

RESEARCH ARTICLE

Determination of Potential Runoff Coefficient using Geographic Information System for a Small Basin in Balakayety Watershade, Kurdistan Region of Iraq

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ABSTRACT

Runoff coefficient is an index for losses in rainfall required in most hydrological models and water resources projects. Generally, in the Balakayety water shade in Kurdistan region of Iraq, no runoff data are available as almost basins are ungagged. The Geographic Information System (GIS) techniques and available data for a small basin in Balakayety watershed within the Erbil governorate (Kurdistan Region of Iraq) were used to estimate the coefficient of potential runoff coefficient (PRC). The estimated PRC will be then used to calculate the depth of runoff. The Satellite Imagery (Landsat 7 ETM+) for 2015 was procured to create land cover classes, the classifications accuracy equal to 88.4%, and the Kappa index is 83.7%. The slope map developed from the digital elevation model with 30 m resolution. The area's hydrologic soil map is digitized from the Iraqi soil map. The inverse distance weighting method was used to interpolate the rainfall of the study area into the Arc GIS. It was found that the most study area covered by moderate to high (PRC) values ranged from 55% to 83%, and runoff depth values vary from 398.1 mm to 610.3 mm. The present study indicates that the integration of all obtained thematic maps into GIS provides a powerful tool for calculating the runoff coefficient for catchments lacks streamflow data which can result in flood/drought predictions that will be not accurate. These findings are helpful in identifying flood areas, selecting proper sites for water harvesting, and enhancing water resources management programs.

Keywords: Geographic information system; Land cover; Runoff coefficient; Slope map; Soil data

INTRODUCTION

Runoff coefficient is a dimensionless factor that is used to convert the rainfall to runoff, and it represents the integrated effect of catchment losses and hence depends on the nature of the land surface, slope, degree of saturation, and rainfall intensity (Goel, 2011). These coefficients are useful for understanding the flood frequency controls in a particular hydrologic or climatic regime (Mahmoud et al., 2014). In recent times, using the remote sensing and the Geographic Information Systems (GIS) have appeared in almost articles to estimate watershed runoff coefficient as Shadeed and Almasri, 2010, Mahmoud et al., 2014, Mahmoud, 2014, Nasiri and Alipur, 2014, Ahmad et al., 2015, and Hameed, 2013. All of the aforementioned researchers integrated soil data, land use, slope, and rainfall intensity in a GIS environment to estimate runoff, runoff coefficient, and runoff depths. They used a linear equation of runoff coefficient and surface slope developed by Liu and De Smedt (2004) or the soil (SCS-CN) method developed by the United States department of agriculture (USDA,1986) and pre-prepared tables by Liu and De

Smedt 2004 for different catchments in Palestine, Saudi Arabia, Egypt, Iran, India, and Iraq, respectively. In the present study, a small basin of 57.6 km² area was selected. It represents a rugged mountainous area that has elevation ranges from 1138 to 3347 m, located in the north-eastern part of Iraq in the Erbil Government (Kurdistan Region). The main goal of this study is to determine the runoff coefficient and the runoff depth in the study area which lacks streamflow measurements. The analysis involves processing spatial data (Landsat 7 ETM+), DEM, land cover, soil texture, rainfall, and slope maps using (GIS) tools.

MATERIALS AND METHODS

Study Area Illustration

Geographically, the study area located in the north-eastern part of Iraq within Erbil Government (Kurdistan Region), lying between (36° 44' 0.00" to 36° 42' 68" Northern Latitude and 44° 48' to 44° 50' Eastern Longitude) and has 56.7 km² area. Its mountain areas characterized by shallow lithosolic soils in limestone, steep slopes, rock outcrop,

and deep valleys have a Mediterranean climate region with plenty of rains (Buringh, 1960). Figure 1 shows the location map of the study area.

Digital Elevation Model (DEM) and Slope Map

Satellite Imagery (Landsat 7 ETM+) for the year 2015 with 30 m resolution was imported from the USGS website into the Arc GIS software and displayed as 5, 4, and 3 (RGB) composite. The image geo-referenced, according to UTM WGS84_38N, projected coordinate systems (metric). All sink areas were filled using Arc GIS, and a 30 m DEM was obtained. The DEM is used for watershed delineation, including streams, outlets, and inlets definitions. The slope map was then generated. Figure 2 illustrates the DEM for the considered study area.

