Egypt's Sinai Desert Cries: Utilization of Flash Flood for a Sustainable Water Management

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Abstract

Water demand will increase and augmenting freshwater resources from the rainwater and flash flood will decrease the gap between supply and demand. Flash floods, which is considered as one of the worst weather-related natural disasters are highly unpredictable following brief spells of heavy rain. The eastern desert and the Sinai Peninsula are subjected to flash floods, where floods from the mountains of the Red Sea and Sinai are causing heavy damage to man-made features. The central focus of this chapter was to achieve a sustainable water resources management in the Sinai Peninsula. The objective of the current chapter is to mitigate and utilize the floods water as a new supply for water harvesting in Sinai. Applying water harvesting of the flash flood will reduce the flood risk at the outlet. In addition, it could be used for recharging the groundwater aquifers, which are the basis for sustainable development in Sinai. Furthermore, Bedouins usually move from place to place searching for fresh grazing for their animals and water for their families. These locations sometimes are hazardous areas as flash floods occur there. This chapter helps to make developed sustainable planning for the Bedouins, as hazard areas were defined. Established places to harvest and store the flooded water would allow the Bedouins to resettle the area. The total amounts of rainfall affecting the different drainage systems in Sinai is of the order of 2000 million m^3/year, and the most of possible runoff water is about 150 million m^3/year rainfall was roughly determined at some sites; for El-Arish region is about 1000 million m^3/year (100 million m^3/year runoff), 75 million m^3/year (4 million m^3/year runoff) for El-Gerafi region, 240 million m^3/year (10 million m^3/year runoff) for the Gulf of Suez region, 150 million m^3/year for Bitter Lakes region, 300 million m^3/year for south El-Bardawil region, and 100–600 million m^3/year for the Gulf of Aqaba.

Keywords

Flash flood • Remote sensing • Water harvesting • Dams • Groundwater harvesting • Water management • Sinai

1 Introduction

Nile water is insufficient to meet all the Egyptian demands, especially in the future due to increasing of the population. Water security and flood hazards are of great environmental, economical, and political importance for arid regions (Tooth 2000), especially in Egypt. The problem of water shortage in Sinai is due to low rainfall and uneven distribution throughout the season, which makes rainfed agriculture a risky enterprise. Rainfall in Sinai is characterized by its instability and scarcity from one year to another. This instability could denote a wave of flash floods with devastating and undesirable environmental and social impacts. Flash floods, as well as floodwater resources (Abdelkarim et al. 2019), are very destructive and have a significant impact on local society, economy, environment, agriculture, and cultural heritage. Flash floods are furthermore not well understood from a hydrological, meteorological as well as from a socioeconomical point of view because they come unexpected and often at a very localized scale (WRRI 2010). It is therefore extremely difficult to forecast flash floods with sufficient lead-time to take emergency actions. In arid regions, flash floods are the main cause of loss in infrastructure, property, and human life. The eastern desert and the Sinai Peninsula are subjected to flash floods, where floods from the mountains of the Red Sea and Sinai are causing heavy damage to man-made features (Abuzied and Mansour 2018; Mohamed and El-Raey 2019). Despite this, floodwater

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could be used to create a great amount of Sinai water resources, and be utilized to fulfill part of the increasing water demand in areas prone to flooding that are currently experiencing high population growth and economic development. This is especially true in the wadi system of Southern Sinai, where flash floods have become an unlucky annual occurrence.

Flood risk management (Jalilov et al. 2018) can be defined as a combination of comprehensive and continuous societal analysis, assessment, and interventions for a reduction in flood risk (Schanze 2006). However, the magnitude of potential water savings and controlling water in order to sustain life has always been one of the basic difficulties faced by mankind. Water saving is an important objective of Egypt's water strategy to serve a growing population with limited resources, which are a big problem inherent in the opening up of the deserts in Egypt to modern development. The chapter's overall aim was to achieve sustainable water resources management in the Sinai Peninsula through the utilization of flash flood water.

Water resources management is a critical issue in arid regions due to the shortage of precipitation, high evaporation, as well as increasing population, together with restricted water resources and associated increases in the need for water. Flash floods are devastating and represent a big threat to human life and arid environments, but can also be utilized and accomplished appropriately to make such floods valuable as water resources. One of the significant targets is thus to evaluate the flash flood water as an additional water resource.

Flash floods spread violence and fear over the land. They sometimes bring peace and grace. Despite their hazardous impacts, flash floods in Sinai, and different parts of southern Egypt represent a potential for non-conventional freshwater sources. However, the majority of the floodwater goes waste as runoff to the Gulf of Suez and this could meet part of the water demands for a multitude of uses in this area if efficiently utilized. A major challenge in these areas is the wise use of floodwater to permit the sustainable management of water resources. Therefore, the chapter objective is to put the best ways to mitigate and utilize the floods water as a new supply for water harvesting in Sinai. In addition, guidelines suggestion for floods water utilizing, and at the same time reducing and controlling their hazards on the area has been discussed.

2 Description of Sinai Peninsula

The Sinai Peninsula is located in the northeast of Egypt. The Suez Canal and the Gulf of Suez are separated from the rest of the Egyptian territories. It is a triangular shape in the south at Ras Mohammed and its base overlooks the Mediterranean Sea in the north. More than half of it is located between the Gulf of Aqaba and the Gulf of Suez (Fig. 1). Sinai is described as the hinge that leaves around it the continent of Asia in the east and Africa in the west. "The separation of the two continents caused the form and geographical shape of Sinai the way it looks today" (http://www.allsinai.info/sites/geology.htm). Sinai has an area of about 61000 km^2, or about 6 % of the area of Egypt and about three times the area of the Nile Delta and exceeds the area of some countries. The length of Sinai beaches about 700 km, representing nearly one-third of Egypt's coastline.

The Peninsula of Sinai may be divided into three geological districts, namely, the granitic and metamorphic, limestone, and sandstone rocks of which they are composed (Said 1962). Generally, Sinai reflects all geologic columns of Egypt. "The northern part of Sinai mainly consists of sandstone plains and hills. The Tih Plateau forms the boundary between the northern area and the southern mountainous with towering peaks" (http://www.allsinai.info/sites/geology.htm).

The following are the stratigraphic column described in detail by (Said 1962) is divided into four major units:

1. Upper Calcareous Division is composed of sandstone, shales, conglomerates, evaporates, and foraminiferal marl. They range in age from Oligocene to Pleistocene.
2. Middle Calcareous Division mainly consists of marls, chalks, limestones, and shales of Cenomanian to Eocene age.
3. Lower Clastic Division, in the south; these are Carboniferous to Lower Cretaceous sandstones. Toward the north, the rocks are more calcareous. This complex, as especially its upper part, is also known as the Nubian Sandstone.
4. Basement Complex, Precambrian igneous and metamorphic rocks; many dykes occur crossing the basement rocks and are considered of Tertiary age. Oil is produced along the shore of the Gulf of Suez. Production is mainly from Miocene sandstones, and in certain fields, from Carboniferous, Cretaceous, and Eocene formations (http://www.tandfonline.com/doi/pdf/10.1080/02626667109493772).

Climate conditions vary in different regions, where dry climatic conditions are prevalent in the north and severe drought in the center and southwest. Rainfall is concentrated in the northern region, with rainfall decreasing from north to south. The average rainfall in North Sinai ranges from 100 to 200 mm per year. The highest quantity is recorded in the Rafah area, while in the interior it ranges from 20 to 100 mm/year or less. In general, the intensity and intensity of rain vary greatly. Large amounts of rain may fall within a day or even within a few hours, as in the case of thunderstorms.

