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Creating SCS Curve Number Grid in Diyala River Basin Using Land Cover and Soil Data

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Abstract. It has become necessary to calculate the quantities of surface runoff by knowing the amount of rain or precipitation that falls on an area. The SCS-CN method (Soil Conservation Services – Curve Number) has become one of the most accepted methods at the present time by all specialists and hydrological researchers for several reasons, the most important of which are its simplicity, ease of application, stability and efficiency in finding most of the hydrological parameters. It depends largely on soil type, land use/cover, and topography of the area, in addition to other hydrological factors. Recently, CN grid for any watershed could be done by using remote sense image (RS) and geographical information system (GIS used version 10.3) with its hydro tools and Geo-HMS extension (Hydrological Model System). The study area included the Diyala River Basin (DRB), which has an area of 32600 km^2 located in the north-east of Iraq. It is very important watershed because of supplying the amount of water to the Diyala river which starts after Hemrin dam and meets to feed Tigris River. So, the goal of this study is to estimate the CN for DRB. It was used the DEM (Digital Elevation Model) Tiff file downloaded from USGS site of NASA with a cell size of 12.5m x 12.5m, land use/cover and soil type data from FAO. After re-classifications, the land use/cover of DRB was found in four classes by about 0.5% water, 76.66% vegetation, 5.15% forest, and 17.69% bare areas. Therefore, the land of DRB is covered for about 82% vegetation cover. The soil type of DRB was for about 87% of loam texture and 13% light clay texture. The estimated CN grid was between 60 to 100, the lowest value refers to low runoff and vice versa but 98 to 100 means the area covered by water. The ratios of estimated CN values were 60-70, 71-80, 81-90, and 91-100 were 52.8%, 10.3%, 6.3%, and 0.6% respectively.

INTRODUCTION

Rainfall-Runoff (R-R) is the basic topic for each hydrological study or model. It means the estimated stream flow and its quantity from a catchment through a rainfall storm. Simulation of any model needs to put the dependent and covering equations describing the relationship between the actual rainfall-runoff for the study area [1]. Thousands ways or procedures were used to develop that relation from about 345 years ago. Most of the historical efforts in that way took place in 20th century [2].

In 1940-1945, during the Second World War, a quantum jump happened in mathematical analyses in hydrology. Computer aids, through the digital revolution since 1960, provided many tools to facilitate R-R model.
More than one elements that may affect directly on the direct rainfall processes; (a) catchment characteristics such as catchment-length, area, shape, slope, and drainage-patterns; (b) precipitation; and (c)hydrologic abstraction such as infiltration, soil moisture, evaporation, evapotranspiration, interception, surface detention, and depression storage; and (d) runoff.

The first work of plotting relationship of storm rainfall to the direct runoff might done by Sherman in 1949 [3] which was adopted by Mockus in the same year to present that relation by model as in eq. (1).

$$Q = P_e[1 - 10^{-b\,P_e}] \tag{1}$$

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Where; P_e = rainfall storm amount (inches); Q=direct runoff (inches), and b=index depends on the storm and watershed characteristics as in eq. (2):

$$b = \frac{0.0374\,(10)^{0.229 P_5} (LU)^{1.061}}{K^{1.990}\, T_S{}^{1.333}\, (10)^{2.271 (K_b/T_S)}} \tag{2}$$

Where; P_5 = the 5-day antecedent rainfall (inches); LU = land cover practice index; K = the seasonal index, a function of the time of the year and temperature F0; T_S=the storm duration (hr); and Kb is the soil index (inches/hr).

As results of studies for the Mockus model, it is clear it is suitable for mixed-land cover than single, and large-storms than for small-storms.

All early studies focused on collecting data related to infiltration and the carrying out the runoff [4]. In 1954, Andrews took into account the complex of soil-type and texture, and amount of land-cover with land-use to group the data of infiltration and then plotting R-R [3]. While Mockus used a single soil-cover and one group pf land-use. In general, Mockus and Andrews (1949-1954) contributed directly to yield the method titled SCS-CN (Soil Conservation Service-Curve Number). Although the major problem of modelling R-R is how to estimate the infiltration and abstractions, SCS-CN method was one of the widely used which was published in 1956 by the National Engineering Handbook of Soil Conservation Service, U. S. Department of Agriculture [5].

