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The impact of climate and land changes on a runoff parameter: Al-Adhaim basin in Iraq

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Abstract

This research aims to assess the impact of climate change and land use changes on the CN in the Al-Adhaim River Basin, one of the most important tributaries of the Tigris River in Iraq and its environmental and economic importance for passing through important agricultural areas. NASA, remote sensing images within GIS, and HEC-GeoHMS software were used to analyze changes in land cover and soil types during the period 2017–2023. The results showed an increase in CN values ranging from 6 to 14.4 due to forest shrinkage (from 0.11% to 0.06%), agricultural expansion (from 30% to 34%), and urbanization (from 2.4% to 3.2%), which led to increased surface runoff and flood risk. The highest values (85–98) were concentrated in areas with clayey and saline soils near the riverbed, while the lowest values (55–65) appeared in the northern regions with higher absorption capacity. So, Al-Adhaim Basin has become increasingly vulnerable to hydrological stresses due to climate and human changes, necessitating the adoption of integrated water resource management policies. The practical value of this study lies in supporting plans to establish floodwater storage projects, enhance urban drainage networks, and reforestation programs to reduce runoff and desertification.

Keywords: Al-Adhaim River, Climate changes, CN, HEC-GeoHMS, land use/cover, Remote sensing.

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1. Introduction

One of the biggest challenges that facing the world is climate change and global warming [1]. It affects many phenomena on the earth. Global temperature rising, glaciers re-treating, snow cover decreasing, sea level rising, dust storms increasing, frequently occurs of extreme events (droughts and floods) are vivid examples of the influence of this challenge on the earth [2, 3].

Precipitation is one of the substantial phenomena for human beings that was affected by the climate change [2] . On the one hand, some areas experience extreme rains and floods. On the other hand, other areas suffer from severe and frequent droughts [4].

Iraq, as well as all MENA region, is one of the most water stressed region due to decreasing precipitation and climate change [5, 6]. The annual precipitation of the country decreases from about 300 mm in 1980 to about 200 in 2020 [7]. Furthermore, it is expected to decrease 100 mm within 2099 [8]. The mean annual temperature is around 24 °C [9]. The temperature in summer midday can surpass 50℃ [10]. During 1971-2020, Anomaly of temperature increased to + 2.1℃, and the precipitation decreased to -84 mm/year [8]. Accordingly, the country is classified as the fifth most susceptible country to water resources decreasing, food availably, and extreme temperature [3]. Thus, the surface water, as well as all the potential water resources, is substantial to the country.

The country depends on surface water, represented by Euphrates and Tigris rivers, to secure about 98% of its demand [11]. Both of these two rivers originate/rise from Turkey [12]. About 46% of their basin is located in Iraq, while only 22% in Turkey. The remainder part is located in Islamic Republic of Iran, Syrian Arab Republic, Saudi Arabia, and Jordan [10]. Despite the fact that the majority of the basin is located within Iraq, all the tributaries (for Euphrates) and main them (for Tigris which contribute about 61% of total flow) are located out of Iraq [10]. Turkey contributes 89% of Euphrates and 51% of Tigris, and began constructing dams on the two rivers in the mid of 1960s [13]. Whatever, water supplies through these rivers decrease from 30 billion cubic meter in 1933 to about 9.5 billion in 2023 [3]. Therefore, it is a top priority to sustain each potential water resource in the country.

There are six tributaries feed it within the country, considering Tigris River. These tributaries sorted from the north to the south with their basin area (in km^2) and contribution to Tigris river (in $km^3/year$) are [13]: (1) The Greater Zab: 25,810 km^2 basin area, 13.18 $km^3/year$ contributes; (2) The Lesser Zab: 21,475 km^2 basin area, 6.8 $km^3/year$ contributes; (3) The Al-Adhaim: About 13,000 km^2 basin area, 0.79 $km^3/year$ contribution; (4) The Diyala: 31,896 km^2 basin area, 5.74 $km^3/year$; (5) The Nahr al Tib, Dewarege and Shehabi rivers(together): 8000 km^2 basin area, 1 $km^3/year$ contribution of high salinity water; (6) The Karkheh: 46000 km^2basin area, 6.3 $km^3/year$ contribution.

Among these tributaries only Al-Adhaim has all its catchment inside the country [14]. The contribution of this feeder to Tigris River varies between 25 and 50 m^3/s [15]. It is a considerable quota of the mean annual flow of Tigris River of 300 m^3/s [16]. Hence, improving the water management policy of this catchment will affect positively on the streamflow of Tigris River.

After receiving an effective rain storm, the catchment contributes the rivers and canals through surface runoff [17-20]. Based on availability of the streamflow data, there two methods to find the surface runoff: (1) ∅-index: for available historical data; (2) Curve Number (CN) method: for Unavailable historical data [21].

In the second method the surface runoff is estimated based on: (1) a group of curves (standardized from 0 to 100) which are recognized by a dimensionless quantity called Curve Number (CN); and (2) watershed characteristics [22]. Through knowing the CN identity and precipitation, the surface runoff can be determined. The CN depends on surface conditions which can be summarized in two types of factors: soil type and land use [22]. Thus, land use and land cover conditions play a significant and crucial role in determining the sur-face runoff for a region.

There are many studies considered Al-Adhaim catchment as study area. Hamdan, et al. [15] built a hydrological model to guess the surface runoff of Al-Adaim catchment at Al-Adaim dam. They used software called Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) to build this model. The study extended through the years 2015-2018 [15]. Another study considered the climate change effect on the water resources and power generation in Al-Adhaim dam [23]. A flood risk is also considered in a study. In that study a proposal was suggested to in install gates on the spillway. The aims of the study were to reduce the impact of water releases on Tigris watercourse and the downstream cities. Another benefit was to increase the dam storage capacity of water to use it in dry season [24]. Other researchers considered dam operation [25] soil erosion [26] reservoir geometry influence on routing techniques [27] and stream flow modeling in their studies [28].