Soil Data

The study area is located at Zagros Thrust Zone (Nappe), which has Naopurdan–Walash Series and Qandil (Metamorphic) Series formations which are semi-permeable to impermeable layers and most precipitation runoff (Buringh, 1960; Fouad and Sissakian, 2015; Sissakian, 2018). In general, the landscapes have shallow brown lithosolic soils in limestone, and soil that does develop is regularly washed down the hillsides into the valleys below. By digitization, the soil data were extracted using Arc GIS tools, and the hydrological soil map (hydrologic soil groups [HSG]) was generated as per the standard norms given in chapter 7 of the National Engineering Handbook (Natural Resources Conservation Service, 2009).

Land Cover

Land cover/land use has a significant influence on infiltration and hence on the runoff coefficient (Sharma, 1986). For the image classification process to be successfully, several factors should be considered, including the availability of quality Landsat imagery and secondary data, a precise classification process, and user's experiences and expertise of the procedures (Rwanga and Ndambuki, 2017). Supervised classification methods, with maximum

likelihood clustering in ArcGIS Spatial Analyst extension, were applied to the (Landsat 7 ETM+) for 2015 for the study area to develop the land cover map classes.

Accuracy Assessment and Kappa Index for Image Classification

Accuracy assessment and Kappa index mean to compare the classified image to another data source that is considered to be accurate or ground truth data. This process uses three geoprocessing tools in Arc Map: Create Accuracy Assessment Points, Update Accuracy Assessment Points, and Compute Confusion Matrix. (Cohen, 1960).

Potential Runoff Coefficient (PRC)

The soil texture, land cover classes, and the slope map of the required area in this study were merged in ArcGIS as one map. Then, the PRC is estimated by applying a linear equation relating the runoff coefficient to the slope, as shown in Eq. (1) (Liu and De Smedt, 2004).

$$C = C_o + (1 - C_o) \frac{S}{S + S_o} \quad (1)$$

Where, C is the PRC for a surface slope S (%), C_o is the PRC for the near-zero slopes in reference to the first row of every land use class in the PRC values for different land use, slope, and soil texture, which are taken from Table 1. The data in Table 1 are published by Liu and De Smedt, 2004, which are sourced from published materials (Beven and Kirkby 1979, Fetter, 1980, Chow et al., 1988, Browne, 1990, Mallants and Feyen, 1990, and Mahmoud, 2014). Furthermore, the S_o (%) is a slope constant for different land use and soil type, their values are given in Table 2 (Liu and De Smedt, 2004). Figure 3 demonstrates the conceptual framework for runoff coefficient mapping.

Rainfall and Runoff Depth

Average of monthly rainfall data around the study area for 4 years (2012–2015) was obtained from four precipitation

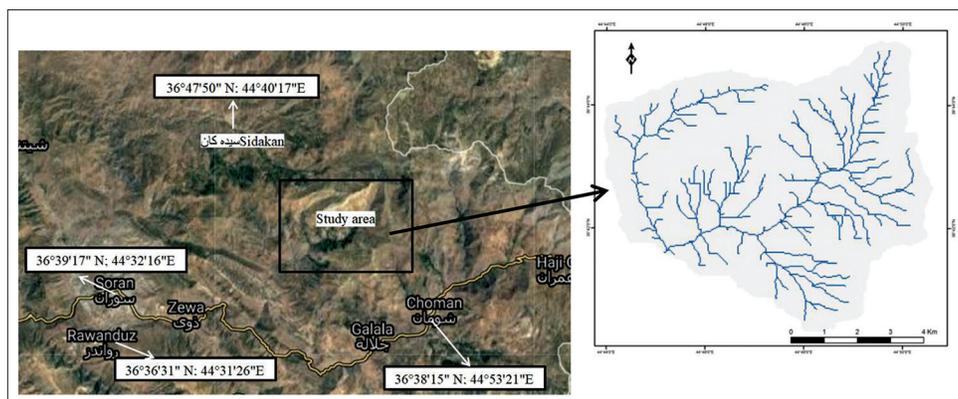


Figure 1: Illustration map of the study area

Table 1: PRC (Liu and De Smedt, 2004)

