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A GIS-based Approach for Determination of Potential Runoff Coefficient for Al-Baha Region, Saudi Arabia

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Abstract. In Al-Baha region no runoff coefficient data are available, and the experimental data are limited. This study was conducted to estimate the Potential Runoff Coefficient (PRC) using geographic information system (GIS) based on the area's hydrologic soil group, land use, and slope. The soil map was developed using GPS data to identify the soil texture to be used in building a soil hydrological groups map. Unsupervised and supervised classification was done to Landsat 5/7 TM/ETM image to generate land use and land cover (LULC) map. A 30m DEM was used to generate the slope map. The GIS technique combined the three maps into one map. Then a new field was added to the map for the CN values and generated PRC map. This study shows that the runoff volume for a certain amount of rainfall is less or even not affected by slope beyond a critical slope.

Keywords: Potential runoff coefficient (PRC), geographical information system (GIS), hydrological soil group (HSG), digital elevation model (DEM), land cover/land use (LCLU).

1. Introduction

Runoff coefficient is defined as the portion of rainfall that becomes direct runoff during an event. The concept of event runoff coefficients dates back to the beginning of the 20th century [1]. The runoff coefficient can be defined either as the ratio of total depth of runoff to total depth of rainfall, or as the ratio of peak rate of runoff to rainfall intensity for the time of concentration [2]. Runoff coefficients can be used in event-based derived flood frequency models for estimating flood occurrences from rainfall frequencies [3]. These coefficients are useful for understanding the flood frequency controls in a particular hydrologic or climatic regime.

In the Al-Baha region of Saudi Arabia, for which no runoff coefficient data are available and the experimental data are limited. At the time rainfall-producing runoff occurs, the coefficient varies with topography, land use, vegetal cover, soil type, and moisture content of the soil [4]. The rational runoff coefficient is strongly dependent on land use and to a lesser extent by watershed slope, as suggested by [5]... The runoff curve number was developed from an empirical analysis of runoff from small catchments and hill slope plots monitored by the USDA. The runoff curve number is based on the area's hydrologic soil group, land use, treatment, and hydrologic condition. References such as USDA indicate that the runoff curve numbers for characteristic land cover descriptions and a hydrologic soil group

The GIS has become a critical tool in hydrological modelling because of its capacity to handle large amount of spatial and attribute data. Some of its features, such as map overlay and analysis, help for deriving and aggregating hydrologic parameters from different sources such as soil, land cover, and rainfall data [6]-[7]. The main objective of this research work is to determine the potential runoff coefficient for Al-Baha Region, Saudi Arabia using geographical information system (GIS) and available data.

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2. Data and Methodology

Implementation of this study required distinctive efforts in different fields or disciplines. In addition to office work, a field survey, an assortment of supporting techniques such as the use of geographic information system, GIS, remote sensing, RS, and satellite images were necessary.These efforts and technics were utilized for identifying potential runoff coefficient.

The following are the materials and software used in the implementation of this study. The material includes the family raster software of ArcGIS (MAP family, Erdas) and remote sensing data. The following are the main materials and collected data used.

ArcGIS software with spatial analysis licenses, Erdass imagine software, Remote sensing data, and GPS the collected data include: (Soil texture map, Digital elevation model , Ground truth point for land cover generation, Remote sensing data for Al-Baha region, Landsat satellite images (from 2000) and GPS ground truth points)**.** The methodology used to determine the potential runoff coefficient for the study area using GIS is shown in the flow chart in Fig. 1.

