



Water Harvesting for Sustainable Development of El-Hraka Basin in The North-western Coast of Egypt



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WATER resources in the Northwestern Coastal Zone (NWCZ) of Egypt are very limited in terms of quantity, as they are produced mainly from rainwater in the winter season. Water scarcity is the main impediment to development activities in the region. Prepare Rain Water Harvesting (RWH) is one of the most effective solutions to beat this problem. The study area (El-Hraka basin) is located in northwest coast of Egypt near Matrouh city. The aim of this study is to assess the potentiality of El Harak basin for water resources management and agricultural development activities. The study aimed also to predict annual peak flow and runoff water volume, as well as the 20, 10, 5, 3, and 2 year return periods. Results referred that El-Hraka basin characterized by an area of 178.31km², basin length of 33.70 km, perimeter of 132.8 km, and gentle slope of 0.012 m/m. There are four types of land use/land cover in the study basin named: agriculture land, bare land, rocky areas and urban representing 3.45, 92.98, 3.41 and 0.16% of El Hraka basin, respectively. There are two hydrologic soil group of the study basin A and C depending on the soil texture. The Curve Number (CN) depending on the land use / land cover and the hydrologic soil groups. Its average values are 73.67 for El-Hraka basin. The annual runoff water volumes are 10583.29 m³ that recharge the groundwater reservoir. However, the annual infiltration volumes are 8195.01 m³. The peak flow of the 20, 10, 5, 3 and 2 year return periods flash flood is 29.24, 17.98, 9.50, 3.78 and 0.75 m³/s respectively. The runoff volume of the 20, 10, 5, 3 and 2 year return-periods is 2.78 million, 1.71 million, 906,578.6, 359,883 and 69,989.4 m³ respectively for the study basin.

Key words: NWCZ, Wadi El-Harak, RWH, CN, WMS Modeling, DEM HSG and SCS.

Introduction

The sustainable development aims at maintaining the equilibrium between the human needs and economic developments within the parameters of environmental conservation through efficient use of natural resources to ensure trade-off between desired productions—consumption levels. The development of natural resources is based on maintaining the fragile ecosystem balance between the productivity functions and conservation practices through monitoring and identification of problem areas (Yousif et al., 2013). The NWCZ of Egypt is one of the most

attractive desert regions for sustainable agriculture development due to its abundant qualifications, which have not sufficiently used yet (Mohamed et al., 2015). Water scarcity is the main impediment to development activities in the region. Prepare Rain Water Harvesting (RWH) is one of the most effective solutions to beat this problem.

The surface water in the coastal area is very limited in magnitude as it originates from the rainfall of the winter season (El Bastawesy et al., 2008). Low rainfall affects the agricultural activities in these areas. Rainfall is characterized by its low value and uneven distribution. In

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addition, most of the rainwater is lost by soil surface through turbulent flow and runoff to different small valleys. Several factors can affect agricultural production, but water is the most important factor (Oweis and Hachum, 2003).

RWH is defined as a method for inducing, collecting, storing, and conserving local surface runoff for agriculture in arid and semi-arid regions, Rainwater harvesting may include micro-catchment or macro-catchment runoff farming (Abd-El Aaty *et al.*, 2017). As well as, RWH should be prioritized either for surface storage or for artificial recharge since this support in sustainable management of water resources. The water harvesting process of concentration of runoff from a large area within the watershed. The concentrated runoff can later be used in a smaller area for various activities. RWH deals with a large number of spatial data that can be easily treated using geospatial techniques. Remote sensing and geographic information systems applications are used in the fields of hydrology and water resource development (Sharma and Kujur, 2012).

Temporary surface runoff occurs immediately after rainy periods and represents a definite percentage of the rainfall. Water runoff differs from one locality to another depending on some factors such as slope, topography, nature of cap rock, field water capacity and the catchment area. Therefore, water harvesting systems are applied through the construction of soil, cemented and/or stony dykes established between different levels along the streams. In limited areas, supplemental irrigation with shallow well water is used (DRC 2015). Assess the rainfed natural resources of Marsa Matrouh area by integrating RS, GIS and hydrological modeling methodologies. Many studies have been conducted on flood susceptibility mapping using RS data and GIS tools (Abdel-Kader and Yacoub 2009). The watershed modeling system (WMS) approach involving the integration of digital elevation model (DEM), meteorological data, land use/land cover, soil type and hydrological model to assess the potentiality of two important basins (Umm Ashtan and Umm El-Rakham) near the city of Mersa Matrouh for water resources management (Abdel Ghaffar *et al.* 2019).

The main objective of this research is to assess the potentiality of El Harak basin near the city of Mersa Matrouh in NWCZ of Egypt for water resources management and agricultural development activities. The study aimed also

to predict annual peak flow and runoff water volume, as well as for the 20, 10, 5, 3, and 2 year return periods.

Materials and Methods

Location of the study area

The study area (El-Harak basin) is located near the city of Mersa Matrouh in NWCZ of Egypt. It lies between longitudes 27° 25' 45.747" E and 27° 20' 5.097" E and latitudes 31° 13' 23.926" N, 30° 55' 54.439" N, with total area of 178.31 Km² (42454.7 Fadden) (Fig.1) shows the geographical location of the study area.

Metrological data

The climatic conditions of the NWCZ including the study area is typically arid to semi-arid, characterized by a long hot dry summer, mild winter with little rainfall, high evaporation with moderately to high relative humidity. Table (1) showed the meteorological data (2001-2015 year) in the Matrouh station obtained from CLAC (2015). According to UNESCO (1977), the study area is classified as arid with mild winter and warm summer.

