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MAPPING RAINWATER HARVESTING IN COASTAL ZONE USE OF REMOTE SENSING TECHNIQUES - CASE STUDY NORTHWESTERN COAST OF EGYPT

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ABSTRACT

The increasing pressures on fresh water resources with progressive demands and requirements for the development process necessitate including more resources into account. While considered with semi-arid nature, Egypt experiences seasonal heavy rainfall in the northern coastal zone, followed by dry seasons and scarcity in fresh water resources. This research study investigates the potentiality of using Earth Observation (EO) technology in predicting rainwater accumulation pattern and harvesting potentials within the coastal zone. The research presents the constructed hydrologic network based on Hydro-processed satellite imageries, using Integrated Land and Water Information System (ILWIS) model and Geographical Information Systems (GIS) software, validated with ground truth observed features. Water flow accumulation pattern were overlaid with land cover/land uses to select optimum rainwater harvesting locations in the North-Western coastal strip of Egypt.

The study results proves effectiveness of remotely observed data for planning an improved water resources management in Northwestern coast of Egypt. A continual research is, however, recommended to follow the probable responses of harvesting measures to sediment erosion and/or accretion patterns within the coastal region as well as the Environment Impacts.

Keywords:

Rainwater Harvesting, Remote Sensing, ILWIS Model, Northwestern coastal zone

INTRODUCTION

Water resources are facing challenge worldwide with increasing population and water-dependent development activities, especially in arid and semi-arid regions. Aridity nature of Egypt makes the river Nile the principal provider in fulfilling demands, which cause major concentration of population in the Nile Delta and Valley, representing only 4 % of land area in Egypt while leaving 96 % of land uninhabited (Yousif et al, 2013).

With growing concerns of scarcity, the country is in need of rationalizing in water resources use on one hand, and exploiting more resources to meet the increasing development requirements, in the other. Therefore, approaches such as water reuse of wastewaters as well as rainwater harvesting have been processed. Recorded rainfall events in coastal areas, while seasonal, yet represent high potential for expanded development activities.

Potentiality of rainwater harvesting as boost to water resources shortage have been confirmed by researcher around the world (Handia et al , 2003; Zhu, et al., 2004; sazakli et al., 2007; Cowden et al, 2008; Vohland and Barry, 2009; Abu-Zreig and Hazaymeh, 2012; Kihila 2014). Yet, it has been acknowledged that there is limited application of rainwater harvesting despite its high potential of playing a role in the water security, (Kahinda et al., 2010). Same is the case in Egypt, while in use for years; rainwater harvesting is not being utilized to its full potential with wider scale application.

Egypt experiences rainfall events with rather limited locations and frequency. Historical records show that rainfall events are mainly concentrated within coastal zones of Egypt, and drastically degrade towards Upper Egypt southward. Communities realized the advantageous of seasonal precipitations and rainwater harvest potentials for establishing rain-fed activities (mainly agricultural), beside living requirements to settlements. Accordingly, local communities have had previous scattered applications to make use of the seasonal rainfall in a modest scale. This paper is an attempt to map rainwater harvesting potentials for a rather lengthy strip stretched along the north-western coastal region that witness expanding developments and increasing needs for fresh water resources. Eventually, optimal sites for rainwater harvesting are concluded on basis of hydrologic behavior; topographic features and land cover/land uses in the region.

The research study also demonstrates the prospective use of Earth Observation (EO) techniques and Remote Sensing-based hydrologic processing in the field of water resources management. By application in coastal zone of Egypt, EO imageries have been used for mapping potentiality of rainwater harvesting, while overcoming the coastal and time consuming conventional topographic mapping and geographical survey. The application in a case study covers the north-western coastal strip, stretching from coordinates 30° N to 32°N and 25°E to 30°E. However, the study features the followed procedures to assess confidence on the information extracted from the

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remotely sensed imageries, by means of validating with ground truth and actual featuring in the region of interest. Therefore, primary application in a strip cover the sub-region, bordered by coordinates 31°N to 31°30'N and 26°30'E to 28°E , was carried out for calibration purposes. Consequently, with acceptable matching results, the second part of the research expands the study area to cover wider north-western coastal strip with high potentials for rainwater harvesting. The Shuttle Radar Topography Mission (SRTM) imageries and Integrated Land and Water Information System model (ILWIS) have been used to define hydrologic pattern in the region under consideration. Then, in a Geographical Information Systems (GIS) environment, land cover/ land uses were overlaid to verify feasibility and reach optimized rainwater harvesting locations.

Study Area

Driven by fresh water resources availability, the Mediterranean coastline North of Egypt witnesses a well-developed over populated region in the middle part (the Nile Delta region), while the east and west sides still under developed with great potentials, Figure (1). This research study addresses the North-Western (NW) coastal zone, west to the Nile Delta, which extends from Alexandria in the east for 520 km to El-Salloum in the west, on the Libyan border. This coastal strip suffers limitation in surface water resources, while rainfall in winter season is considered the principal source of fresh water, (El Bastawesy et al. 2008).