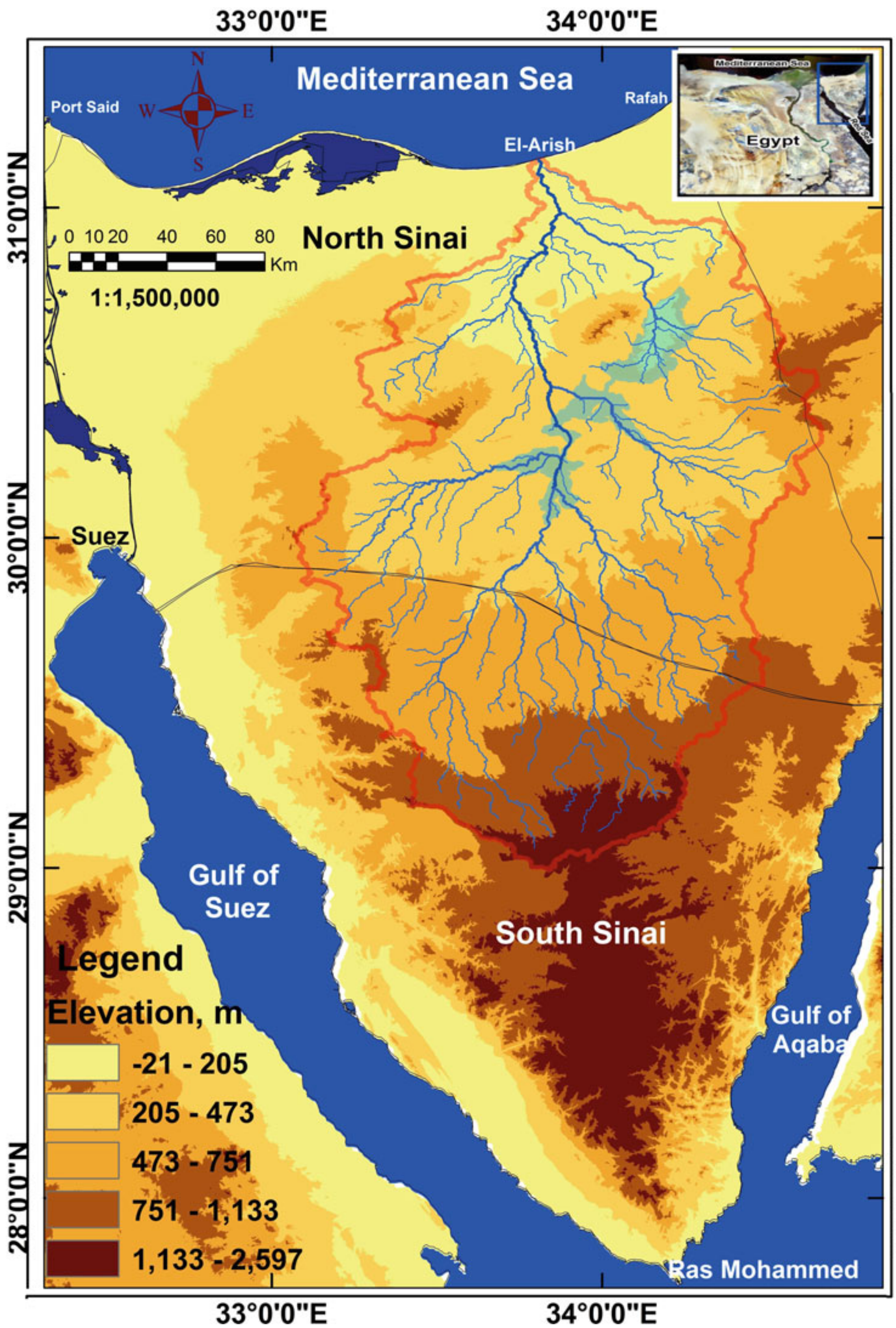

Fig. 1 A digital elevation model representing the topography of Sinai

Soil resources of the Sinai are enormously influenced by the related landform types. The Sinai was classified into six landform units (Dames and Moore 1983), which are Highlands (southern mountains, central tableland, El-Egma tableland, and northern folded blocks); northern piedmont plain; western outwash plain (Feiran, Sidri-Baba, and Sudr-Abu Suweira plains); morphotectonic depressions (El-Qaa plain, Wadi Araba, El-Saghir, Bitter Lakes, Temsah Lake, the area between El-Maghara-Risan Aneiza and the area between Gabal Yelleq and El-Halal); northern coastal plain; and sand dunes. Geomorphologically, the Peninsula includes seven regions (Fig. 2a). The southern elevated mountains area includes the southern part of the Sinai assuming a triangular shape with its apex at Ras Mohamed to the south. The central plateau district includes the central part of Sinai as two principle questas; El-Egma to the southwest, and El-Tieh to the north (Abu Al-Izz 1971). A hilly region lies to the northeast of the Sinai. It is gently sloping toward the northeast and is characterized by local isolated hills. Likewise, sand ridges of thick sandstones set a coastal district of gently undulated surface apart. Muddy and marshy land districts occupy the shorelines and some lakes (e.g., El-Bardaweel, El-Temsah, and Bitter Lakes).

Generally, Sinai soils lack pedagogical features indicating the soil development, under arid condition. El-Tina plain is clay flat consisting of fluvio-lacustrine deposits of loamy and clayey texture. Flat sandy terrain is formed of Aeolian sand deposits and is very gently undulating. The soils are of non-saline deep sandy-textured, and the water table is moderately shallow. Undulating sandy terrain is susceptible to wind erosion. The water table is expected to be very deep and the drainage is excessive. The soils of the Wadi El-Arish bed have been formed of calcareous fluvio-marine deposits and are loamy texture with moderate drainage. Calcareous sandy terraces are located between Rafah and El-Sheik Zuweid. The soils are fine sand or loamy sand texture and have a moderately deep water table. Factors restricting land reclamation are lowland sabkhas and mobile sand dunes. All of the good agricultural lands (Fig. 2b), those having 0–8 % slopes, 0–50 m of local relief, and a deep soil cover, are located in northern and central Sinai. The good agricultural land is located along the wadi channels. The main areas are