No of the previous studies considered the development of land cover and curve number values of Al-Adhaim catchment due to climate change.

This paper considers the influences of climate change and land use on the values of CN of Al-Adhaim catchment using ArcMap GIS supported/utilizing by satellite imaging.

The aims of this study are to answer the following research questions: (1) what are the effect of the climate change on the Land Use and Land Cover (LULC) of Al-Adhaim catchment through the years 2017-2023? ; (2) What is the influence of the climate change on the CN values of the considered region through the referred period? Based on the answer of these two questions an approach can be produced introduced to have a better water resources management of Al-Adhaim catchment. Though this study considered Al-Adhaim catchment as study area, it is applicable on all the region that have water resources deficiency, to optimize the water resources management policies. Even the regions that have sufficient water resources can use the approach to conserve water resources.

2. Methodology

2.1. Study Area

ARB is located in the northeastern part of Iraq, extending between latitudes 34° to 35° north and longitudes 44° to 45° east. The basin is considered part of the Tigris River and is one of its main tributaries. The basin extends across the governorates of Diyala, Salah al-Din, and Kirkuk, and covers a total area estimated at 13,000 km^2 [29] (Figure 1).

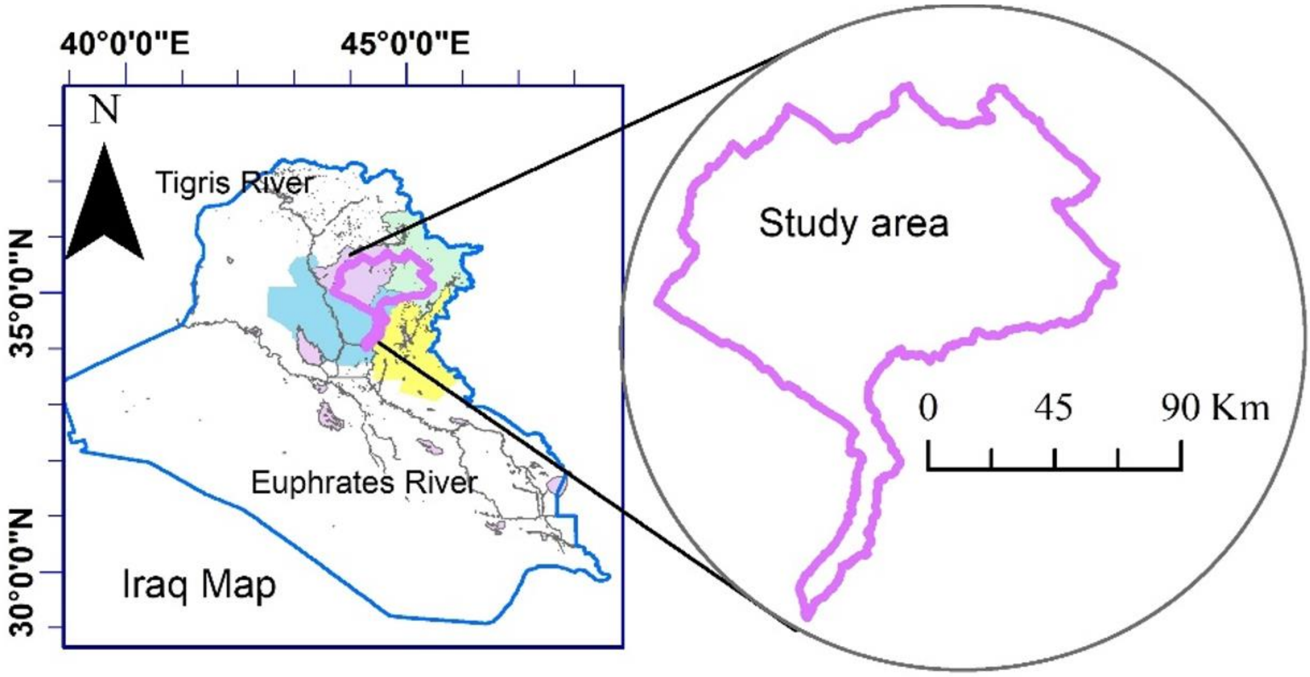


Figure 1.
Location of Al-Adhaim River Basin in Iraq.

The surface of this basin is covered by different types of polygenetic sediments, dominated by fine clastics. The slope is less than 1° degree [19].

ARB has a semi-arid climate, with a mean annual air temperatures ranging between 22° and 24° C. Maximum temperatures recorded in summer reach 48° C, while winter temperatures may drop to around 5° C. Annual rainfall ranges between 325 and 375 mm [6] with most of the precipitation occurring between November and April. The basin is characterized by severe seasonal drought during the summer months when precipitation rates are at their lowest. The prevailing winds are usually northwesterly with mean annual velocity of 2 m/s. The mean annual evaporation rates that may reach 2,600 mm/year [6].

ARB has experienced several floods and droughts over the years. The most notable flooding in the basin occurred in 2019, when water levels reached their highest levels ever, reaching 230 meters above sea level. In contrast, the basin experienced its worst drought in 2008, when water levels dropped to about 180 meters above sea level, leading to a significant decline in water and agricultural resources.

