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Potential of Rain Water Harvesting along the North Western Coast of Egypt as Revealed by Remote Sensing and GIS Capabilities

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Abstract: The North Western Coast of Egypt forms a promising land resource for its potential rain fed agriculture. The region falls under arid climate with a total average annual rainfall of 150 mm. Occurrence of one or two rain storms with intensities of 10 mm or higher would generate considerable runoff. This rainfall however, is sporadic and unpredictable. Cultivation and grazing are the only wide activities practiced by the settled and nomadic inhabitants. The nomadic sort of life is carried out in the plateau areas and depends on grazing and related activities. Improved and planned regional surface water management is urgently needed to maintain sustainable development of the region. Local rain water harvesting is undertaken on some areas but not on regional scale. Vast areas pertain to the higher tableland though having lower rainfall; still can be subjected to storms and flash floods. The low lying areas of the tableland are almost devoid of any recognizable drainage lines. Field work however, revealed the presence of shallow basins filled with moderately deep and fine textured soils. Delineation of catchments areas and drainage basins could be elaborated from topographic maps and SRTM imageries by using ArcGIS software and applying of D8 algorithm. Landsat ETM images, taken in 2001, were used to generate DEM using ENVI software. Flow directions, accumulations and drainage networks were specified as a result. The volume of water stored in the drainage basins is very important for several purposes. Limitations concerning depth of soils and their water holding capacities determine selection of appropriate crops. The study revealed that the volume of water collected depends on several factors. Careful planning of cultivation in the water shed areas is decisive. In small basins, water pounding may occur while in large ones water content may not be adequate for crop requirements if only one rain storm event is considered.

Key words: Water harvesting • Flash floods • Drainage networks • Catchment

INTRODUCTION

Surface water management in arid lands is an important concern both environmentally and economically. Runoff in these environments is not fully evaluated due to its relative infrequent occurrence and lack of recording. The paucity of appropriate discharge quantity presents a particular problem for the analysis of arid zones runoff. There are several scientific and practical imperatives for the study of dry lands runoff. Despite the general events nature, many dry lands experience numerous infrequent flows and flash flood. Proper management of this water could be very beneficial for the development of the region. Understanding of runoff processes controlling factors and their interaction is crucial to better estimate and manage these water resources.

Factors controlling runoff includes; catchment geomorphology, soils, geology, land use and climate conditions. The geomorphologic factors include areas of catchments, channel network geometry, shape, slope and flow lengths. Accurate delineation of catchment boundaries (i.e. watershed divides) is prerequisite for the surface runoff magnitudes estimation. In the studied area, these catchments may roughly range from few hundred square meters to several hundreds of square kilometers. The common problem to all arid zones is the fragility of the arid ecosystem and the consequent threat of desertification [1, 2]. The status of aridity can be defined on the bases of the ratio of mean annual precipitation (P) / potential evapotranspiration (PET).

The northern coast of Egypt represents the arid zone of southern Mediterranean. At Roman times and apparently under more humid conditions than that of

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today, the area witnessed a prosperous epoch. Some sort of water management was practiced. By the advent of aridity, the whole region was neglected and relatively deserted. It is a controversial subject whether it is the advent of aridity or the neglect of a proper surface water management which resulted in the present situation in the region. History and some field evidences however, are in favor of the last reason. Recent studies of surface water resources started probably by Ball [3] where the relation rainfall-runoff was developed. Several other studies were undertaken on major wadis with their catchment areas [4, 5]. Numerous other relatively small catchment areas especially those located on the plateau adjacent to the coast are not fully recognized and evaluated. This is due to the lack of intensive land survey and contour maps of appropriate scale. This obstacle is now successfully overcome by using remote sensing and GIS capabilities.

Agriculture and range land activities are the current land use. Lack of sufficient water resources is severely affecting intensive and efficient land use. Lack of water resources and appropriate evaluation of the existing situation of surface water is affecting intensive and better land use [6].

