

# Curve Number Analysis in the Upper Euphrates Basin to Support Regional Decision-Making

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## ABSTRACT

This study examines changes in land use and soil types in the Upper Euphrates River Basin from 2017 to 2023, and their impact on Curve Number (CN) values, a key hydrological tool for estimating surface runoff. The study area is located within the upper Euphrates River Basin, extending from Turkey and Syria to the Iraqi border at Al-Qaim. The study utilized remote sensing and geographic information system techniques, employing the Soil Conservation Service – Curve Number (SCS-CN) method and the HEC-GeoHMS model. The results revealed a significant increase in the area of natural pastures, a marked decline in Barren lands, and a relative expansion of agricultural and Built-up land. Gypsisols and Calcisols were found to be the most widespread soils, exhibiting medium to high permeability. These changes led to a gradual decrease in high CN values (79-84) and an increase in average values (64-69), reflecting improved soil permeability and reduced flood risk, while increasing the region's resistance to drought. The study proposes adopting sustainable water policies in Iraq and enhancing regional cooperation to address the ongoing decline in the flow of the Euphrates River, which has decreased by 50% between 2000 and 2023.

*Keywords-Euphrates River; ArcGIS Pro; HEC-GeoHMS; land use/land cover; curve number*

## I. INTRODUCTION

Climate change is among the most significant factors affecting the world's water supply [1]. Iraq is likely one of the Middle Eastern nations most impacted by climate change [2]. The Tigris and Euphrates Rivers (ER) are the primary sources of fresh water in Iraq. The ER is regarded as the most influential for internal use in Iraq [3]. Iraq is experiencing a significant decline in the amount of water flowing through the ER due to several factors [4-5]. Iraq witnessed a substantial decrease in ER flow from 2000 to 2023. Iraq received approximately 33 billion m<sup>3</sup> of water annually from the ER in the 1970s, while the annual flow decreased to 8 billion m<sup>3</sup> in the 1980s [3]. From 2000 to 2023, it decreased to approximately 50% of what Iraq used to previously receive. This decline is due to the construction of dams in upstream countries and climate change [6]. Despite the significant challenge facing Iraq owing to the severe water shortage, there is a lack of serious attempts of research into this matter [7].

This fact highlights the necessity of adopting sustainable water policies and fostering regional cooperation to ensure Iraq's fair share of Euphrates water.

Many hydrological factors influence climate change and runoff quantities [4]. These factors encompass vegetation cover, land use, soil type, rainfall, and others [8]. Each of these factors significantly impacts water storage, whether in terms of the quantities that can be retained or the amounts of surface runoff resulting from rainfall. For example, rainfall rates in the Upper Euphrates Basin (UEB) decreased significantly from 2000 to 2023 [3]. The annual rainfall rate for the period of 2000-2010 was approximately 400-600 mm. Between 2011 and 2015, it was less than 400 mm. The data recorded a decrease in annual rates to 350 mm for the period from 2016 to 2023 [2]. Moreover, increasing green areas results in a greater amount of water retained by the soil [9], while increasing the area of buildings leads to greater surface runoff [10]. However,

without water conservation programs, this signifies a substantial loss of water storage during the rainfall period.

The hydrological parameter used to measure surface runoff quantities is the so-called CN [11], which provides an indication of all the above factors. This highlights the importance of studying and evaluating the CN for any basin.

The CN is regarded as one of the key tools for estimating the amount of surface runoff, which largely depends on soil type, Land Use/Land Cover (LULC), and moisture levels. Thus, changes in land use and vegetation cover resulting from human activity pose significant challenges in managing water resources. Decision-makers' understanding of the changes occurring and expected in CN represents a significant indicator for water management in the target area. At high values of CN, the probability of flooding is greater during the rainy season, and there is also a higher probability of exposure to drought conditions when the expected amounts of water are not retained in the non-rainy seasons [8, 12]. Therefore, the CN directly addresses the probabilities of flood and drought risks.

There are many attempts to adjust the CN values around the world. Perhaps the most important research center in publishing hydrological programs, tables, and tools is the Hydrological Engineering Center (HEC) of the US Army Corps of Engineers [13]. Since its establishment in 1964 until its last publication on 22/05/2023 [6], it has provided updated tables on estimating CN values based on soil type, land use, and moisture data [14]. Professionally, the surface runoff quantities, affected by changing the value of the CN, were studied in Pakistan [12]. It was found that reducing the CN from 90 to 40 led to a decrease in surface runoff to approximately 78%, from 362 to 78 m<sup>3</sup>.

