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Rain Water Harvesting Using GIS and RS for Agriculture Development in Northern Western Coast, Egypt

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Abstract

Study area lies in the north western coast of Egypt extending along the Mediterranean Sea. It occupies an area of about 1690 km2 it's called Fuka-Matrouh, This area is suffering of dry season in summer and flash floods in winter that impact the agricultural system as well as natural disasters in terms of human hardships and economic losses. Arc hydro model was used to derive watershed of the investigated area. In this study, remote sensing was combined with GIS environment for land and water resources assessment. Reconnaissance and semi detailed field surveys were carried out for collecting information required to produce various thematic maps; such as soil, capability, and land use and drainage system. A geographical database was stored as attributes. Modeling approaches are powerful tools for decision making in the study area. The present study aims at setting up recommendations for surface water development in terms of best sites selection and surface runoff. GIS and multi-criteria analysis were applied to locate a new dam location in study area to get the benefit for agricultural development.

Keywords: Water resources; Land resources; Agricultural development; GIS; RS

Introduction

Agriculture area grows but not as fast as the nonagricultural sector, also rapid rural to urban migration in developing countries influences farming practices and water demand [1]. Many study focus on development of agriculture methods and equipment [2-4].

Information and Geo database about the land and water resources is urgent for any planned project to satisfy the environmental conditions. Land and water resources data are spatial in nature and they could be easily handled and analyzed using Remote Sensing and Geographic Information Systems, many study used of FAO database to investigate the variations of cropping intensity in Asia-Oceania, Europe, and Americas from 1962 to 2011 by using information of Food and Agriculture Organization (FAO) [5-7].

Hence the advantages of using multi spectral data in handling land and water resources data would be demonstrated in the current work belong the Northern coast. Remote sensing data has been an attractive source in the determination of land cover thematic mapping, providing valuable information for delineating the extent of land cover classes, as well as performing temporal land cover change analysis and risk analysis at various scales. Decision-makers operate at different scales of interest to deal with different types of environmental problems seeking for adequate solutions putting into their considerations the complexity of natural and human impact that cause these problems. The linkage of environmental assessment tools, remote sensing and geographical information systems (GIS) and their capability of handling available geo-spatial data sources to prepare valid spatial models are in high demand. Fuka-Matrouh area has promising, sensitive and ecological systems.

Remote sensing techniques and more detailed climatologically and process models now available provide new possibilities for detailed modeling of small reservoirs in order to capture their surface areas for estimating their storage capacities to have a clear picture of available water resources. Geospatial techniques such as geographical information system (GIS) and remote sensing (RS) have pulled out significant attention for locating the suitable water recharging/harvesting sites in the recent history [8]. Remote sensing technique gives us directly the water spread area of the reservoir at a particular elevation on the date of pass of the satellite [9-12]. Al-Suhaili and Hassan studied of GIS to investigate the potential of having enough runoff in the five selected sites to establish water harvesting dams based on rainfall, evaporation data and catchments' areas for the selected sites. The aim of this paper was to develop spatial GIS modeling for suitable site selection for Dam and locating of reservoirs water supply in dry wadi based on the integration between remote sensing and GIS.

In December 1996, Egypt had issued its framework program of Integrated Coastal Zone Management (ICZM),The program covered the coastal area that lies between the village of Fuka and the town of Marsa Matrouh, approximately 70 km wide [13].

The aim of this study is to assess land and water resources for agriculture development as well as proposing suitable sites of dams to catch flashflood water for the agricultural development.

Study Area

Location of the study area

Fuka-Matrouh area lies in The North Western Coast of Egypt extending along the Mediterranean Sea. It occupies an area of about 1690 km^2, The Fuka-Matrouh area is very important region in Egypt for development and planning, it is located between latitudes 31°01'00–32°21'22 N and longitudes 27°59'00-27°11'50 E, with the elevation of the area varies from 0-200 m, above sea level and the general slope of land decreases from South to North and from western and eastern borders toward the center (Figure 1).

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Climatic condition

Study area has a semi-arid Mediterranean climate characterized by brief, mild, rainy winter and a long warm summer (Figure 2). The temperature does not exceed 28.5°C in the summer and does not go below 10°C in winter, from June till October where the maximum and minimum average temperature are around 27°C and 2°C respectively(planbleu.org), the wind speed doesn't exceed 10 m/sec, over almost 95% of the year and the average relative humidity is between 62% and 74% throughout the year; The average annual rainfall ranges from 110 mm/yr to 155 mm/yr from Fuka to Mars Matrouh (Table 1). Most of the rain (60% or more) occurs during winter (November to March). Also, the rainfalls represent the main source for the recharge of the perched groundwater [14].