The nature of rainfall in the region in which several but sporadic rainstorms are occurring mainly during winter season (December, January, February) and partly in Spring (March and April). These rainstorms are sometimes characterized by sufficient intensity and duration to generate runoff. Intensive land survey is needed especially, to delineate micro catchment boundaries and divides to evaluate runoff yield in a specific area. Manual delineation of the catchment divides is subjected to severe problems if several divides are discordant, or the topography is relatively flat. Depending on the nature of micro topography in many cases, it is desirable that surveyed contours are as fine as possible, (at least 1:25000).

Location and Physiographic Features of the Study Area: The study area is located at the northwestern coast of Egypt. It is bordered from the east by wadi EL Garawla and from the west by Mersa Matruh town. The extended territory lies between longitudes 27° 10' to 27° 30'E and latitudes 31° 00' to 31° 25'N, Fig. 1.

Surface geology of the region is essentially composed of Tertiary and Quaternary ages [7, 8]. The Quaternary is mainly exposed in the raised beaches. The Pliocene of the Tertiary is exposed in the area, while the Miocene is forming the surface beds of the plateau. Along the whole northwestern coast of Egypt, a dominant pattern, consisting of a coastal plain, raised beach, an escarpment abruptly separating the plateau in many localities and a dissected peneplained plateau exist. The coastal plain is mainly consisted of Quaternary features, including several parallel coastal bars and lagoons. The inter-ridges swales are filled with soil materials of highly calcareous loams and silt clay loams. At the foot of the escarpment separating the costal plain from the plateau, fans and fan convexities are formed of calcareous sandy

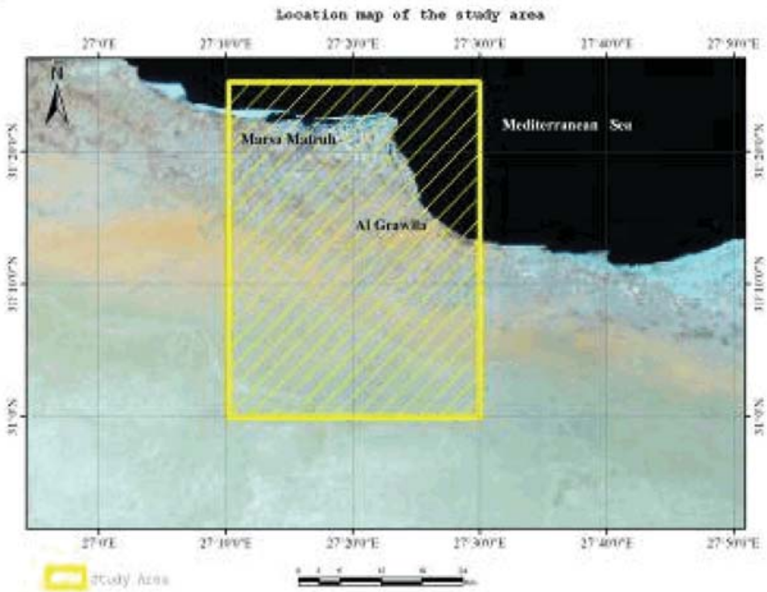

Fig. 1: Location of the studied area

Table 1: Average monthly and annual rainfall, mm of different localities along the Northwestern coast of Egypt. (Land Master Plan, ARE, Hammad 1986)

	J.	*F.*	*M.*	*A.*	*M.*	*J.*	*J.*	*A.*	*S.*	*O.*	*N.*	*D.*	*Annual*
Alexandria	46.4	27.3	8.9	3.0	1.7	0.0	0	0.0	0.5	7.8	33.4	51.6	180.6
Bur ElArab	42.1	22.1	4.7	4.1	0.6	0.0	0	0.0	0.4	13.7	31.4	35.5	156.6
ElHammam	28.5	18.7	5.3	1.5	0.5	0.0	0	0.0	3.1	8.9	25.1	28.3	119.9
El Dabaa	32.6	18.1	9.2	2.6	2.6	0.0	0	0.3	1.0	8.1	29.3	36.8	140.6
Fuka	21.8	18.5	4.8	1.0	1.5	0.0	0	0.0	0.8	11.7	19.1	29.2	108.4
MersaMatruh	36.4	20.3	10.3	3.8	2.2	1.9	0	0.5	0.9	12.1	23.6	35.6	147.6
Sidi Barrani	38.1	19.4	10.2	1.6	2.8	0.1	0	0.1	0.3	14.4	21.9	35.0	143.9
El Sallum	21.3	15.8	8.2	1.3	2.8	0.0	0	0.5	0.1	7.9	19.8	24.5	102.2

loam and loamy soils, locally with a petrocalcic horizon of various thicknesses. The plateau is generally sloping towards north and drained by several consequent wadis, many are crossing the escarpment to reach the sea while others are forming drainage basins and alluvial fans.