Al-Adhaim River is a seasonal river that depends heavily on rainfall. During the rainy season, water flows increase significantly, while they decrease significantly in the summer. The maximum water discharge recorded in the basin was in the spring of 2019, when the flow was about 400 cubic meters per second, while the lowest flow recorded was in the summer of 2008 when it decreased to 10 cubic meters per second. ARB faces significant environmental challenges due to climate change and unsustainable land use. Water resource management in this basin is vital to maintaining water and agricultural security in the region [12].

2.2. Mathematical Model

After receiving an effective rain storm, the catchment contributes the rivers and canals through surface runoff. There are two approaches to estimate the surface runoff from precipitation: $\emptyset$-index (available historical data); and Curve Number CN (unavailable data), [18]. Since the study area lacks a long-term database, it would be appropriate to use the CN for mathematical modeling. Equations for finding the CN were included in the software used in this research.

CN ranges between (0) and (100), such that $CN = 100$ for impervious surface, and $CN < 100$ for natural surfaces [18]. CN value is affected by two parameters: soil type; and land use [6].

According to the literature [30] soils are divided into four main hydrological groups based on their infiltration rate. Type A soils have the highest infiltration rates, while soil D is the least permeable (Table 1).

Table 1.
Details of soil type.

Soil type	Description	Rate of infiltration (cm/hr)
A	Low-potential of surface runoff, such as: deep-sand, deep-loess, aggregated-silts.	$greater\ than\ 0.762$
B	Moderate infiltration rate, such as: shallow-loess, sandy-loam.	$between\ (0.381 - 0.762)$
C	Low infiltration rates, such as: clay-loams; shallow-sandy-loam; soils low in organic-content; and usually soils with high in clay.	Between $(0.127 - 0.381)$
D	High-potential to surface-runoff, such as: that wet swell; heavy-plastic clays; and certain saline-soils.	$less\ than\ 0.127$

Source: Chow, et al. [18].

LULC are classified according to the surface cover and the degree of its coverage by vegetation or natural and structural elements. The classification includes lands permanently covered with water. While open land devoid of vegetation or human structures is defined as bare ground. In general, this classification is based on the characteristics of the surface cover, whether natural, agricultural, or urban, and the amount of vegetation coverage or human intervention. Table 2 explains some types of these land covers.

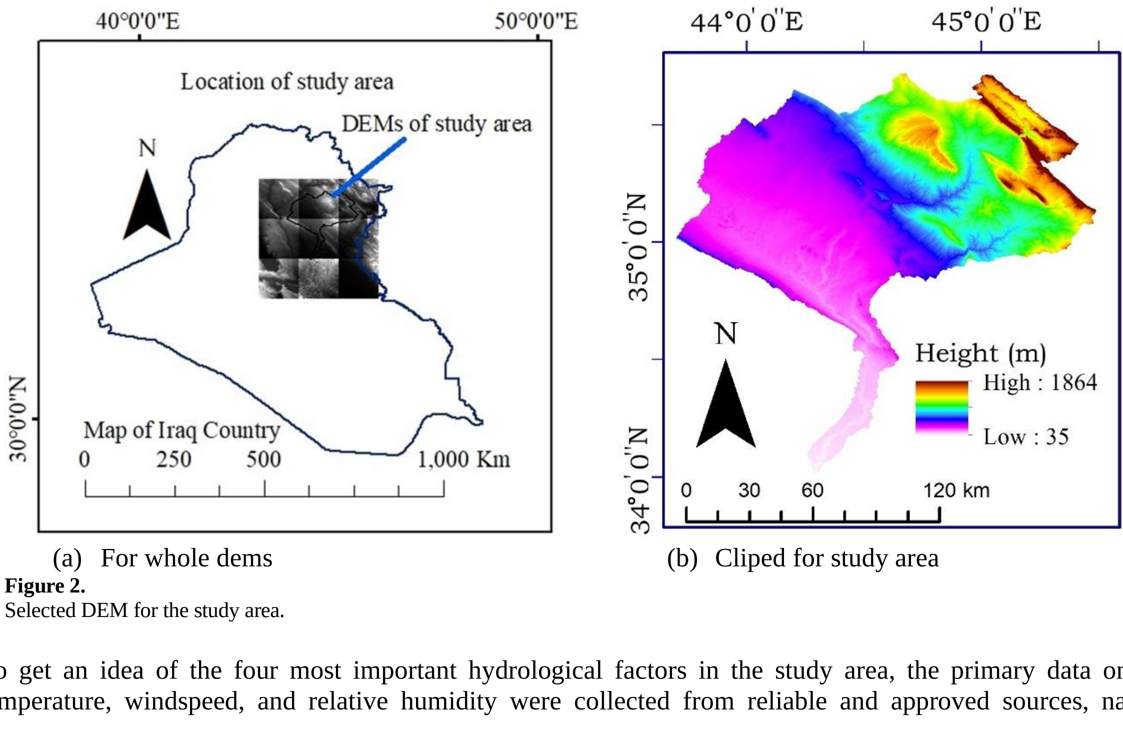
Table 2.
Classification of the Land use/cover of l-Adhaim River Basin.

ID	Term	Explanation or details
1	Water	Areas that are mostly covered by water year-round
2	Trees	Regions with vegetation (~15 feet) height with dense.
4	Flooded vegetation	Areas with vegetation covered by water evaporation most of the year.
5	Crops	Humans have planted or placed grasses and should be under tree height.
7	Built Area	Large, homogeneous, impermeable land cover
8	Bare ground	Open spaces that are not covered by plants and in which there is no human intervention from buildings and other things.
9	Snow/Ice	Permanent ice areas are found on mountains and are usually located in high-latitude
10	Clouds	That do not have land cover data due to the permanent presence of clouds represent
11	Rangeland	Open spaces covered by some trees, grass, golf courses, pastures, etc.