Several methods have been used to estimate the CN values. In 2021, the impact of changes in the CN was studied using the SWAT model in the Little Ruaha basin in Tanzania [15]. The researchers demonstrated a significant increase in surface runoff of 2.78 mm due to changes in land use, which resulted in a notable CN alteration, while the same result was proven in the same year in the Kania and Esamburmbur basins in Narok town, Kenya [16]. Authors in [17] investigated the Sirba Basin in West Africa using the HEC-HMS model to analyze CN sensitivity. They demonstrated significant changes in surface runoff due to changes in the CN. There have been several attempts to demonstrate which models are the most effective and accurate. Perhaps the comprehensive review presented in [18] conclusively demonstrated that remote sensing images are reliable for estimating surface runoff quantities and their effect on the CN. This was also confirmed by [19], where a study on the city of Kut in Iraq was conducted. A wide range of basins worldwide was confirmed in [20].

Among the most renowned and accurate approaches used in remote sensing images is the SCS-CN method [21]. It is an empirical method for estimating surface runoff caused by rainfall. It relies on land use, soil type, and prior soil moisture. This method is based on [21]:

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \quad (1)$$

where  $Q$  is the runoff (mm),  $P$  is the precipitation (mm),  $I_a$  is the initial abstraction equal to  $0.2 * S$ , and  $S = \text{Maximum soil retention} = \frac{25400}{CN} - 254$ . Therefore, this will be the approved method for this research, especially since it has been included in the renowned program, Geographic Information Systems (GIS).

Despite the significant challenges facing Iraq due to its declining supply of fresh water, there have been limited attempts to study water resources and the important hydrological processes that affect them. Even though numerous studies have addressed the impact of LULC changes on hydrological processes, the UEB lacks similar research, and the present study aims to fill this significant gap. Furthermore, the research aims to address the substantial gap in scientific studies/the specific discrepancy by conducting a long-term analysis to assess how climate change and land use changes have affected the CN between 2017 and 2023 in the region and by implementing integrated modeling that combines remote sensing data with hydrological processes. This research will therefore provide an accurate spatial database that can be used for future planning in water resource management in Iraq. Additionally, water policies in Turkey, Syria, and Iraq should be improved to address the impacts of climate change and other factors on the UEB.

## II. METHODOLOGY

### A. Study Area

Figure 1 accurately depicts the study area. The UEB lies between latitude 38°N and longitude 39.2°E at the source location (Turkey) and between latitude 34.4°N and longitude 41.2°E at the entrance to Iraq in the Al-Qaim region. The basin area ranges from 400 to 500 km<sup>2</sup>.

The hydrological year begins each October [22]. Table I displays the average temperatures and relative humidity in both winter and summer, along with other climatic factors in the basin [1-2].

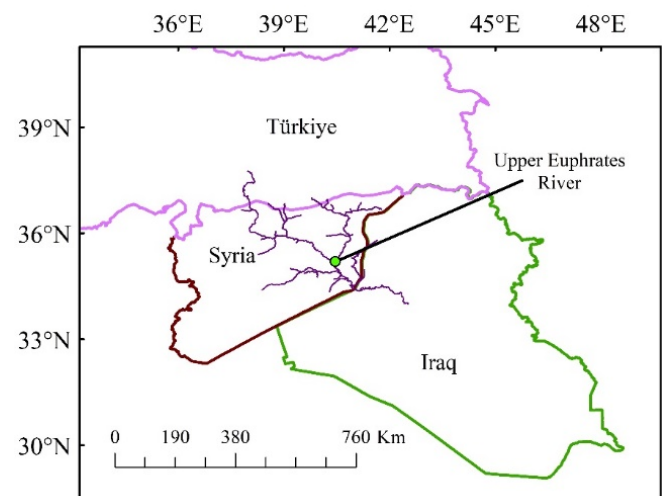


Fig. 1. Location of the study area (UEB).