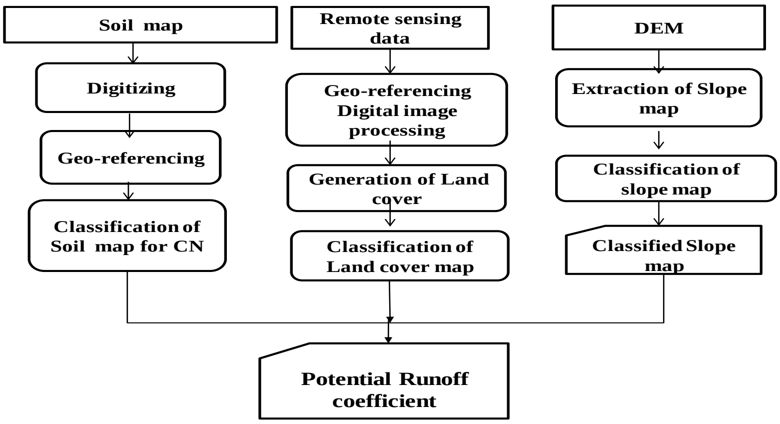

Fig. 1: Conceptual Framework of Runoff coefficient Potential mapping

2.1. Area of study

The Al-Baha region is situated in Hejaz, western part of the Kingdom of Saudi Arabia (41 °42E and 19 ° 20 N) between the holy Makah and Asser (Fig. 2). It is the smallest of the Kingdom's provinces at 12,000 km^2 [8]. Al-Baha was selected as a case study due to the considerable divergence in its topography and climate. Rainfall is much higher than the Saudi average, yet it ranges between 200 and 600 mm/year.

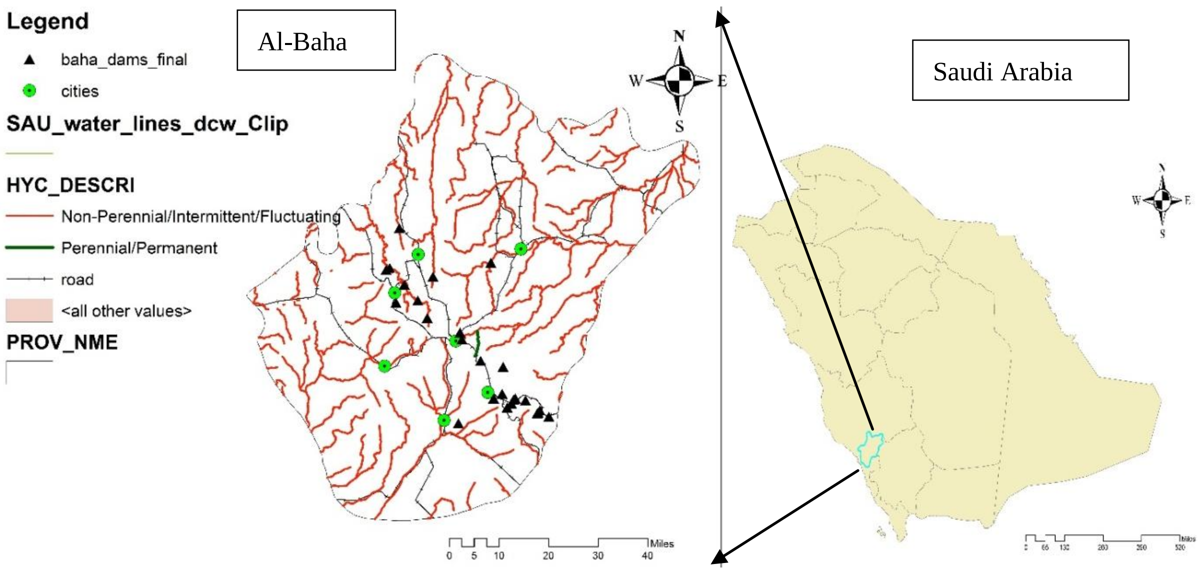

Fig. 2: Location map of the area of study

2.2. Soil map

The soil map developed for the study area using GPS data with support of soil experts to identify the soil texture in the site. The following is the soil texture map for the study area (Fig. 3). The four Hydrologic Soils Groups (HSG) are A, B, C, and D, where A has the smallest runoff potential and D has the greatest, according to [9]. The developed map was then reclassified according to its soil hydrological group into two classes B and D in Fig. 4.