Geology of the study area

The geologic of study area from the base to the top is Middle Miocene rocks (Marmarica Formation) The Marmarica Formation is made up of fissured, cavernous fossiliferous, limestone which is occasionally dolomitic and is intercalated with clay and marl [15]. Subdivided the Middle Miocene rocks into two zones forming the structural plateau. The first includes chalky, marly, fossiliferous and sandy limestone, and the second comprises shale and clay beds intercalated with limestone has the same characteristics of the first zone. The Middle Miocene fissured limestone is considered the sole aquifer in the study area containing groundwater under perched conditions [14].

Along the Mediterranean coast, the fractured limestone aquifer systems of Middle Miocene rocks could be found in the littoral zones. Groundwater at the northwestern coast of the Fuka Basin lies under phreatic conditions in the form of thin lenses floating over saline water and rainwater. Specific conditions for the presence of a water table known as perched groundwater in this aquifer exist in the Fuka Basin at the northwestern coast of Egypt [14] (Figure 3).

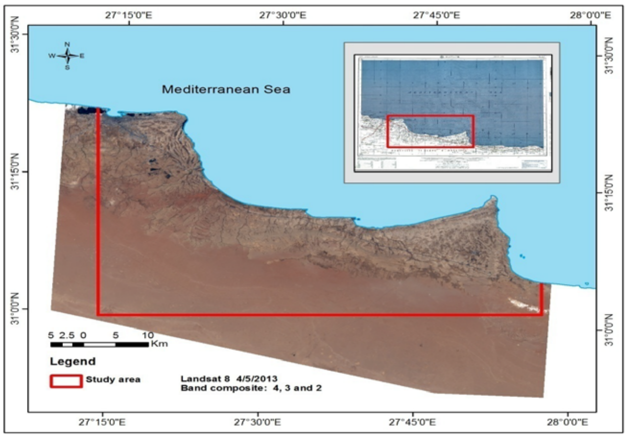

Figure 1: Landsat 8 image composite (bands 7, 5 and 3) showing the location of the study area.

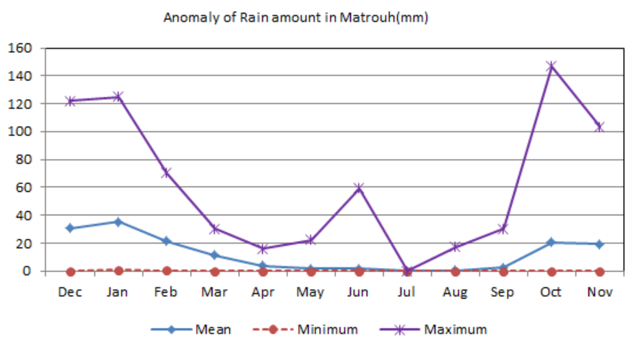

Figure 2: Variation of rain amount monthly in Mars Matrouh.

Data and Methodology

Landsat 8 images

The Landsat8 operational land imager (OLI) and thermal infrared sensor (TIRS) instruments, in 2013 the spatial resolution of this sensor is 30 m (except thermal band-10 and band 11 of 100 m resolution). Landsat 8 image (path 177/rows 39) was acquired at 4-5-2013 (Figure 1). Data were merged using multi-spectral bands (30 m) as a low spatial resolution with band 8.0 as a high spatial resolution (15 m) [16]. The image was calibrated to radiance, then it stretched using linear 2%, smoothly filtered. The images were rectified using ENVI 5.1 software. Satellite images were draped over a DEM for 3D terrain analyses. Multispectral landsat 8 satellite images were used to construct the land-cover; normalized deferent vegetation index (NDVI) through the composites of bands; Band4 0.64-0.67 µm visible red, Band5 0.85-0.88 µm Near Infrared (NIR) displayed as red, and Extracting data included vegetation and cultivation reflectance during a single season.