2.3. Software, Data, and Processing

Three software are used in this study: Arc-Map GIS 10.3, FAO's HWSD Viewer software, and HEC-GeoHMS 10.3.

- Remote sensing (RS) images were downloaded from NASA website and then analyzing them by ArcGIS 10.3, it could be gotten the specific DEM of the study area (see Figure 2).



(a) For whole dems (b) Cliped for study area

Figure 2.
Selected DEM for the study area.

- To get an idea of the four most important hydrological factors in the study area, the primary data on rainfall, temperature, windspeed, and relative humidity were collected from reliable and approved sources, namely the

NASA web-site.

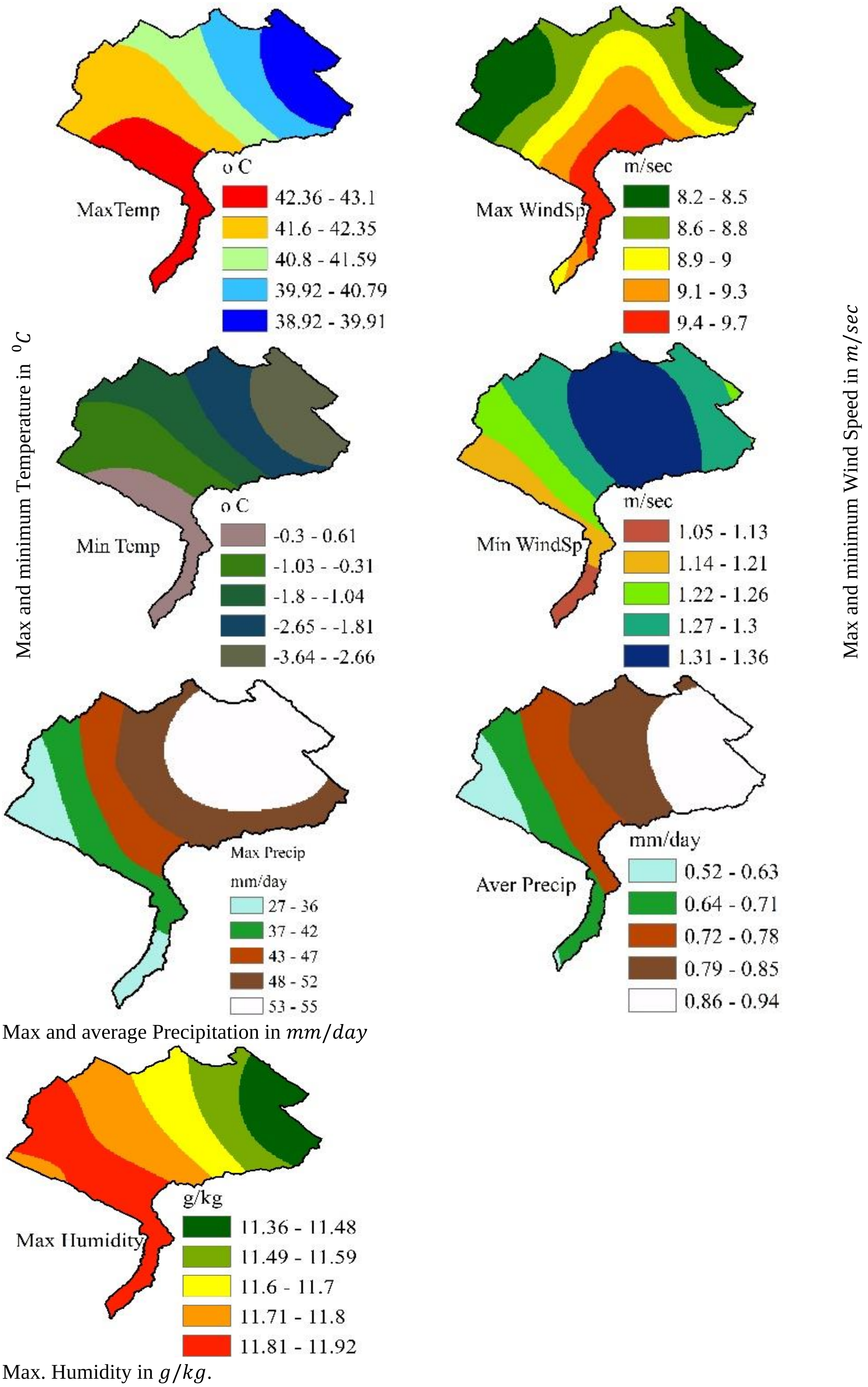
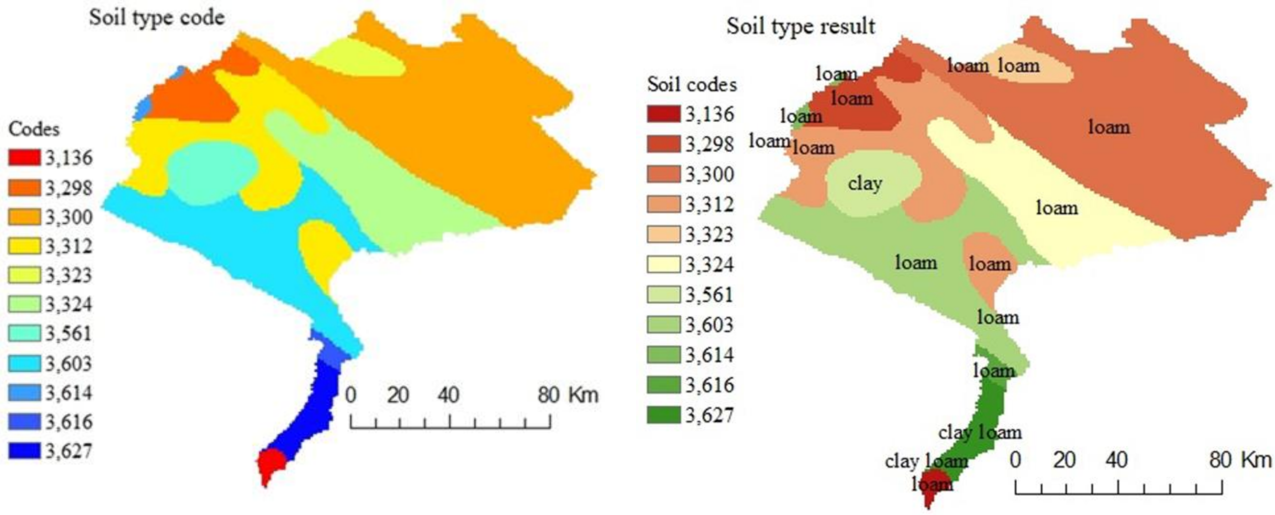