SCS-CN Method

This method depends mainly on the water balance equation as shown in Eq. (3) and two essential hypotheses [3].

$$P = I_a + F + Q \tag{3}$$

Where $P = total\ rainfall$, $I_a = Initial\ abstraction$, $F = actual\ infiltration$, and Q=direct runoff.
The first SCS-CN hypothesis is that the ratio of maximum potential surface-runoff $(Q/(P - I_a))$ equates to the ratio (F/S), where S refers to the potential maximum retention, as shown in Eq.(4).

$$\frac{Q}{P - I_a} = \frac{F}{S} \tag{4}$$

While the second SCS-CN hypothesis says that the I_a is direct proportionate to the S as shown in Eq. (5) and two hypotheses are shown in fig.(1).

$$I_a = \lambda\, S \tag{5}$$

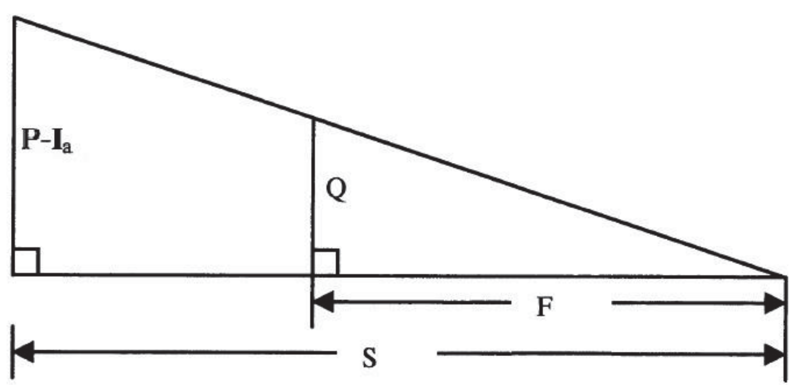


FIGURE 1. The proportionality of SCS-CN Hypotheses

$\boldsymbol{\lambda}$ is a factor depending on the geological and climate conditions such as soil data, land use/cover, hydrologic boundaries and conditions, and antecedent moisture condition (AMC). λ has to be reviewed for every period of years [6]. SCS-CN method assumes λ=0.2 for field applications. The other methods and studies assumed λ in the rage of 0 to 0.3 [3]. Initial abstraction depends on some important parameters such surface storage, infiltration, and an interception.

For re-writing the above two equations (4 and 5), which was adopted by the SCS-CN method, and λ=0.2, it will appear as shown in Eq. (6):

$$Q = \frac{(P-0.2\,S)^2}{(P+0.8\,S)} \tag{6}$$

Equation (6) refers that the SCS-CN method depending on one parameter (S) to compute the surface runoff. The value of S is ranged in from 0 to ∞, then and by mapping the dimensionless values of curve number (CN) in the range of $0 \leq CN \leq 100$ as shown in Eq. (7) [5]:

$$S = \frac{1000}{CN} - 10 \tag{7}$$

Acceptable values of CN in practical models are in the range of (40-98), where lower CN value means lower runoff and vice versa.

The essential catchment characteristics affecting on the S and CN are; (a)soil type, (b)Land Use/Cover, (c)Hydrologic Conditions, and (d)AMC, Initial abstraction and Climate, (e)Duration and intensity of rainfall [7].

Four hydrologic groups of soil type were classified by the SCS-CN method depending on the rate of infiltration and transmission[3]. In general; Group A has soils with a high rate of infiltration and transmission such as sands and gravels, while last Group D has a very low rate of infiltration and a very slow rate of water transmission such as clay soils[8].

By the SCS-CN method, the land use/cover was broadly classified into urban, cultivated land, and woods and forest. Urban lands refer to the lands with no or a little rate of infiltration or the permeability is insignificant and so on.