Land use	Slope (%)	Sand	Loamy sand	Sandy loam	Loam	Silt loam	Silt	Sandy clay loam	Clay loam	Silty clay loam	Sandy clay	Silty clay	Clay
Forest	1.5	0.03	0.07	0.10	0.13	0.17	0.20	0.23	0.27	0.30	0.33	0.37	0.40
	0.5–5	0.07	0.11	0.14	0.17	0.21	0.24	0.27	0.31	0.34	0.37	0.41	0.44
	5–10	0.13	0.17	0.20	0.23	0.27	0.30	0.33	0.37	0.40	0.43	0.47	0.50
	>10	0.25	0.29	0.32	0.35	0.39	0.42	0.45	0.49	0.52	0.55	0.59	0.62
Grass	<0.5	0.13	0.17	0.20	0.23	0.27	0.30	0.33	0.37	0.40	0.43	0.47	0.50
	0.5–5	0.17	0.21	0.24	0.27	0.31	0.34	0.37	0.41	0.44	0.47	0.51	0.54
	5–10	0.23	0.27	0.30	0.33	0.37	0.40	0.43	0.47	0.50	0.53	0.57	0.60
	>10	0.35	0.39	0.42	0.45	0.49	0.52	0.55	0.59	0.62	0.65	0.69	0.72
Crop	1.5	0.23	0.27	0.30	0.33	0.37	0.40	0.43	0.47	0.50	0.53	0.57	0.60
	0.5–5	0.27	0.31	0.34	0.37	0.41	0.44	0.47	0.51	0.54	0.57	0.61	0.64
	5–10	0.33	0.37	0.40	0.43	0.47	0.50	0.53	0.57	0.60	0.63	0.67	0.70
	>10	0.45	0.49	0.52	0.55	0.59	0.62	0.65	0.69	0.72	0.75	0.79	0.82
Bare soil	<0.5	0.33	0.37	0.40	0.43	0.47	0.50	0.53	0.57	0.60	0.63	0.67	0.70
	0.5–5	0.37	0.41	0.44	0.47	0.51	0.54	0.57	0.61	0.64	0.67	0.71	0.74
	5–10	0.43	0.47	0.50	0.53	0.57	0.60	0.63	0.67	0.70	0.73	0.77	0.80
	>10	0.55	0.59	0.62	0.65	0.69	0.72	0.75	0.79	0.82	0.85	0.89	0.92
Mp		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

PRC: Potential runoff coefficient

Table 2: Slope Constant (Liu and De Smedt, 2004)

Land use	Sand	Loamy Sand	Sandy Loam	Loam	Silt Loam	Silt	Sandy		Silty		Sandy Clay	Silty Clay	Clay
							Clay Loam	Clay	Clay Loam	Clay			
Forest	0.680	0.650	0.620	0.590	0.560	0.530	0.500	0.470	0.440	0.410	0.380	0.350	
Grass	0.580	0.551	0.522	0.493	0.46–1	0.435	0.405	0.376	0.347	0.318	0.29	0.260	
Crop	0.500	0.471	0.442	0.413	0.38–1	0.355	0.325	0.296	0.267	0.238	0.209	0.180	
Bare soil	0.420	0.393	0.365	0.338	0.311	0.284	0.256	0.229	0.202	0.175	0.147	0.120	

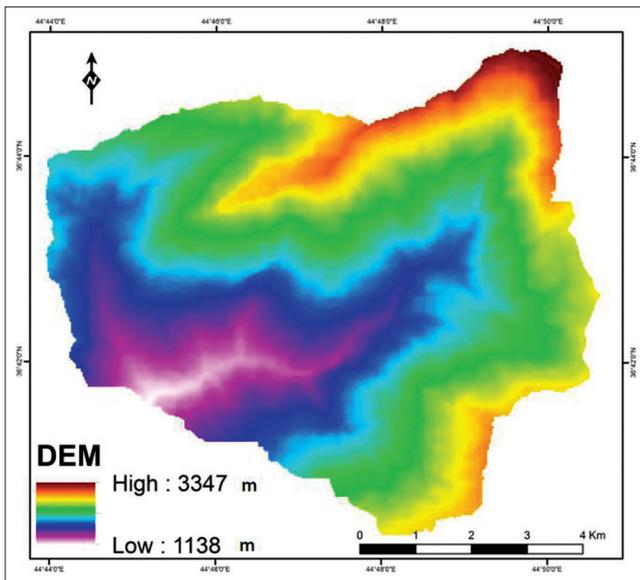


Figure 2: Digital elevation model of the study area

stations: Rawanduz (36°36'31" N; 44°31'26"E), Soran (36°39'17" N; 44°32'16"E), Choman (36°38'15" N; 44°53'21"E), and Sidakan (36°47'50" N; 44°40'17"E), as shown in Figure 1, which is available at the General