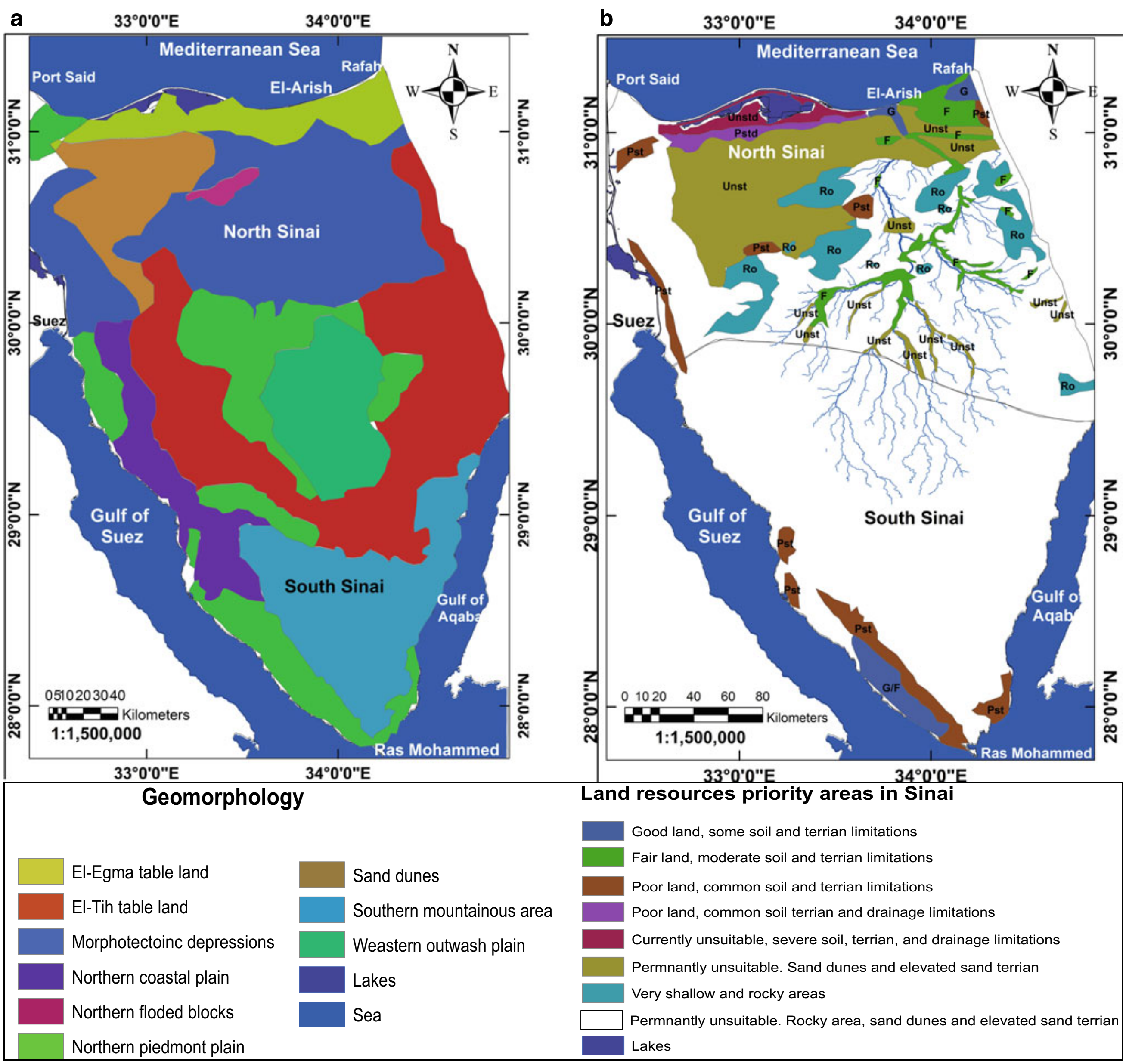

Fig. 2 **a** The main geomorphological units (EGSMA 1981) and **b** the mainland resources of Sinai

along Wadi El-Bruk, extending from Gabal El-Kaib north to Bir El-Thamada, and then east to the confluence of Wadi E1-Arish near Gabal Kherim and the Wadi El-Arish main channel and its tributary. Wadi El-Aqabah also forms a good agricultural area, but a smaller and narrower one than the Wadi El-Bruk area. The Wadi El-Arish agricultural area extends from the confluence of Wadi Abu Gidi north to Wadi El-Bruk. There are several significant areas of fair agricultural land in the Sinai (Fig. 2b). On the western, northern, and southern sides of Wadi El-Bruk, between the wadi and the mountains, there is an uneven, narrow band of fair agricultural land. An extensive area of fair agricultural land lies around the base of Gabal Libni. Another large region of fair agricultural land in North Sinai is a 5–20 km strip that trends north–south along the Great Bitter Lakes area. In South Sinai, the largest area of fair agricultural land lies in the El-Qaa Plain. Two extra areas of fair agricultural land are found at Abu Rudeis and Belayim. These areas occupy alluvial fans developed by Wadis Baba and Feiran, respectively. Long narrow strips of fair agricultural land are found in most of the main wide wadis of South Sinai.

3 Maximum Utilization Flash Flood Water as Significant Water Resources

3.1 Existing Versus Potential Sites for Dam Construction with High Flash Flood

Seven dams in Sinai (Table 1) are mentioned in the literature (Shata 1992). Three are masonry dams (Rawafaa Dam, Ein Gudeirat Dam, and Perkins Dam). Rawafaa and Wadi Nefuz (near Feiran Oasis) are currently silted up. The dam built at El-Wadi, north of El-Tor, has been washed away. Ein Gudeirat is masonry and badly damaged. Locations of seven historic dams are shown in Fig. 3, along with sites proposed for future development. Of the seven dams, Rawafaa is the most interesting from several points of view. An arched masonry dam is located on Wadi El-Arish, about 52 km south of El-Arish town. It was built in 1946 and reportedly had an initial capacity of about 3 million m^3. The dam is silted up and it was reduced in capacity from 3.03×10^6 m^3 in 1949 to 2.94×10^6 m^3 in 1958 (equivalent to an average loss of capacity of only l0,000 m^3/year). Assuming that the useful life of the reservoir would end if its capacity dropped to 1×10^6 m^3, and assuming an average siltation rate of 10,000 m^3/year.

It would appear that the reservoir should have a useful life up to the year 2150. In addition to the problem of siltation, the Rawafaa reservoir experienced or is experiencing, both evaporation and seepage losses. Several investigators have noted the presence of well-fractured Eocene limestone underlying the reservoir. This could lead to high seepage losses if the sediment has not been deposited thickly and uniformly enough over the entire reservoir area.

3.2 Water Harvesting

Rainwater harvesting, instead of enabling it to run off, is the accumulation and storage of rainwater for reuse on site. It offers an autonomous water supply during regional water constraints and is often used to complement the primary supply in developed countries. Rainwater harvesting offers water when a drought happens, can assist mitigate flooding in low-lying regions, and decreases usage of wells that can sustain groundwater levels. It also contributes to the supply of drinking water, since rainwater is significantly free of

Table 1 Inventory of existing dams in Sinai (Shata 1992)

Dam location	Description
Rawafaa Dam	Arched masonry dam located on Wadi El-Arish, about 52 km south of El-Arish; capacity about 3,000,000 m^3; reported to be silted up
El-Gudeirat Dam	Masonry dam, located about 9 km west of the Israeli border; built by the Turks in World War I, but presently silted up
Perkins Dam	Masonry dam on Wadi El-Gudeirat located on Wadi Sad, one of the short wadis draining the southeastern flank of Gebel Dalfa (east of Gebel El-Halal)
Wadi Gharandal Dams	Two small diversion dams in Wadi Gharandal, located 10–12 km from the Gulf of Suez, used for irrigation. The uppermost one ponds back 300–400 m of slightly brackish water; presumably an earthen structure in both cases
Wadi Nefuz Dam	Wadi Nefuz flows from Gebel Banat to Wadi Feiran and is located north of the Oasis of Feiran; the dam is located in the upper part of this wadi, where it flows through a red granite canyon, exhibiting springs; the dam is filled with eroded soil
El-Wadi Dam	A large dam built by the Bedouins at El-Wadi, north of El-Tor, for irrigation purposes; it was subsequently washed away
Wadi Shellal Dam	Formerly supplied piped water to Umm Bugma