The amount of grassed cover is an essential term to define the hydrologic condition of a study watershed. A larger amount of grassed cover will lead to less runoff and then an increasing amount of infiltration. There are three used items to describe the situation of hydrologic conditions which are poor, fair, and good. The item poor is used for less amount of grass-cover which will lead to less infiltration and the soil cover will be poor against the erosion but a larger amount of runoff. On the contrary, good hydrologic condition, which means larger grass-cover, will lead to less amount of runoff but still the soil cover be good against the erosion factors. So, the curve number CN will be the highest for poor-hydrologic conditions and the lowest for good-hydrologic conditions but in the average for fair-hydrologic condition [5].

AMC is usually used to describe whether the soil was dry or wet before starting the rain storm. SCS-CN method has three levels of AMC which are AMC I, AMC II, and AMC III [3]. The dry soil is described by AMC I, while AMC III refers to the wetted soil and AMC II means the soil is in average conditions. On the other hand, the AMC I will refer to dry CN i.e. less runoff but AMC III for wetted CN leads to larger runoff. The average one for CN is in the case of AMC II [3].

Interception, surface-detention, infiltration, and evaporation are basic contents of the initial abstraction (I_a). Some of water detention by interception or surface-detention goes back to the atmosphere by evaporation. The potential maximum retention S depends on the I_a and then on the evaporation. All related parameters of evaporation such as humidity, sunshine, etc. describe the climate. So, the evaporation is a significant factor for initial abstraction. The lower is the amount of I_a , the higher will be the surface runoff for a specific amount of rainfall and vice versa. Thus, the CN is affected by I_a clearly.

Duration and intensity of rainfall have a very important role to determine the water staying on land and then the infiltration [9]. For larger intensity and lesser duration, the infiltration will be lesser and greater the surface runoff, then the CN will be larger.

Research Significance and its Goal

The studied area is considered one of the important areas in Iraq in feeding the Tigris River, as well as all the areas it passes through, which they are very large ones. Therefore, calculating the expenses resulting from rain, whether in the watersheds in Iranian territory or Iraqi territory, is an important step to avoid probable droughts as well as expected floods as that flood happened in the first quarter of 2019.

Because of the lack of field data related to the matters necessary to calculate the value of the required curve number, it was necessary to find an alternative in its calculation, and therefore the used methodology according to the research is considered an important tributary for all specialists, whether at the research level or at the level of making important decisions in water management in the country relating to the studied area. So, the goal of this study is to estimate the CN for Diyala River Basin (DRB).

Scope of SCS-CN Method and its Advantages

This method represents a quantum leap in finding the amount of direct runoff generated by precipitation. It possesses a set of features, the most important of which is that it deals with a single factor in finding direct runoff, as well as a simplified concept in estimating the quantities of that runoff. Finally, the field data proved its closeness to the real values of these quantities[10].

In 1964, Mockus showed some problems that could be taken on this method, for example, that this method does not take into account the effect of the intensity of rain and its distribution accurately [2]. It also did not provide a clear expression of time for that effect. In addition, in 1982, Miller and Rallison presented some of the limitations of this method, for example, the lack of field data for different geographical and environmental conditions, etc., which reinforce this method for its suitability or not. While Ponce in 1989 and some authors showed that this method did not show the amount of change that occurred in the antecedent moisture conditions. In 1996, Ponce and Hawkins cautioned to use this method for to watersheds larger than 250 sq. km. In 1998, Glove and his colleagues as well as recently by Moglen (2000) found that the computed amounts of direct runoff by the SCS-CN method were clearly different comparing with those recorded for low precipitation. Although the major problem of modelling R-R is how to estimate the infiltration and abstractions, SCS-CN method was one of the widely used [11].

METHODOLOGY

Area of Study

The Diyala River Basin River (DRB) is sharing the eastern border with Iran by Zagros mountains for about 30 km, and the totally drained area is about 32600 km^2 [12]. It is bordered by four Governorates; Baghdad and Salah Al-Din westwards, Sulaymaniyah to the north, and Wasit to the south as shown in Fig. (2). It is located in between of $33^0 4'59''$ N and $35^0 49'58''$ N, and $44^0 30'00''$ E and $46^0 49'58''$ E. It has three main attributes which are; Wand, Tanjeru, and Sirwan Rivers [12]. The studied area has two main dams; the first at the upstream of the catchment named Derbendekhan and the other Hemrin at the end of it and all of them in Iraq. The basin is very important one because of supplying the amount of water to the Diyala river which starts after Hemrin dam and meets to Tigris River in Al-Nahrawan city at the south of Baghdad. The annual average rainfall is $420\,mm$, while the annual average temperature is 36^0. The maximum possible run-off is in April, while the lowest is in July. Forests cover it by 77%, while the rest can be flat, bare or covered with agricultural areas.