Figure 3.
Four important hydrological parameters over the study area.

The climate data included time series for the period 2017-2023, which were obtained from the Iraqi Meteorological Centers, FAO, and the World Climate Center. It was found that the values recorded for the years 2017 to 2023 regarding temperatures, relative humidity, wind speed, and the amount of rainfall were drawn through Figure 3.

- Remote sensing (RS) technology was used to analyze changes in LULC over the study period. Image processing software ArcGIS ver10.3 was used to analyze satellite images, identifying changes in land use such as conversion from forest to agricultural land or urban areas. Land cover was classified into different classes using image classification algorithms such as Support Mechanism Classification (SVM) and Maximum Likelihood Classification (MLC). ArcGIS ver10.3 was also used to analyze the soil types in the study area.
- Based on RS images, through a map of the study area, and based on the FAO's HWSD Viewer software and then by ArcGIS, soil layers were analyzed and their types and contents were identified in the study area. See Figure 4.



(a) Coded classified soil types (b) Named soil types

Figure 4.
Soil types of the study area.

3. Results and Discussion

3.1. Results with Linking

After obtaining data on LULC in ARB, a comprehensive analysis was conducted to assess the changes in land cover during the period from 2017 to 2023. The aim of this analysis is to understand the relationship between LULC changes and their effects on hydrological processes in the basin. Based on RS data and satellite images analyzed using Geographic Information Systems techniques and ArcGIS image processing software, the land cover's changes were as shown in Table 3.

Table 3.
LULC changes through 2017-2023.

Land Cover Type	2017	2018	2019	2020	2021	2022	2023
Water (as %)	0.46	0.66	1.40	1.01	0.67	0.52	0.54
Tree (as %)	0.04	0.03	0.09	0.11	0.02	0.02	0.06
Flooded vegetation (as %)	0.01	0.02	0.09	0.02	0.00	0.00	0.01
Crops (as %)	30.15	23.37	35.32	36.63	29.02	26.88	34.12
Built area (as %)	2.40	2.43	2.70	2.85	3.00	2.80	3.12
Bare area (as %)	4.13	1.13	0.27	0.24	0.24	0.33	0.20
Rangeland (as %)	62.81	72.35	60.13	59.15	67.05	69.44	61.96

Based on Figure 4 and the analysis of soil types in the study area, a clear diversity in soil properties can be observed, ranging from clay soils that enhance surface runoff and increase the possibility of flooding, to loam soils and stony soils that contribute to reducing runoff and less water storage, also see Figure 5. This diversity in soils directly affects the behavior of water in the basin, especially in light of climate changes and different land uses.

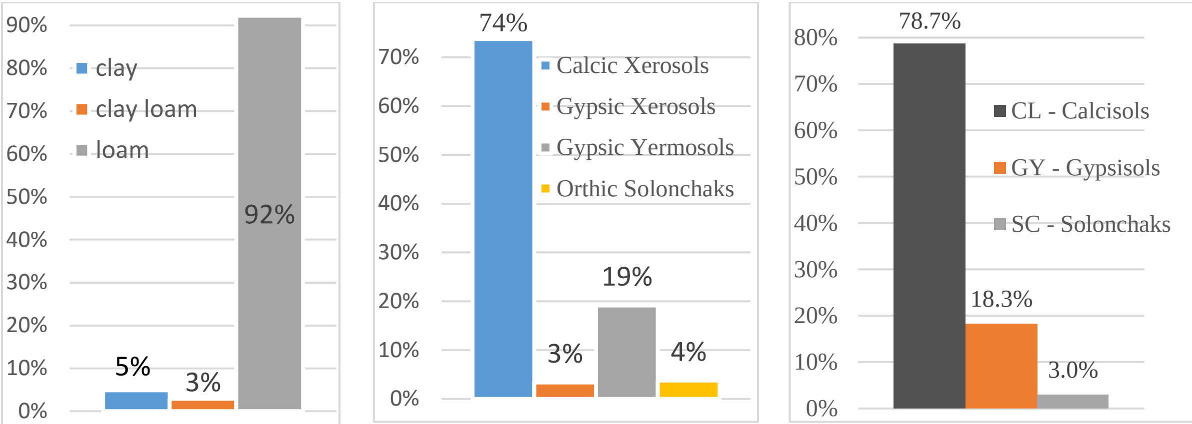


Figure 5.
Soil types of study area according to name and behavior.

After conducting geospatial analysis of LULC and soil types data in ARB using HEC-GeoHMS, the Hydrological Curve Number was calculated, which is an indicator that reflects the ability of soil and land use to absorb water or convert it into surface runoff. Figure 6 shows the amount of the hydrological number during the study period, starting from 2017 to the end of 2023.