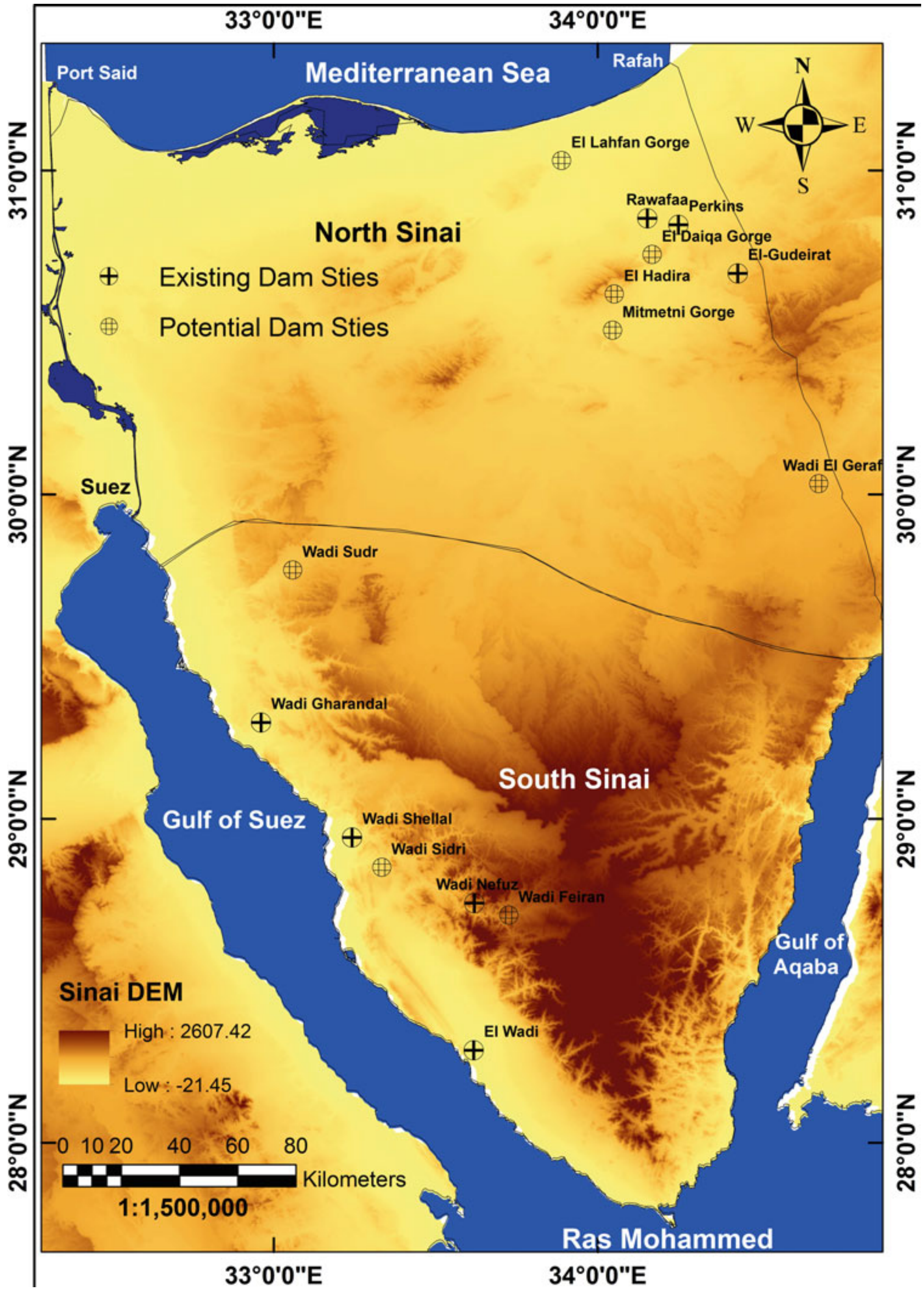

Fig. 3 Existing versus potential dam sites in Sinai

salinity and other salts. Water harvesting, with its different types, is getting a new interest to be evaluated as traditional water management, especially in Sinai. This old technology is gaining new popularity these days. Water harvesting is a traditional water management technology to ease future water scarcity in many arid and semi-arid regions (Shadeed and Lange 2010).

The harvesting of rainwater has numerous positive advantages. It is cheap and extremely decentralized, empowering water management for people and communities. It is secure from the environment and can be used fairly. It offers a reliable renewable resource with limited investment and unique management. It is possible to transport the harvested water with little energy. In agriculture, rainwater harvesting has shown the potential of enhancing food output by 100 % compared to the 10 % rise in food manufacturing from irrigation (Shadeed and Lange 2010).

It is possible to distinguish three groups of water harvesting (Prinz and Singh 2000): (1) Rainwater harvesting is described as a technique for generating, gathering, storing, and preserving local surface runoff for agriculture in arid and semi-arid areas. (2) The collection and storage of creek flow for irrigation purposes can be described as flood water harvesting. Flood water harvesting, also known as "large catchment water harvesting" or "Spate Irrigation." (3) Groundwater harvesting is a rather modern word that is used to cover both traditional and unconventional methods of extracting groundwater. There are few examples of groundwater harvesting methods in Qanat systems, underground dams, and unique kinds of wells.

3.3 Best Locations for Possible Water Harvesting Dams in Sinai

It is critical to construct new dams to protect the Sinai city and its provinces from feature flooding. Abd-El Monsef (2010) uses the precise mapping capabilities of remote sensing and GIS to find the best locations for new dams in Wadi El-Arish to reduce the impact of any future flash flood. Drainage network of Wadi El-Arish Basin was interpreted from Enhanced Landsat TM image. The basin divided into 6 sub-basins. The drainage network of each sub-basin had been analyzed, and their geomorphometric parameters were calculated. Digital elevation model (DEM) was used to determine the slope and aspect of the sub-basins. The geomorphometric parameters of Wadi El-Arish sub-basins reveal their low flash potentiality. The occurrence of a flash flood in the northern part of Wadi El-Arish Basin is mainly due to its high circularity that drives runoff water to come out of the southern sub-basins outlets nearly at the same time. The runoff water is combined at the area between Daikat El-Khorm and Daikat El-Halal. Two sites had been selected, as recommended sites to construct new dams to effectively mitigate the Wadi El-Arish flash flood located at the entrance of Daikat El-Khorm and Daikat El-Halal.

All the Wadi El-Arish sub-basins have low flash potentiality, due to their low drainage density, stream frequency, moderate bifurcation ratio, and their elongation shape (Abd-El Monsef 2010). The possibility of the initiation of the flash flood is still high in the area located between Daikat El-Khorm and Daikat El-Halal. This is due to the high circularity of Wadi El-Arish Basin, that makes the runoff water come through south sub-basins of Wadi El-Arish meet nearly at the same time in this area. The initiation of such flash flood needs a heavy precipitation storm, to allow runoff to go through the long path of the southern sub-basins and overcoming the infiltration capacity of the fractured limestone that covers most of the surface, and the high evaporation rate characterized the area. This might be why the flash flood happened once every two decades in Wadi El-Arish Basin. The idea of developing a retardation dam system through Wadi El-Arish Basin will be faced with a critical objective, in addition to delay the flow time, retardation dams should not allow the runoff water from reaching Daikat El-Khorm at the same time. On Monday, January 18, 2010, the runoff water filled the embankment of El-Rawafaa dam by 5.5 million cubic meters and started to pass the dame toward El-Arish town. The fallen of El-Rawafaa dam to protect El-Arish town raises the high demand of other dams to protect the city.

Two suitable locations for new dams (Fig. 4) were proposed by Abd-El Monsef (2010). The first location is sited at the entrance of Daikat El-Khorm. An embankment for this dam can easily be constructed on the southwest side of the dam where an area of about 80 km^2 and an average depth 8 m compared with the surrounding heights is existing. This embankment can store the runoff water coming from Wadi El-Bruk, Wadi El-Arish, Wadi El-Ruaq, and Wadi El-Aqaba sub-basins. The second location is sited at the entrance of Daikat El-Halal. An embankment for this dam can be constructed in the area located on the south side of the dam where an area of about 77 km^2 and average depth 6 m compared with the surrounding heights is present. This embankment can store the runoff water coming from Wadi El-Quraia sub-basin. This embankment can work as backup reservoir for the first dam.

