control: use of wastes on local engineering works in the coast of Gaza City

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Abstract Investment in the coastal resources of Gaza City is vital to various developmental issues and projects. Access to the coast and coastal erosion represent two major geo-environmental problems to the city. This paper describes local engineering works developed by the municipality and local people to overcome such problems. A cliff of calcareous sandstone – Kurkar as it is locally known – (up to 18 m high), is located at a distance of 20–50 m from the water–land contact. People who need to reach the beach must cross this Kurkar cliff. The engineering works used to facilitate access to the beach are: old automobile tires, white waste skeletons (refrigerators) and construction waste, where long stairs were designed using these materials. Meanwhile the engineering works which were used as erosion control measures include: rock gabions, concrete wastes, construction waste, concrete walls and shallow excavations. Such practices are commonly used in third world countries and are characterized by inexpensive transportation and implementation costs. The performance of these methods was evaluated from an economic, environmental and safety point of view. Suggestions were made to improve the performance of these practices in the future.

Key words Coastal erosion · Coastal access · Gaza · Erosion control · Mediterranean Sea · Engineering geology

Introduction

The length of the coast of Gaza City is 5 km along the Mediterranean Sea (Fig. 1a). In the north of the city and along the coast, Esh-Shatea refugee camp is located. This camp represents 2 km of this coast. In some parts of this camp, homes are located directly on the coast, while in other parts, the coastal road separates homes, houses and apartments from the coast. Some homes and apartments are affected by the coastal erosion. Some measures were taken to control this risk. The population of Gaza City is 300000 including the inhabitants of Esh-Shatea camp. Several hundred of them work in the fishing industry. There are several archaeological and historical sites along the beach, but these are not well managed and not even well conserved. One of these sites is directly located to the north of the city (Blakhyia site). A large sewage pipe passes through this site, where the waste water drains to the sea. The limited area of the Gaza Strip suggests major developmental efforts. These include making use of the coast in many aspects (Al-Agha 1995 1997).

Wind is an important factor that affects the natural coastal environment. It contributes to building the coastal dunes which extend along most of the coast of the Gaza Strip. Human activities have impacted the sand balance on the beach and the sea. These sand dunes were used as a sand source for construction purposes and other related activities in the Gaza Strip and the West Bank in the last three decades. Most of these sand dunes were destroyed as a result of such use, and consequently many of the plant and animal species disappeared from the area according to the local people. Some animals and plants are now in a real threat if no legislative measures are considered soon.

The coast of the Gaza Strip is considered as a lung to the Palestinians living in the area. Although the development of the coast was neglected during the last few decades, and the environment deteriorated to a great extent, the Palestinians used the coast for recreation activities during the same period. In summer, many people bathe in the sea and spend several hours, from sunrise to sunset, along the beach. Most of the coast is open to the public for recreation and swimming, so that tens of thousands of people are touring and bathing along the beach daily. Children represent about 60% of the total people present at the beach during the summer season.

The coast is used for several activities such as agriculture, urbanization, transportation and some police installations also exist. Protecting the coast from pollution and from the conflicting demands of urbanization, agriculture and recreation must be considered as one of the important strategic tasks of the coastal management. Coastal man-

