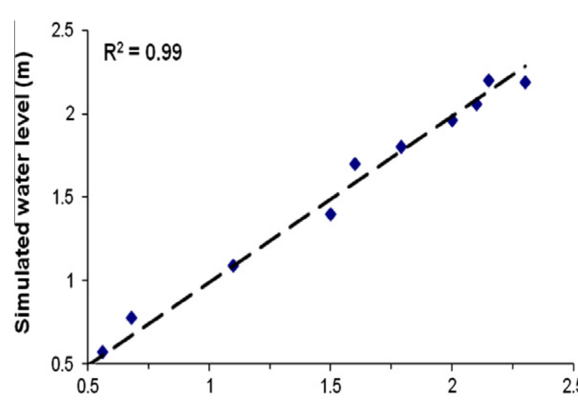

Fig. 8. Comparison of average measured and calculated groundwater levels.

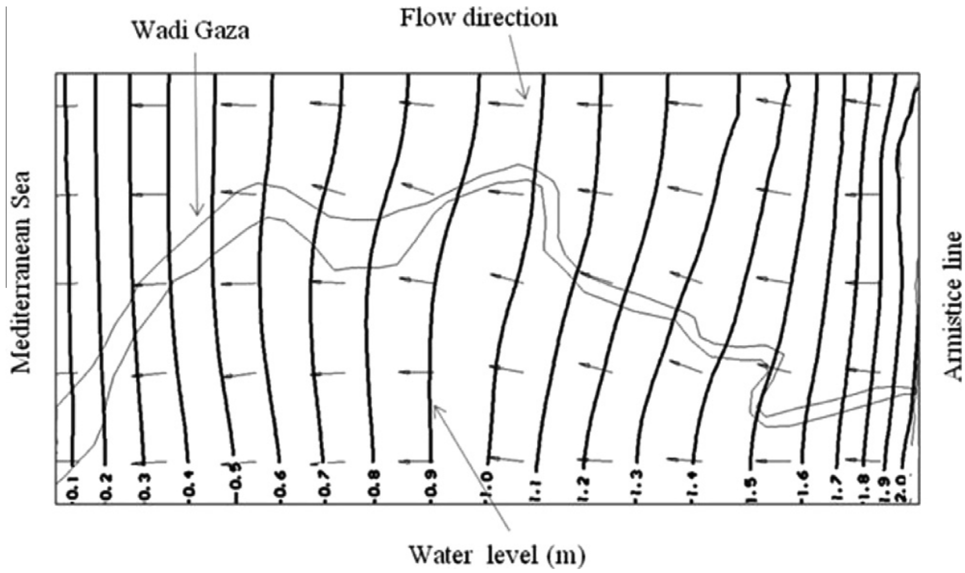

Fig. 9. Simulated groundwater flow direction in the Wadi Gaza area (coordinates for location: N 31 25 40–N 31 25 20, E 34 26 40–E 34 22 30).

Fig. 10. Garbage in the Wadi Gaza (coordinates for location: N 31 26 21.1, E 34 25 59.9).

2. Destruction of some parts of the shoulders along the Wadi.
3. Erection of buildings besides the Wadi.
4. Inappropriate grazing in the area of the Wadi.

10. Water management and conservation of Wadi Gaza

To protect the area from these problems and to transform Wadi Gaza into a natural reserve, measures should be taken and procedures should be put in place:

1. Development of an appropriate management plan to regulate the use of the Wadi Gaza area in a sustainable way.
2. Create awareness with the people about the importance of the Wadi Gaza.
3. Curb the practice of disposing of garbage and sewage into the Wadi.
4. Protect the Wadi from environmental damage.
5. Put the grazing in Wadi Gaza to regulation.
6. Establish cooperation with the adjacent country in the management of Wadi Gaza
7. Stop the discharge of untreated wastewater into the Wadi
8. Safeguard and respect the Palestinian water rights for the water drained into the upper reaches of the Wadi Gaza from the Hebron Mountains catchment area.

11. Conclusion

The current study confirms the existence of loess sediments along the meandering course of the Wadi Gaza that is characterized by meandering features. A Digital Elevation Model (DEM) confirmed the existence of three Kurkar ridges within the Gaza Strip: (i) Sheikh Ejlin Ridge which extends up to the current coastline in the west, (ii) Al Montar Ridge lying near the armistice line in the east, and (iii) Bait Hanon Ridge occurring to the northeast of the Gaza Strip and to the east of the armistice line, its connection between these two parts being obscured for confidentiality reasons. The three ridges strike NE–SW, parallel to the Mediterranean coastline.

The groundwater flow direction is from ESE to WNW and is influenced by groundwater extraction in the Wadi Gaza area.

Wadi Gaza area must be kept as a natural reserve for the diversity of plant and animal life that characterize this important environment.

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