Sumi et al. (2013) forecast flash floods and propose mitigation strategies in order to reduce the threat of flash floods and water harvesting. A combination of RS data and a distributed Hydrological model so-called hydrological river basin environmental assessment model (Hydro-BEAM) has been proposed for flash flood simulation at Wadi El-Arish, Sinai. Simulation has been effectively done to flash flood occasion that hit Egypt in January 2010. Simulation results present remarkable characteristics, for example, the short time to the maximum peak, short flow duration, and serious damage resulting in difficulty in evacuating people from the vulnerable regions. Six outlet points have been selected based on sub-catchments of the target wadi for this simulation as depicted in Fig. 4. Simulation results of this event show that flash flood characteristics are highly variable from one outlet to another in terms of flow rate and time needed to reach the maximum peak within the whole watershed. Furthermore, at the downstream outlet at Wadi El-Arish catchment, the flow was very severe, at 2864.84 m^3/s. At W. Abu-Tarifieh, one of the sub-catchments of Wadi El-Arish, the discharge was calculated about 240.52 m^3/s, and the discharge of all sub-catchments was also calculated.

Time to peak and flow duration in flash flood simulations have been estimated. Time to peak averaged between 8 h in the upstream regions and 17 h at downstream outlets, which mean that time is very short. In other words, evacuating people are very difficult in such arid regions. In terms of evaluation of sub-catchments water contribution toward Wadi El-Arish, the flow volume of water that can reach the downstream point of each sub-basin has been calculated (Table 2).

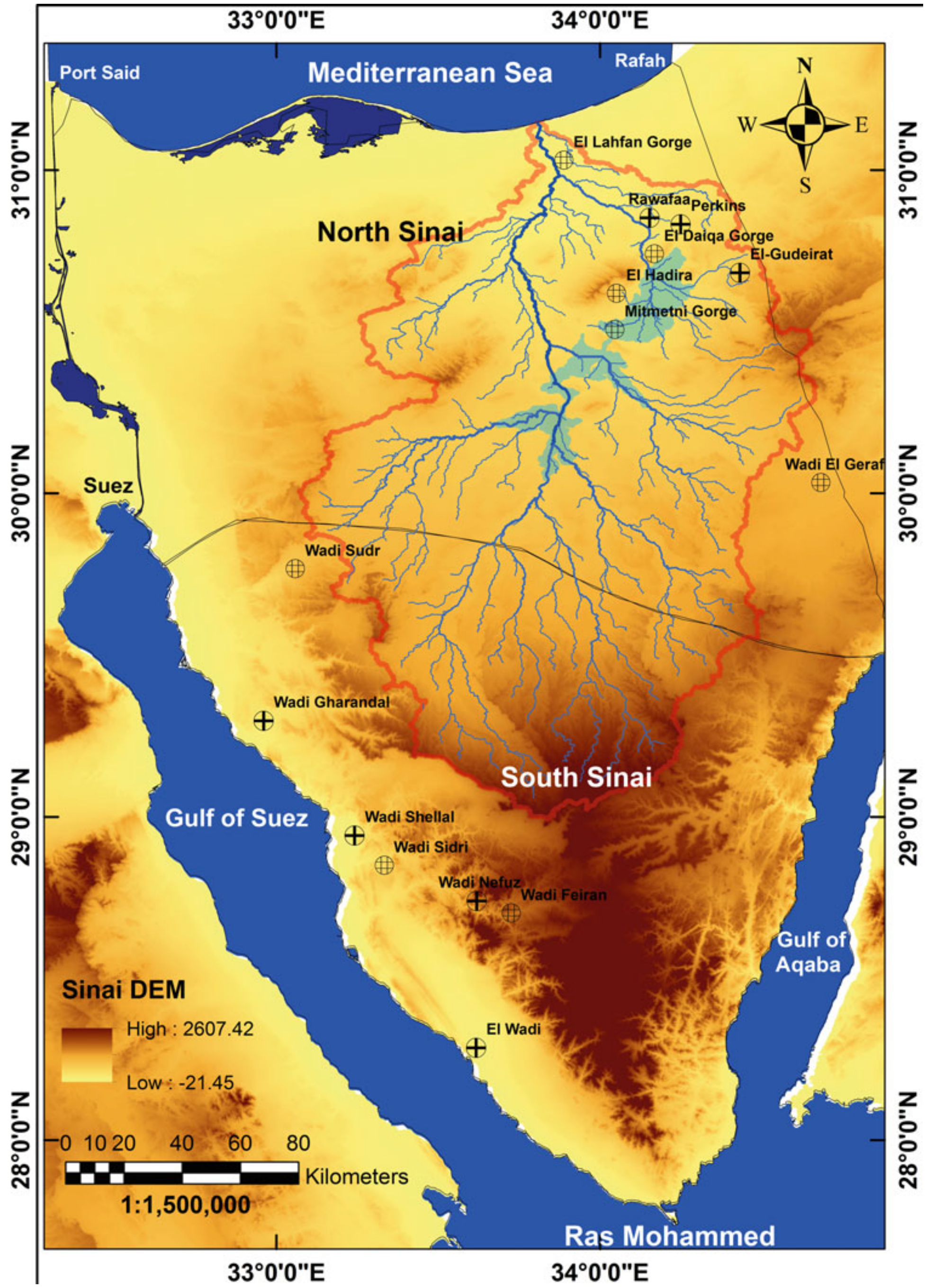

Fig. 4 Suitable locations for new dams of Wadi El-Arish catchment, Sinai

3.4 High Potential for Groundwater Recharging

Masoud (2011) predicted the runoff infiltration volume, and the sites demarcated to conceivably have a high potential for the flash flood in Southern Sinai. The groundwater recharge could enhance the solutions for the flood risk mitigation and the accessibility of water from the wadi systems. Runoff controlling systems could reduce flood vulnerability and save a considerable amount of water in these harsh environments. Located sites for conceivable high flash flood hazards and groundwater recharging appear in Fig. 5. About 50 % of the sites determined to likely have a high potential for groundwater recharging their wells dug for domestic use by the local Beduin in particular in W. Feiran, W. Sidr, St. Catherine area, and Sudr and El-Qaa Plains where shallow Quaternary aquifer underlies the terrain. Among the catchments anticipated having high flash flood potential, the catchment of W. Dahab displayed the highest rank followed by the W. Fieran and W. Watir catchments. W. Kid and W. Al-Awaj had an intermediate potential. The catchments of

Table 2 Simulation results of event (Jan. 18–22, 2010) at Wadi El-Arish

Sub-catchments of Wadi El-Arish Outlets	Time to peak (h)	Peak discharge (m^3/s)	Flow volume (m^3)
Wadi El-Arish1	17	2864.84	3.54×10^8
Wadi El-Arish2	14	1080.38	1.26×10^8
Wadi Griha	13	1050.41	1.26×10^8
Wadi El-Barok	10	885.38	9.9×10^7
Wadi Eqabah	7	386.66	4.5×10^7
Wadi Abu-Tarifieh	8	240.52	2.7×10^7

W. Sidri, W. Gharandal, Ras Nusrani, W. Sudr, W. Samra, W. Tayyibah, W. Lahata, and W. Wardan exhibited low potential. Among the catchments that had high groundwater recharge potential, W. Watir had the highest potential, followed by W. Al-Awaj. The catchments of W. Feiran, W. Dahab, W. Sidri, and W. Samra had intermediate groundwater potential. W. Gharandal, W. Sudr, W. Kid, W. Tayyibah, Ras Nusrani, W. Lahata, and W. Wardan fell inside the low potential class. Ghodeif and Gorski (Ghodeif and Gorski 2001) indicated that the recharge rate (32,000 m^3/day) of the Quaternary aquifer underlying the El-Qaa Plain where W. Al-Awaj flows surpasses the discharge (26,000 m^3/day). Thus, W. Watir could be promising for groundwater exploration as it has significantly higher potential than W. Al-Awaj. The present rainfall-runoff model displayed a rainfall volume sum of 725.5×10^6 m^3. The rainfall distribution over the three components was 307.8×10^6 m^3 (43.4 % runoff volume), 131.5×10^6 m^3 (18.1 % initial loss), and 286×10^6 m^3 (39.4 % transmission loss). The shallow groundwater aquifer recharge was estimated about 57.5 % of the total rainfall. An assessed recharge over the mountainous St. Catherine area resulting from the individual large storm was 135.4×10^6 m^3, which was 50 % of the total precipitation (Masoud 2011).