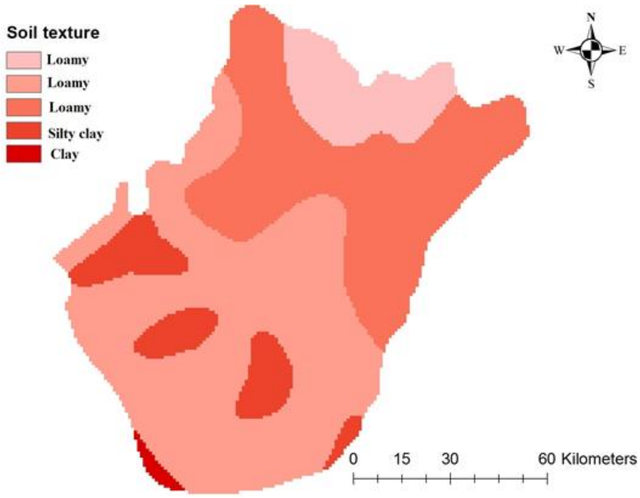

Fig. 3: Soil Texture map for the study area

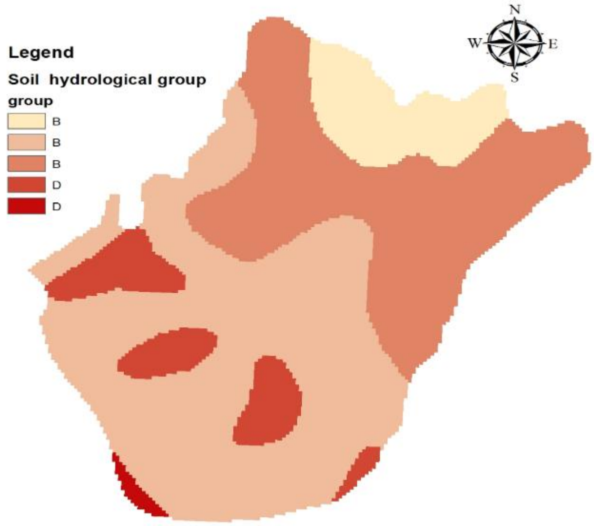

Fig. 4: Soil hydrological group map for the study area

2.3. Land cover / land use

Landsat 5/7 TM/ETM images obtained for the year 2000 from the King Abdul-Aziz City for Science and Technology (KACST). This image was incorporated with collected data from the specified region, and ultimately utilized in categorizing land use and land cover (LULC). Unsupervised (Fig. 5) and Supervised classification (Fig. 6) and Were done to the image using spectral signatures obtained from training samples (polygons that represent distinct sample areas of the different land cover types to be classified). These samples collected during the filed survey, the image analyst, to classify the image.

After preparing the training file, the classifier then attached labels to all the image pixels according to the trained parameters. Maximum likelihood classification (MLC) is the most commonly used supervised classification method; The LULC map classified into four main classes: cropland, sparsely vegetated, forest and shrub land, and bare soil, as shown in the map.