Meteorological Director, Erbil (Kurdistan Regional Government, 2015). The rainfall data were interpolated into the Arc Map using the inverse distance weighting method. Using the raster calculator tool, which is provided in the Arc Map toolbox, all estimated (PRC) values from the previous steps were multiplied by the rain falls data, and a runoff depth map is generated. Eq. (2) indicates the percentage of rainfall that is transformed into runoff (Chow et al., 1998).

$$\text{Runoff coefficient (C)} = \frac{\text{Runoff (mm)}}{\text{Rainfall (mm)}} \quad (2)$$

RESULTS AND DISCUSSION

In the present study, the soil texture, land cover classes, rainfall, and surface slope maps have been adopted to estimate the runoff coefficient and runoff depth maps for the study area using GIS tools as follows:

Slope Map

Figure 4 shows the variation of the steepness of the slope from moderate to steep for the study area. The slope map was classified into three classes, namely gentle (<22.5°), moderate (22.5°–45°), and steep (>45°).

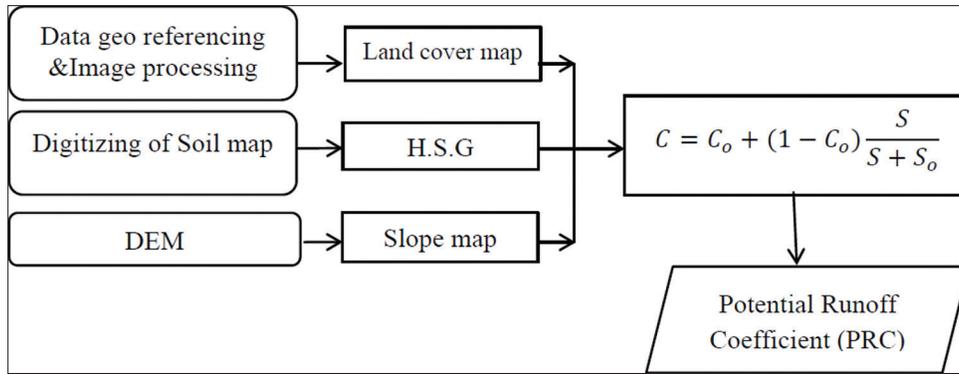


Figure 3: Conceptual framework of PRC mapping

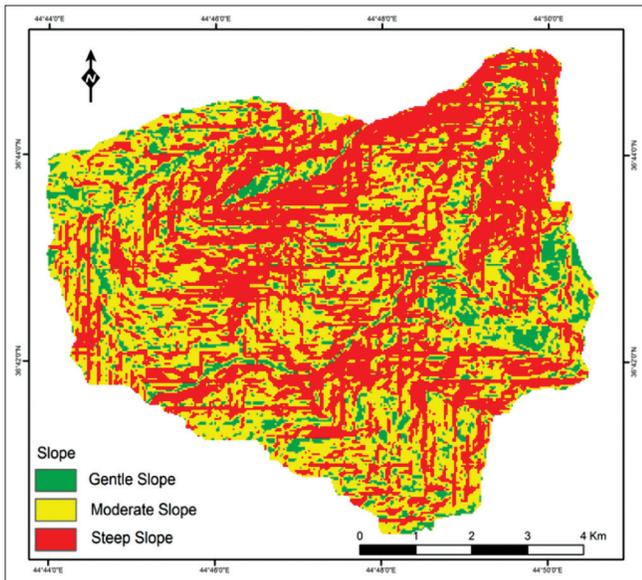


Figure 4: Slop Map of the study area

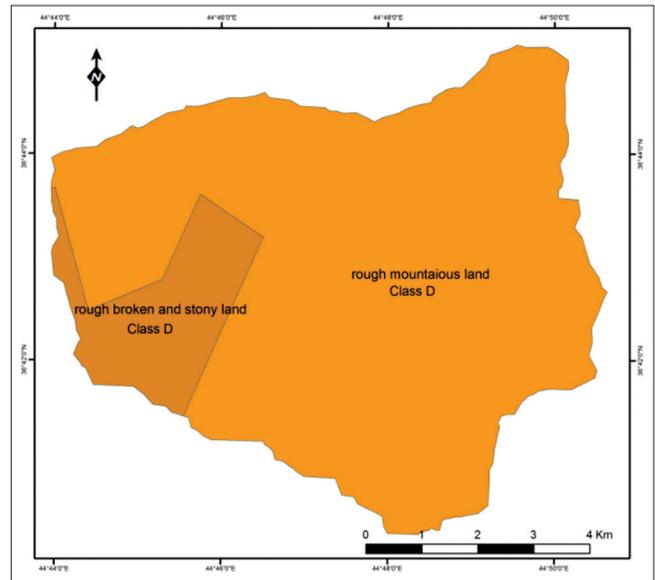


Figure 5: Hydrologic soil groups of the study area

HSG

Figure 5 demonstrates the hydrological soil (HSG) map which, according to the Natural Resources Conservation Service (2009) classification for the whole area, is grouped HSG D. The soil texture is a rough mountainous land, loamy to clayey soils with variable stone content, and rock outcrops (Hameed, 2013); Having, a moderate to high runoff potential when thoroughly wet (Maidment, 1993).

Land Cover Classes

Table 3 illustrates different land cover classes obtained for the area under study using unsupervised classification and maximum likelihood classification function in the ArcGIS. The highest ratio of 57.55% of the area is covered with grass and forest and 37.2% of the total dry land area covered by bare soil. The overall classification accuracy was 88.4%, and the Kappa index was 83.7%, which is an excellent agreement, according to Cohen (1960). Figure 6 demonstrates the land cover classes in the study area. From the figure, it can be seen that the runoff value is lowest for

Table 3: Areas covered by different land cover classes

Land cover	Area (ha)	Area %
Bare soil	2143.85	37.20
Built up land	40.66	0.71
Water	1.42	0.02
Farmland	260.8	4.52
Grass and open forest	3316.9	57.55

forest and grassland, more for cultivated field crops and higher for bare soils.

PRC

Figure 7 indicates that the values of estimated runoff coefficients in this study ranged from 55% to 83%, which are high for lands covered by bare soils as they are impervious, and most precipitation runs off, and moderate for land classes grass and forest. Furthermore, the variations of the PRC values with the surface slope are less. This result confirms the findings of Sharma (1986) and Mahmoud (2014) that the runoff coefficients strongly dependent on land cover and, to a lesser extent, on a water shade slope.