The Mediterranean coastal zone of Egypt receives noticeable amounts of rainfall, especially in winter. The rainy months are October, November, December, January, and February. In summer, no rain is recorded, while in autumn, occasional heavy rain may occur (Yousif *et al.*, 2013). Climatic change in coastal zone of Egypt (with 500 km long and 20 km width) would increase drought with high fluctuation in precipitation (FAO 2008). The NWCZ receives amounts of annual rainfall where distributed in the form of surface runoff, and/or infiltrate to recharge the groundwater (El-Sharabi, 2000).

Bonnet *et al.* (2014) showed that the average annual long-term rainfall in the NWCZ of Egypt is low (about 150 mm/year) in the vicinity of the seashore with gradually decreasing rainfall to the south. The means of annual rainfall ranged from 263.13 mm/year during 2007 to 60.96 mm/year during 2014 with an average of 127.2 mm/year (increasing from West to East and from South to North). The mean Annual precipitation (mm) is showed in Fig. 2.

Data

- Planet Scope satellite imagery was used to extract the information and base map for the study area. The images characteristic shows that, the resolution is 3 meter, with multispectral imager of 4 spectral bands. The acquisition date in 16 September 2018 with 0% of cloud covers.



Fig. 1. The geographical Location of the study area and soil profiles

TABLE 1. The meteorological data (2001-2015) in the Matrouh region

Year	Tmax.	Tmin.	Tmean.	SLP	H	PP	VV	V	VM	VG	RA	SN	TS	FG
2001	24.98	15.55	20.34	1015.60	66.25	98.30	9.97	17.70	28.30	0.00	1.75	0.00	0.00	0.42
2002	24.81	15.70	20.36	1015.74	67.03	183.10	10.06	15.10	25.61	0.00	2.25	0.08	0.08	0.17
2003	24.72	15.57	20.14	1014.92	66.40	160.53	9.81	15.93	26.79	0.00	3.17	0.00	0.00	0.25
2004	24.54	15.55	20.07	1015.82	62.63	93.98	10.11	16.53	26.55	0.00	1.75	0.00	0.00	0.17
2005	24.13	15.94	20.03	1015.88	62.34	103.37	10.14	18.27	29.30	0.00	2.17	0.00	0.00	0.33
2006	24.40	15.67	20.00	1015.63	65.55	114.55	9.98	19.94	31.69	0.00	2.58	0.00	0.08	0.17
2007	24.48	15.75	20.17	1015.26	67.52	263.13	9.99	20.89	31.87	0.00	2.00	0.00	0.00	0.25
2008	25.21	16.05	20.68	1015.67	65.74	137.16	9.97	16.36	26.38	0.00	3.00	0.00	0.25	0.50
2009	24.76	15.80	20.38	1014.71	63.28	109.50	9.74	15.73	25.53	0.00	1.42	0.00	0.25	0.50
2010	25.90	16.48	21.13	1014.38	62.98	87.12	9.75	17.98	29.51	0.00	0.67	0.00	0.00	0.33
2011	24.42	15.59	20.03	1015.38	66.06	185.72	9.90	17.13	27.59	0.00	2.58	0.00	0.08	0.33
2012	25.07	16.34	20.71	1014.55	67.11	103.62	9.87	18.83	29.62	0.00	2.00	0.00	0.08	0.08
2013	25.01	16.08	20.52	1014.92	67.48	120.39	9.61	19.95	30.49	0.00	1.42	0.00	0.00	0.25
2014	25.43	16.06	20.71	1015.50	68.20	60.96	9.48	18.30	29.23	0.00	1.17	0.00	0.25	0.00
2015	25.15	15.75	20.38	1016.23	68.47	86.37	9.63	18.47	30.39	0.00	2.67	0.00	0.42	0.17
Average	24.87	15.86	20.38	1015.35	65.80	1907.80	9.87	17.81	28.59	0.00	2.04	0.01	0.10	0.26

Interpretation

Tmax: Maximum temperature (°C)
 Tmin: Minimum temperature (°C)
 T mean: Mean temperature (°C)
 SLP: Mean sea level pressure (hPa)
 H: Mean humidity (%)
 P: Precipitation amount (mm)
 VV: Mean visibility (Km)

V: Mean wind speed (Km/h)
 VM: Maximum sustained wind speed (Km/h)
 VG: Maximum wind gust (Km/h)
 RA: Indicator for occurrence of: Rain or Drizzle
 SN: Indicator for occurrence of: Snow or Ice Pellets
 TS: Indicator for occurrence of: Thunder
 FG: Indicator for occurrence of: Fog