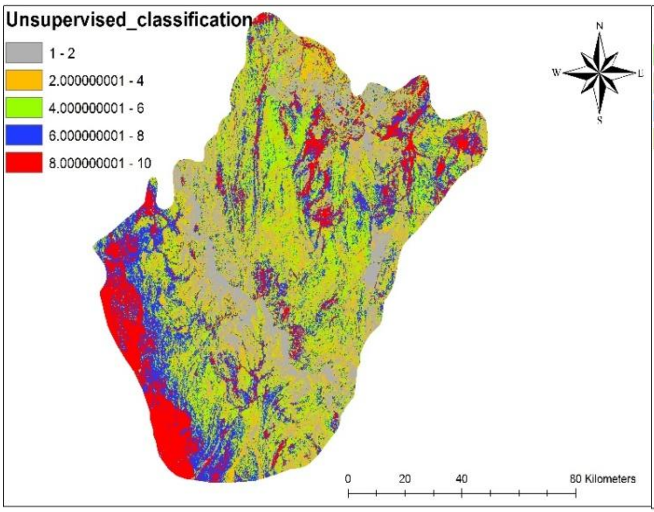

Fig. 5: Unsupervised Landcover for the study area

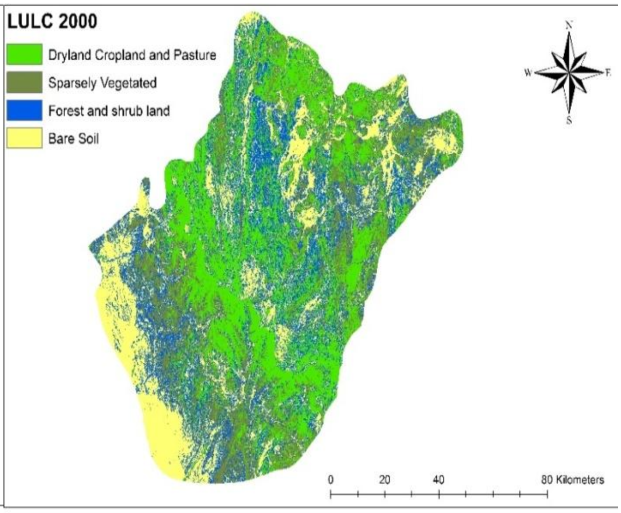

Fig. 6: Classified LULC map for Al-Baha

2.4. Digital elevation model

Digital elevation model **(DEM), 30 m** obtained from King Abdul-Aziz City for Science and Technology (KACST) used to generate the slope map for Al-Baha. The DEM analysed to remove sinks and flat areas to maintain continuity of flow to the catchment outlets. The GIS used for DEM preparation by filling the sink areas (Fig. 7). Slope map (Fig. 8) generated from the fill_DEM. The slope map created for the entire area shows an impression of the steepness of the terrain.