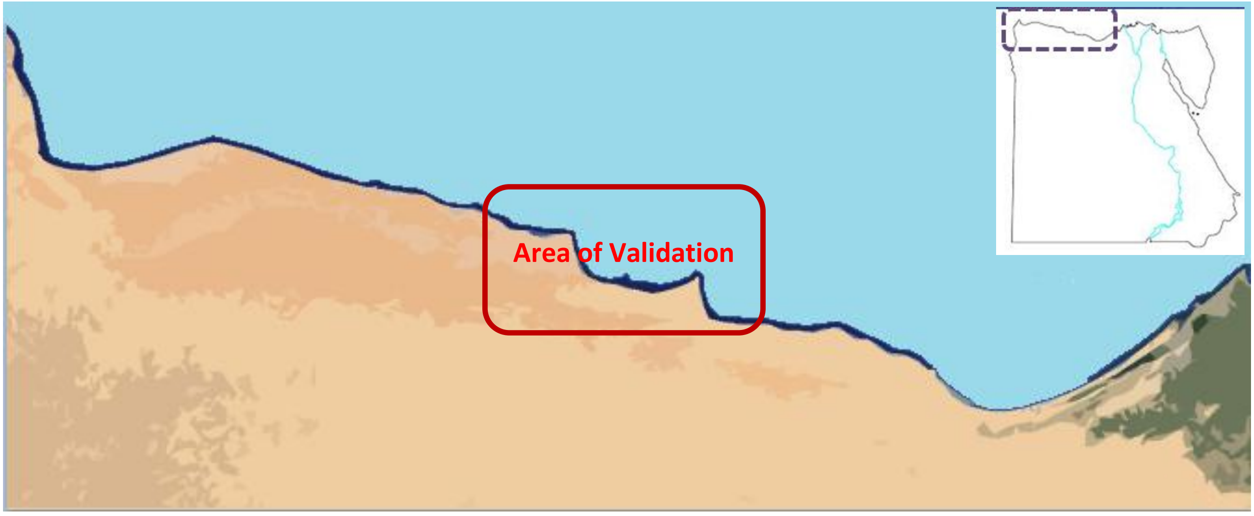

Figure 1: Northwestern Coastal Region of Egypt identify also the validation area

As the study area represents a section of the semi-arid belt of North Africa, historical records of weather stations within the area show average rates of annual precipitation from 101.5 to 155 mm, mainly occurring in winter season (from December to March), (Yousif and Bubenzer, 2012). Despite that this region is experiencing relatively highest rate of precipitation in Egypt during winter. Effat and Hegazy (2007) stated that major land cover in the study area is still classified as undeveloped desert areas. However, El-Kaffas et al (2000) have noted the promising trend of development expansion and land use changes due to constructions of tourist sites and summer resorts along the NW coastal strip. This region is subject to flooding events followed by scarcity state of water resources, after the extra rainfall fresh water lost into the Mediterranean Sea. Therefore, the concept of alleviating flood impact while making the best use of abundant rainfall intensified in limited duration is found worth investigating.

Topographic characteristics of the study area show significant change in levels that exceed elevation of 150 m above sea level within relatively narrow coastal strip, whereas generally featured by surface slopes northward. Elongated ridges and dry valleys are naturally found, that either ends in internal depressions or lead directly into the sea (Yousif and Bubenzer, 2012). These features can be considered advantageous for rainwater harvesting with minimal structural costs.

MATERIAL & METHODS

This study presents an application of remotely observed data together with advanced technology in the field of hydrologic processes and water resources management. Reviewed literature showed successful recent applications for Remote Sensing (RS) in the field of rainwater harvesting investigations and planning in different regions. Through an application in a semi-arid region in India, Kadam et al (2012) discussed the capacity of covering larger catchment area while having results with reasonable accuracy by using Remote Sensing techniques. The study presented an approach to delineate potential locations for rainwater harvesting by coupling parameters derived from Landsat Thematic Mapper imageries, with conventional Soil Conservation Service Curve Number (SCS-CN) method. Ramakrishnan et al. (2009) also identified proposed locations for

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runoff harvesting structures; e.g. check dam, percolation pond, and subsurface dykes, to be considered by decision makers. In 2008, Bakir and Xingnan presented the use of Remote Sensing techniques in establishing suitable sites for rainwater harvesting activities, based on data derived from the Indian satellite Imageries, together with ERDAS IMAGINE and GIS software. Recent research by Elhag and Bahrawi (2014) presented an application of Remote Sensing usage for potential rainwater harvesting in Asir region at the southwest of Saudi Arabia. The study related clouds distribution and soil moisture content extracted from Landsat 8 and 59MERIS satellite imageries.

In Egypt, the efficiency of using of remotely sensed data and GIS in the coastal environment were presented by Effat and Hegazy in 2007. That research study addressed environmental assessment for the constructed international coastal highway. Using ERDAS imagine software, 2001 Landsat ETM+ Satellite image, processed with unsupervised classification algorithm, and Egyptian military survey topographic map dated 1993 with1:50,000 scale, authors investigated the impact of highway on neighborhood land use/land cover, on one hand, and impact of land uses on highway stability and performance on the other hand. The study showed the potentials of remote sensing use in coastal management. In 2012, Yousif and Bubenzer discussed the groundwater resources of the Egyptian Northwestern coast aquifer systems as an important renewable source. Through a case study application in Fuka Basin, located about 80 km east of Matrouh city and stretches along the coast for 29 km, the study presented potential rechargeability during winter season by rainfall. Authors used GeoCoverage Landsat image (2000), ERDAS IMAGINE (9.3), and PHREEQC model in hydrogeochemical analysis.

Recently, a research by Yousif et al (2013) demonstrated current situation of water resources, in a coastal strip stretching from 26°30' E to 28°E , within latitudes 31°N and 31°30'N. The study addressed the shortage in water resources facing population growth and expanding agricultural activities in that northwestern region of Egypt. The research study covered aspects of potential development in groundwater resources and recharge planning in two main aquifer of the region bordered by coordinates 31°N 26°30'E to 31°30'N 28°E. Elevation pattern in the study area was concluded from the Egyptian survey topographic maps scaled 1:25,000. The authors reached some recommendations to develop the surface and groundwater resources in that study area, which was the basis for the current research study to build on.

Topographic data were derived from Satellite images by the Shuttle Radar Topography Mission (SRTM). The SRTM-based Digital Elevation Model (DEM) dataset has a near global scale, covering 80% of the Earth's land surface between 56° South and 60° North latitude at a relatively high resolution, considered suitable for hydrological analysis (Rabus et al 2003, Maathuis and Wang, 2006, and Farr et al 2007)

Data for the Northwestern coastal area between N30E025 and N32E030 were extracted in ten tiles, Fig (2-a). Each tile in the SRTM based DEMs cover one degree of latitude and one degree of longitude, named according to the south western corner with three arc second resolution averaged from the original one arc second raw data resolution.

Downloaded SRTM imageries were imported into the **I**ntegrated **L**and and **W**ater **I**nformation **S**ystem (ILWIS) model for processing and hydrologic analysis. The ILWIS software package has been developed in the Department of Water Resources, Unit of Geo Software Development, in the International Institute for Geo-information Sciences and Earth Observation (ITC), University of Twente, the Netherlands, (ITC, 2001).

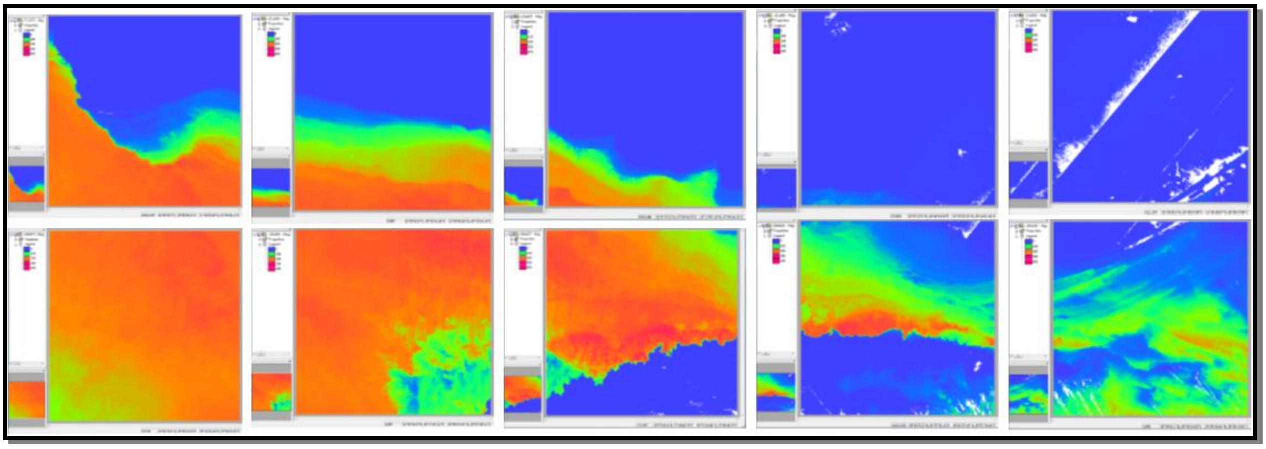

Figure 2a: SRTM Imageries Covering Egyptian Northwestern Coastal Region (From N30E025 to N32E030)