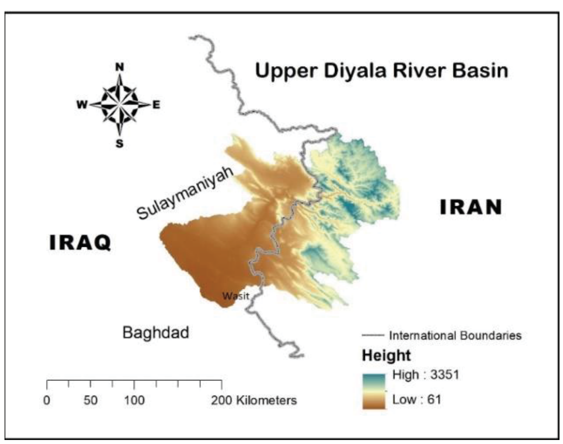


FIGURE 2. Basin of Diyala River (DRB)

GIS and Geo-HMS Softwares

Because of scientific progress in the scope of computers and the modeling of mathematical models, the use of electronic programs has become very important in accelerating and facilitating the calculation of mathematical equations, as well as entering data and boundary conditions surrounding the studied area[13].

In this research, two softwares will be used, namely the GIS and the Geo-HMS softwares.

GIS, which is produced by Environmental Systems Research Institute (ESRI) [10], uses to reinforce the basic principle of geography. Through this research, GIS version 10.3 will be used in processing the digital elevation model (DEM) from satellites, as well as in modifying it and conducting operations for calculating watersheds, as will be shown in the next clauses.

Geo-HMS, Geospatial Hydrologic Modeling Extension, is a software (tools) under the environmental of GIS software. The earliest version was in 1970 [14]. It is used to establish an elementary hydrologic model from the geospatial information and data gotten by GIS and its Hydro Tools.

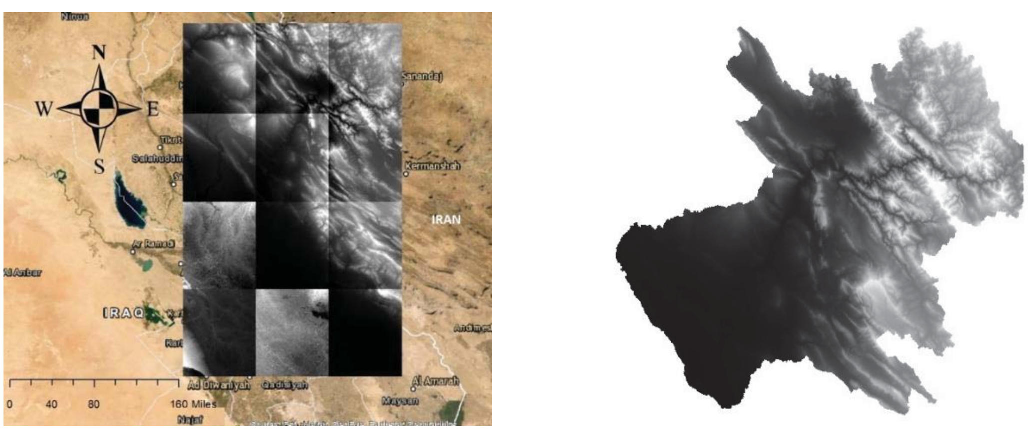
Required Data

Using the programs will greatly facilitate the calculation of the values of the CN for the study area. These programs need three main things:

- Information about the topography: The ArcMap of GIS was used to prepare the special data of the studied area [15]. According to the related coordinates, the digital elevation model (DEM) rasters that describe the DRB topography were downloaded from the site: https://earthexplorer.usgs.gov , which gives about 30*30 size raster. By the ArcGIS and its Hydro tools, it is possible to draw flow-directions, flow-lengths, slopes, drainage-area, and watersheds [1].
- Information about the Land use and Land cover: There are many trends in identifying the nature of the land use/cover of global land, one of the most famous site that gives a global map of the land use/cover is: http://due.esrin.esa.int/page_globcover.php, which was used to download the required file named"Globcover2009_V2.3_Global_.zip " (USGS, 2000).
- Information about the type of soil: The raster file of global soil type, which is named "HWSD Raster ", has been downloaded from the website: http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/ .