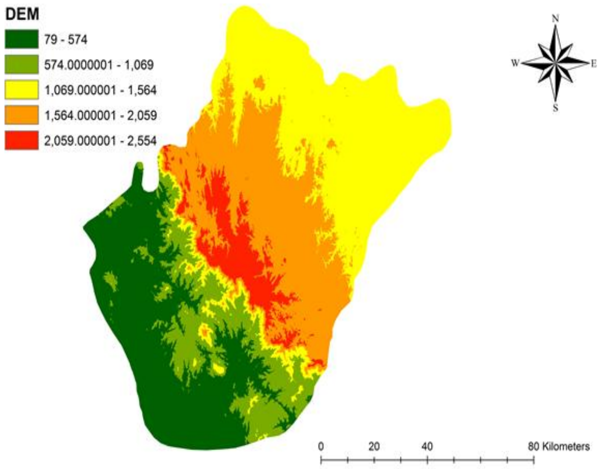

Fig. **7**: The exploitation of digital elevation model for Al-Baha

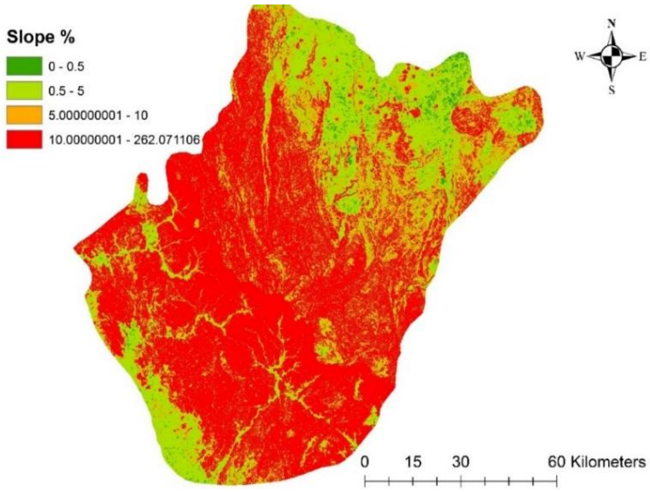

Fig. 8: Slope map for the study area

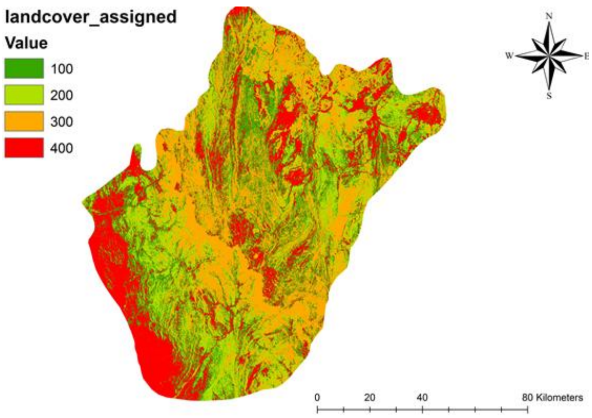

Fig. 9: Reclassified Landcover map

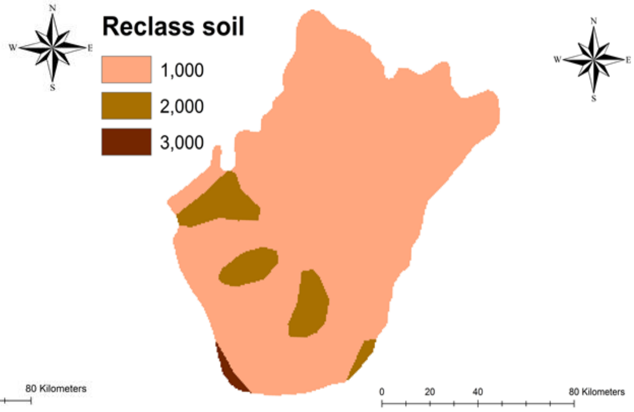

Fig. 10: Reclassified soil hydrological group map

Land cover map (Fig. 9) reclassified into four main classes (forest, grass and shrub, cropland, and bare soil). Moreover, these groups were given weight values 100, 200, 300, and 400 respectively. Soil hydrological group map was given values of 1000, 2000, and 3000 for the 3 classes (Fig. 10). The slope map was reclassified into four classes and then given values from one to four (Fig. 11).