Digital elevation model (DEM)

The digital elevation model (DEM) of the study area (Figure 4) was extracted from the SRTM data using Envi 5 software. DEM was employed to offer varieties of data that assist in produced landforms map, soil types and hydrology information. Drainage networks and sub-catchment boundary of the studied areas were extracting from DEM in order to investigate the spatial relationship of agriculture fields and the catchment-drainage networks [17].

TRMM

A joint project between NASA and the Japan Aerospace Exploration, the purpose of the tropical rainfall measuring mission (TRMM) is to monitor and study tropical rainfall. Running from 1998 till the present, the TRMM data sets have a spatial resolution of 0.25° × 0.25° and cover a global band extending from 50° S to 50° N (until February 2002, the coverage was 40° S to 40° N).

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Mean	30.9	35.4	21.6	11.2	3.9	1.9	1.8	0	0.5	2.4	20.6	19.3
Std.Deviation	27.3	30.0	19.3	7.6	4.3	4.2	10.4	0.0	2.9	5.9	31.8	19.9
Minimum	0.0	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maximum	121.8	125.1	70.3	30.5	16.2	22.5	59.5	0.0	17.3	30.5	146.8	103.5

Source: The Meteorological data of Marsa Matrouh station, 1961-1997.

Table 1: Oscillation of monthly rain amount in Mars Matrouh.

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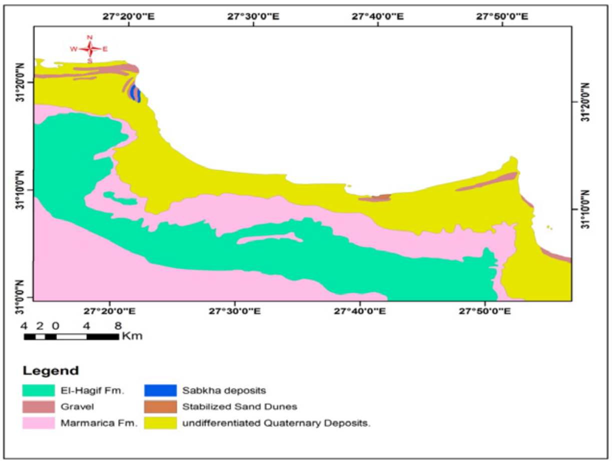

Figure 3: Geology of the study area.

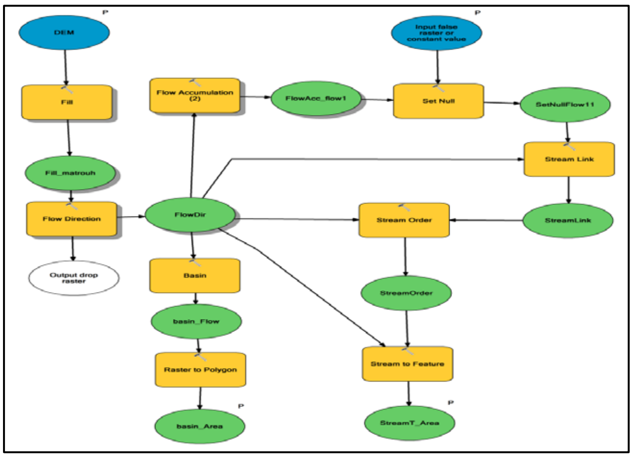

Figure 4: Hydro model designed by ArcGIS model builder.

There are two main methods for satellite estimation of precipitation. The first is based on the detection of clouds in visible or infrared data. The basis of this indirect method is the fact that rainfall is associated with clouds, and that higher and/or thicker clouds are associated with heavier or more frequent precipitation. The second method is based on observations of the radioative effects of hydrometeors in the micro-wave region of the spectrum.

GIS hydrological modeling

Hydrological modeling for this study utilized terrain processing tools of the Arc Hydro module (Harrower) [18]. This study used Strahler methods to determine the stream orders. Hydro model was designed depending on ArcGIS model builder (Figure 4).

Field studies

The main objectives of the field survey were to verify the main land use patterns that existed in the studied area. Field work includes the following:

- Preparation; Google earth satellite images, gives details of the main land use and land features.
- Verification; Vegetation characteristics and location of Fuka-Matrouh area.