TABLE I. AVERAGE VALUES OF THE CLIMATE FACTORS COVERING THE STUDY AREA

Country/ season	Turkey		Syria		Iraq	
	Winter	Summer	Winter	Summer	Winter	Summer
Temperature (C°)	-10	30	5	40	5	45
Wind speed (km/hr)	5	15	10	20	15	25
Relative humidity (%)	60	40	70	30	50	20
Annual rainfall (mm)	1,500		600		600	

The most important tributaries of the basin are the Muradsu and Karasu rivers in Turkey, while the Balikh and Khabur rivers are in Syria. There are numerous dams along the ER, with the most significant ones in Turkey being Keban, Atatürk, and Birecik Dams. In Syria, the key dams are the Tishrin and Tabqa Dams. The river encounters the Haditha Dam at its entrance in Iraq [23]. The basin experienced floods and droughts between 2000 and 2023 [22]. The most severe floods occurred in Syria and Iraq in 2003 due to heavy rains, while severe droughts took place between 2007 and 2009. In 2018, the region faced a significant drop in water levels, impacting agriculture and hydropower generation.

### B. Materials and Methods

This research relied on satellite imagery to determine topographic elevations and analyzed reliable satellite imagery for soil type and land use during the period 2017–2023. Data were processed and analyzed using ArcGIS Pro 3.0.2 for geographic analysis [24], while HEC-GeoHMS was utilized for hydrological processes. The data were subsequently subjected to statistical analysis to identify interannual temporal differences and examine the areas most impacted by hydrological and environmental changes.

- Downloading satellite images: all data were downloaded for the period from 2017 to 2023 to monitor geographic changes in the UEB [25]. These were as follows:
  1. The digital model from NASA (<https://urs.earthdata.nasa.gov>), Digital Elevation Model (DEM), was used to extract and analyze the topography of the area.
  2. The Sentinel-2 satellite was employed (<https://arcgis.com/landcoverexplorer>) to obtain LULC and contingency data at a resolution of 10m.
- Soil type data: The related data for the study area were obtained from the FAO website. The HWS viewer program, published on its website was employed to provide information about soil details, moisture status, quality, salinity, and other data necessary for hydrological analysis [26].
- Geo-Hydrological software: The ArcGIS Pro 3.0.2 was used to convert and analyze data, terrain, and other spatial data, providing all the necessary data for hydrological analysis. The HEC-GeoHMS ver.10.3 was deployed for hydrological analysis, identifying surface runoff trends, watershed areas, and watershed boundaries of the study area [8].
- Evaluating CN values: The SCS-CN method included in ArcGIS version 10.3 was utilized to estimate the CN value

for each point in the study area and for every year throughout the study period.

- Standard values of CN: Recently published standard values from relevant locations were used to determine the CN value based on the hydrological parameters of each individual case [27]. These standard values were then combined with the extracted field values from this research and matched to determine the corresponding values at each point in the study area. All standard values and tables are taken from the USDA website (United States Department of Agriculture) [27].

For each sub-basin, the average CN values were extracted using the arithmetic mean [11]:

$$\text{Average}(CN) = \frac{\sum cn * a}{\sum a} \quad (2)$$

where  $a$  = the sub-basin area and  $cn$  refers to the related  $CN$ .

## III. RESULTS

### A. Remote Sensing Image Extraction

After conducting analytical operations with ArcGIS Pro version 3.0.2 and using remote sensing images from the NASA website, a DEM was extracted [28]. This DEM contributed to providing an accurate representation of the topographic nature, which aids in the understanding of the hydrological and hydraulic characteristics of the region, such as identifying valley courses and modeling water behavior, as shown in Figure 2.

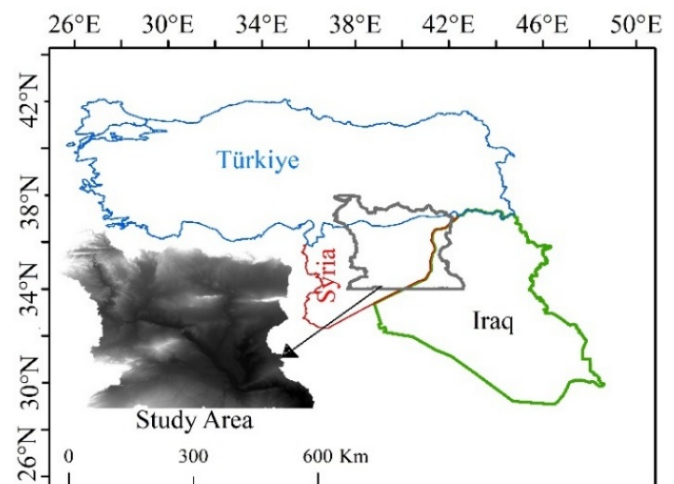


Fig. 2. Extracting the DEM of the study area.