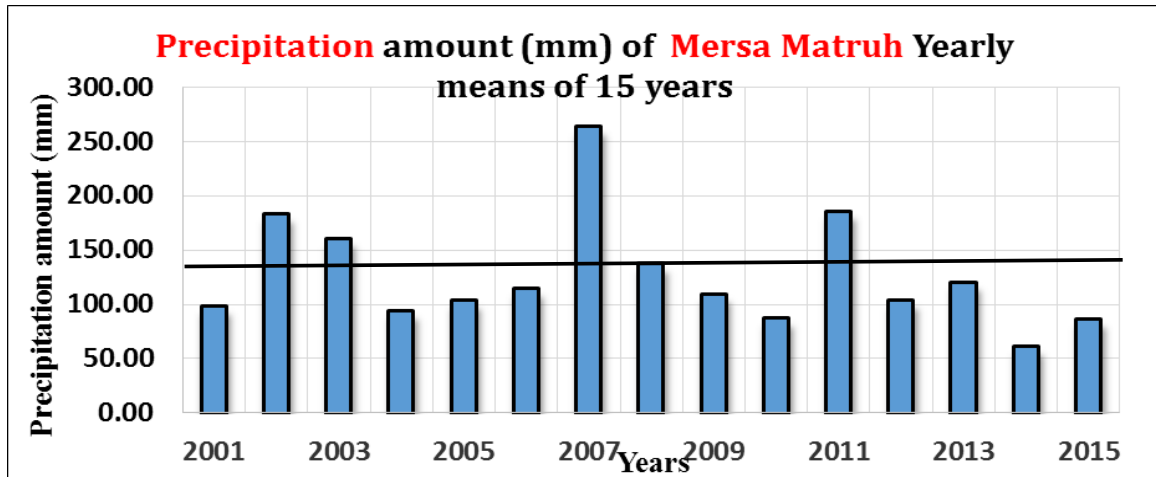


Fig. 2. Mean annual precipitation (mm) of Matrouh station (2001-2015)

- Fourteen topographic maps of the study area scale 1: 25000 produced by the Military Survey Authority (MSA; 1986) of Egypt to extract the contour lines and spot highs for create the Digital Elevation Model (DEM).

Softwares

- ERDAS Imagine version 2015 software for land use/ land covers image analysis.
- Arc GIS version 10.4.1 software for constructed DEM and define the hydrological parameters and curve number (CN).
- Hyfran plus software was used for estimation of the rainfall intensity for different return periods.
- Watershed Modeling System (WMS 10.0) software to determine basin boundaries, drainage lines, morphometric parameters and rainfall-Runoff values.

Field work

Field work includes investigation of the study basin and collect of soil profiles. The locations of soil profiles were definite by using Global Position System (GPS). Fifteen soil profiles were morphological described and collected according to the differences between the layers in profiles (see Fig.1). Soil profiles were described and defined according to guideline of Soil Survey Manual (2017).

Laboratory analyses

Soil samples collected to represent the different variations of soil profiles were air-dried, crushed and sieved through a 2 mm sieve for some physical and chemical analysis.

Hydrological studies

a. Generating the Digital Elevation Model (DEM)

The contour lines and spot height extract from topographic maps were using to create DEM.

b. Hydrological processing

Hydrological parameters of El-Harak basin was extracted by using digital elevation model (DEM) using the Arc hydro and hydrology tools (spatial Analyst Tools -Arc Tool Box) in Arc GIS V.10.4.1 software (ESRI (2017) and Maathuis and Wang, 2006).

c- Morphometric parameters

The basin boundaries and drainage lines of the study area were generated by using digital elevation model (DEM). In addition, the morphometric or geometric parameters were obtained for basin by using WMS 10.1 software.

d- Rainfall data analysis

The daily rainfall data from meteorological station of Matrouh (2001-2015) (provides only the daily rainfall data) have been used in order to conclude the maximal annual rainfall necessary data for the estimation of the rainfall intensity for different return periods by using Hyfran plus software.

e- Curve number (CN)

According to Zhan and Huang (2004) Curve Number "CN" values were computed by using the soil type and land use / land cover maps developed by Arc GIS 10.4.1 software.

f- Hydrological modeling

The Watershed Modeling System (WMS 10.1) was applied for the selected basin in the study area. The WMS provides tools for all phases

of watershed modeling including automated watershed delineation, morphometric parameter computation, hydraulic parameter computation {e.g. Time of concentration and Lag-Time (TL)} and result visualization EMRL (2015). The Natural Resources Conservation Service (NRCS) runoff equation was developed to estimate the total storm runoff from total precipitation (NEH, 1993).

HEC-1 model "Hydrologic Engineering Center" in WMS software was used for simulation of the El-Hraka agricultural watersheds in the study area. The model was developed mainly for coastal regions and for large watersheds (USACE, 2000).

Results and Discussions

The NWCZ of Egypt consists of three geomorphic units namely; northern coastal plain, southern tableland and piedmont like plain (Hammad et al. 1981). According to Yousif (2019) the main landform units were extracted using the digital elevation model DEM, slope map, aspect map, Landsat 8 image (path 179, row 38) and field work data.

El Hraka basin was chosen as one of the largest basins in the NWCZ of Egypt (178.31 Km²) to study the hydrological and morphometric parameters in addition to the rainfall-runoff model

for annual and different returned periods.

Digital Elevation Model (DEM)

The elevations of the study area Fig (3), which ranges from – 0.58 m Below Sea Level (BSL) to 209.40 m Above Sea Level (ASL) with an average of 146.6 m and standard deviation of 54.90 m, were estimated by Arc GIS.

Some physical and chemical properties of the study soil

Jalhoum et al. (2014) conducted a study on the NWCZ of Egypt, mentioned that, in the soils of basin the pH values vary between 8.0 and 9.5. Soil EC values revealed that the salinity was low to moderate in surface layers and high in sub surface as it ranges between 5.68 and 26.74 dS/m. Calcium carbonate content ranges between 20.45 to 81.82 %. Also, Bahnasawy (2018) showed that soil texture of the studied profiles ranges between loamy sand and light clay except the subsurface layer of profile 3 in the soils of Marsa Matruh which is sandy texture. Organic matter (OM) content is quite low being in the range of 0.2 to 1.4 g/100g. Total CaCO₃ it ranged from as low as 16.6 and up to 73.8 g/100g. The distribution pattern of CaCO₃ tends to increase with soil profile, depth, except for the soils profiles, which did not portray any specific pattern with depth.