RESULT AND DISCUSSIONS

Figure (3 a) shows the DEM of DRB (Basin of Diyala River) which downloaded by the explained site, and then gathering and exploded in the watershed area by Hydro tools of ArcGIS as shown in fig. (3 b).



(a) DEMs covering DRB (b) watershed area

FIGURE 3. Initial DEM's of Basin of Diyala River

There were fourteen steps to complete all basic elements, which are called preprocessing of terrain, to begin Geo-HMS basic model. These were Fill sink, Flow direction, Flow accumulation, Stream definition-area, Stream segmentation, Catchment grid delineation, Catchment polygon processing, Drainage line processing, Adjoint catchment processing, Drainage point processing, Create Batch Point, Batch watershed delineation, Flow path tracing, and Slope. All these steps are shown in fig. (4).

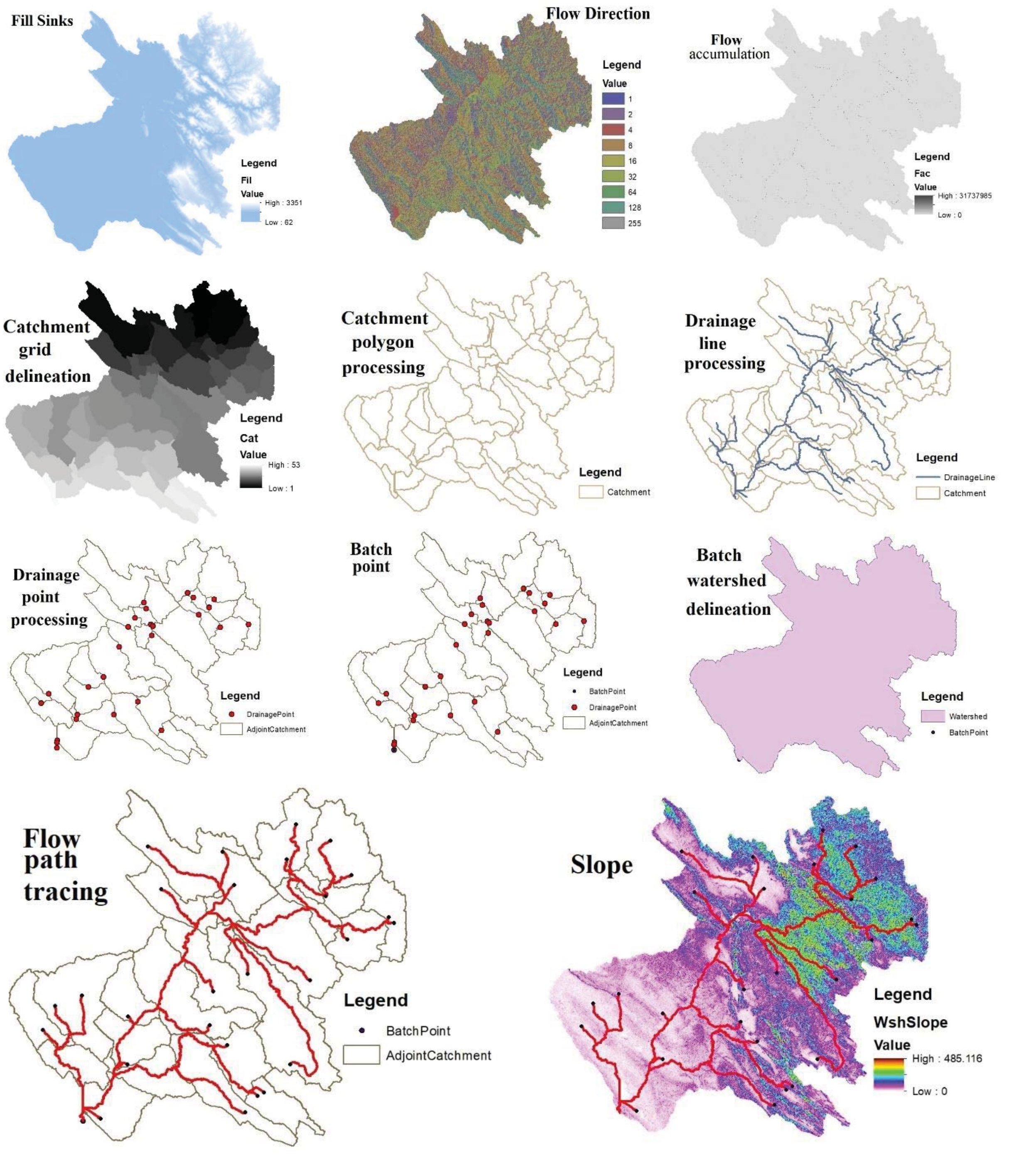


FIGURE 4. All Hydro and some of Geo-HMS processes for DRB