Received: 18 November 1998 · Accepted: 15 February 1999

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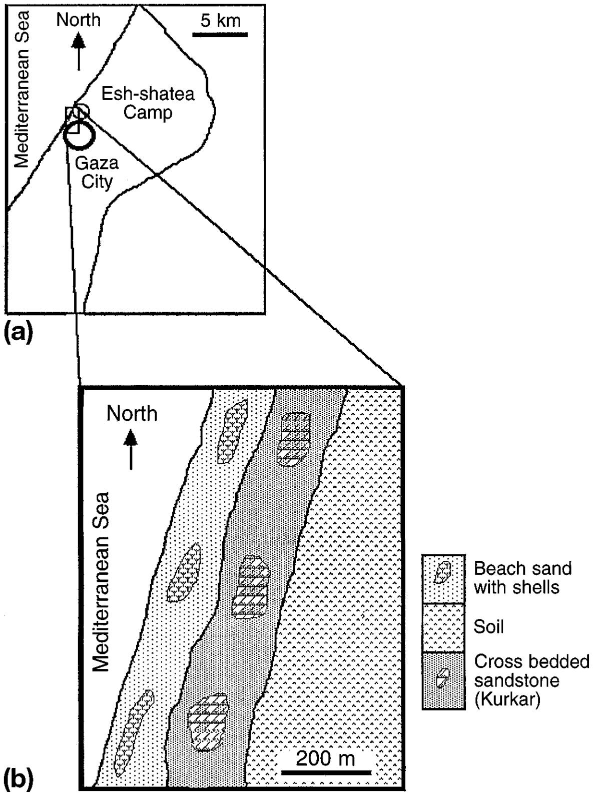

Fig. 1
a Location map of the Gaza City **b** simple geologic map of the area showing the sedimentary facies

agement in the Gaza Strip is still in its embryonic stage. Coastal research, safety and proper uses are still very limited, and nothing has yet been published in this regard. A few internal reports were carried out by the Ministry of Planning in the last two years. These reports are not easy to access even for specialists and scientists due to inexplicable reasons.

This article aims to summarize the local engineering methods and techniques used by the municipality of Gaza City and the local people to:

1. facilitate access to the coast,
2. control erosion in some parts of the coast and
3. evaluate these measures and controls in the light of economic, environmental and safety aspects.

Hydrology and geology of the coast

In the Gaza Strip, it is not easy to define the coast or the coastal zone due to its limited area. If the international definition of the coastal zone is to be considered in this case, all the Gaza Strip must be located in the coastal zone, where the maximum distance between the water–land contact and the eastern border of the Gaza Strip is about 12 km. In this article, and as it is locally defined, the coastal zone is the area located 1–3 km to the east from the land–water contact.

Hydrology

The mean annual rainfall on the coast of Gaza City is 400 mm. Rainwater is the only source of natural recharge of the shallow aquifer in the area. In the Gaza Strip, there are two aquifers: the shallow aquifer (5–20 m deep), and the deep aquifer (40–60 m deep). The shallow aquifer is known in the southern parts of the Gaza Strip as "Mawasi aquifer". It is believed that most of the rainwater along the coast infiltrates the shallow aquifer. While the deep aquifer is recharged from the other parts of the Gaza Strip, including the area behind the eastern borders of Gaza Strip in Naqab desert and the West Bank.

Geology

Geology of the coast is rather simple, where few types of sediments are reported. These sedimentary facies are shown in Fig. 1b and include the following:

Kurkar sediments

Kurkar sediments belong to the Pleistocene age, and they form the main aquifer in the Gaza Strip. They are formed of calcareous sandstone with high porosity and permeability. The Kurkar sediments extend along the coast but are more exposed in the northern part of the Gaza Strip than in the southern part. In some parts of the coast, Kurkar sediments are highly eroded and occasionally they form the bottom of the water–land contact. Kurkar sediments form high coastal cliffs in some parts of the coast, the height of these cliffs ranges between 5–18 m. They are normally formed of calcareous sandstone interbedded with 1–2-m thick clayey or silty clay beds. The thickness of the calcareous sandstone ranges between 5–10 m. The distance between this Kurkar cliff and the water–land contact ranges between 0–25 m. Most of the buildings and other permanent installations are constructed behind, or on this Kurkar ridge or cliff. Sandstone is formed of well-sorted and well-rounded quartz and feldspar grains. These grains are cemented by calcite.

Sand

White and non-cemented quartz grains are common along the coast of the Gaza Strip from the extreme north to the extreme south (Fig. 2a). Sand extends just from water–land contact to several meters and rarely tens of meters. It is normally about 1 m higher than the sea water level. Sand grains are mixed with shells and shell fragments with variable shapes and sizes.