Results and Discussion

Digital elevation model

The rapidly expanding availability of digital elevation model (DEM) data and release of software tools for GIS hydrological modeling offer a wide range of opportunities for examining irrigation and agriculture development. Digital elevation models (DEMs) are increasingly used for visual and mathematical analysis of topography, landscapes and landforms, as well as modeling of surface processes (www.geocarto.com.hk). The studied area has elevations from 0 to 230 m above Sea level, coastal plain zone elevation is ranged between 0 and 80 m, the plateau elevation ranges between 80 and 230 m, and occupies the northern extremity of the Marmarican homoclinal plateau. The plateau is characterized by three steps varying in elevation between 80-120 zone 1, 120-150 m (zone 2) and 150-200 m zone. These steps have different land scape feature due to the difference in the erosion and accumulation processes [19].

Generally, the coastal plain slopes gentle towards the north, it comprises elongated ridges, shallow depressions and dunes. The ridges stretch parallel to the coast line. has an elevation from 30 m in the west to 15 m in the east and a length of 17 km, The first ridge consists of friable, highly porous limestone. The second and third ridges consist of cemented limestone and have lengths of 16 and these ridges act as water divides where the surface water seeps along the slopes towards the bounding low depressions [14,20] (Figure 5).

Soil

The soil of Fuka-Matrouh area includes shallow sandy non to moderately saline soils (Lithic Torripsamments) which represent 7% of the total area ; non- to moderately-saline soils deep sandy loam to loam soil (Typic Torriorthents) that comprised 4% of the area, the rock outcrops comprise 11% of Matrouh region, Plateau that comprised 63% of the area (Table 2).

Soils of the coastal ridge and dunes are loose or moderately consolidated calcareous grains of sand dimensions almost free from salts. Near the shore line the soils may be mixed with lacustrine saline

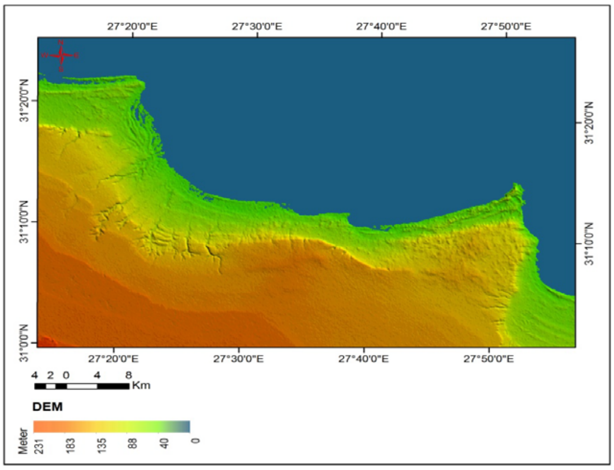

Figure 5: Topography (SRTM DEM) of the study area.

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Type (Sub great group)	Area (Km²)	%
Consolidated rocky ridge	11.22	0.66
Lithic Torripsamments	120.73	7.13
Plateau	1077.03	63.60
Rock escarpment	23.61	1.39
Rock land	168.20	9.93
Typic Haplocalcids	92.86	5.48
Typic Petrogypsids	19.84	1.17
Typic Torriorthents	72.71	4.29
Typic Torripsamments	107.35	6.34
Total	1693.56	100

Table 2: Soil characterized of the study area.

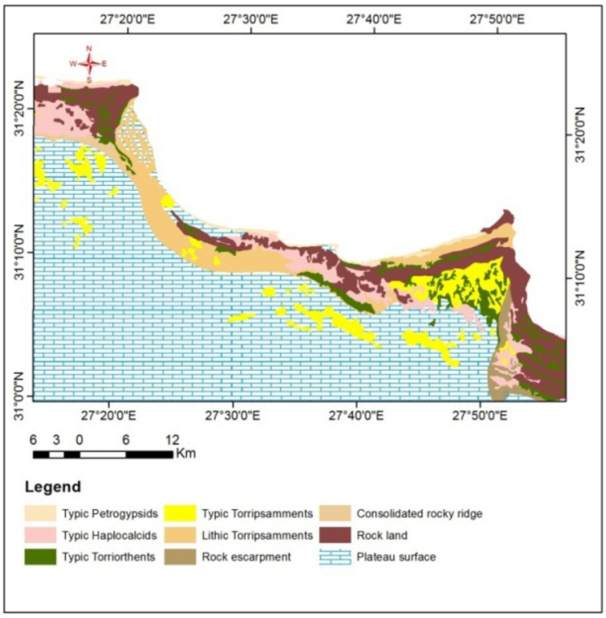

Figure 6: Soil map of the study area.

sand clays, and in lagoonal salt marshes the soils are very shallow profiles usually covered with thin salt crusts (planbleu.org) (Figure 6).