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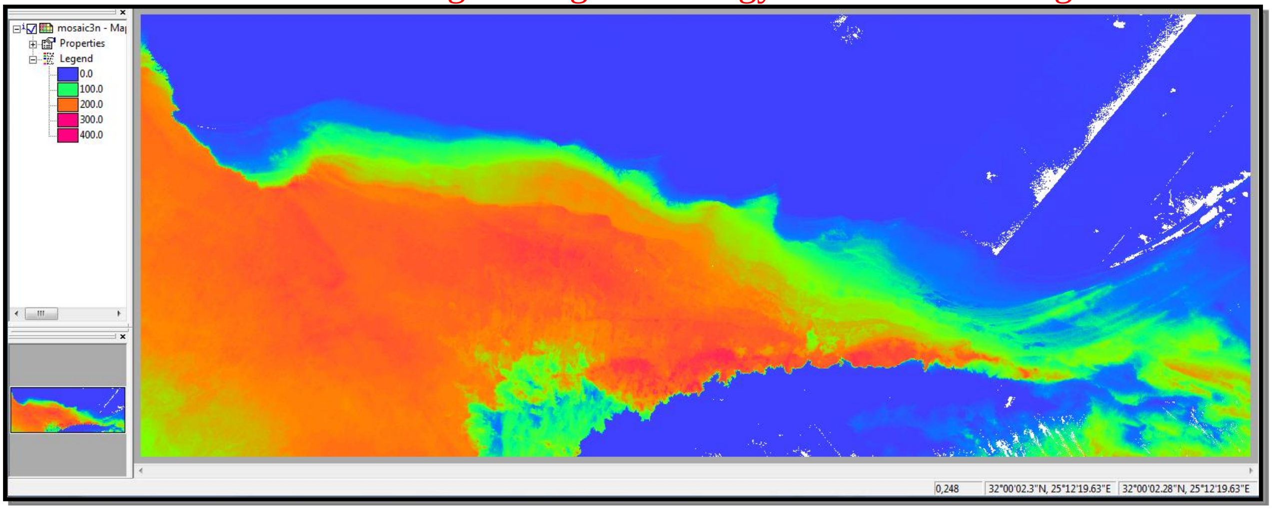

Figure 2b: Mosaicked Georeferenced Satellite Imagery for the Study Area

Within ILWIS software environment, ten individual imageries covering the study area in the Northwestern coastal region of Egypt; (N30E025, N30E026, N30E027, N30E028, N30E029, N31E025, N31E026, N31E027, N31E028, N31E029 were imported, georeferenced and merged (mosaic process), Figure 2a and b. Resampling operation was required to have imageries transformed from the geographic Lat/Long coordinate system projection into equivalent metric coordinate, using the nearest neighbor method.

Imported satellite imageries showed inherited undefined values, viewed as fussy and white spots. These data voids are partially caused by the atmospheric effects commonly experienced in extracted remote sensing products. In addition, the Shuttle Radar Topography Mission (SRTM) 3arc-second (90 meters) DEMs have been averaged from the original 1arc-second (30 meters) spatial resolution, and therefore, corrections were needed prior to further processing.

To resolve the problem of undefined pixels' data, kriging operation that use weighted average method were applied (Maathuis and Wang, 2006). First, a sub-map of a representative region relative to the delineated study area was selected, as shown in Figure 3. Figure 3 illustrates the error map with voids detected.

Trials with different semi-variance operations (e.g. Exponential, Gaussian, Circular, Spherical…etc.) showed best fit, in this case, with weight factors by applying Spherical semi-variogram model. Figure 4 illustrates the selected submap after performing the kriging operation. Accordingly, the spherical model was chosen for kriging process to overcome data voids in the resampled mosaic imagery covering the entire Northwestern coastal region under consideration figure 5.

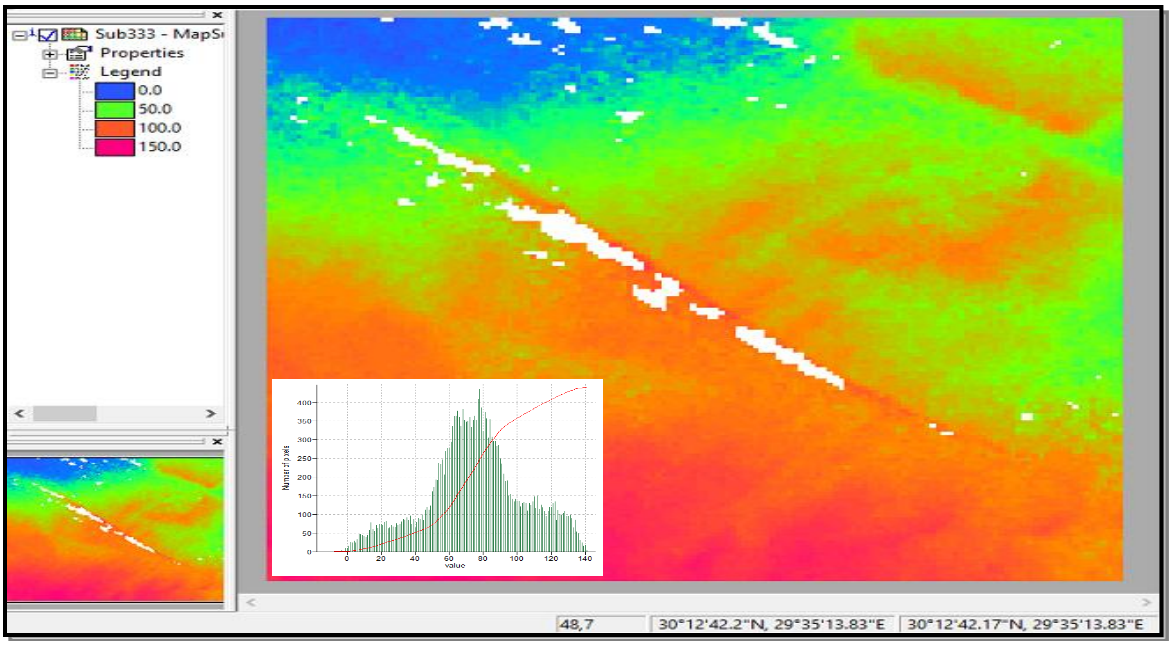

Figure 3: Histogram of Representative Submap for the Region under Consideration with Detected Voids