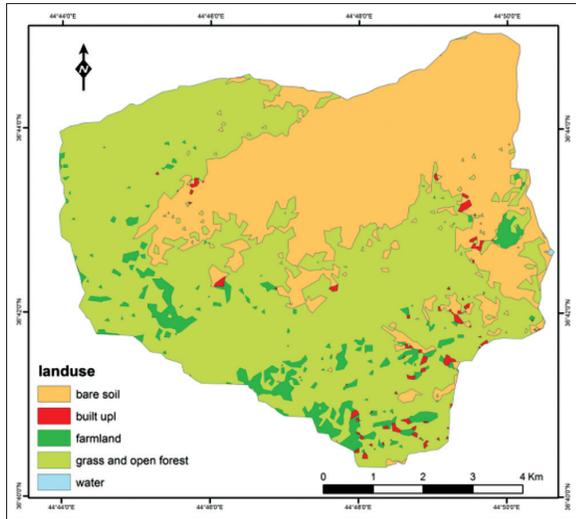


Figure 6: Land cover classes in the study area

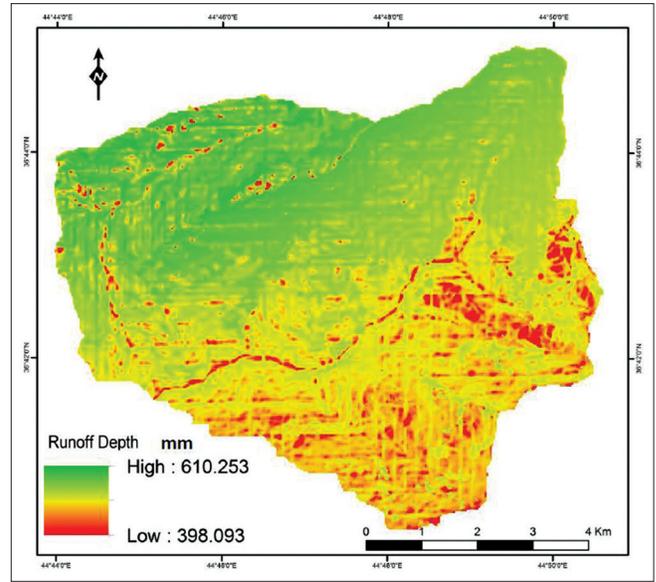


Figure 9: Runoff Depth Map of the study area

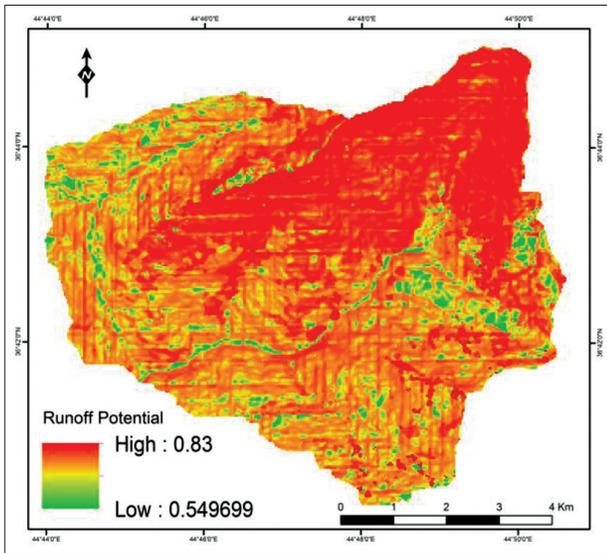


Figure 7: Potential runoff coefficient map for the study area

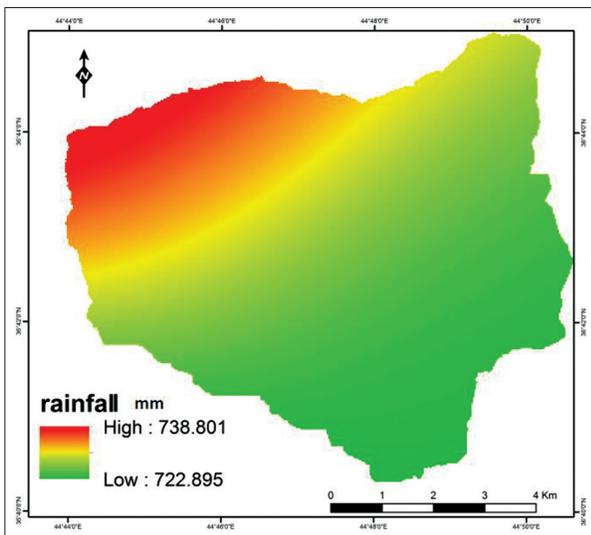


Figure 8: Rainfall distribution map of the study area

Runoff Depth

Figure 8 indicates that the spatial variability of average rainfall over the study area ranged from 723 to 739 mm. Figure 9 indicates that the estimated average runoff depth increases with increasing the intensity of the precipitation and ranged from 610.3 to 398.1 mm. It is observed that the runoff depth is lowest for forest and grassland, more about cultivating field crops, and higher for bare soils.

CONCLUSIONS

In the present study, the following conclusions are summarized:

- The study area is rugged terrain and entirely is grouped HSG D. The soil texture is a rough mountainous land, loamy to clayey soils with variable stone content, and rock outcrops. Having a moderate to high runoff potential ranged from 55% to 83%
- The land cover classes were bare soil, built-up land, grass and forest, water, and farmland. The runoff coefficients were significantly dependent on land cover. It was high for lands covered by bare soils and moderate for grass and forest lands. The overall classifications accuracy and Kappa index were 88.4% and 83.7%, respectively
- The runoff depth ranged from 610.3 to 398.1 mm and increased with increasing the intensity of the precipitation. It was lowest for forest and grassland, more about cultivating field crops and higher for bare soils
- Integration of GIS techniques with a linear equation developed by Liu and De Smedt (2004) provides a powerful tool for determining the runoff coefficient for ungagged basins that do not have sufficient

historical records and can help in mitigating the potential impact of flooding

- The study has helped to visualize the impact of variation in land cover on the runoff volume and can support water harvesting and water resource exploitation projects
- Lack of streamflow data and records in the interesting area has limited the verification of the results.

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