Water resources

Surface water: The area is limited in magnitude as it originates from the rainfall of the winter season. In the extreme southern portion of the area, where the landscape is elevated but almost flat in topography, water of the rainfall is partially lost through evaporation and the rest infiltrates into the shallow soil where it may subsequently either be lost by evaporation or utilized by some native vegetation. Ongoing northward, the landscape shows some wadis catchments areas. Runoff is possible after rather heavy rains, and a considerable amount of water may percolate to deeper soil layers. People store the surface running water in underground tanks (Roman reservoirs), 36 of which still exist in the area. The storable volume of drinking water is estimated to be 10,000 m^3/year [21].

The TRMM is the first and currently the only precipitation radar in space. It provides detailed information on the three-dimensional structure of rain systems with a horizontal resolution of approximately 4 km and a total of 80 levels in the vertical with a resolution of 250 meters.

The average annual precipitation derived from TRMM throughout the investigated period (1998-2007) (Figure 7). the minimum accumulated annual rainfall ranges from 80 mm/yr to 120 mm/yr, in The east of studied area which located in Fuka village while north west of the studied area obtain the maximum accumulated annual rainfall ranges from 120 mm/yr to 220 mm/yr, most of it occurring during winter; the main reasons are tracking of cyclonic storms that associated with the westerly wind belt and topographic location (Figure 8).

Along the northwestern coast, water-harvesting techniques have been developed for growing crops, rehabilitation and development of rangelands. An amount of surface runoff in the study area is collected by means of stony dams built across drainage basins, and man-made underground storage cisterns or galleries, while the remaining surface runoff is going to the sea [22-24].

Cisterns in the study area are constructed at the ends of the slopes of ridges and tableland. Generally, they are constructed below the ground surface at the lowest level of the collection basins or of small stream to entrap the rainwater overland flow. Their depth varies between 2 and 4 m and capacity ranges between 100 and 300. The inside surface is

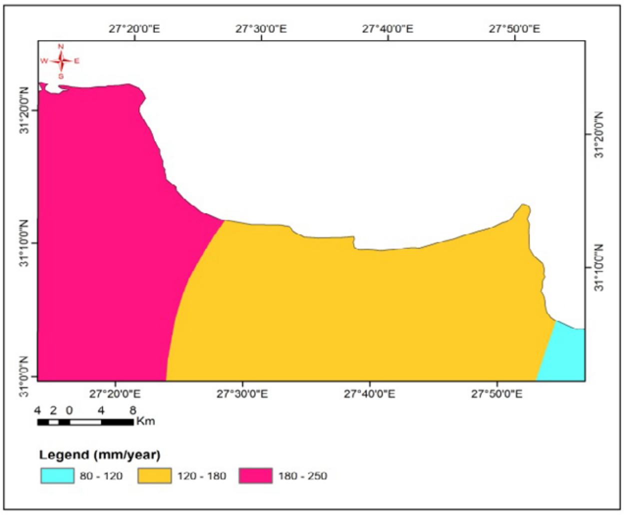

Figure 7: Average annual precipitation derived from TRMM 0.25°× 0.25° degree data.

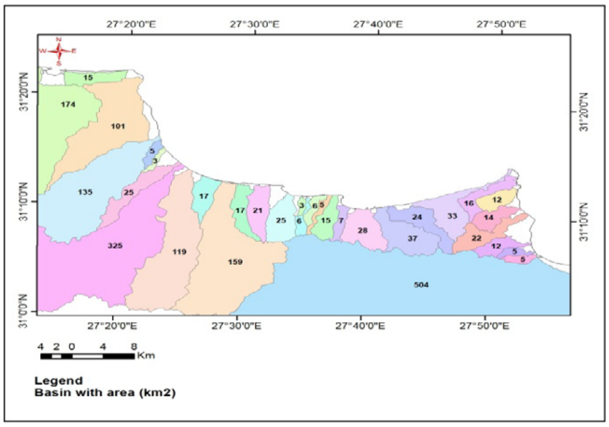

Figure 8: Basins of study area.

lined with cement. The stored water inside these cisterns can be used for human and animal consumption and in some cases for irrigate the young tress [17].