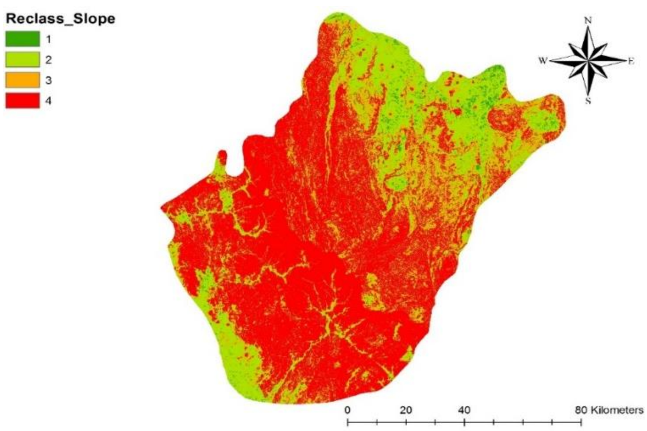

Fig. 11: Reclassified slope map

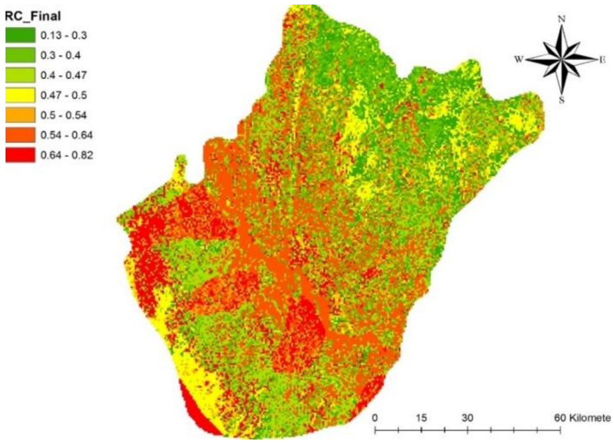

Fig. 12: Distribution of potential runoff coefficient

3. Potential Runoff Coefficient

Land cover, slope map, and soil hydrological group map were combined in ArcGIS in one map. Then a new field added to the map for the CN values. These values are taking the reference from literature [10]-[13] and adjusted after [14] and inserted to GIS from the Potential runoff coefficient table for different land use, soil type and slope available on [15]. In this table the potential runoff coefficients for impervious (including open water surface) were set to 1. In addition, surface slope discretized into four classes. In order to estimate the potential runoff coefficient based on a continuous slope, a simple linear relationship between potential runoff coefficient and surface slope is used, which is described as [15].:

$$C = C_0 + (1 - C_0)\frac{S}{S+S_0} \tag{1}$$

Where C is the potential runoff coefficient for a surface slope $S\,(\%)$, C_0 is the potential runoff coefficient for a near zero slopes. In addition, $S_0(\%)$ is a slope constant for different land use and soil type combinations.

4. Results and Discussion

The map of potential runoff coefficients (Fig. 13) are calculated from the slope, soil type, and land use class combinations as described by [15]. In this map, due to the 50 m grid size, urban cells may not be 100% impervious due to the 50 m grid size. In this study, the percentage of impervious area in a grid cell is computed based on land use classes, with 30% for residential areas, 70% for commercial and industrial areas, and 100% for open water areas (lakes and ponds). In this map (Fig. 13) default potential runoff coefficients for these areas calculated by adding the impervious percentage with a grass runoff coefficient multiplied by the remaining area.

It is clear from Fig. 12 that either dense plants or impervious areas cover the region. Impervious areas have a significant influence on runoff production because they can generate direct runoff even during small storms. Fig. 13 shows that the potential runoff coefficient for a slope ranging from 0 to > 10, where 1 = 0 - 0.5 %, 2 = 0.5 - 5%, 3 = 5 - 10% and 4 = >10% approaches to C_0 when slope is very small, and 1 when slope is infinite. In addition, the changing magnitude of potential runoff coefficient is decreasing along with the increasing of surface slope. That confirms that the runoff volume for a certain amount of rainfall is less or even not affected by slope beyond a critical slope [16]. From Fig. 14 points to the conclusion that the runoff from urban areas is dominant for a flood event compared with other land-use classes in the study area. These results in runoff coefficients are 40 to 82 % in urban areas, while other areas have much smaller values, down to 5% for forests in valleys with practically zero slope.