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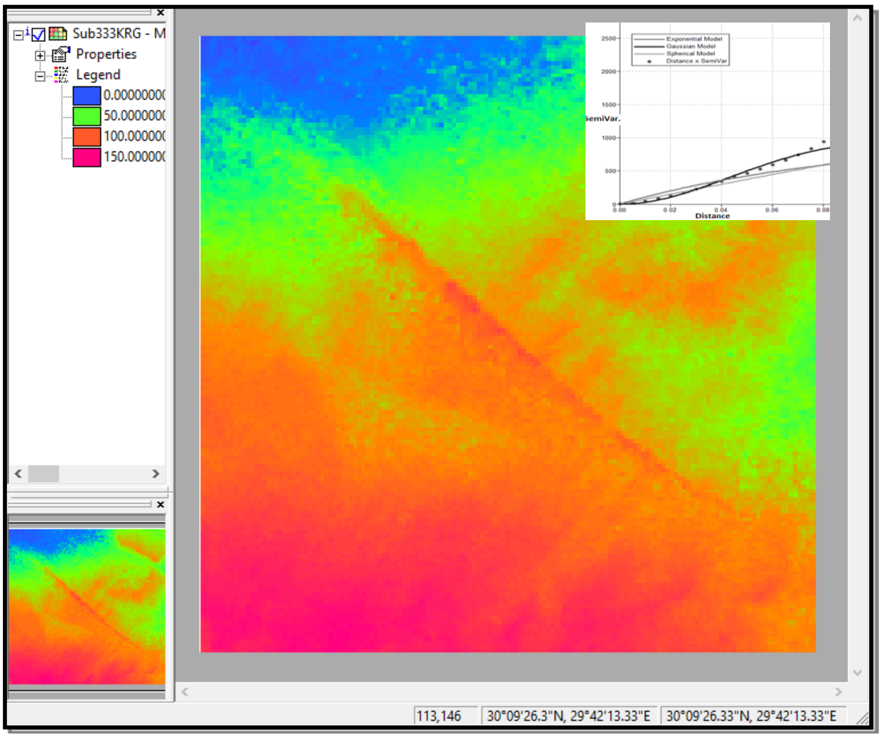

Figure 4: Kriging Process for Sub-map Correction

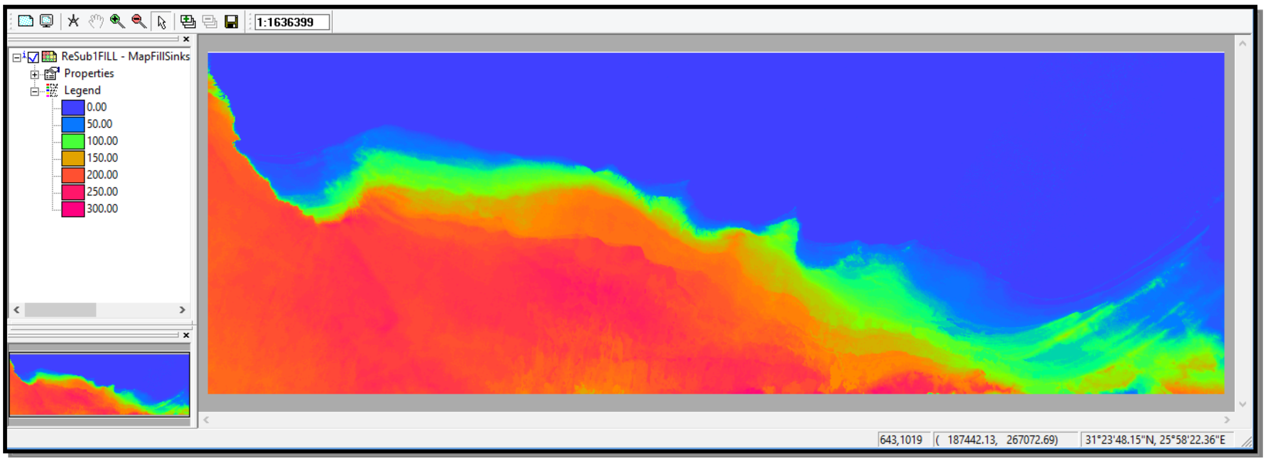

Figure 5: Processed Imagery for Northwestern Coastal Region under Consideration

Hydrologic processing

In order to extract potential drainage network and catchment delineations from the corrected Remote Sensing imagery, three stages of flow determination operations were needed. First, in ***Fill Depression Operation***, pixel(s) with distinct smaller height value than all eight adjacent pixels were smoothed to the smallest height value of the surrounding pixels to avoid local sinks. Subsequently, ***Flow Direction Operation*** was applied using steepest slope method with ILWIS software. The output map classifies flow directions into 8 possible directions North (N), West (W), East (E), South (S), North West (NW), North East (NE), South West (SW), and South East (SE), as shown in Figure 6 with example focused sub-area for demonstration. Then, ***Flow Accumulation Operation*** was carried out to conclude draining pattern, defined in terms of cumulative contribution counts for drained water into outlets, as demonstrated in Figure 7 with an example focus section. Accordingly, drainage network and catchments parameters were generated using appropriate threshold.