Numerous studies (Ramli 1982) have shown that a large part of rainwater is lost by evaporation and surface runoff. The total annual precipitation of the Sinai is about 3 billion m^3, most of which is lost by evaporation or surface runoff, and only about 300 million m^3 of groundwater (Dames and Moore 1985). The majority of rainwater falling on the Sinai was lost and not used. In addition to the devastating impact of the floods on the facilities and crops, it also has an impact on desertification of large areas of Sinai. Therefore, it is necessary to develop a scientific plan to harvest the largest amount of rainwater by establishing different dams at the appropriate sites. There are several dams in Sinai, the most famous and the oldest and the largest is the Ruwafa dam.

There are some of the proposed sites for the construction and building of some dams based on the study of satellite images and the field study. The following proposed 37 sites for the construction of dams (Ramli 1982): (1) At the intersection between Wadi Heirdeen with Wadi El-Arish. (2) At Wadi El-Garor. (3) At Wadi Qaria (West South Gebel umm Hadira). (4) At the intersection between Wadi Gadei with Wadi El-Arish (North Gebel Magmel). (5) At Southwest Gebel Al-Khatemia (North Gebel ummKhosheib). (6) Mittla Pass area (the area between Mittla Pass and Wadi Al-Hag). (7) At Wadi Akaba (North and Northeast Qalaet-Nakhel). (8) At Wadi Akaba (West Gebel Al-Reesha). (9) At Awlad Ali area. (10) At Wadi El-Geifi (South El Qussiema). (11) At Talaet Al-Badan (at Al-Rawafa George). (12) At Wadi El-Bruk, at its crossing with Wadi El-Arish, West and Southwest Gebel Khereem. (13) At Wadi El-Hassana (North Gebel El-Monshareh). (14) At the connection between Wadi El-Bruk with Wadi Abou Kanadu, Northeast El-Kuntilla well, and Wadi El-Geifi. (15) At Wadi Al-Tamarni (Southwest El-Kontilla). (16) At Wadi Al-Rawaq. (17) At Wadi Al-Thamad (north Bir Al-Abd). (18) At South of Nakhel (at the crossing of Wadi Abu-Aligana with Wadi Ei-Arish). (19) At Wadi Sudr. (20) At Wadi Werdan (North East Ras Matarma). (21) At North East Wadi Al-Massagid (West Gebel Lobna). (22) At Wadi Graa (West Al-Aqaba Gulf). (23) At Wadi Sidri (East Abu Rudees). (24) At Wadi El-Garaf (East Abou Zinema). (25) At Wadi Al-Akhadar (North East Feiran oasis), and Wadi Feiran (West and Northwest Feiran oasis). (26) At the Wadi which drains in El-Qaa plain from Gebel Qobyliat (North and Northwest El-Tor). (27) At Wadi Berriraq and Abu Tarika (El-Egma plateau). (28) At Wadi Al-Aaeb, Wadi Al-Nasseib, and Wadi Nasaib (draining in the Delta, Dahab). (29) At Wadi Kid, Wadi Umm Adwi Lethi, and Nabaq area. (30) At Wadi Zelefa and Wadi Arada (North and Northwest Gebel Gena). (31) The Wadis which pour in El-Qaa plain from Gebel umm shomer and Gebel Al-Thabat, Wadi Al-Mahash, and umm Qterkha. (32) At Wadi Al-Tamrani and Wadi Al-Qries. (33) At Wadi Zelieq and Wadi El-Biar (Southeast El-Emag plateau). (34) East Sant Khathrine and Gebel El-Banat, Northwest Sant Khathrine, West and Northwest Gebel El-Banat. (35) Al-wadi area, (West Gebel Al-Thabat and Gebel umm Homata), pour in El-Qaa plain. (36) At Al-Wadi area, between Ellatt and North Gebel El-Asafeer (West Gebel El-Barga and Wadi El-Qaseeb area).

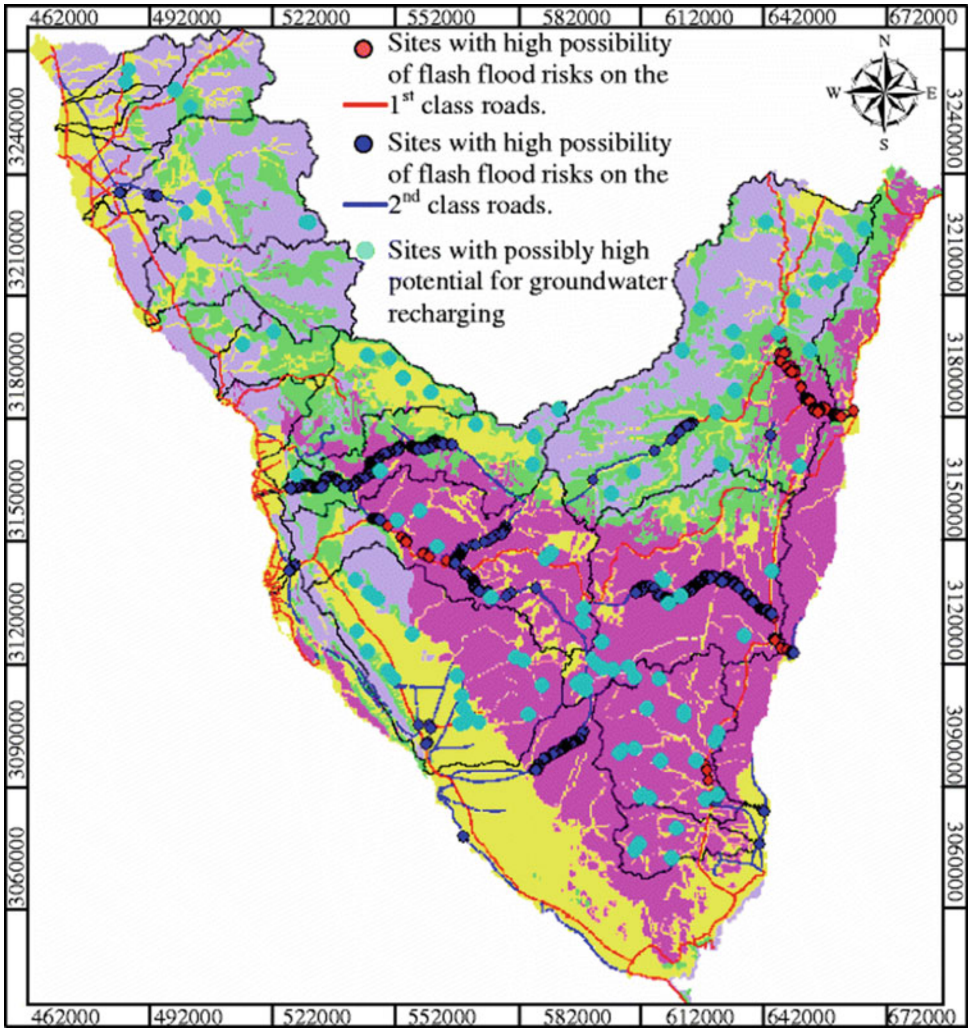

Fig. 5 Located sites for possible high potential for groundwater recharging in the South Sinai catchments (Masoud 2011)

(37) At Wadi Azala area (between Gebel Abu-Khusheib, Gebel El-Safra).