The final results were obtained using the HEC-GeoHMS software, as illustrated in Figure 3. These operations included a series of computer processing tasks, such as defining flow paths, updating the hydrological boundaries of subbasins, and determining the main basin of the study area according to recognized hydrological divisions. Subbasins were categorized according to topographic and hydrological criteria. Main basins and connected subbasins were identified. This processing

improved the accuracy of the hydrological model, facilitated advanced analysis of runoff behavior, and enhanced understanding of water flow dynamics within the study area.

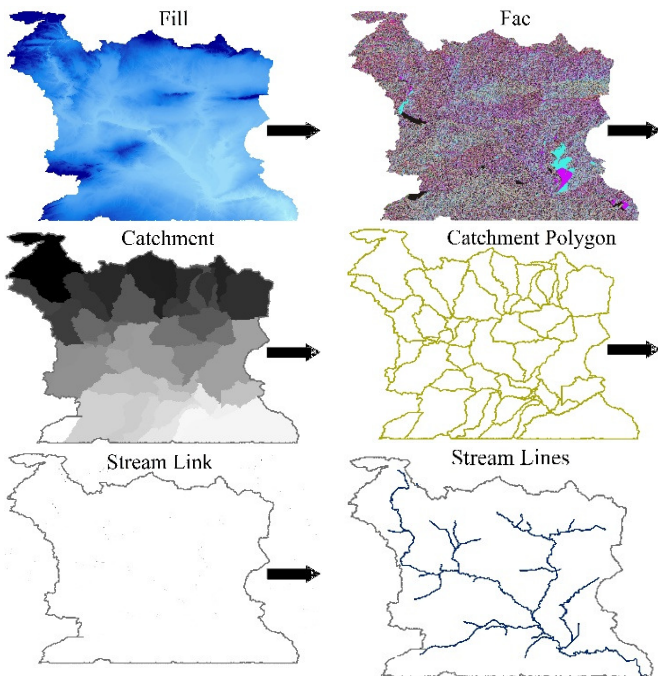


Fig. 3. Hydrological processes for UEB using HEC-GeoHMS.

**B. Classification of Land Cover/Land Use**

The results of the 2023 LULC analysis showed that natural pastures (Rangeland) dominated, accounting for 72.14% of the total area, Crops accounted for 21.39% of the total area, Barren lands represented 3.43%, while Built areas comprised just 2.17%. In addition, water bodies accounted for 0.76%, while forests and flooded vegetation were minimal, each accounting for 0.10%. These results clearly indicate the limited availability of aquatic and forest vegetation, requiring wise and sustainable management of these resources to maintain the region's ecological balance, as portrayed in Figure 4.

**C. Classification of Soil**

The results of the 2023 soil analysis in the basin showed a clear dominance of loam soils, covering most of the basin area. Clay soil was also clearly present in the northern and northwestern parts of the basin, with limited distribution in other scattered areas. In contrast, loam clay soils were quite limited, nearly nonexistent, found only in narrow areas in the northwestern part of the study area. These results confirm that the vast majority of the basin's lands are characterized by soils relatively suitable for agriculture, with the presence of clay soils in the northern areas requiring special management due to their properties that affect water movement and drainage. This spatial distribution necessitates careful planning for optimal LULC and water resource management in the basin, as illustrated in Figure 5.

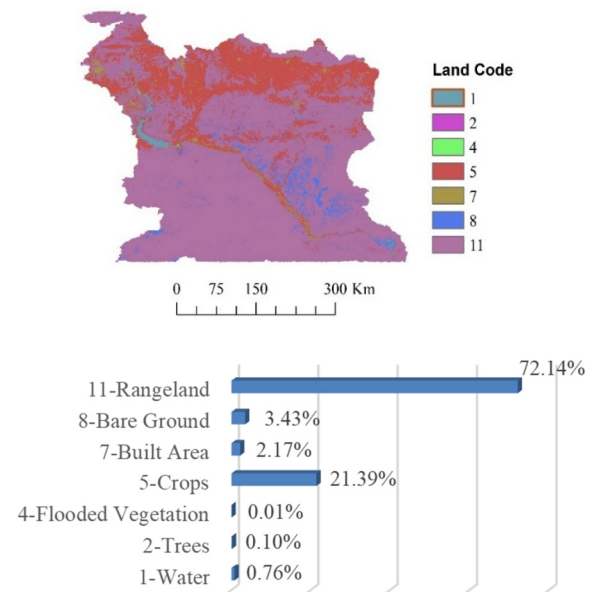


Fig. 4. LULC of UEB in 2023.