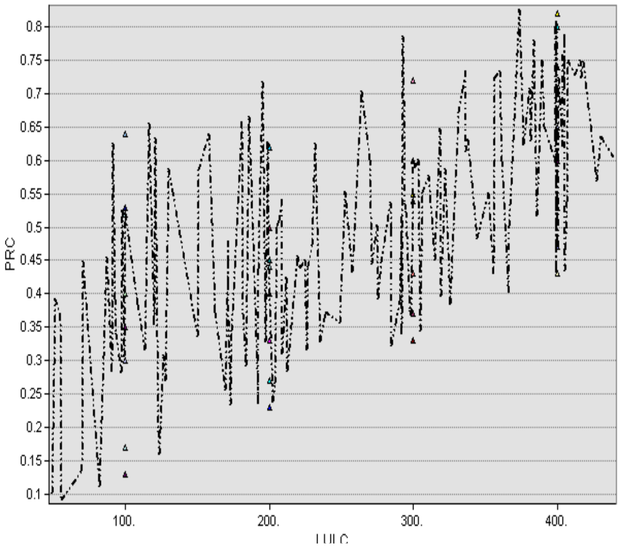

Fig. 13: PRC vs. slope for different land cover and soil types

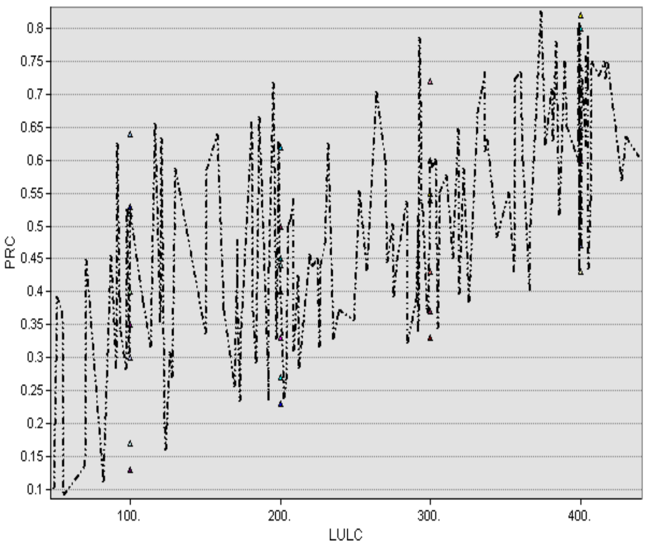

Fig. 14: PRC vs. LULC for different slope and soil type

5. References

[1]. Sherman, L., (1932). Stream flow from rainfall by unit hydrograph method. Engineering News Records 108, Chicago, pp. 501–505.

[2]. Wanielista, M. P. and Yousef, Y. A., (1993). Stormwater Management, John Wiley & Sons, Inc., New York.

[3]. Sivapalan, M., Blöschl, G., Merz, R., Gutknecht, D., (2005). Linking flood frequency to long-term water balance: incorporating effects of seasonality. Water Resour. Res. 41 (6), W06012. doi: 10.1029/2004WR003439.

[4]. Texas Department of Transportation (TxDOT), (2002). Hydraulic Design Manual. TxDOT Hydraulics Branch of the Bridge Division, Austin, TX 78701.

[5]. American Society of Civil Engineers (ASCE) (1992). Design and Construction of Urban Stormwater Management Systems. New York, NY: American Society of Civil Engineers.

[6]. Cheng, Q., Ko, C., Yuan, Y., Ge, Y., & Zhang, S. (2006). GIS modeling for predicting river runoff volume in ungauged drainages in the Greater Toronto Area, Canada. Computers & geosciences, 32(8), 1108-1119.

[7]. De Winnaar, G., Jewitt, G. P. W., & Horan, M. (2007). A GIS-based approach for identifying potential runoff harvesting sites in the Thukela River basin, South Africa. Physics and Chemistry of the Earth, Parts A/B/C, 32(15), 1058-1067.

[8]. Saudi Geological Survey, (2012). Facts and Numbers (In Arabic)

[9]. Cronshey, R. (1986). Urban hydrology for small watersheds. US Dept. of Agriculture, Soil Conservation Service, Engineering Division

[10]. Beven, K. J., & Kirkby, M. J. (1979). A physically based, variable contributing area model of basin hydrology/Un modèle à base physique de zone d'appel variable de l'hydrologie du bassin versant. Hydrological Sciences Journal, 24(1), 43-69.

[11]. Te Chow, V., Maidment, D. R., & Mays, L. W. (1988). Applied hydrology. Tata McGraw-Hill Education.

[12]. Browne, F. X. (1990). Stormwater management, Standard Handbook of Environmental Engineering RA Corbitt, 7.1–7.135.

[13]. Fetter Jr, C. W. (1980). Applied Hydrology, Charles E. Merrill, Columbus.

[14]. Mallants D. and Feyen J., (1990). Kwantitatieve en kwalitatieve aspecten van oppervlakte en grondwaterstroming (in Dutch), Vol. 2, KUL: 76

[15]. Liu, Y. B., & De Smedt, F. (2004). WetSpa extension, a GIS-based hydrologic model for flood prediction and watershed management. Vrije Universiteit Brussel, Belgium, 1-108.

[16]. Sharma, K. D. (1986). Runoff behaviour of water harvesting microcatchments.Agricultural water management, 11(2), 137-144.