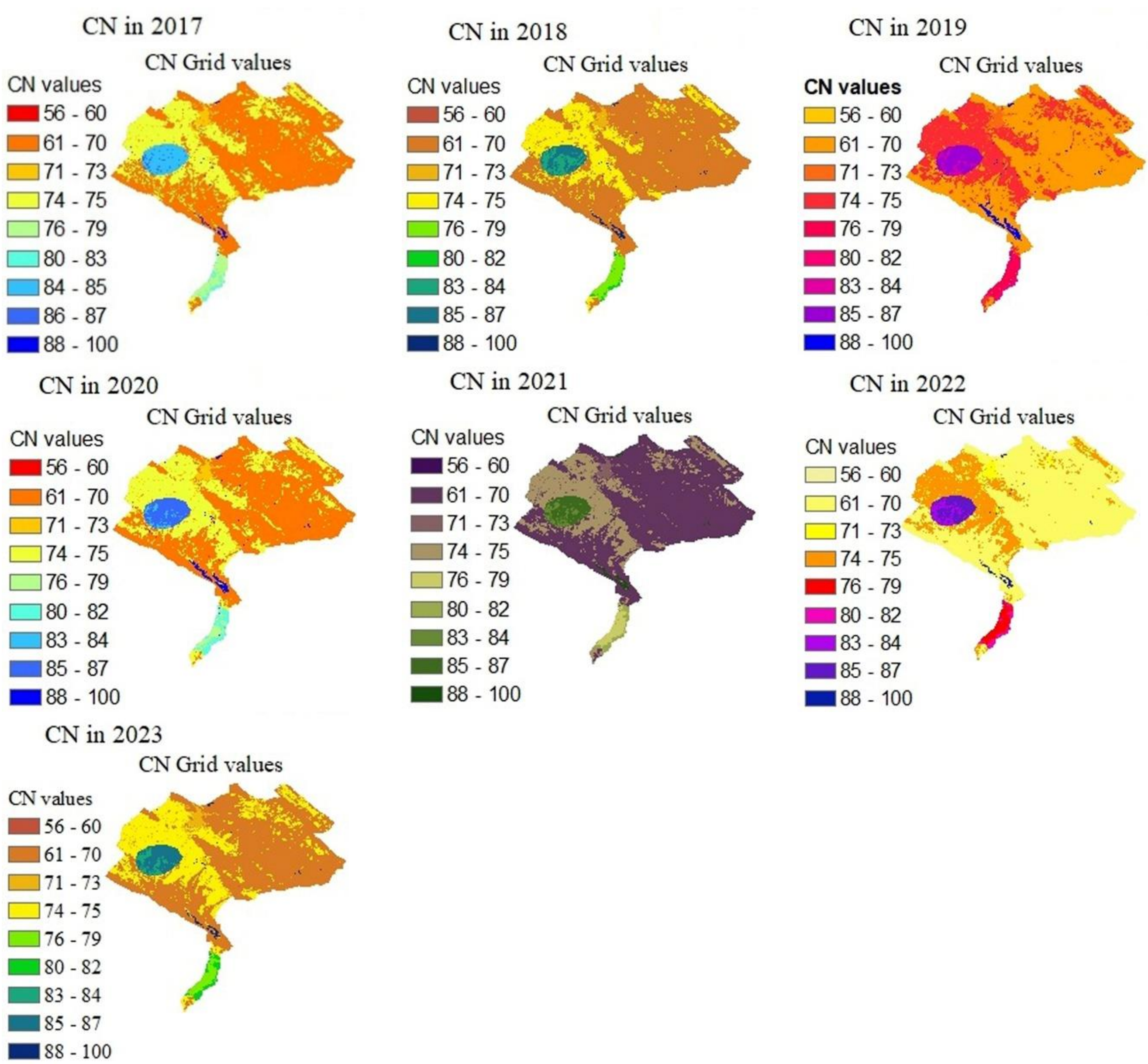


Figure 6.
Curve number values through 2017-2023 in the study area.

The clay soils, which constitute a large part (5%) of the lowlands near the river, showed a very high curve number (85-100), indicating a low capacity to absorb water. This enhances runoff and increases the risk of flooding, especially during periods of heavy rainfall. This high number reflects the impermeable nature of the clay soils, which makes the area susceptible to rapid waterlogging. The loamy soils, which are widespread (93%) in the basin, showed low curve numbers (60-65) reflecting their high capacity to drain water. This type of soil reduces the risk of flooding but at the same time reduces water retention, which can exacerbate the drought problem during dry periods. Saline-alkaline soils (79%) exhibit a very high hydrological number (80-90), which means that these soils are unable to absorb water effectively, leading to increased runoff and contributing to worsening flooding in areas containing these soils.

To make a comparison between the values of CN and the change that occurred as a result of climate variables and LULC, the study area was divided into a mesh of points to identify the places where the changes occurred, as shown in Figure 7.