Climatic Characteristics: The average rainfall recorded for the coastal areas west to Alexandria is 150 mm. Rainfall is mainly occurring during winter season beginning at the second half of October and ends almost in March. Average monthly rainfall values are recorded where November, December and January are receiving the highest amounts, Table 1.

Concerning rainfall conditions, fluctuation is rather common than stability. This fluctuation in rainfall is forming a serious constraint for any sustainable agricultural policy. The average inter-annual variability reaches 62 mm. Dry years receiving less than 100 mm occur two or three years out of ten, while a rainfall of more than 200 mm occurs twice in ten years. Intensity of rainfall reaches a maximum of 50 to 98 mm/day. A general intensity distribution of rainfall may be as follows;

-more than 2 mm/hr: 100% of the cases
-more than 5 mm/hr: 85% of the cases
-more than 10 mm/hr: 30% of the cases
-more than 20 mm/hr: 15% of the cases

MATERIALS AND METHODS

Catchment and Associated Drainage Features Delineation: Available topographic maps are of scale 1:50 000 and the contour intervals is 10 meters. As the southern part of the study area (plateau) is characterized by low relief and poor drainage networks, the manual insertion of the catchment water divides is extremely difficult, if not impossible and fraught with uncertainty. Similarly, the Landsat ETM+ images (Fig. 2), reveals that

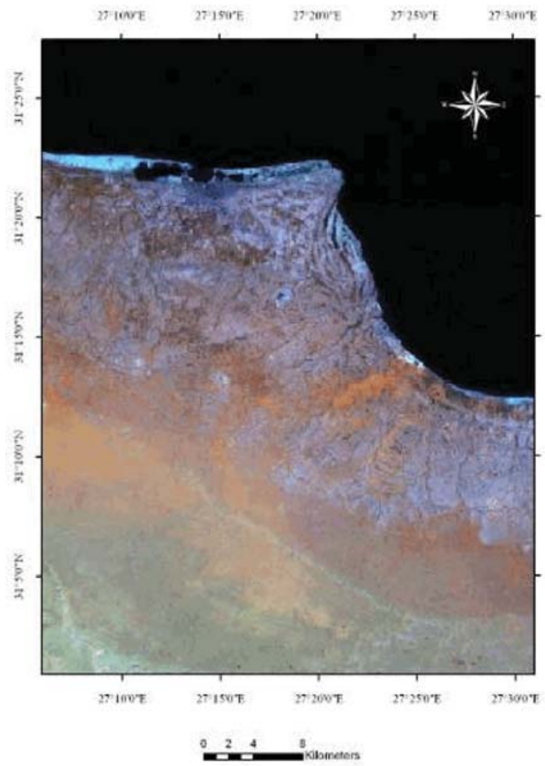

Fig. 2: Landsat ETM+ image (2001) of the study area

the southern part of the study area (plateau) is almost devoid of recognizable drainage features. Consequently, DEM interpolated from digital contours with the help of SRTM images using Arc View GIS 3.2 software is used for deriving a drainage network and catchment divides according to Jenson and Domingue [9].

Landsat Image Processing and Field Work: Landsat images (ETM+2001) covering the study area were processed using ENVI software. Classification of images and field work enabled the authors in modifying the Soil Landscape Map of FAO [4]. Soil conditions and properties of the watershed basins are then evaluated. A soil profile in a catchment at the plateau area was described and sampled.