Shells and shell fragments

There are many shelly spots along the coast which interfere with sands. These shells mainly belong to the pelecypods. They are of variable colors and range between white and black. These shells also are found sometimes to be highly fragmented and occasionally kept non-fragmented. Such phenomena may give clues to direction of currents, waves and wind, and consequently to the reworking process or processes. This sandy and shelly coast

Fig. 2
a Rock gabions transported from the West Bank located in the sea water, white beach sand (*base of the photo*). The size of the largest block in the centre is about 1 m^3. **b** White wastes (*refrigerators skeletons*) engineered in the form of stairs (*centre of the photo*), dumping of solid wastes along the Kurkar ridge, note the destruction of the coastal vegetation as a result of the dumping. The length of the skeleton is about 2 m. **c** Concrete walls with concrete stairs to the left of the photo, solid waste dumping to the *right of the photo*

is one of the resources which should be given a priority in the recreation activities and/or the coastal management plans.

Sand dunes

Sand dunes are common along the coast of the Gaza Strip extending from the extreme north to the extreme south. These dunes belong to the Cainozoic (Quaternary) deposits in the Gaza Strip. These dunes are parallel to the coast. They are formed of friable and non-cemented quartz grains, with small amounts of feldspars and other heavy minerals. In the last few decades they were used as a source of sand used in construction and building purposes.

Soil

Soil in the Gaza Strip belongs also to the Cainozoic (Quaternary) deposits. Soil is characterized by its yellow to brown color, where the brown color increases to the east. It is one of the important resources in the Gaza Strip especially for agricultural purposes.

Environmental aspects

One of the important environmental aspects of the coast of Gaza City is the solid waste dumping along the coast, especially on the part that belongs to Esh-Shatea camp.

Solid waste dumping

Solid wastes of different types were dumped along the coast during the last few decades (Fig. 2b, c), during which no landfills were present in the Gaza Strip (Al-Agha 1997). Plastic, kitchen, metal, glass and paper are the main constituents of the domestic wastes dumped along the coast. The food wastes form about 70% of the total wastes in the Gaza Strip. This implies that the amount of leachate produced after the dumping will be quite high. This leachate finds its way either to the coastal Kurkar rocks, which form the main aquifer in the Gaza Strip, or to sea water.

It is very obvious in several parts along the coast that many plant species disappeared or were partially destroyed as a result of waste dumping. On the other hand, solid waste dumping along the beach may change even the species that live along the coast and introduce new species which used to live in the waste dumping sites.

Engineering works

Because of the cliffy nature of the Kurkar ridge along the coast of Gaza City, it is not easy to get to the water–land contact, thus individual initiatives were made to ease the access to the coast. These initiatives are inexpensive, and in some cases may be considered as costless. Stairs are made by use of different types of wastes. The slope of the cliff is normally between 70–80°. Thus, special care and skills are needed for such installations. Construction of these stairs is made by the efforts of the local people who need the coast for different uses and activities. There are three types of engineering practices that are used along the coast to facilitate the access to the coast.

Fig. 3
a Use of old automobile tires for access to the coast (*centre of the photo*), rock gabions and construction wastes located along the Kurkar ridge (*right and left of the photo*), white beach sand (*base of the photo*). **b** Rock gabions located in the water to prevent the advancement of sea water towards the Kurkar ridge, an opening was left between two barriers of rock gabions where an excavation was designed, the excavation is used for playing and swimming of the children. **c** Collapse of the cemetery as a result of coastal erosion

Access to the coast

Old tires

Automobile tires made of synthetic rubber are used as stairs on the Kurkar cliffs along the Gaza City coast (Fig. 3a). Here the slope of the Kurkar ridge is modified to 45–50°. This is made by the dumping of construction wastes on the Kurkar cliff until the slope is changed. This makes it easy for people of all ages to have easy access to the coast. Two or three tires are placed close together horizontally and filled with sand and/or fine aggregates of construction wastes.