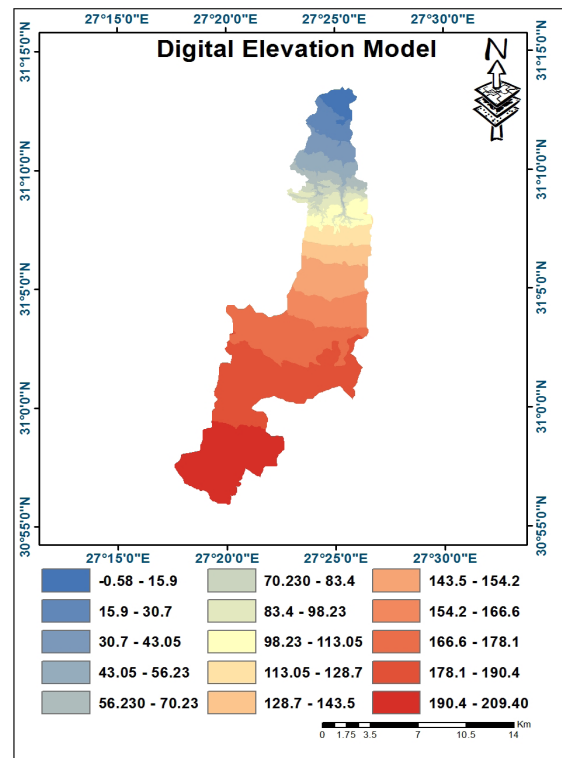


Fig 3. DEM of the study area

Data in Table 2 showed that, the soil profiles depth ranged from shallow (35 cm) to very deep (135 cm). The dominant textures of soil samples in different soil profiles are sandy clay loam, sandy loam, sand and loamy sand, respectively. These soils are moderately calcareous to extremely calcareous soils, where the content of total calcium carbonate ranged from 91.2 up to 281.8 g/kg. The gypsum content is generally low and ranged from 0.9 to 12 g/kg. The organic matter content "OM" is very low and ranged from 1.1 to 2.8 g/kg. These soils are moderately to strongly alkaline, where the soils have pH values in the range of 7.90 to 8.67. The electrical conductivity (EC) ranges between 1.17 and 31.83 dS/m; therefore, these soils were classified as non-saline to strongly saline soil.

According to the soil texture and chemical properties, the study basin is suitable for growing some field crops, *e.g.* wheat, barley and tomato

in shallow and moderately deep units, and horticulture trees, *e.g.* fig, date palm and olive, in the drainage basin.

Hydrological parameters by hydrology tools in Arc GIS software

Hydrology model depends mainly upon digital elevation model (DEM) to extract the required parameters. Slope classes, flow direction, flow accumulation, catchment, stream order and sub basin with optimal cisterns were performed for El-Hraka basin as shown in Figs. (4 to 9).

Daoud (2015) mentioned that, based on the surface analysis of digital elevation model (DEM) for wadi Naghamish in NWCZ; there are seven sub-basins have been identified. Each sub-basin has special characteristics in terms of land cover, soil type, rainfall amount, surface roughness and slope. All those factors have been taken into consideration when calculating the runoff factor.

TABLE 2. Soil texture and some chemical characteristics in the study soil profiles representing the soil landforms

Profile No	Depth (cm)	pH in (1:2.5)	EC (dS m ⁻¹)	CaCO ₃ (g kg ⁻¹)	Gypsum (g kg ⁻¹)	OM (g kg ⁻¹)	Texture
1	65	8.32	4.06	247.5	2.9	1.1	Sandy loam
2	70	7.97	8.24	226.2	2.8	1.6	Sandy loam
3	125	8.21	1.17	281.9	4.5	2.8	Sandy clay loam
4	105	7.99	3.15	91.2	0.9	2.2	Sandy loam
5	60	8.14	31.84	222	5.3	1.9	Sandy loam
6	130	8.04	1.70	245.4	6.2	1.8	Sandy clay loam
7	75	7.90	1.90	98.4	1.3	1.4	Loamy sand
8	135	8.25	2.40	267	5.5	1.6	Sandy clay loam
9	35	7.96	1.69	263.4	3	2.6	Sandy clay loam
10	40	8.22	29.83	238.2	8.4	1.6	Sandy loam
11	55	8.13	1.86	270.1	2.6	1.7	Sandy clay loam
12	40	8.32	1.65	228.7	2.3	2.7	Sandy loam
13	30	8.67	2.50	224	3.7	1.6	Sandy loam
14	30	8.29	3.50	225.4	3.4	2	Sandy loam
15	35	8.09	21.30	278.5	12	1.9	Sandy clay loam