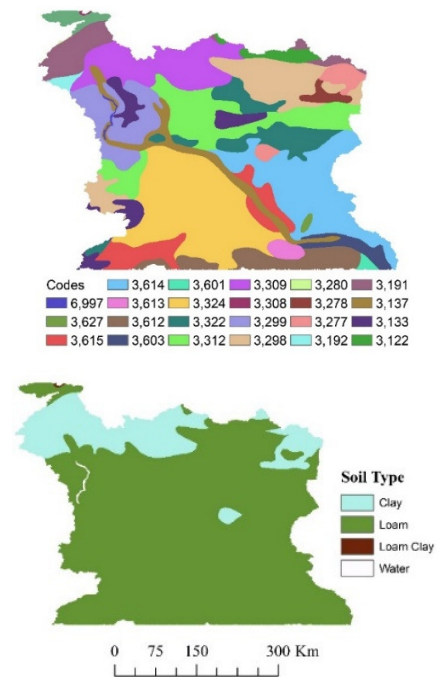


Fig. 5. Soil Type of UEB in 2023.

Figure 6 presents the covered area (%) of soil types. The results of the 2023 soil analysis in the basin revealed that Gypsisols and Calcisols are the most prevalent soils, accounting for 41.67% and 39.21%, respectively. Other less prevalent soil types were also observed, such as Leptosols (6.68%) and Luvisols (5.37%). These results indicate that the region exhibits hydrological features with medium to high drainage capacity, which directly impacts the calculation and estimation of the CN used in runoff modeling. Furthermore,

these results are essential for assessing changes in the CN over time, due to the observed changes in LULC in the basin.

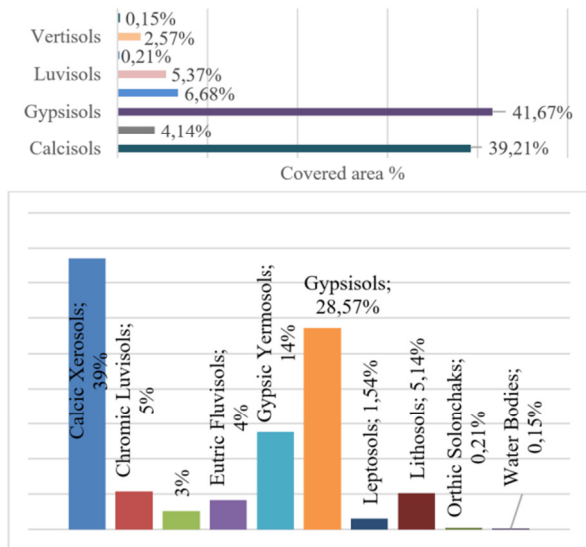


Fig. 6. Covered area (%) of soil type in UEB.

D. CN Values of 2023

The analysis of CN values for the study area in 2023 revealed significant variations among different regions (Figure 7). The majority of the basin recorded relatively medium to high values, indicating a moderate potential for generating surface runoff. Areas with high CN values were concentrated in specific, namely scattered parts of the basin, such as urban areas or regions with poor permeability soils. Low to medium values (up to 35) were found in very limited areas, indicating improved soil permeability and its capacity to reduce surface runoff. These results emphasize the significance of studying LULC and soil changes and their direct impact on CN values and the hydrological response in the basin.

E. Changes from 2017 to 2023

The results of the analysis of LULC changes between 2017 and 2023 revealed a significant increase in the area used as Rangeland, which recorded the highest coverage rate compared to the other types. In contrast, Crops experienced relative stability with minor changes during the same period. Very minor changes were observed in the proportions of water, forests, and flooding vegetation. Limited fluctuations were also observed in Built Area and Bare Ground. These changes in LULC directly affect the values of the CN and, consequently, the runoff dynamics and hydrological response of the study area, as portrayed in Figure 8.