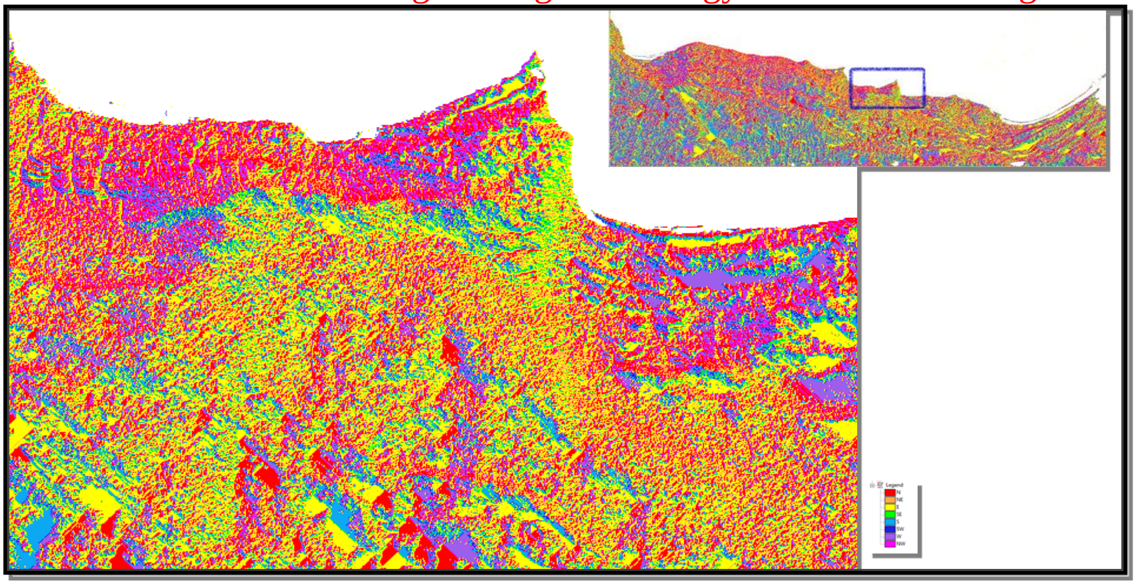

Figure 6: Generated Flow Direction in the Study Area-Example Focus Area

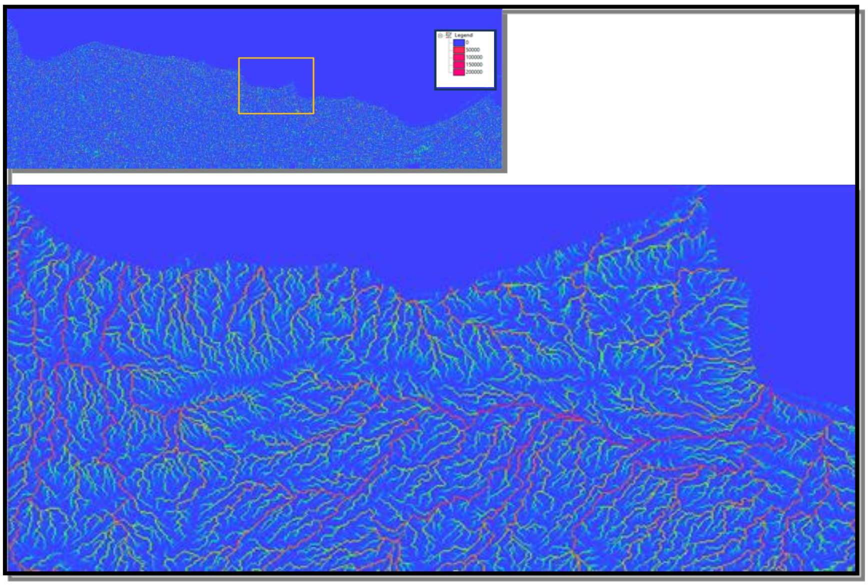

Figure 7: Concluded Flow Accumulation for the Study Area-Example Focus Area

Validation process

To examine efficiency of the applied method and reliability of concluded drainage pattern using remotely sensed imageries, sub-mapping was performed to focus on a test sub-region within the Northwestern coastal zone. That particular sub-region, bordered by coordinates 31°N 26°30'E to 31°30'N 28°E (figure 1), was recently studied by Yousif et al (2013) for water resources management using Egyptian Survey Topographic maps scaled 1:25,000 for elevation data.

Validation results showed satisfactory match between cumulative drainage patterns concluded with Earth Observation SRTM-based hydrologic analysis, on one hand, and the detected valleys (e.g. Wadi Shebity, Wadi Habis...etc.) drainage basins and sites with flood risk found with ground truthing in the test sub-region, on the other. Agreement in comparative features are illustrated by overlaying in figure 8

With acceptable accuracy in results, concluded drainage netwrok for wider area covering the Northwestern coastal zone, stretches between latitudes 30°N to 32°N and longitudes 25°E to 30°E, are used to recommend promising rainwater harvesting sites (figure 9). However, further scrutinize in selections were performed to rank priority with reference to land covers and activities within the study area.

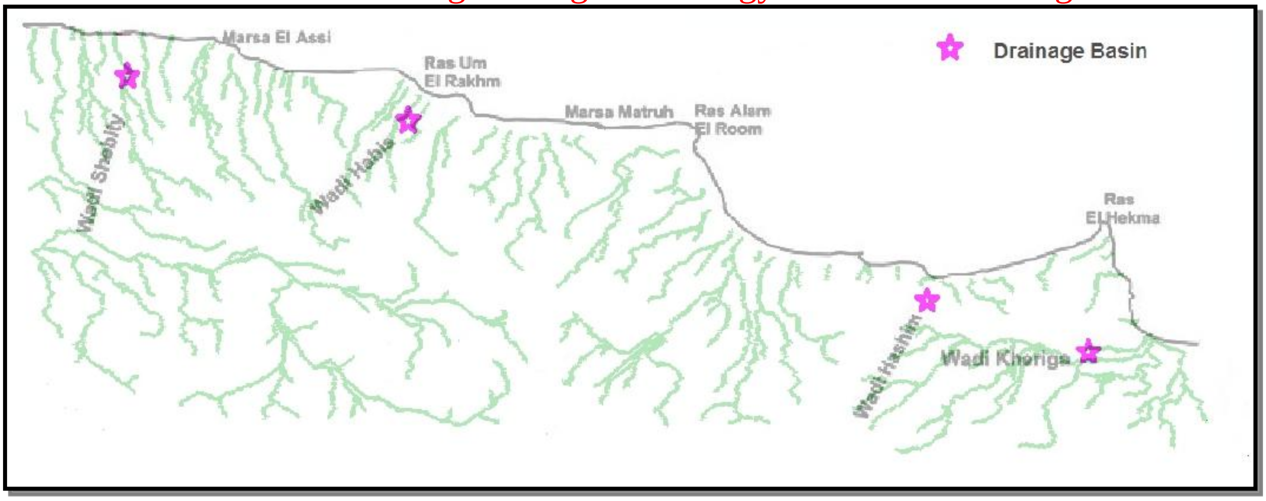

Figure 8: Comparative Analysis: Overlaying Generated Drainage Network on Observed Local Valleys with Ground Truth

RESULT ANALYSIS & DISCUSSION

Hydro-processing with corrected SRTM imageries facilitate constructing drainage stream network for broad coastal strip with acceptable agreement with ground-trusting, as proved in the validation process. Defined drainage network showed two distinct patterns in relation to flow direction and shoreline position. In parts, watercourse takes perpendicular direction into the Mediterranean coastline. Meanwhile, mostly in eastern section of the study area, the drainage water flows in parallel path with the shoreline before changing direction and, eventually, end into the sea, figure 9

Developing drainage network with ILWIS software allows examining various drain length threshold and, consequently, served catchment. Thresholds from 1000 m to 9000 m stream lengthwere tried and 5000 m minimum drain length was decided to have reasonable representative results with acceptable calculation time. Figue 10 presents the developed drainage network and extracted catchment, with chosen threshold, for the study area covering Northwestern coastal region, while figure 11(a and b) give illustration of first selections for potential rainwater harvesting sites, main drains and catchments to take into account.