RESULTS AND DISCUSSIONS

Delineated Drainage Basin: The digital elevation model (DEM) of the study area was interpolated from digitized contours (Fig. 3) and spot heights (Fig. 4), using topo grid module of Arc Info software package. Figure (5) shows the obtained DEM of study area, the spatial resolution is 30 m and the vertical resolution is also in meters. Fig. (6) demonstrates the flow direction as resulted from the application of the D8 algorithm.

The flow direction ensures the connectivity, (i.e. flow accumulation, Fig. 7) of flow from any point in the catchments to an outlet, regardless the obstacles represented by sinks or local depressions. GIS blindly routs a very small amount of water in a given pixel according to the downstream flow directions as far as to the outlet without any reduction of that amount of water. It can be outlined that using GIS alone for hydrological analysis contradicts with the actual physical process occurring in a dry land catchment (i.e. transmission loss). In order to improve the GIS simulation of hydrology, the physical parameters have to be incorporated in the GIS analysis.

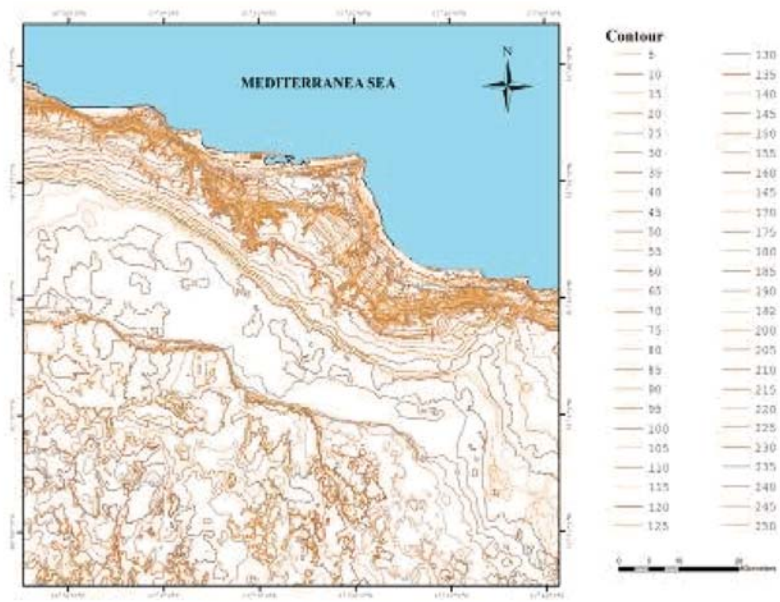