The results of the analysis of CN value changes from 2017 to 2023 showed clear variation among the basin regions (Figure 9). A gradual decrease in high CN values (79-84) was observed over the years, in contrast to a clear increase in areas recording intermediate values (64-69). These changes reflect an increase in the area of land with moderate permeability, which may help reduce the likelihood of flooding by improving the soil's ability to absorb rainwater. Conversely, the decline in CN values in

certain areas could elevate the likelihood of droughts during years of low rainfall. These results highlight the importance of considering these changes in water resource management and in assessing the potential risks of flooding and drought in the study area.

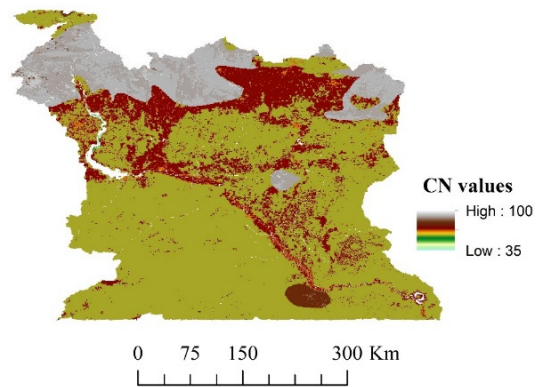


Fig. 7. Distribution and values of CN across UEB.

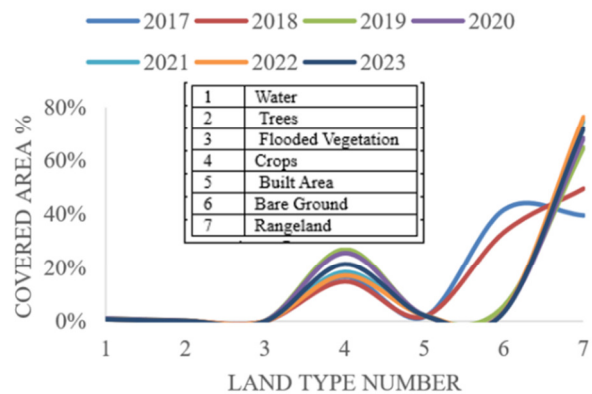


Fig. 8. Changes in the percentage of covered area in LULC from 2017 to 2023.

A comparison between 2017 and 2023 revealed significant changes in LULC patterns within the study area, as displayed in Figure 10. This period was characterized by a significant increase in the area of Rangeland from 39.43% to 72.14%, and a very important decrease in the area of Barred lands from 41.58% to 3.43%. Crop land also increased significantly from 16.55% to 21.39%, with a slight increase in the percentage of Built areas from 1.58% to 2.17%. The increase in Built areas, albeit small, is an important indicator to be monitored in the future, as it may lead to a localized increase in CN values, increasing the risk of flooding due to increased surface runoff and decreased soil permeability.

Conversely, reducing the area of Barred land and increasing vegetation cover, including Rangeland and Crops, are positive changes that lead to an overall decrease in the CN. This enhances the soil's capacity to absorb rainwater, decreases the risk of flooding, and increases the region's resilience to droughts during years of low rainfall. These changes are

generally viewed as positive from a hydrological perspective, considering the expansion of Built areas and their potential future impact.