3.5 Floodwater Resources Management

3.5.1 Structural Dams and Artificial Lakes

The aim of floodwater harvesting is to store floodwater in artificial, closed ponds made of different materials. Different low-cost storage mechanisms for floodwater harvesting were identified to suit the different technical and socioeconomic conditions. Firstly, an underground concrete reservoir is one of the most appropriate water harvesting techniques and easily maintained by the Bedouins themselves. A small underground reservoir is capable of offering drinking water for a small Bedouins community and their livestock. As water is sealed in a concrete case, it is protected from evaporation. Secondly, a Haraba is a low-cost alternative to capture floodwater, often used by Bedouins (Dames and Moore 1985). A Haraba is a superficial basin excavated from limestone or rocks. In the case of sedimentary rock (with a high infiltration rate), stones and cement will be used. The main advantage is that in the construction of a Haraba, no building material needs to be brought in. The use of instruments, such as a compressor can, however, facilitate the excavation. The major disadvantage of a Haraba is that it is an open reservoir, and hence water is rapidly lost due to evaporation. Thirdly, one of the potential technically and highly requested by the stakeholders is a low-cost gabions dam with an underground reservoir as the one constructed in Wadi Ghazala (Fig. 6).

The traditional techniques applied comprise the following (Shata 1992):

1. Man-made cisterns or natural caves in the mountain edges adjacent to a Wadi bed (locally known as Harraba).
2. Low earthen or stone dykes in the Wadi beds (locally known as Oqum). They are usually protected by vegetation remains. The objective of these dykes is to reduce the passage of water downstream; not to store it.

Frequently, these dykes are damaged or destroyed by floods before they are stabilized by the substantial deposit of sediments.

3. Masonry dams for the storage of water. They include El-Rawafaa, El-Gudeirat, Perkins, Gharandal, Nefuz, El-Wadi, and Shellal.

El Shamy (1995) mentioned that traditional water controlling systems mostly depend on the construction of huge masonry dams with big lakes behind at the downstream parts of the hydrographic basins, frequently subjected to flash floods. In addition to their costly construction costs, these structures expose many environmental disadvantages such as the deprivation of pervious upstream formations from the only recharge source, the heavy evaporation from the concomitant, the soil and shrub drift by flash floods and the gradual silting of these dams. (El-Shamy 1992) proposed controlling systems, which must be started at the upstream tributaries of the hydrographic system using simple retardation dams. This will promote the recharge to the existing and fractured rock formations and allow a slow controlled runoff into the downstream areas with a consequent high chance for infiltration. The proposed system stabilizes the soil layer, enhances the growth of the plant cover, and gradually improves the local microclimate. The applicability of the system to some hydrographic basins in Sinai; viz, Wadi El-Arish, Wadi Suder-Wardan, and Wadi Watir, is showed in Fig. 7.

Regardless of their dangerous impacts, flash floods in Sinai, and different parts of southern Egypt represent a potential for non-conventional freshwater sources. Dams have been utilized for protection against floods, diversion of streams, storing of water and irrigation of land, each of

Fig. 6 Underground (Haraba) reservoir construction for water harvesting in Wadi Watier near Nuweiba City. **a** Low-cost gabions and obstacle dam constructed in Wadi Ghazala, **b** (WRRI 2010) artificial lake, **c** water trap, **d** well, **e** water storage tank, and **f** for water saving in Feiran Oasis

which is a technique for water control. They offer for agricultural irrigation. They are utilized to store and give tap water, further to more complex purposes, for example, hydroelectric power generation, rendering barren and infertile lands arable, and avoidance of erosion due to floods and accumulation of sand and clay at river-mouths. Water dams and reservoirs have essentially been utilized to serve four capacities [8]: Irrigate crops, provide hydroelectric power, supply water, and control flooding.

3.6 Check Dams Versus Diversion Dams

Check dams are known in Tunisia and west Libya. They consist of the "Tabia," which is the main structure built on the Wadi floor. These dams are suitable for slopy areas in the Gulf of Aqaba and the Gulf of Suez. Diversion dams and water spreading dykes are usually designed to improve pasture land and to protect plant life. These dams are most suitable for north central Sinai.