The extracted drainage network and served catchments were then imported into the Geographic Information System environment (ESRI ArcMap GIS software package, ver. 9.3) for further analysis. Locations with high potential for rainwater harvesting were overlaid with land cover/land uses for optimal selection. Survey of the study area under consideration revealed on four main land uses; residential settlements, tourism resorts, agricultural practices, and minor industrial facilities, figure 12.

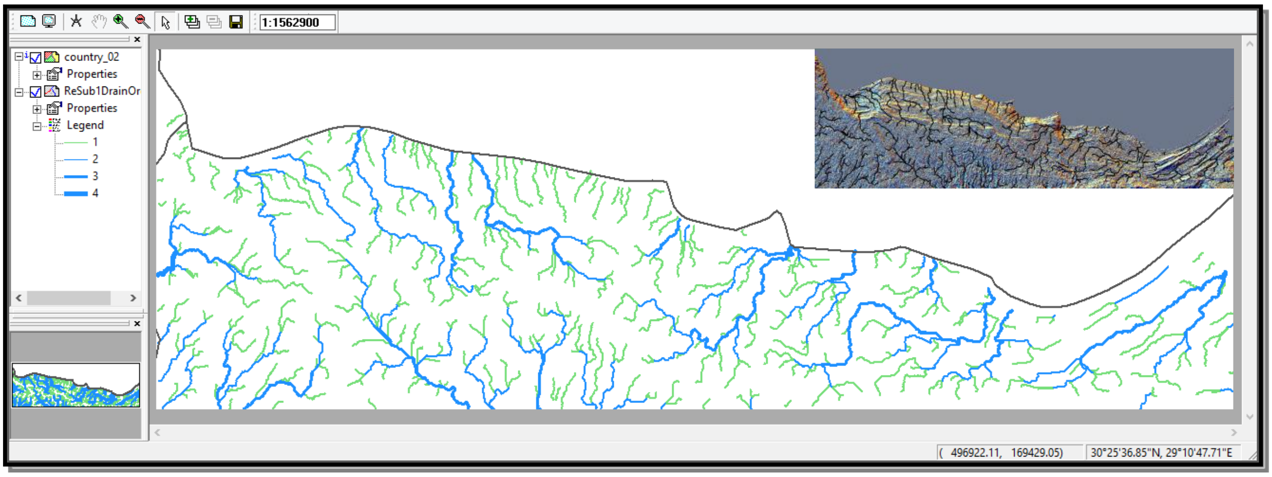

Figure 9: Draining Pattern in Study Area_ Northwestern Coastal Zone

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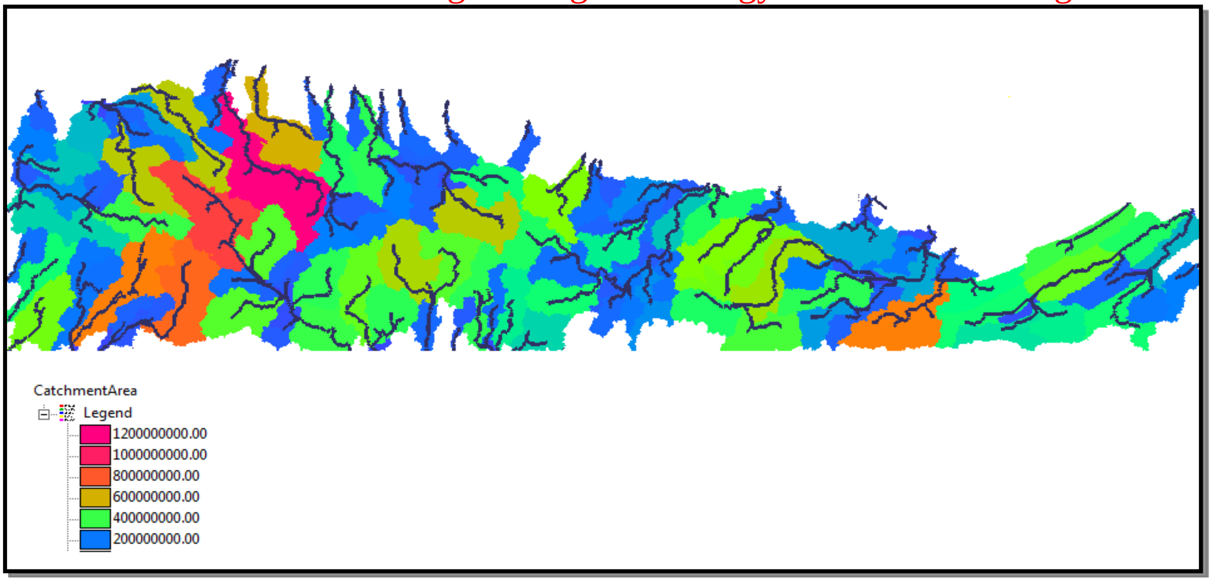

Figure 10: Drainage Network and Served Catchments for Northwestern coastal region