Figure (5) shows the land use/cover which was downloaded from a related site and added to the ArcGIS.

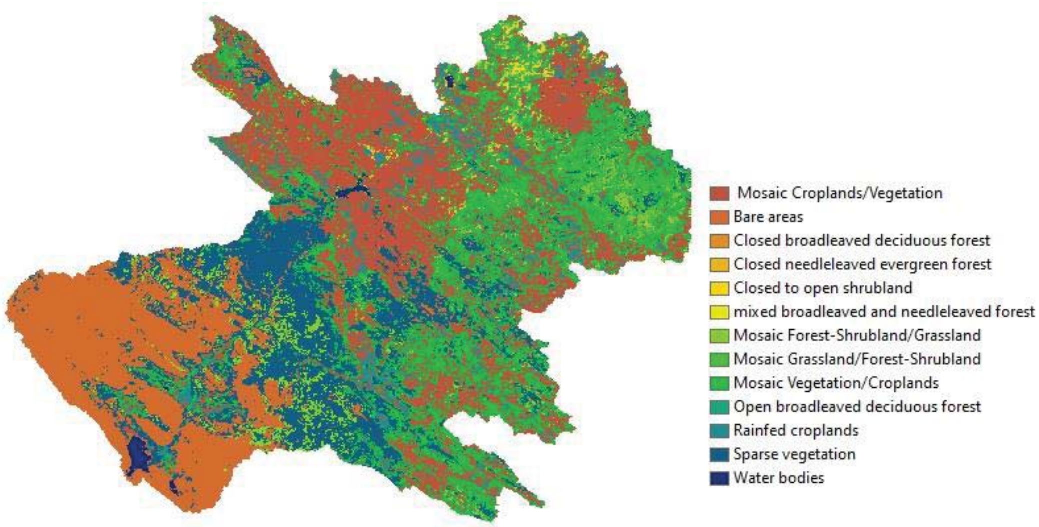


FIGURE 5. All types of DRB land use/cover

There were 13 types of LandUse/Cover and by re-arranging with collecting similar ones, table (1) and fig. (6) show the results.

TABLE 1. New classification of DRB LandUse/Cover

Original NLCD Classification		Revised Classification (Re-Classification)	
NO.	**Description**	**NO.**	**Description**
14	Mosaic Croplands/Vegetation		
20	Mosaic Vegetation/Croplands		
110	Mosaic Grassland/Forest-Shrubland	1	Vegetation
130	Sparse vegetation		
210	Mosaic Croplands/Vegetation		
30	Closed broadleaved deciduous forest		
50	Open broadleaved deciduous forest		
60	Closed needle leaved evergreen forest	2	Forest
70	mixed broadleaved and needle leaved forest		
100	Mosaic Forest-Shrubland/Grassland		
120	Closed to open shrubland	3	Bare Areas
150	Bare areas		
200	Water bodies	4	Water