Old skeletons of refrigerators

Another type of engineering construction made to gain access to the coast of Gaza City is old refrigerator skeletons (Fig. 2b). These skeletons are placed in the same way as the tires mentioned above, where the slope is changed to be suitable for safe access. The skeletons are filled with sand and/or fine aggregates of construction wastes.

Construction wastes blocks (concrete)

These blocks are used in the same way as the two types mentioned above. However, several blocks are placed horizontally together to form one stair unit. These blocks are sometimes supported by steel and/or wood to prevent sliding. The volume of the unit block is $20 \times 20 \times 40$ cm. They are obtained from the waste of demolished homes.

Coastal erosion

In some parts along the coast of the Gaza Strip, coastal erosion is considered a threat to buildings, roads and other installations located directly on the coast. This is clearly seen along the coast of the city of Gaza, where an asphalt road and a cemetery partially collapsed during the last 5–6 decades as a result of coastal erosion (Fig. 3c).

Erosion in the coast occurs in the form of coastal or beach erosion. Beach or coastal erosion is the consequence of sea waves breaking upon the coast, thereby flooding and scouring the area as it ebbs, removing part of the unconsolidated sands (Youdeowei and Abam 1997). In case of higher waves, the flooding water arrives at the Kurkar ridge/cliff removing parts/blocks of sandstone or clay beds. This phenomena continuously takes place, causing the removal and aggregating these rocks. It is common to see the red-brown color of the eroded clay beds on the beach sand as a result of erosion.

Erosion control practices

One of the important observations along the coast is that coastal erosion is taking place in several spots and could not be seen everywhere. Such an observation probably means some differences in the direction and intensity of waves and currents from place to place. Therefore it is expected that sedimentation also takes place in several other areas, but this needs more investigation, while in several other areas, no action was taken where the coastal erosion is not threatening the apartments.

Erosion control practices and measures taken by the municipality of Gaza and the community on the coastal area include:

Rock gabions
Large rock blocks were collected and transported from the West Bank, and placed along areas of active coastal erosion as barriers located at the water–land contact (Fig. 2a, 3b). Sometimes these rock gabions are placed in the contact line between the beach sand and the Kurkar ridge (Fig. 3a). They are formed of limestone rocks which are common in the West Bank. The unit volume of these blocks is generally about 1 m^3. These barriers work as wave breakers, and thus stopping the advancement of waves to the Kurkar rocks. Transportation of these materials from the West Bank is one of the problems that makes this an expensive solution.

Large blocks of construction waste
Construction waste, especially concrete, are also used as barriers for erosion control at the water–land contact along the coast of the Gaza city. Large blocks of this waste are transported from several areas within the Gaza Strip to the site. They are much cheaper than the use of limestone blocks brought from the West Bank. Concrete in these blocks is formed of cement, steel rods, sand and rock aggregates. Corrosion of steel rods is a common phenomena seen along these blocks. Also, dissolution of the natural components of the concrete (e.g. shells and calcareous aggregates) takes place in almost all the blocks, but it is of low rate.

Small aggregates and blocks of construction wastes
In some other areas small aggregates and blocks of construction wastes were dumped along the coast to prevent the coastal erosion (Fig. 3a, c). This type of erosion control is commonly seen on the Kurkar cliff, and rarely in the water–land contact area.

Concrete walls
A few years ago, a 5-m high wall was constructed along the coast. The length of the wall is about 15 m. It is totally composed of concrete. Because of its high cost, such a measure was only constructed in one place along the coast. Stairs are associated with these walls and used for access (Fig. 2c).

Shallow excavations
In some areas shallow excavations were performed to absorb the waves, and consequently to prevent their arrival at Kurkar ridge (Fig. 3b). One of these excavations is located just in front of the main street of Gaza City (Omar Al-Mukhtar Street). The excavation was performed in both the beach sand and under the sea water along the coast. The area of such excavation is estimated to be a few hundreds of square m, while its depth is not more than one meter.