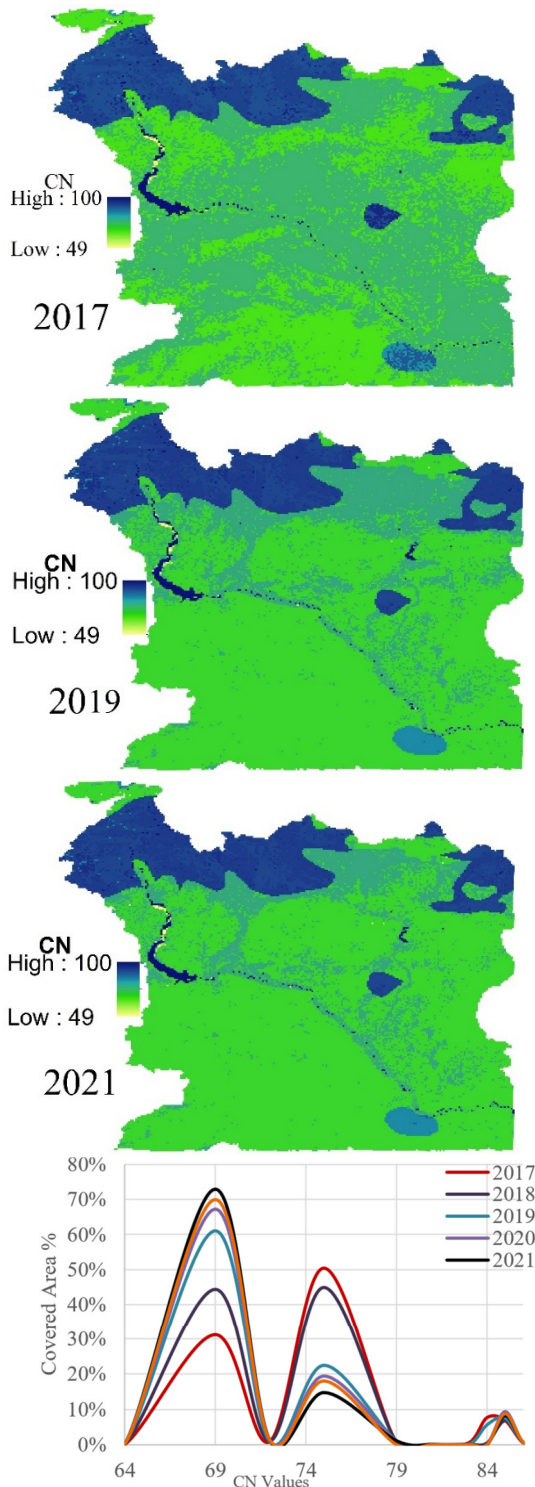


Fig. 9. Changes in CN values from 2017 to 2023.

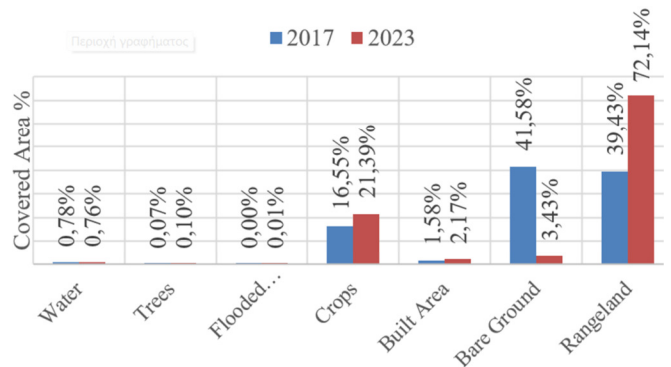


Fig. 10. A comparison of LULC changes between 2017 and 2023.

#### IV. CONCLUSION

The study achieved its objectives by assessing changes in LULC along with soil types and their direct impact on CN values in the UEB between 2017 and 2023. The key findings include:

- An increase in the area of natural pastures from 39.43% to 72.14%.
- A significant decrease in Barred lands from 41.58% to 3.43%.
- A significant increase in the area of agricultural land from 16.55% to 21.39%.
- A slight increase in Built-up areas from 1.58% to 2.17%, which may increase flood risk.
- Gypsisols and Calcisols are the most prevalent soils, comprising 41.67% and 39.21%, respectively, and they exhibit medium to high permeability.
- A gradual decrease in high Curve Number (CN) values (79-84) is observed, while areas with intermediate value (64-69) increase are also reported, reducing flood risk and enhancing the region's resilience to drought.

This study highlights subtle spatial and temporal changes in the characteristics of the Upper Euphrates Basin (UEB) during the period 2017–2023, observing a gradual decline in high CN values coupled with an increase in the average values, indicating an improvement in soil permeability and a reduction in flood risk. These results signify a new scientific contribution in a region that lacks precise quantitative studies on runoff dynamics and the effects of land use changes. Compared to previous studies, such as those conducted in the Diyala River Basin in Iraq [11] and in the Sirba Basin in West Africa [17], the changes in CN within the studied basin are more pronounced and stable. These results enhance the potential of using remote sensing data and GIS/HEC-GeoHMS models as effective tools for hydrological risk analysis and sustainable water resource management planning.

These changes also require enhanced watershed protection measures in areas with high permeability that have recently expanded, along with the need to monitor the impacts of climate change to ensure the sustainability of natural storage

capacity and reduce the risks of floods and drought in the coming years.

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