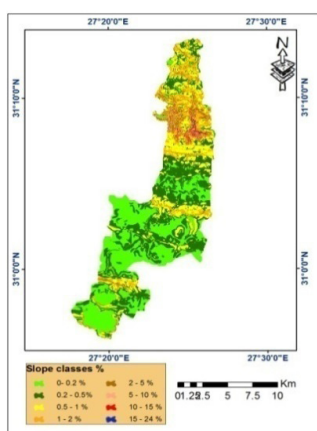


Fig 4. Slope classes

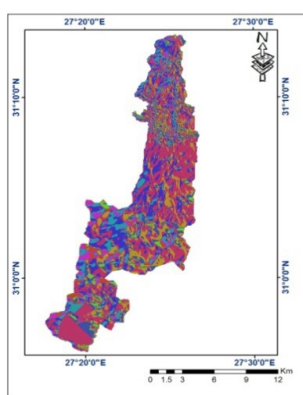


Fig 5. Flow direction

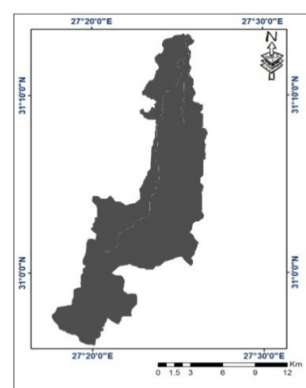


Fig 6. Flow accumulation

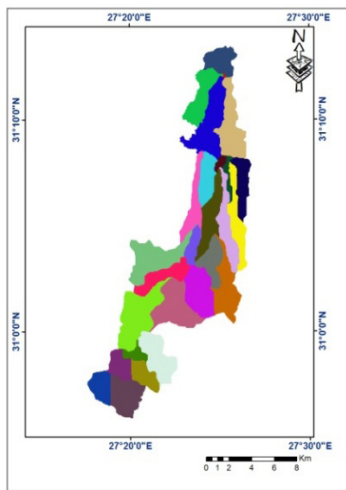


Fig 7. Catchment area

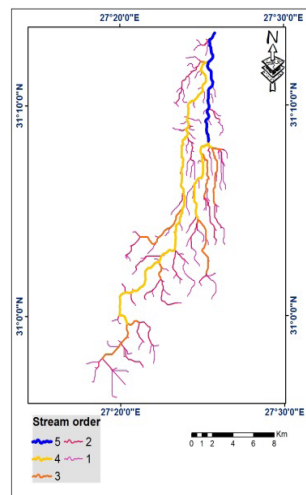


Fig 8. Stream order

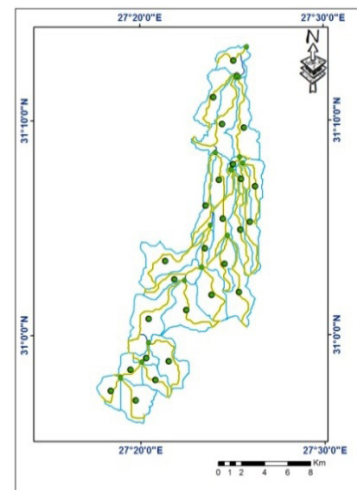


Fig 9. Sub basin and optimal cisterns

Watershed boundary and morphometric parameters by WMS

By using the digital elevation model (DEM) in WMS 10.0 software, the basin boundaries and drainage lines of the study basin were extracted (Fig. 10 a and b). In addition, the morphometric or geometric parameters (e.g. area, basin slope, basin length, maximum stream length, centroid stream distance, perimeter, shape factor and sinuosity factor) were automatic calculated for the study basin (Table 3).

Results showed that El-Hraka basin is characterized by large basin area (178.31km²), basin length of 33,70 km, perimeter of 132. 8 km

and gentle slope (0.012 m/m). Also, maximum stream length (40.1 km), centroid stream distance (21.9km), lower shape (6.38 m²/m²) and sinuosity factors 1.19. Morisawa (1959) and Verstappen (1983) referred that basin area is identified as the most significant of all the morphometric parameters dominating the catchment runoff pattern. This is due to the fact that the larger the size of the basin, the large amount of rain it is exposed to great and the higher the peak discharge that result. On other hands, Jain and Sinha (2003) mentioned that the basin area is highly correlated with some of the other catchment hydro-morphometric characteristics, like as length of basin which influences runoff.

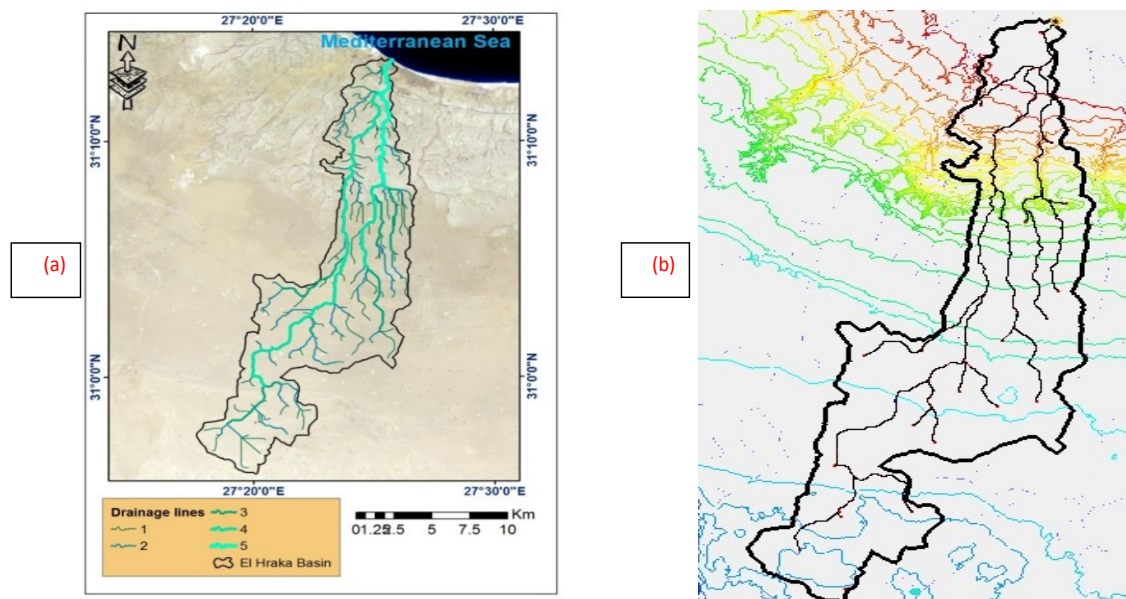


Fig. 10. The drainage lines and basin boundaries of the study area produced from ArcGIS (a) and WMS model (b)

TABLE 3. Some morphometric parameters of the study basin calculated by WMS software