Fig. 3: Contour map for the study area

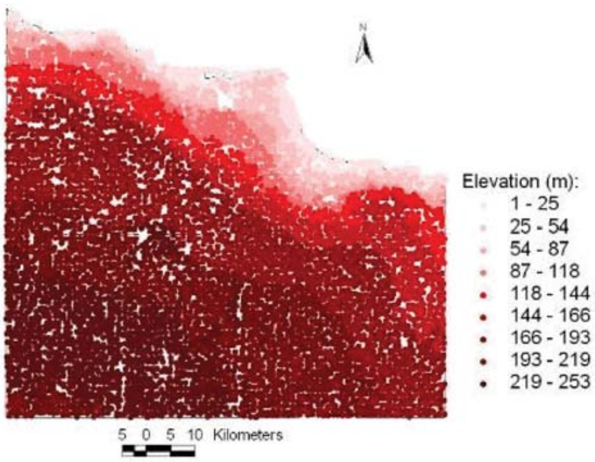

Fig. 4: Spot height map of study area

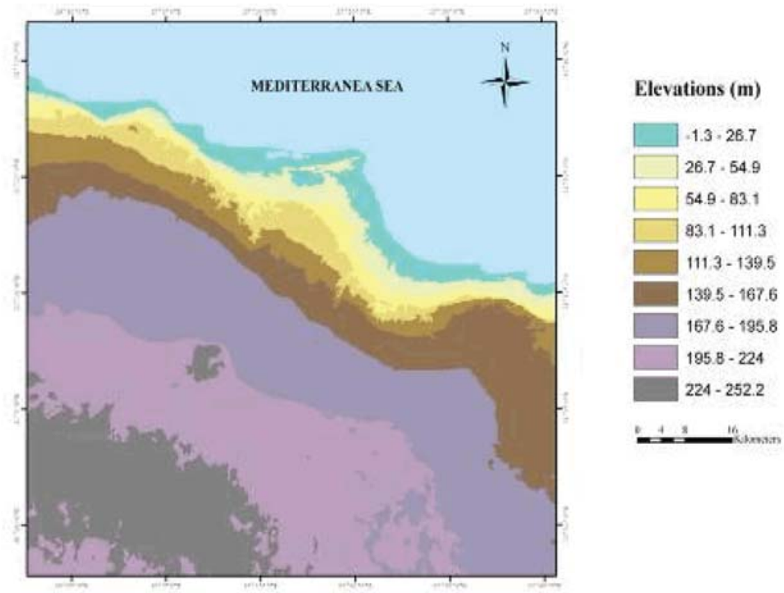

Fig. 5: DEM of the study area (30 m spatial resolution)

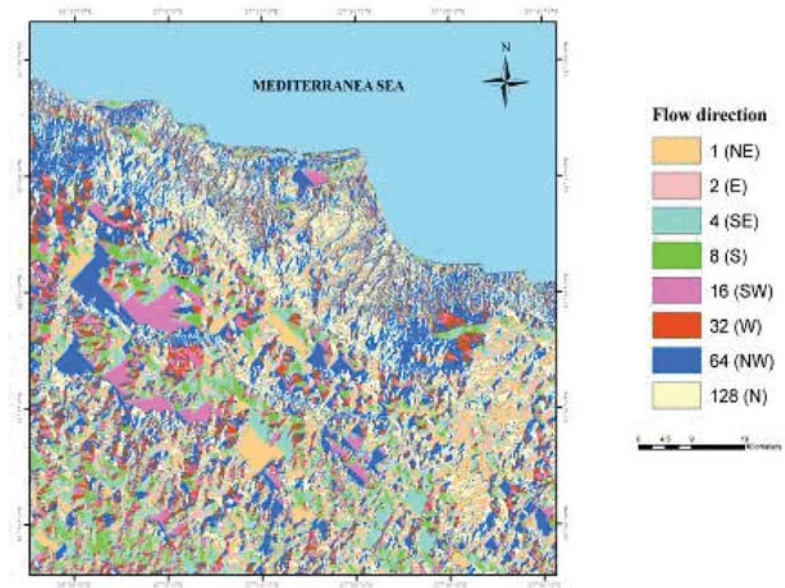

Fig. 6: Flow direction map of study area

Applying a threshold of 1.0 km^2 on the flow accumulation grid resulted in delineating all possible catchments (Fig. 8). It is extremely significant to ensure an accurate catchment area definition. It is believed that catchment area parameter is one of the most important factors affecting surface runoff characteristics in arid zones. Some of the catchment boundaries and drainage networks derived from the DEM, particularly the relatively flat southern area, cannot be checked for accuracy using the digitized topographic maps or the available Landsat images. It is recommended to assure the automatic delineation of drainage networks and catchment areas by field work with particular emphasis on the southern part, which is poorly mapped.

In the delineation of a drainage basin boundary, the calculation of its area is usually the first required step for estimating the surface runoff of that catchment.