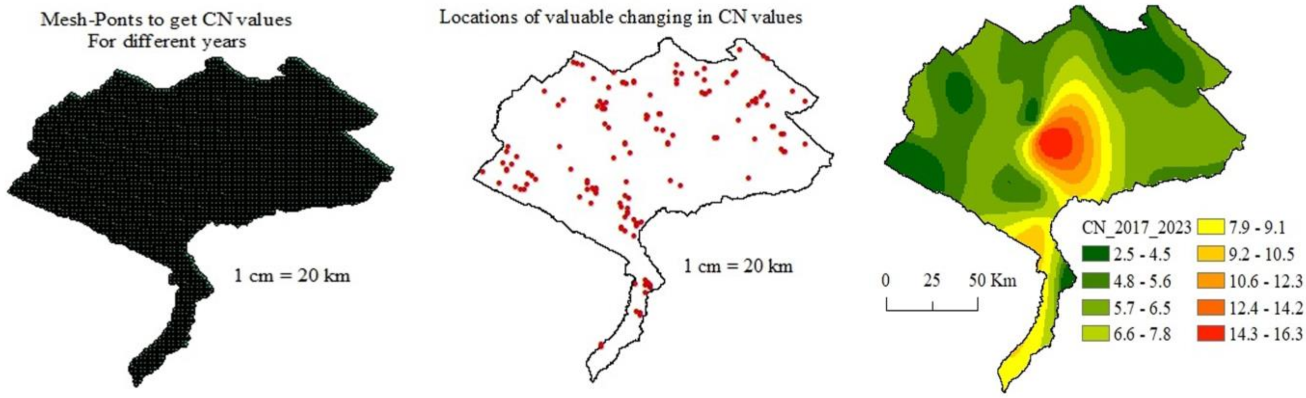


Figure 7.
Locations and amounts of CN values in the study area between 2017 and 2023.

The results showed, after analysis that the most important points in which the values and location of the curve number changed were shown in Figure 8 in between (4-14.4).

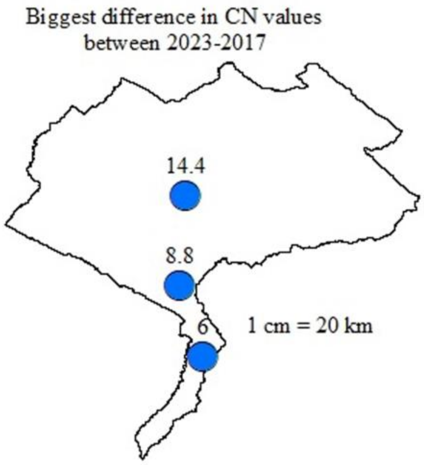


Figure 8.
Locations and values of biggest changes in CN.

To get an idea of the relationship between these changes and climate factors and what happened in LULC, a comparison was made between these variables between 2017 and 2023 at the chosen mesh points, and the results appeared as shown in Figure 9. A clear increase was observed in the amount of rainfall, relative humidity, and temperatures, which are (0.12-0.41) mm/day, (0.8-1) g/kg and $(0.2-0.8)^{o}C$, respectively, while a decrease was observed in wind speed (0.05-0.1) m/s.

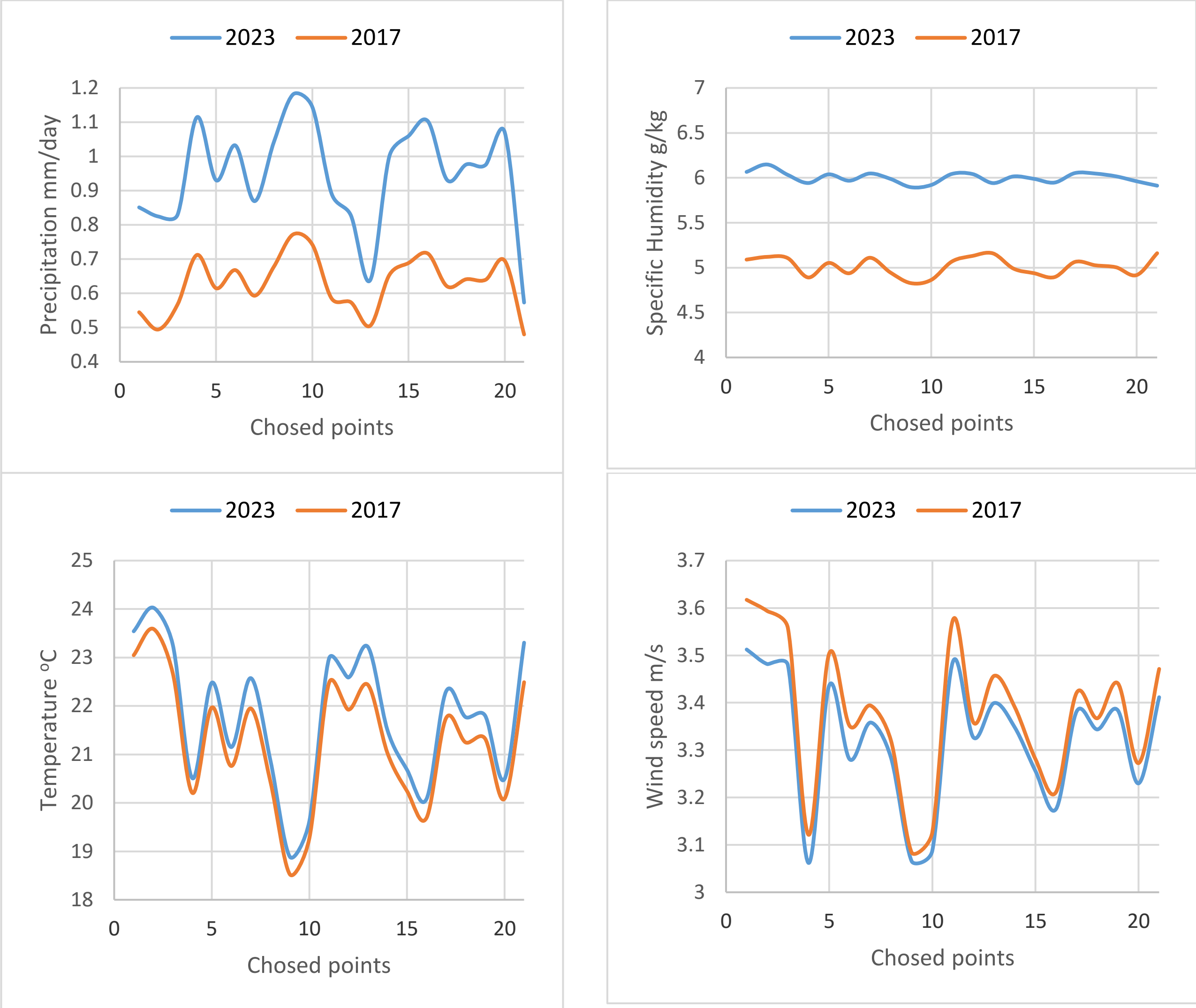


Figure 9.
Changes in hydrological factors between 2017 and 2023.