Water harvest model: The surface water needs a concerted effort to reach a decision for any development activities incorporating all limiting and delimiting factors, and their correlation and interaction [14].

Arc hydro data model: The Arc hydro data model can be defined as a geographic database containing a GIS representation of a Hydrological Information System under a case-specific database. Arc hydro model depends mainly upon digital terrain model (DTM) to extract the required parameters of flow direction, basins, flow length and flow accumulation. Flow direction; the basic D8 algorithm is probably the most popular method for automated drainage recognition and catchment area determinations [25,26].

Flow accumulation might determine how much rain has fallen within a given watershed. The output of Flow Accumulation would then represent the amount of rain that would flow through each cell. Regarding to the none-porous basement rocks of the southern plateau Fuka-Matrouh area is assumed that all the results of Flow Accumulation can be used to create a stream network by applying a threshold value to select cells with a high accumulated flow.

Drainage basins were delineated within the analysis by identifying ridge lines between basins. Basin analyzes the flow direction raster to find all sets of connected cells that belong to the same drainage basin. The drainage basins were created by locating the pour points at the edges of the analysis window, where water would pour out of the raster, as well as sinks, then identifying the contributing area above each pour point. The study area contains 32 basins, those basins areas are ranged between 3 km^2 and 504.4 km^2 (Figure 9).

Stream order: The stream order of the basins is very important to study the amount of water discharge of all valleys. The stream order of the basins reflects the ability of erosion and sedimentation to avoid the effect of erosion on the land, as well as the effect of flooding [27]. The maximum stream order of the study area is 5th order. Wadi El-Khier is one of the largest areas (325 km^2) and longest stream order 1st (24.7 km) (Figure 10).

Drainage density is very important factor related with the geomorphology and hydrology, it reflects the flow method of surface water which effected by geology, gradient, plant cover, quantity and intensity of precipitation [27]. The study was estimated this factor in wadi El-Khier as following;

Longtudinal drainage density (LDD) is the ratio between the summations of the valleys lengths in the basin (SL) to the area of the basin (Ab),

LDD (wadi El-Khier)=SL/Ab

=355.3/37.3=9.5 km/km^2

The results show the drainage density referred the basins of high discharge and the drainage peak is high [27]. This mean wadi El-Khier had low permeability and highest runoff.

Dam site selection: Dam is a structure that creates an artificial lake, or reservoir, by blocking a river or stream. Dams may harness the energy of falling water or provide flood control. They also store water for municipal water supply and crop irrigation, raising the water level to allow for navigation, and divert water into a pipe or channel [28].

Dam Site selection is a drainage point at the most downstream

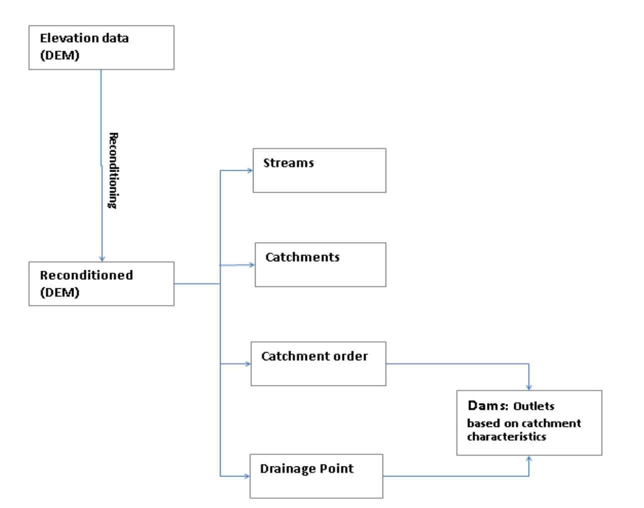

Figure 10: Workflow terrain database construction.

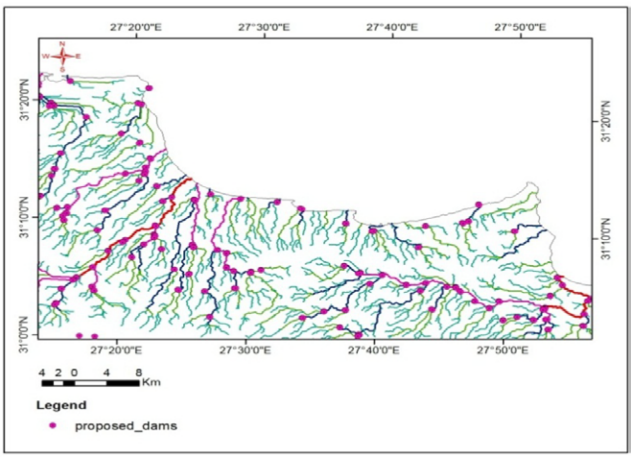

Figure 11: The proposed dams in study area.