Basin name	Basin Area (A) (Km ²)	Basin slope (BS) (m/m)	Basin Length (L) (km)	Perimeter (P) (Km)	Shape Factor (m ² / m ²)	Sinuosity Factor (Sin) (MSL/L)	Max Stream Length (MSL) (Km)	Centroid Stream Slope (CSD) (km)	Centroid Stream Slope (CSS) (m)
El-Hraka	178.31	0.012	33.70	132.8	6.38	1.19	40.1	21.9	0.0070

Curve Number (CN) of the study basin

The Curve Number parameter is dimensionless and varies between 0 (maximum infiltration) and 100 (zero infiltration). Low CN values mean that the surface of the basin has a high potential to retain water, whereas high values indicate that the rainfall could only be stored to a limited extent (Xiao et al., 2011). The CN is depending mainly on the land use / land cover and the hydrologic soil groups (HSG) of the study basin as follows:

a- Land use / Land cover map

There are four types of land use / land cover in the study basin: agriculture land, bare land, urban and rocky areas according to the field observation, Google earth and visual interpretation of Planet Scope satellite (3m resolution) (Fig. 11).

b- The hydrologic soil groups (HSG) map

Soil types were simplified and reclassified as soil textures by using Kriging interpolation in ArcGIS Desktop 10.4.1. The soil texture classifications were reclassified to Soil Conservation Service (SCS) Soil Types (hydrologic soil groups; HSG) A, B, C and D depending on soil infiltration (Table 4) (USDA, 1986). Type A has the highest infiltration rate, while type D has the lowest infiltration rate.

The hydrologic soil groups (HSG) in the study basin include only two types according to the soil texture (Fig. 12). Soil group (A) which have loamy sand (LS) and sandy loam (SL) textural classes and it has a high infiltration rate.

Data in Table 5 indicated that, the average curve number "CN" values using different combinations of land use / land cover and HSG for El-Hraka is 73.67.

Annual runoff and infiltration volumes for the study basin

In basins where monitoring activity doesn't present, the SCS-CN method can be used to appreciate the depth of direct runoff from the rainfall depth, providing an index describing

runoff response characteristics. To clarify these curves mathematically, the model assumes proportion between the ratio of actual retention (F) to potential maximum retention (S), and the ratio of actual runoff (Q) to potential maximum runoff (P) {expressed as rainfall (P) minus initial abstraction (Ia)}.

The equations are expressed as follows:

$$P = Ia + F + Q \quad (1)$$

$$F/S = Q/P - Ia \quad (2)$$

where: F = actual retention (inch)

S = potential maximum retention (inch)

Q = accumulated runoff depth (inch)

P = accumulated rainfall depth (inch)

After runoff has started, all additional rainfall becomes either runoff or actual retention.

$$F = P - Ia - Q \quad (3) \quad Ia = 0.2S \quad (4)$$

Combining equations (1), (2), (3) and (4) gives an expression for Q:

$$Q = (P - 0.2S) / (P + 0.8S) \quad (5) \text{ according to Bedient \& Huber (1992).}$$

Eq. (5) is valid for $P \geq Ia$, otherwise, $Q = 0$.

The equation for the potential maximum retention is defined as:

$$S = (1000/CN) - 10$$

The runoff water and infiltration volumes are calculated as follows:

Volume of runoff water (m³) = A * Q where A: Basin area

Infiltration volume (m³) = F * A * area exposed percent; after convert Q from inch to cm (by multiple in 25.4) and A from Km² to m² (by multiple in 1000).

Results referred that, the annual runoff water volume for EL-Hraka basin is 10583.29 m³, however the annual infiltration volume is 8195.01m³ which recharge the groundwater reservoir (Table 6).

TABLE 4. Hydrologic soil groups, Infiltration Rate classes and Soil Texture of the study basin

Group	Infiltration Rate classes	Infiltration rate (mm/hr.)	Soil texture
A	High	> 25	Sand, Loamy sand, or Sandy loam
B	Moderate	12.5-25	Silt loam or loam
C	Low	2.5-12.5	Sandy clay loam
D	Very Low	< 2.5	Clay loam, Silty clay loam, Sandy clay, Silty clay