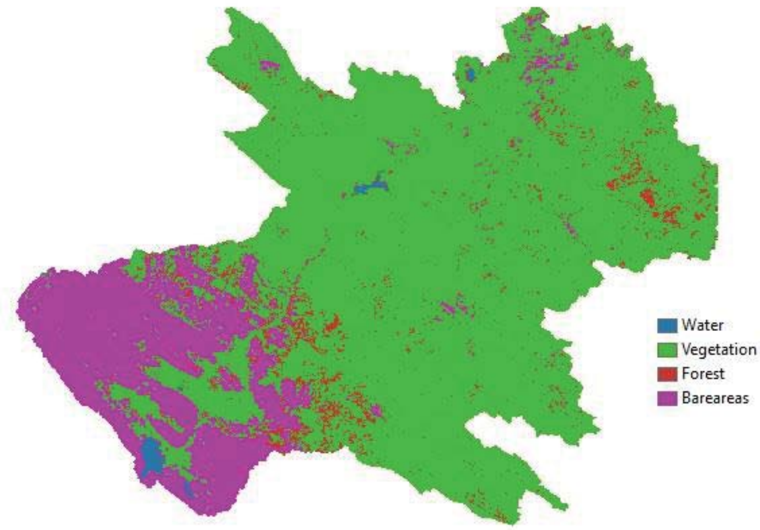
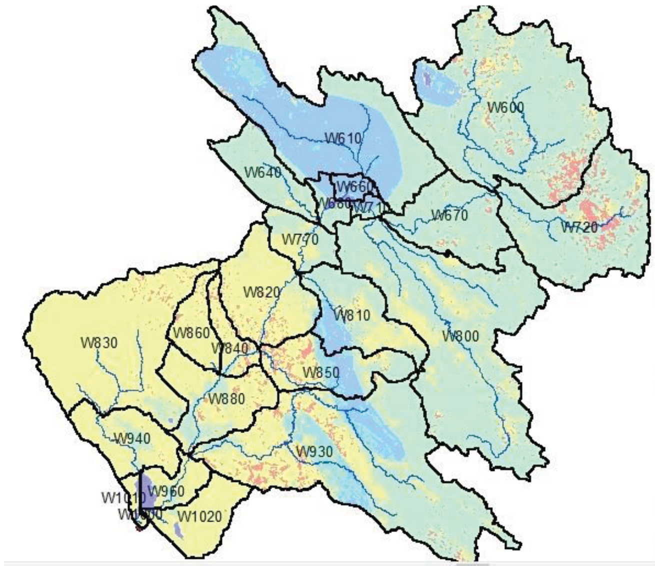


FIGURE 6. Final land use/cover of DRB after Reclassifications

The soil type of studied subbasins, the final raster file has been converted to shape file using ArcGIS Tools as shown if fig. (7):

FIGURE 7. Soil type of DRB

By matching and involving all three data (topography, land use/cover, and soil type) using Geo-HMS processes, the following CN values were gotten as shown in fig (8).



Name	BasinCN
W600	69
W610	75
W640	73
W660	82
W670	68
W680	89
W710	79
W720	66
W770	75
W800	74
W810	76
W820	70
W830	67
W840	63
W850	68
W860	60
W880	67
W930	72
W940	78
W960	78
W1000	99
W1010	85
W1020	94

FIGURE 8. Values of CN for DRB

CONCLUSION

The use of available information and data regarding the topography of the area, maps related to land use/cover, as well as the type of soil, gave good results. This fact was gotten where after re-classifications, the land use/cover of DRB was found four classes for about 0.5% water, 76.66% vegetation, 5.15% forest, and 17.69% bare areas. Therefore, the land of DRB is covered by about 82% vegetation cover. The soil type of DRB was for about 87% of loam texture and 13% light clay texture. The estimated CN grid was between 60 to 100, and as known, the lowest value refers to low runoff and vice versa but 98 to 100 means the area covered by water. The ratios of estimated CN values were 60-70, 71-80, 81-90, and 91-100 were 52.8%, 10.3%, 6.3%, and 0.6% respectively. The CN method with data from NASA and FAO is acceptable way. Although those were a good estimation, it was noticed during the estimation of the CN values that there were negative values, that have been omitted. This basically means the loss of some data, that is, the global maps did not give some accurate matters for all types of soil as well as its land use/cover, which requires treatment in the future so that the results are more appropriate for the cases studied.

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