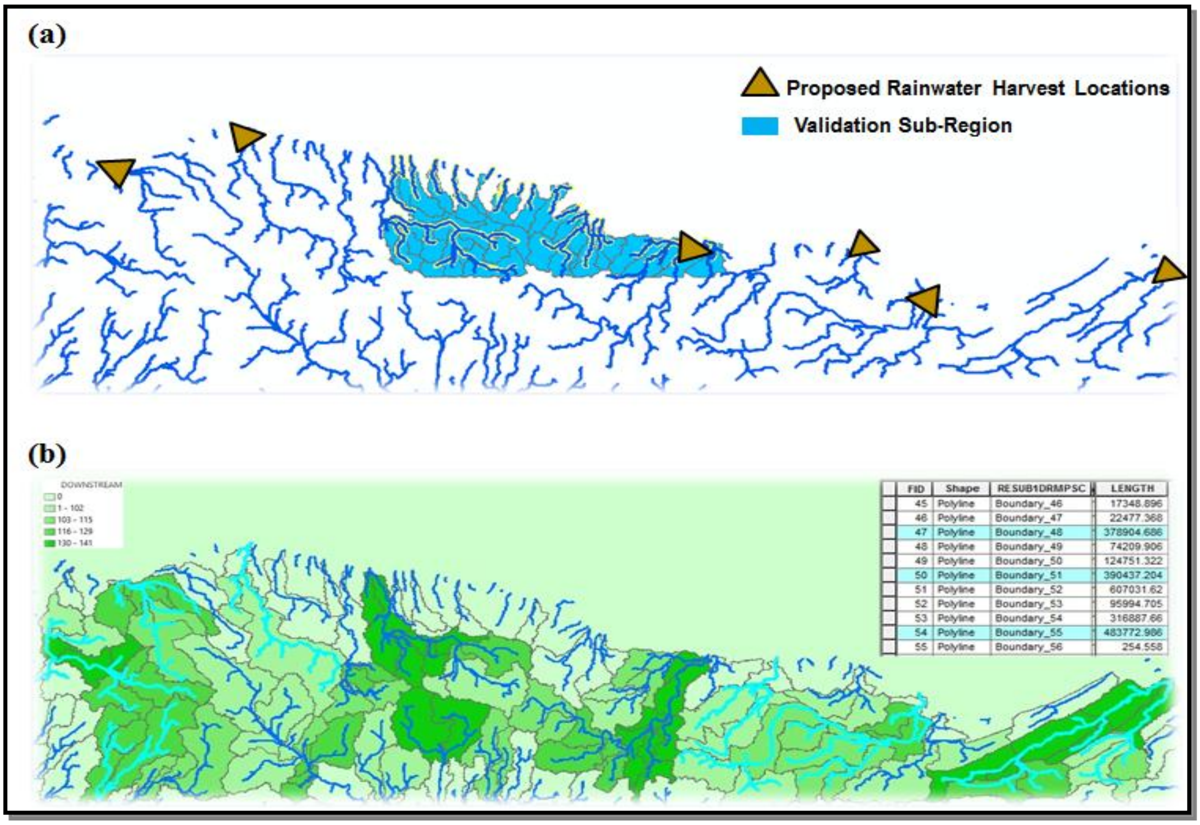

Figure 11a: Preliminary Proposed Locations for Rainwater Harvesting
Figure 11b: Selection Main Streams and Drained Catchments Information

The criteria applied for selecting optimal rainwater harvesting locations utilizes indicators for development encouragement as well as cost-effectiveness considerations. In addition, the selection criteria also considered securing areas with rough topography that are subject to flood risks, previously experience in region. Main factors include; high flow accumulation potentials in rainfall season, benefit for developments in place, and activities with promising expansion with sustained availability of water resources.

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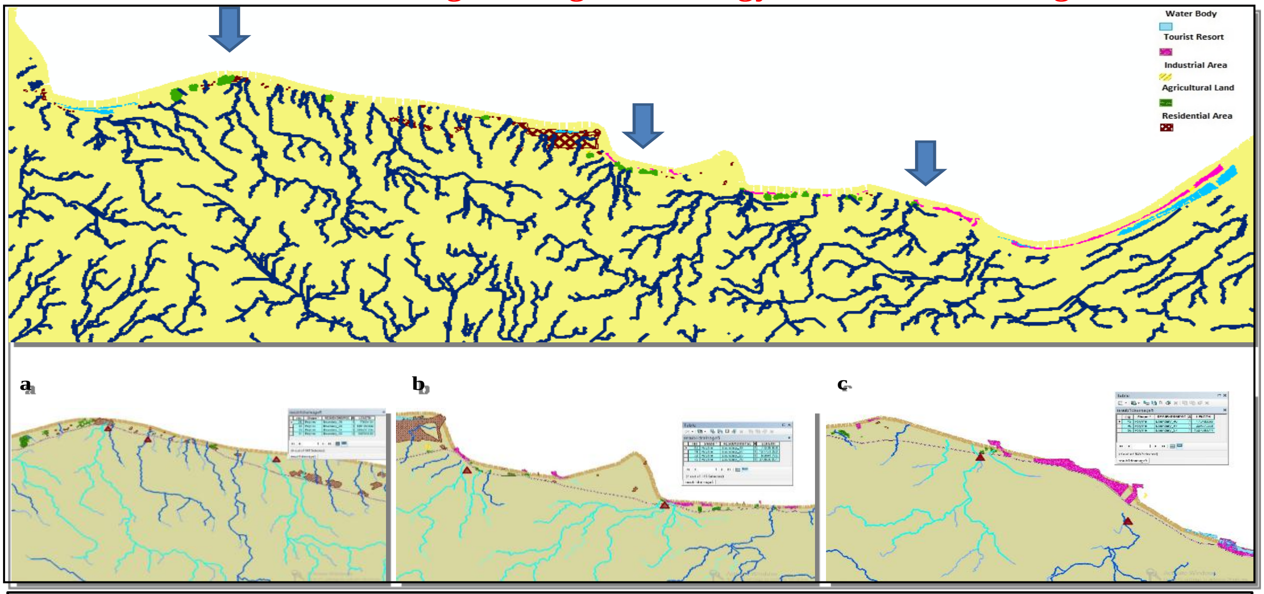

Rainwater harvesting potential benefit:
(a): Alleviate flood risk to residential settlements while expanding agricultural practices
(b): serve development with potential expansion; e.g. tourism, rain-fed agricultural activities
(c): Protect tourism resorts and encourage developments

Figure 12: Recommended Priority Sites for Rainwater Harvesting Measures

Sustainable availability of fresh water resources; e.g. in reservoirs, is expected to boost development activities in the Northwestern coastal strip. Figure 12 highlights the recommended optimal sites for rainwater harvesting in Northwestern coastal region based on; maximum potential rainwater collection, land-uses with importance and progressive developments, as well as location with need to flood hazard alleviation measures in rainfall season. As shown in the figure, three sites (a, b and c) are recommended to have priority for rainwater harvesting measures with the potential benefits in terms of; (a) alleviating flood risk to residential settlements while expanding agricultural practices, (b) serving development with potential expansion; e.g. tourism, rain-fed agricultural activities, and (c) protecting tourism resorts and encourage more developments. Significant rainwater harvesting would be expected from site (a), coordinates location of 31°30'13"N 25°54'07"E, with total upstream catchment area of 1089.14km^2 and main flow stream length of 94.37km. Phased application of construction is also possible with sub-basin area ranging from 132.07km^2 (main flow stream length of 27.47km) and 569.73km^2 (main flow stream length of 72.67km).

CONCLUSION & RECOMENDATION

Aridity nature of Egypt is the reason that major part of lands are uninhabited, resulting in population concentrated in the Nile Delta and Valley. Meanwhile, rainfall events in coastal areas, while seasonal, yet represent high resource potential for expanded development activities. Literature revealed that rainwater harvesting practice is, even though in use for decades in Egypt, not applied in full capacity, mostly initiated locally and with a scattered manner.

This research demonstrates the role that Earth Observation (EO) and Remote Sensing (RS) techniques can play to overcome difficulties customarily faced in the collection, updating, and analysis of hydrology-related geoinformation. However, limitations and sources of errors associated with RS data sources were also discussed and dealt within ILWIS software environment. Through an application in the northwestern coastal zone of Egypt, between latitudes 30°N to 32°N and longitudes 25°E to 30°E, the use of processed satellite imageries minimized cost and time consuming requirements for data collection. Validated results proved effectiveness and reliability of RS data to extract hydrologic patterns in such broad coastal region.