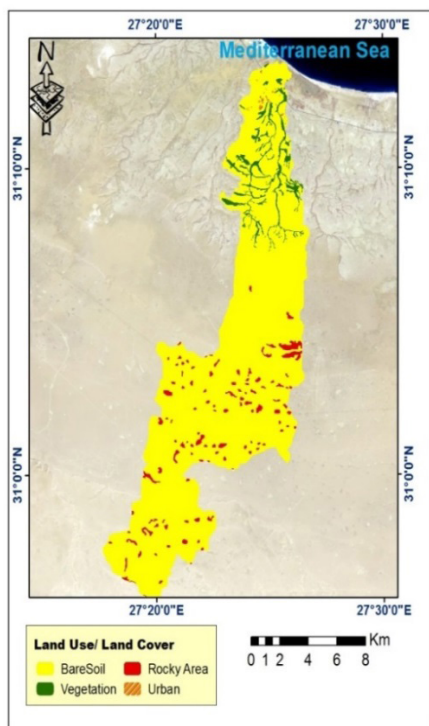


Fig 11. Land use or Land cover map of El Hraka basin

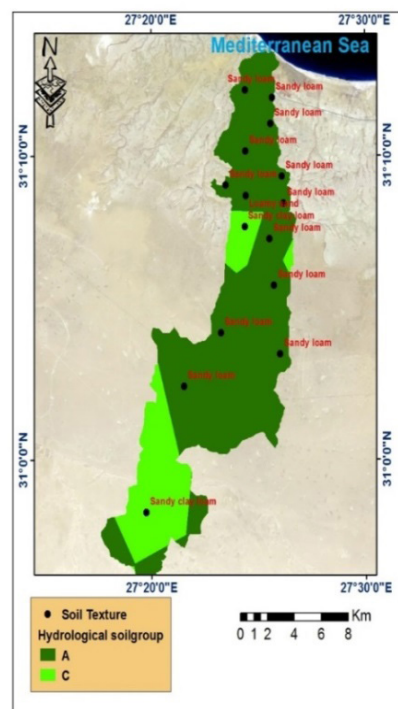


Fig 12. Hydrologic soil group map of El Hraka basin

TABLE 5. Calculate average Curve Number value for El Hraka Basin

Land use or Land cover	Area (Km)	Area (%)	Soil group (A)		Soil group (C)		Total CN	Average CN
			%	CN	%	CN		
Bare soil	165.8	92.98	72	68	28	86	73.04	73.67
Vegetation	6.15	3.45	90.75	67	9.25	85	68.67	
Rocky area	6.07	3.41	72.5	95	27.5	98	95.83	
Urban	0.29	0.16	100	77	-	0	77	
Total	178.31	100						

TABLE 6. Calculated of annual runoff water and infiltration volumes in the basin of El-Hraka

Average annual rainfall (inch)	S (inch)	Ia (inch)	Q (inch)	F (inch)	Area exposed (%)	Runoff water volume (m ³)	Infiltration volume (m ³)
5.001	3.57	0.714	2.339	1.948	92.98	10583.29	8195.01

Where:

S: maximum potential abstraction of water by soil

Ia: initial abstraction

Q: excess rainfall or direct runoff volume (direct runoff depth)

F: cumulative infiltration excluding Ia (i.e. actual retention)

Surface runoff water volume for different returned periods

The prepared precipitation for estimating the rainfall intensity values at different returned periods (2, 3, 5, 10 and 20 years) depended on the assumption of Generalized Extreme Value "GEV" distribution maximum likelihood, was calculate with the help of the specialized statistical analysis HYFRAN PLUS software (Fig. 13). In this study, the maximum annual series of daily rainfall for a long series of observation (2001-2015), taken from the meteorological station of Matrouh, were used to obtain long-term discharge series as shown in (Table 7).

In this study, the SCS-24 hour's rainfall distribution in HEC-1 model was used to create rainfall hietograph on the day of the event. The results indicated that the SCS-24 storm type II represents the better distribution to simulate the rainfall-runoff event for different return intervals. This is because it is more similar to the noticeable. The model designed to create the hydrograph and calculates the peak discharge (m3/sec), peak time (min) and volume of runoff water (m3).

Abdel-Kader *et al.* (2005) referred that, the rainfall – runoff relationship was estimated by using the curve number method. The study indicated that a total number of 46 cisterns are required for collecting and reserve 4121 m3 in November and 19202 m3 in January of runoff water for eleven natural undisturbed watersheds.

The resulted runoff hydrographs for the watershed of the storm event is shown in (Fig. 14 and Table 8). The peak flow of the 20, 10, 5, 3 and 2 year return periods flash flood is 29.24, 17.98, 9.50, 3.78 and 0.75 m3/s respectively. The runoff volume of the 20, 10, 5, 3 and 2 year return-periods is 2.78 million, 1.71 million, 906,578.6, 359,883 and 69,989.4 m3 respectively for the study basin. The runoff in the watershed predicted by the SCS-CN model is increases gradually with rainfall increase.

In addition that, the runoff water volume of the 20 year return-period is 2777883.3 m3, while for the 10 year return period is 1713298.9 m3. The Runoff volume for the 5 year return-period reaches 906578.6m3; and for the 3 year return period runoff volume is 359883m3, while the 2 year return period is 69989.4 m3 for the study basin.