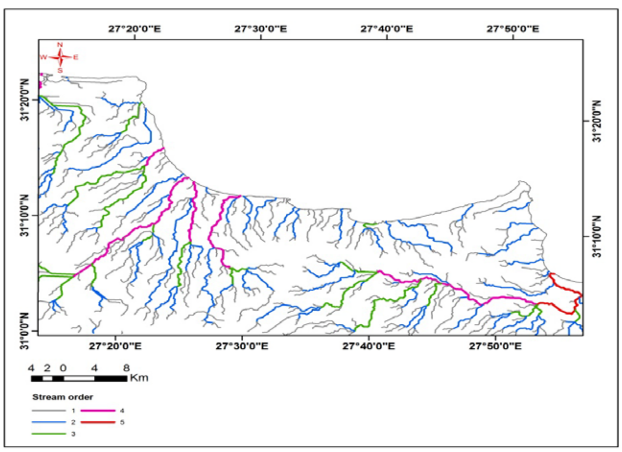

Figure 9: Stream order drainage according Strahler method.

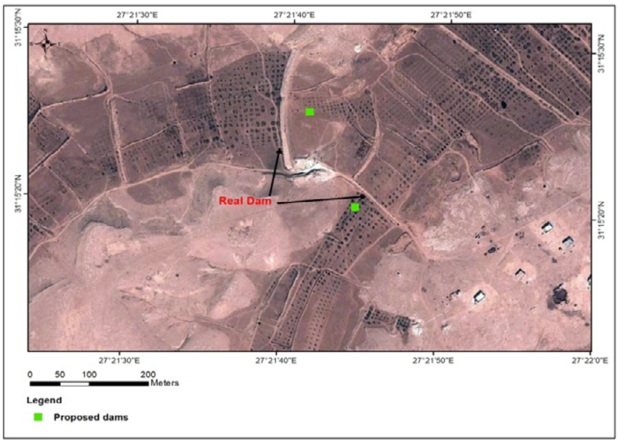

Figure 12: Sample of real and propose dams in wadi El-Khier in study area (Google earth image).

point in the catchment, its main in Archydro as center of a grid cell with the largest value in the flow accumulation grid for that catchment [29].

The best site dam for agriculture was proposed to verify the criteria of less dam length, less amount of earth works and higher storage volume with a minimum ratio of surface area to the storage volume. The essential hydrological conditions and factors such as available storage volume, geomorphologic, stream order, slope, and rain accumulated characteristics of the site (Figure 11). Also Remote sensing and GIS techniques were applied to assess and determined suitable areas for large-scale water harvesting applications for agriculture reclaiming.

The study compared between the suggested dams and some actual dams in downstream drainage of wadi El-Khier, as shown in (Figure 12). The suggested dams were matched with actual dams with shift less than 35 m.

Conclusion and Recommendations

The Fuka-Matrouh area is an important and sensitive ecological system. Studied area consists of 32 basins, with areas ranged between 3 km^2 and 504.4 km^2. Within this basins flow drainage that consist of 1314 stream order with accumulated length more than 2030 km. This study suggests 263 dams which it will increase the potentiality of agricultural development in the study area.

The integration of remotely sensing data into GIS can be a powerful tool in planning, managing a research work and spatial data analysis to develop a decision-support system; to build and consulted for proper decisions in the agriculture, grazing and continues development.

Study area suffers from long dry season and insufficiency of the water resources; the study presented here is to calculate the catchment areas of stream and identify optimal site of Dams and agriculture continuous development. Water harvesting applications is very useful to store rainwater during the wet season for use at dry season, especially for agricultural and domestic water supply in study area. This research use GIS capabilities with digital data to control and harvesting water in Matrouh-Fuka area. The field study showed that there's no role for the government to supervise or to help in building dams. So, there's a need for governmental cooperation. The study recommends building centralized geo data base for Wadis and climatic characteristics.

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