The hydro-processed SRTM imageries, with established drainage network and served catchments, were imported into Geographic Information System and overlaid with actual surveyed activities and land uses in region of interest. Results were then used to assign optimum rainwater harvesting locations based on criteria that consider; hydrologic characteristics including catchment area, surface steepness, stream length to outlet, sustainability of current land uses and development activities with promising expansion, as well as ensuring protection against seasonal extreme events and flood risk. Accordingly, prospective collecting points for rainwater harvesting were defined for surface storage and /or groundwater recharge before fresh water resources are lost into the sea. Three sites are recommended to have priority for rainwater harvesting measures with the potential benefits within the Northwestern coast of Egypt.

In conclusion, the research results prove successful employing of Remote Sensing technique in addressing such a promising planning for water resources development in Egypt's northwestern coastal region with minor field works. The well-defined drainage network and hydrologic feature obtained can be used to parameterize most of hydrological model for further water resources and catchment management related studies.

Continual research is, however, recommended to investigate the expected change in harvesting rates and catchment responses, based on terrain characteristics, soil properties and predicted rainfall with climate change prospective. Also the environmental impact of the harvesting should be taken into consideration.

REFERENCES

[1] Abu-Zreig M. and Hazaymeh A. (2012), Urban Rainfall Harvesting to Alleviate Water Shortages and Combat Desertification in the Arid Land of Jordan, Journal of Arid Land Studies, 22-1: pp 87-90.

[2] Bakir M. and Xingnan Z. (2008), GIS and Remote Sensing Applications for Rainwater Harvesting in the Syrian Desert (Al-Badia), Proceedings of the Twelfth International Water Technology Conference, IWTC12 2008 Alexandria, Egypt.

[3] Cowden J., Watkins D. and Mihelcic J. (2008), Stochastic Rainfall Modeling in West Africa: Parsimonious Approaches for Domestic Rainwater Harvesting Assessment, Journal of Hydrology, 361: pp 64-77.

[4] Effat H. and Hegazy M. (2007), A GIS-based Tool for Mapping a Coastal Highway's Sensitivity Index: A Case Study of the Mediterranean Coastal Highway in Egypt, The Egyptian Journal of Remote Sensing and Space Science, 10: pp 3-20.

[5] El Bastawesy M., Ali R. and Nasr A. (2008), The Use of Remote Sensing and GIS for Catchments Delineation in Northwester Coast of Egypt: An Assessment of Water Resources and Soil Potential, Egypt, Journal of Remote Sensing and Space Science, 11: pp 3–16.

[6] Elhag M. and Bahrawi J. (2014), Potential Rainwater Harvesting Improvement Using Advanced Remote Sensing Applications, The Scientific World Journal, Article ID 806959,

[7] http://dx.doi.org/10.1155/2014/806959.

[8] El-Kaffas S., El-Aref S. and El-Raey M. (2000), Remote Sensing of Environmental Changes of New Burg El Arab, Egypt, Proceedings of the 2nd International Conference on Earth Observation and Environmental Information, 11-14 November, 2000, Cairo, Egypt.

[9] Farr T., Rosen P., Caro E., Crippen R., Duren R., Hensley S., Kobrick M., Paller M., Rodriguez E., Roth L., Seal D., Shaffer S., Shimada J., Umland J., Werner M., Oskin M., Burbank D. and Alsdorf D. (2007), The Shuttle Radar Topography Mission, Reviews of Geophysics, 45 (2): RG2004. Bibcode:2007RvGeo..45.2004F. doi:10.1029/2005RG000183.

[10] Handia I., Tembo J. and Mwiindwa C. (2003), Potential of Rainwater Harvesting in Urban Zambia, Physics and Chemistry of the Earth, 28: pp 893– 896.

[11] ILWIS 3. 0 Academic, User's Guide. Unit Geo Software Development (2001) Department of Water Resources, the International Institute for Geo-information Sciences and Earth Observation (ITC), University of Twente, the Netherlands.

[12] Kadam A., Kale S., Pande N., Pawar N. and Sankhua R. (2012), Identifying Potential Rainwater Harvesting Sites of a Semi-arid Using SCS-CN Method-Basaltic Region of Western India, Water Resources Management, 26: pp 2537–2554, DOI 10.1007/s11269-012-0031-3.

[13] Kahinda J., Taigbenu A. and Boroto R. (2010), Rainwater Harvesting as an Adaptation Measure to Climate Change in South Africa, Strategic Focus (Pty) Ltd, South Africa, Physics and Chemistry of the Earth, Parts A/B/C 35(s 13–14). DOI: 10.1016/j.pce.2010.07.004.

[14] Kihila J. (2014), Rainwater Harvesting Using Ferro Cement Tanks, an Appropriate and Affordable Technology for Small Rural Institutions in Tanzania, International Journal OF Civil and Structural Engineering, Vol. 3, No. 3.

[15] Maathuis B. and Wang L. (2006), Digital Elevation Model based Hydro-Processing, Geocarto International Centre, Vol. 21, No. 1.

[16] Rabus B., Eineder M., Roth A. and Bamler R. (2003), The Shuttle Radar Topography Mission - A New Class of Digital Elevation Models Acquired by Spaceborne Radar, Journal of Photogrammetry and Remote Sensing (ISPRS), 57(4): pp 241-262.

[17] Ramakrishnan D., Bandyopadhyay A. and Kusuma K. (2009), SCS-CN and GIS-based Approach for Identifying Potential Water Harvesting Sites in the Kali Watershed, Mahi River Basin, India, Journal of Earth Syst. Sci., 118, No. 4: pp 355–368.

[18] Sazakli E., Alexopoulos A. and Leotsinidis M. (2007), Rainwater Harvesting: Quality Assessment and Utilization in Kefallinia Island, Greece, Water Research, 41: pp 2039–2047.

[19] Shuttle Radar Topography Mission (SRTM) Digital Elevation Data were downloaded from the official web sites. SRTM products available at: http://seamless.usgs.gov), http://srtm.csi.cgiar.org, usgs.gov/srtm/

[20] Vohland K. and Barry B. (2009), A Review of in situ Rainwater Harvesting (RWH) Practices Modifying Landscape Functions in African Drylands, Agriculture, Ecosystems and Environment, 131: pp 119–127.

[21] Yousif M. and Bubenzer O. (2012), Perched Groundwater at the Northwestern Coast of Egypt: a case study of the Fuka Basin, Applied Water Science vol.2: pp 15–28, springer, DOI 10.1007/s13201-011-0023-0.

[22] Yousif M., El Abd E. and Baraka A. (2013), Assessment of Water Resources in Some Drainage Basins, Northwestern Coast, Egypt, Applied Water Science, 3: pp 439–452.

[23] Zhu K., Zhang L., Hart W., Liu M. and Chen H. (2004), Quality Issues in Harvested Rainwater in Arid and Semi-arid Loess Plateau of Northern China, Journal of Arid Environments, 57: pp 487–505.