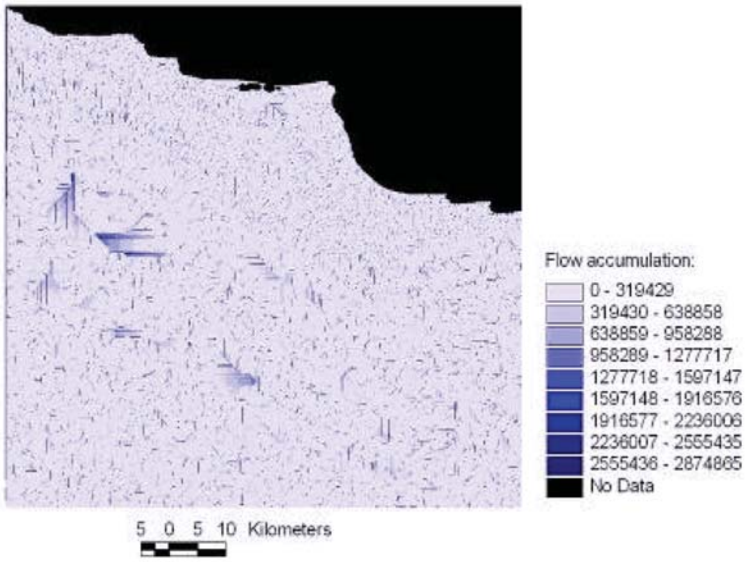

Fig. 7: Flow accumulation map of the study area

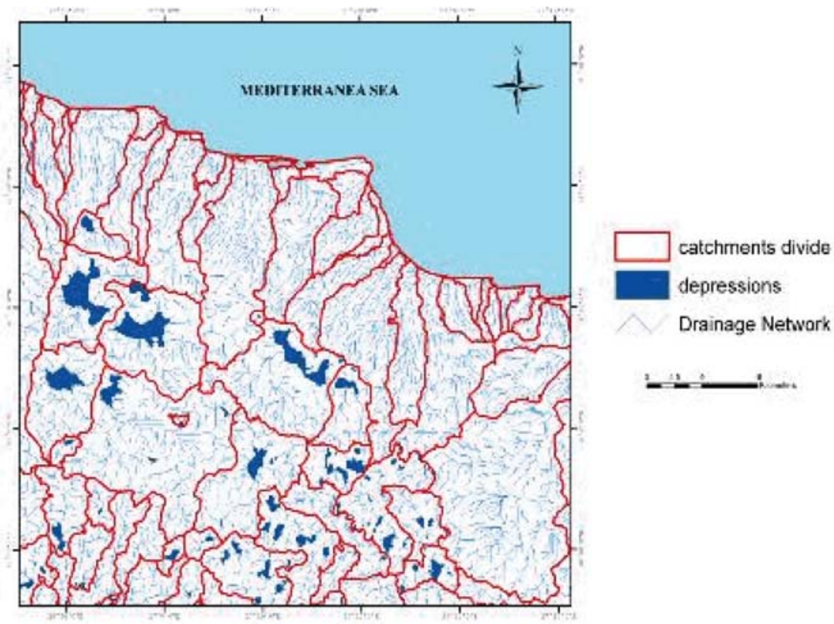

Fig. 8: Automatically delineated drainage networks and catchments in the study area

The effectiveness of rainfall for producing runoff is extremely variable for different storms, catchments and even within a single catchment. This variation is controlled by many factors including: 1) rainfall pattern; intensity, duration and spatial variation 2) geomorphologic and geological characteristics such as flow lengths, drainage network pattern and density, alluvium and the rock units-forming hillslopes.

Potential Runoff Calculations: Overall, the annual potential runoff production of the delineated catchments will be based on an assumed rainfall intensity, duration and coverage. Given the mean annual rainfall of 80- 150 mm and the occurrence of one or two major storms with intensities of 10 mm or higher every year, it is assumed that the effective rainfall is 20 mm/year. The potential harvesting of 20 mm/year is strongly supported by dominance of hard limestone rocks capping most of hill slopes. However, it is very necessary to install and nest rainfall and discharge gauges within a catchment to verify runoff prediction, particularly sustainable development plans require such data and measurements. The estimated runoff volume (m^3) of each catchment was recorded on basis of 20 mm effective rainfall intensity.

The Agricultural Aspects of Water Harvesting: Rainwater harvesting in arid regions is a technique used to support sustainable agricultural production where rainwater is not adequate for the requirements of cultivated crops. In severe arid regions however, as in the north coastal regions of Egypt, the common climate characteristics are the short duration and the limited amount of rainfall. The precipitation in the region prevails during the winter season commonly within three months (December, January and February) but occasionally rainstorms may occur during March and April. Cultivation in the region is limited to the short duration crops (barley in general), which are commonly grown in shallow to moderately deep soils on the plateau. In the coastal plain, cultivation is generally limited to trees of olives and figs. Precipitation is decreasing significantly due south (on the plateau).