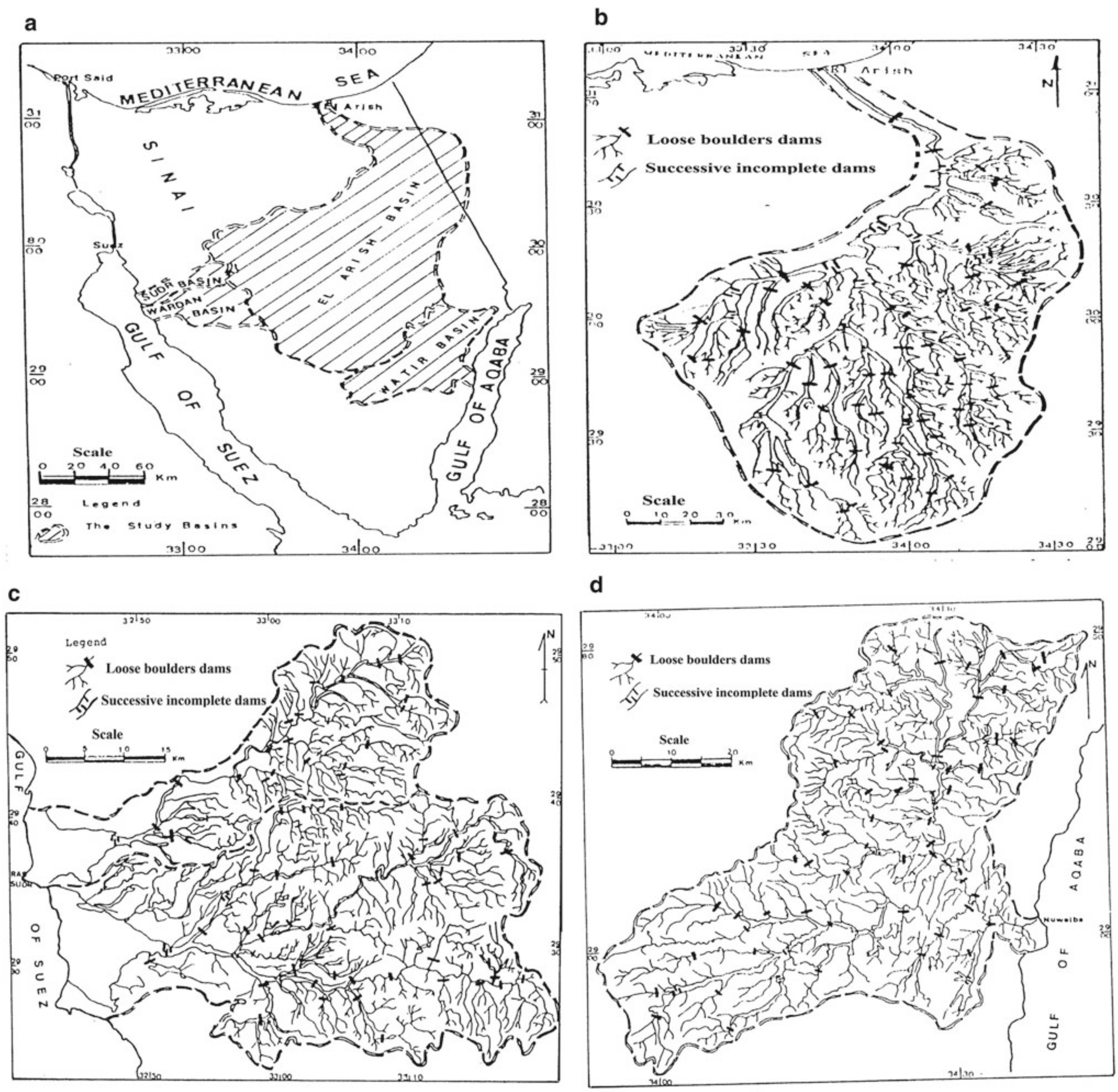

Fig. 7 **a** Location map of the Sinai' basins, **b** The proposed system for El-Arish mega-basin, **c** Proposed rainwater controlling system for Sudr-Wardan basin, and **d** for Watir basin (El-Shamy 1992)

Some workers (Dames and Moore 1985) referred to eight potential sites for this purpose (Table 3), which include the following: El-Daiqa, El-Mitmetni, Lehfin, and El-Hadhira in Wadi El-Arish Basin, Sudr, and Sidri in west Sinai, Feiran in South Sinai, and El-Gerafi in east Sinai. This type of dams is not suitable for an arid area like Sinai. Several reasons stand for this and include (Shata 1992) erratic rainfall and infrequent runoff water, high evaporation losses, pronounced seepage in the country rocks dominated by fractured carbonates, rapid siltation of the reservoir due to degradation of the surface (10,000 m^3/year), shortage of recharge of the areas downstream the dam site, and relatively high cost of construction of the dam and of water conveyance.

For such reasons, plans aiming at the construction of three new storage dams at El-Karm, El-Maghara, and El-Gudeirat, and increasing the height of El-Rawafaa old dam should be modified. Fourteen dams proposed for Wadi Wasit (Watir) in eastern Sinai can be completed in a similar way to the check dams known in Tunisia and western Libya. For Wadi El-Gerafi, the landscape is most suitable for conversion dams and water spreading.

Appropriate controlling systems must be started at the upstream tributaries of the hydrographic systems using simple retardation dams. This will promote the recharge to the existing previously and fractured rock formations and allow a slow controlled runoff into the downstream areas with a consequent high chance for infiltration. Moreover, the system stabilizes the soil layer, enhances plant growth, and gradually improves the local microclimate (El Shamy 1995).

It is expected that the establishment of adequate number of diversion dams and water spreading dykes in central and north Sinai as well as in the outlets of a number of wadis in west Sinai, (e.g., Wadi Sudr, Wadi Wardan, Wadi Baba, Wadi Sidri, and Wadi El-Qaa) is very important for many reasons. These reasons include increasing the agricultural and grazing activity, minimizing the degree of desertification, contributing to the productivity of the already degraded surfaces, harvesting a lot of water, recharging the underground water in the area, and decreasing the velocity of the runoff water which minimize the soil erosion. These dams also help in improvement of water supply system for irrigated agriculture.

The establishment of the various dams leads to the presence of communities around the areas of these dams to work with agriculture and grazing, as well as to reduce wastage of water, and reduce the speed of the flooding and thereby protect the soil from water erosion. Disasters such as floods disaster in El-Arish in 2010 may not return to the floods alone but as a result of the random nature of the establishment of the buildings in the corridors of the floods and without the work of the previous geological study of the area where the various facilities will be installed on them.

The total amount of rainfall and flash floods that could be used annually is estimated at around 1.3 billion cubic meters. This quantity can be increased to 1.5 billion cubic meters

Table 3 Possible dam sites in Sinai

Location	Possible purpose	Possible problems
El-Daiqa Gorge, El-Arish	Supply of water to El-Arish town; flood protection for El-Arish town	Deprivation of downstream areas; requires long conveyance system; evaporation loss relatively high
Mitmetni Gorge, El-Arish	Supply of water to El-Arish town; flood protection for El-Arish town	Deprivation of downstream areas; requires long conveyance system; evaporation loss relatively high
El Lahfan Gorge, El-Arish	Supply of water to El-Arish town; flood protection for El-Arish town	Possible foundation problems; long dam required; seepage losses could be high
Gebel El-Halal, El Hadira	Supply of irrigation water to El-Arish flood plain south of Gebel El-Halal	Expected yield is relatively low
5 km west of Ain Sudr, Wadi Sudr	Public supply at Ras Sudr; irrigation supply for Wadi Sudr delta; cultivation in bed of reservoir	Rate of siltation expected to be high; evaporation loss relatively high; expected yield is not high
Near Gebel Maghara (South Sinai), Wadi Sidri	Public supply for Abu Rudeis; irrigation water for Wadi Sidri Plain	Rate of siltation expected to be high; evaporation loss relatively high; expected yield is not high
Upstream of the Oasis of Feiran, Wadi Feiran	Flood protection for oasis; irrigation supply to the oasis and northern El-Qaa Plain	Rate of siltation expected to be high; evaporation loss relatively high
Near Kuntilla, Wadi El Geraf	Irrigation supply; groundwater recharge	Rate of siltation and evaporation expected to be high; modest yield; would require negotiations with Israel

upon taking the following measures (https://propertibazar.com/article/egypts-national-strategy-for-adaptation-to-cli):

- Extended development of dams and reservoirs to capture and use this water directly for drinking or farming, or for storage in reservoirs of groundwater.
- Using modern techniques in the field of water harvestings, such as RS and GIS, in order to study the basic properties of the flood-prone areas. This involves studying and analyzing surface runoff as well as identifying basin and soil type features. Avoid the hazards of flash floods by mapping risk assessments for each region and taking suitable precautions to prevent potential risks (https://propertibazar.com/article/egypts-national-strategy-for-adaptation-to-cli).

4 Conclusions and Importance of the Study

Sinai is progressively suffering from an overwhelming water crisis. Flash flood and runoff water could be an answer for this issue. The central focus of this chapter rotates around utilization of the floods water as a new supply for water harvesting in Sinai. Applying water harvesting of the flash flood will reduce the flood risk at the outlet. In addition, it could be used for recharging the groundwater aquifers, which are the basis for sustainable development in Sinai. Furthermore, Bedouins usually move from place to place searching for fresh grazing for their animals and water for their families. These places sometimes are hazardous areas as flash floods occur there. This chapter helps to make developed sustainable planning for the Bedouins, as hazard areas will be defined. Proved locations to get use of the flooded water and store it will encourage the Bedouins to resettle the area. The total amounts of rainfall affecting the different drainage systems in Sinai is of the order of 2,000 million m^3/year, and most of possible runoff water is about 150 million m^3/year.

Structural dams and artificial lakes are highlighted in this chapter to utilize the flash flood.

Because of their features, flash floods are hard to handle through traditional approaches to flood management. The following must be regarded during the development of a management plan for flash floods.

– Flash flood prediction and warning play a key role in flash flood management. However, providing users with precise and timely forecasting and warning data is still a challenge at times. Appropriate technical methods and suitable legal and institutional frameworks are needed to address these issues.
– Appropriate spatial planning can assist decrease exposure and decrease flash flood risks.

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