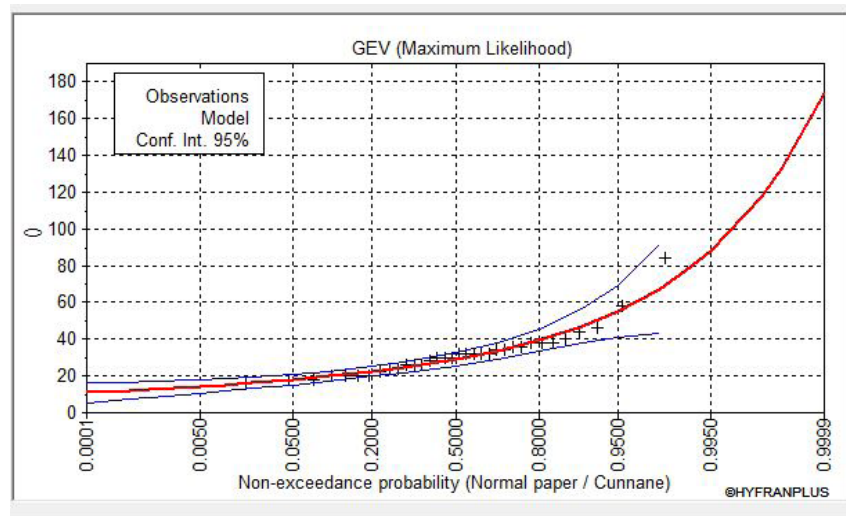


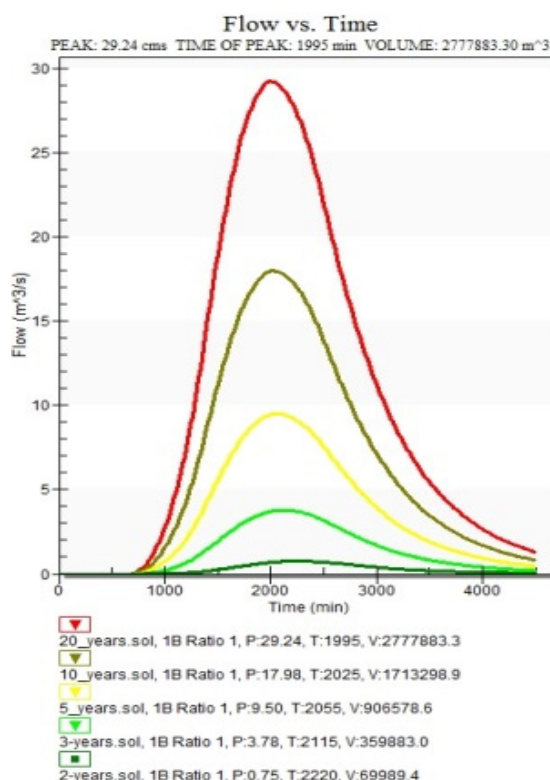
Fig 13. Probability of occurrence of annual rainfall data.

TABLE 7. Rainfall intensity values for different return periods.

Return period (years)	Rainfall depth (mm)
2	24.4
3	32.89
5	42.57
10	53.22
20	64.80

TABLE 8. Rainfall-Runoff data of El Hraka basin

Return Period (years)	Rainfall Intensity I (mm)	Peak Discharge Q (m ³ /sec)	Peak Time (min)	Runoff Water volume (m ³)
2	24.4	0.75	2220	69989.4
3	32.89	3.78	2115	359883
5	42.57	9.50	2055	906578.6
10	53.22	17.98	2025	1713298.9
20	64.80	29.24	1995	2777883.3

**Fig. 14. The predicted rainfall-runoff values of different return periods for El - Hraka basin**

To improve run-off efficiency necessitates constructing water-harvesting structures (*e.g.* cisterns, and dykes). Water stored in cisterns is mainly used for domestic and livestock, and partly for summer irrigation of trees. Dykes are exclusively used for spreadsheet irrigation (Abdel-Kader et al. 2004).

Conclusions and Recommendations

According to the soil texture and chemical properties, the study basin is suitable for growing some field crops, *e.g.* wheat, barley and tomato in shallow and moderately deep units, and horticulture trees, *e.g.* fig, date palm and olive, in the drainage basin. The basin can be recommended to have priority for rainwater

harvesting with agriculture potential benefits within the Northwestern coast of Egypt. The research results prove the successful employment of a new methodology based on WMS, HEC-1, and DEM which lead to a good estimation of surface runoff. Using advanced water harvesting techniques for growing crops, where rainfall is inadequate for rainfed agriculture and irrigation water is lacking. The stony dams construct across the drainage basins, and man- made underground storage cisterns or galleries are using for collected the surface runoff. The integrated methodology of this study could be considered as a ready module for applying at different locations and represents a significant participatory management tool for rainfed agriculture in Egypt.

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حصاد المياه للتنمية المستدامة في حوض الهراقة بالساحل الشمالي الغربي، مصر

مصادر المياه في منطقة الساحل الشمالي الغربي بمصر محدود للغاية من حيث الكمية حيث انها تنشا بصفة رئيسية من مياه الأمطار في فصل الشتاء. ندرة المياه هي العائق الرئيسي لأنشطة التنمية في المنطقة. يعد حصاد المياه (HWR) أحد الحلول الأكثر فعالية للتغلب على هذه المشكلة. أشارت النتائج إلى أنه من خصائص حوض الهراقة كأحد الأحواض الهامة في منطقة الساحل الشمالي لمصر أن مساحته (١٣,٨٧١ كم^٢) ، طول الحوض ٣٣,٦٩ كم ، محيط الحوض ١٣٢,٨٤٣ كم وزاوية ميل ٠,٠١٢ مم/مم. توجد أربعة أنواع من الغطاء الأرضي وإستخدامات الأرضي تغطي منطقة الدراسة وهي الأراضي الخالية (٩٢,٩٨٪) ، الأراضي المنزرعة (٣,٤٥٪) ، المناطق الصخرية (٣,٤١٪) و المناطق السكنية (٠,١٦٪). بلغ متوسط قيم المنحنى (NC) ٧٣,٦٧ لحوض الهراقة. في حين بلغ الحجم السنوي لمياه الجريان السطحي ١٠٥٨٣,٢٩ م^٣. ومع ذلك فإن معدل الترشيح السنوي بلغ ٨١٩٥,٠١ م^٣ والذي يغذى الخزان الجوفي في المنطقه. بلغت أعلى قيم للسريان لفترة ٢٠ سنة ٩٢,٢٤ م^٣ / ثانية بينما بلغت قيمته لفترة ١٠ سنوات ١٧,٩٨ م^٣ / ثانية . أعلى قيمة للسريان لفترة ٥ سنوات وصلت إلى ٩,٥٠ م^٣ / ثانية و لفترة ثلاث سنوات ٣,٧٨ م^٣ / ثانية بينما لفترة سنتين أعلى قيمة للسريان هي ٠,٧٥ م^٣ / ثانية. حجم الجريان السطحي لفترة ٢٠ سنة ٢,٧ مليون م^٣ بينما لفترة ١٠ سنوات ١,٧ مليون م^٣. وصل حجم الجريان السطحي لفترة ٥ سنوات ٩٠٦٥٧٨,٦ م^٣ و عند فترة ٣ سنوات وصل حجم الجريان السطحي إلى ٣٥٩٨٨٣ م^٣ بينما عند سنتين وصل حجم السريان الى ٦٩٩٨٩,٤ م^٣.