Rainfall-Runoff Ratio: It is commonly assumed that the quantity or volume of runoff is a proportion of rainfall depth. The proportion expressed as percentage and the rainfall-runoff as depths in mm

$$\text{Runoff (mm)} = K * \text{Rainfall (mm)}$$

Rainfall generating runoff is not only depending on the amount expressed as depth in mm but rather on the intensity and duration. The catchment characteristics are depending on infiltration, relief, slope and vegetation cover. The watershed or the catchment is consisting of two main parts; the collecting area with drainage lines and divides and the infiltration basin where the collected runoff is stored. This infiltration basin is forming the soil profile (the root zone), where roots of the cultivated plants can absorb stored water. Several methods are used for conservation of the harvested water by minimizing losses induced by evaporation. In Marsa Matruh region in particular, the collecting areas of the watersheds identified and delineated are dominantly rocky hill slopes. The proportion of runoff lost by infiltration is usually negligible and assumed as zero in this preliminary study. However, water intake or infiltration rate of the soils of this area (loam to silt clay loam) is ranging between 12.0 mm/h to 7.0 mm/h. This range is suggesting a rainfall intensity between 10 mm/h and 20 mm/h to be effective to generate runoff.

The Ratio of Catchment-Cultivated Area: Depending on the amount of collected runoff and storing capacity of the infiltration basin (soil) a ratio can be elaborated as mentioned in the literature. This ratio ranges between 1:2 to 1:10. In arid regions and where delineation of soil boundaries is sometimes absent, 1:10 ratio is commonly adequate.

Catchment Design and Techniques: This is a wide and diversified subject depending on several local and general conditions. In this study macro and micro catchment techniques is considered. Locals however, are applying a long slope catchment technique in large catchments consisting of wadis and hill slopes together with a short or steep slope system at the field level. This observation was noticed in the eastern part of the study region, namely in the upper reaches of the elongated depressions.

Crop Water Requirements: Plants are using water for building their tissues and for running their biological functions. As water supply is maintained by irrigation and direct rain or water harvesting, the water need is not only meant for the previous purpose. The water use is also primarily including evaporation from the surface of the soil. The two components of water requirement of any crop is called evapotranspiration (ETc). Several methods of obtaining the consumptive use of crops are known. The current work depended on the general values reported for the different crops grown in the different regions of Egypt. These requirements, under the study area conditions, reach 800 mm/fed. ($3360m^3$) annual ETc for olives and 368 mm/fed. (1545.6 m^3) annual ETc for barley.

Soil Requirements: Different soils have different capacities for water storage. This characteristic is generally expressed as the soil-water holding capacity. This capacity depends on several soil factors such as texture, structure, homogeneity, etc. Plants however, cannot use the entire amount of water present in the soil. There are effective tensions or pressures expressing the power of water holding by soils. Soil particles are adsorbing water molecules by a negative power expressed as mass potential. Without extensive elaboration of this relationship, soils are retaining water at a certain potential that plants can not use. The percentage content of the soil moisture at this level is called the welting point (WP). On the other hand, soils can not hold any amount of water. The maximum holding capacity is called field capacity (FC). Water held between these two extremes is called the available moisture for plant use. Beyond field capacity, water is moved by gravity to lower depths or drain to underground aquifers. The two limits are not constant for all soils. Their values depend on several factors. If there are cultivated crops, a minimum or threshold point should be defined to begin adding water by irrigation or be provided by rain.

How much water could be stored in a certain depth of soil and what depth of soil could be wetted (depth of wetting) by a certain volume of water? These two questions are very common in surface water management. The present moisture content and the bulk density of soil are the effective parameters used to calculate both of the former requirements.

The following equation is used:

dw = BD * (% water content in soil/100) * ds

Where:

dw = Depth of water (content expressed in depth over certain area)

BD = Bulk density of soil

ds = Depth of soil

The following is an example of the calculation of the depth of wetting and the depth of water that can wet a certain depth of soil. In other words, if we have a runoff volume of water expressed as depth of water on the watershed, what depth of soil can store this water?