Referring to the LULC analysis between 2017 and 2023, we notice a clear decrease in bared areas (0.14%) and vegetation areas (0.015 to 0.006) %, which is matched by a clear increase in built-up areas (2.4 to 3.1) %.

Therefore, based on these changes in hydrological factors, the effect appeared clearly on CN, and a clear increase in its amount was observed in more than one important location in ARB. Figure 10 shows the amount of increase that occurred in it.

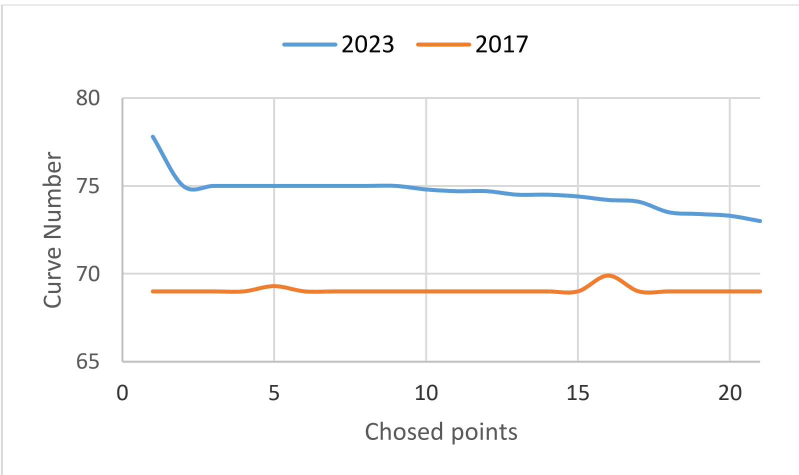


Figure 10.
Change in curve number values between 2017 and 2023.

3.2. Discussion

Deforestation (from 0.11% to 0.06%) has led to increased runoff and decreased soil water absorption rates, increasing the likelihood of flooding in the lower parts of the basin. Agricultural expansion (from 30% to 34%) has contributed to increased runoff rates in agricultural lands, especially those converted from natural lands. High hydrological number values (increasing by 14.4 to 6) indicate that these lands have become more susceptible to runoff during periods of heavy rainfall. Urban expansion (from 2.4% to 3.2%) has contributed to increased runoff and increased the risk of flooding in areas surrounding cities and urban areas. Climate change and its impact on hydrological patterns in the basin have made some areas more vulnerable to drought, especially with the shrinkage of green spaces and the increase in desertification in some parts.

Clay soils are found in the lower parts of ARB, especially in areas close to the riverbed. These soils have a high water-holding capacity due to the small size of the particles that make them up. However, they have a low water drainage rate, which makes them susceptible to rapid saturation and increased runoff during periods of heavy rainfall. Clay soils promote runoff and increase CN, making the area prone to flooding during rainy seasons. Loamy soils are concentrated in flat plain areas, especially on the banks of the River. These soils are rich in organic matter and provide a balance between water retention and drainage. This type of soil has a medium to high absorption capacity, which reduces the likelihood of flooding and contributes to stabilizing CN at moderate levels. Sa-line-alkaline soils are found in the northeastern parts of the basin, where the area is ex-posed to high evaporation rates leading to salt accumulation. These soils suffer from drainage and salinity problems, making them unsuitable for agriculture without corrective interventions such as freshwater washing. They increase surface runoff due to poor water absorption and contribute to a high CN, which increases the risk of flooding.

As results finally, the values of CN ranged from 55 to 98, reflecting the wide variation in the soil’s ability to absorb and drain water. The low values, ranging from 55 to 65, were concentrated in the northern part of the basin and constituted about 50% of the basin area. The average values, which ranged between 70 and 85, are mainly found in the plateau areas, representing about 35% of the basin area. This area contributes to a balance between surface runoff and absorption. The high values, ranging from 85 to 98, were concentrated in areas with clayey and saline-alkaline soils near the riverbed and low-lying parts of the basin, and these soils constitute about 15% of the basin. These high values indicate a significant weakness in water absorption, which increases the risk of flooding in these areas.

4. Conclusions

Based on the data and results, it has become clear that local governments and the central government should take a series of measures and activities to reduce the possibility of floods and, on the other hand, ward off the risks of drought.

It is recommended to develop projects to build dams and reservoirs in low-lying are-as with high CN to store floodwater and reduce its impact on population centers and agricultural areas. Improve and expand urban drainage systems, especially in areas that have experienced urban expansion (from 2.4% to 3.2%) to reduce surface runoff and flood-related risks in surrounding urban areas.

Local governments should develop land use plans that reduce the uncontrolled con-version of natural lands to agricultural lands, with a focus on areas that have experienced agricultural expansion (from 30% to 34%). Sustainable agricultural practices should be promoted to reduce runoff rates in these lands. Given the decline in forest cover (from 0.11% to 0.06%), reforestation programs should be implemented to increase the capacity of the land to absorb water and reduce runoff, which helps reduce flood risks.

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