Discussion

Performance of the coastal access works
The materials of the three types of local engineering practices used in access to the coast of the city are formed of different types of wastes. Use of waste has a merit of inexpensive costs, where the material does not cost more than the transportation from the source to the site. The different types of waste are: construction waste, tires and white metal waste. These types represent, in fact, a real problem to the environment if no recycling and/or landfilling services exist. Tires and construction waste prove to have a high resistivity to the prevailing conditions along the coast. Atmospheric and seawater corrosion have no observable impacts on such materials. On the other hand, the metal white wastes are affected by the atmospheric and sea water corrosion. Corrosion of these white skeletons is very clear as the white color of the skeletons are gradually changing into brown, red brown and black colors and sometimes mixtures of these colors are seen. Atmospheric corrosion is known to be very effective near the coast, where Cl plays an important role in the reactions between the metal and the other atmospheric components (Al-Agha and others 1995).
From the environmental point of view, both tires and construction waste will have no environmental impacts in the foreseeable future, although tires are not classified as environmentally friendly materials. The degradation products of rubber material have bad environmental impacts, but this could not be seen in the short term. It needs at least a few hundred thousand years for this impact to be detected or assessed. On the other hand, white metal wastes have more impacts that could be seen in tens of years or even less. It is common to see the leachate of the corrosion products coloring the soil or the other materials forming the ground of the stairs. It causes contamination of land, and this leachate or plume could reach the groundwater in tens of years, or in some cases less. It is known that the water table in this area is located at a few meters depth.

Performance of erosion control works
Two types of materials are used in erosion control: the first is limestone rock gabions and the second is the construction material including concrete blocks, walls and construction aggregates. The second type has an advantage, as the transportation costs are less than that of the first type. The rock gabions are transported from the West Bank, this means that the distance of transportation is about 150 km. Meanwhile in the case of the construction waste, the maximum transportation distance does not exceed 35–40 km and in most of the cases it is very much less. Limestone rock gabions prove that they are very resistant to coastal erosion. Growth of algae and other pelecypod settlements on these blocks makes them more resistant than in their natural state.
Concrete and/or construction waste blocks or aggregates are also considered to be good measures to control the

coastal erosion. Concrete walls are used in many areas in the world for such purposes. In our case, these blocks were not originally designed for this purpose, but they are used for this purpose after buildings have been demolished. The problem is that the steel within the concrete corrodes at a very high rate as a result of the reaction with sea water. This is very obvious on the blocks along the coast, where the corrosion leachate moves on these blocks forming new iron compounds, e.g. ferric oxides and hydroxides (Al-Agha and others 1995). Coating of the steel rods in these concrete blocks may reduce the corrosion rate. However, this is not easy to do as the original design of these materials does not need coating.
Excavations may be considered as a solution to the coastal erosion, but this may cause deformation of the coastal landscape and, in the meantime, it may cause destruction of parts of the coastal ecosystem.

Conclusion

Use of local engineering works in both access to the coast and erosion control was determined by the following factors:
1. availability of the materials,
2. costs of transportation of the material and
3. costs of implementation.

It should be mentioned that this work is carried out on the individual initiatives of the people living along the coast, except for both rock gabions and concrete walls and blocks, which were made by the municipality of Gaza City. Thus, sites of such engineering works were not scientifically tested or chosen, so processes leading to their construction must be proceeded by topographic, geomorphologic and hydrologic studies. Soil investigations are also to be considered, so as to maintain the minimum measures of safety for people using such construction.
As nearly all the used materials in these locally engineered works are derived from waste, they should be inexpensive, or even costless. Thus, from an economic point of view, these materials are considered economically viable. However, when they are considered from an environmental point of view, some have environmental impacts that may cause pollution of land, sea water, the coast and most probably groundwater in the long term.
More care should be considered regarding the safety of these access works, and more measures and supporting materials should be taken during the implementation of such works. Also, bathers and swimmers should be warned not to walk on the rock gabions and the concrete blocks, as there is a risk of slipping.

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