Concerning one of the delineated watersheds, given the following values:

Texture Class	WP (%)	FC (%)	BD (g/cm^3)
Loamy	9.7%	18.4	1.16

The depth of water (dw) that saturate a depth of soil assumed as 30 cm is possible as follows:

dw = 1.16*(18.4 – 9.7 /100) * 30
= 1.16* (8.7/100) * 30
= 3.03 cm = 30.3 mm

Assuming a cultivated area of 1/10 of this catchment (23.813 km^2) of the total area of this catchment (238.13 km^2), the volume of water in the 30 cm depth is given by:

3.03 cm * 23.813 km^2
= 0.0303 * 23813000 =721533.9 m^3

Assuming that the total volume of runoff in the catchment is collected in the infiltration basin, water depth is considered to be 20 mm of one rain storm runoff; this amount of water would have a wetting depth in this basin calculated as follows:

20 mm = 1.16 * 8.7/100*ds
2cm = 1.16 *8.7/100* ds
ds = 19.82 cm

The amount of water needed to wet 80 cm depth is similarly calculated as follows:

1.16* (8.7/100) * 80 = 80.736 mm

Accordingly, the volume of water contained in the infiltration basin is then,

8.0736 cm * 23.813 km^2 = 1,922,566 m^3

However, total runoff (4,762,600 m^3) if all diverted to the infiltration basin (23.813km^2) and the depth of soil is limited to 80 cm will be beyond the capacity of the basin by the following value;

4762600 -1922566 = 2,840,034 m^3.

Concerning the referred catchment, the total runoff estimated as 4,762,600 m^3 (20 mm/h), can presumably satisfy the cultivation of 1417.5 fed. with olives. AS mentioned before, the total calculated water needed to wet a depth of 80 cm for the basin area is 1,922,566 m^3. This calculated runoff is beyond its capacity and would result under the specified conditions in ponding unless otherwise the soil is deeper than 80 cm. Replenishment of the consumptive water should be satisfied during the growing season, especially if field crops are cultivated. This is provided by frequent rainfall and runoff harvesting of other storms generating more runoff to restore water conditions appropriate for normal growing. If trees are grown such as olives or figs with higher consumptive use than barley, replenishment of water lost by evapotranspiration could be provided by more than one storm of the same intensity and by moisture potential gradient from deeper soil layers, or laterally from adjacent soils. Supplemental irrigation from stored runoff (cisterns) is not commonly practiced in the region which would help in restoring water deficit.

Fig. 9: Ponding of runoff water in a catchment located on the plateau

In the case of other catchments located on the plateau, barely is commonly grown with short duration and low water consumptive use. This would extend the cultivated area but with the lower storage capacity induced by the loamy textures and the limited depth of the soil. Ponding of runoff water is greatly anticipated, Fig. (9).

Techniques for lowering evaporation from the barren surface of soil and storing of excess water are advisable. No such conservation practices were noticed in the area.

CONCLUSIONS

The rarity of natural resources and the severe aridity are natural constraints characterizing the Northwestern Coast of Egypt. Under such conditions, using remote sensing and GIS techniques are widely and successfully used to evaluate surface water resources. Without intensive and elaborate land survey, remote sensing and GIS capabilities could effectively achieve the job.

Elaboration of a soil-landscape map and the identification of landforms together with the delineation of drainage network and defining the catchments divides are all important results achieved. Arc-view GIS 3.2 is powerful tool software used to create digital elevation model used in the study of physiographic features and associated soil characteristics. Surface water resources provided by the sporadic and scanty rainfall (aver. 150 mm) can be used within a designed framework of a social and water conservation regime. This is very important and vital for providing water balance for the different usage in the region. Rainfed agriculture could be practiced if wise and rational conservation practices are applied. On this stage the establishment of physiographic features including the main landforms and soils associated with them together with a preliminary evaluation of surface drainage features such as, catchments delineation, surface flow directions, of possible runoff; are elements dealt with in the paper.

The previous calculations are giving some deep insight of the problem. Developing a model of rain water harvesting, then the input elements may include; rainfall intensity, catchment characteristics including soil water holding capacity, depth of soil, slope and topography, crop water requirements and the number of possible storms and storing capability.

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