Chapter 13

Rethinking homo economicus
ISBN: 978-9915-704-23-4
DOI: 10.62486/978-9915-704-23-4.Ch13
Pages: 167-177

Spatiotemporal Analysis of Rainfall Variability in Najaf, Iraq (1980-2020) Using CRU Data and MATLAB

Análisis espaciotemporal de la variabilidad de las precipitaciones en Nayaf, Irak (1980-2020) utilizando datos de CRU y MATLAB

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ABSTRACT

Variability in rainfall significantly affects the availability of water resources, agricultural production, and environmental sustainability, especially in desert places like Najaf, Iraq. This study investigates the timing and spatial distribution of rainfall in Najaf for 40 years (1980-2020) using the CRU precipitation dataset. High-resolution precipitation maps at nine-year intervals were developed by incorporating advanced geospatial methodologies with MATLAB computational tools. The analysis revealed that precipitation varies significantly, temporally, with a progressive decrease in recent decades that may be linked to climate change. On the other hand, the spatial patterns clearly demonstrated inequalities in the distribution of rainfall where some areas receive more rain compared to others. These findings raise an alarm for the urgent need to develop localized climate adaptation methods to help mitigate the adverse effects of rainfall unpredictability on water resources and agriculture. This paper contributes to our understanding of the climate dynamics of Najaf and showcases the efficiency of integrating global datasets with advanced computational techniques in climate analysis.

Keywords: Rainfall Variability; Najaf; Climate Research Unit (CRU); MATLAB; Spatial Analysis; Temporal Trends; Climate Change; Geospatial Mapping.

RESUMEN

La variabilidad de las precipitaciones afecta significativamente la disponibilidad de recursos hídricos, la producción agrícola y la sostenibilidad ambiental, especialmente en zonas desérticas como Nayaf, Irak. Este estudio investiga la distribución temporal y espacial de las precipitaciones en Nayaf durante 40 años (1980-2020) utilizando el conjunto de datos de precipitación CRU. Se desarrollaron mapas de precipitación de alta resolución a intervalos de nueve años mediante la incorporación de metodologías geoespaciales avanzadas con herramientas computacionales de MATLAB. El análisis reveló que las precipitaciones varían significativamente a lo largo del tiempo, con una disminución progresiva en las últimas décadas, lo cual podría estar relacionado con el

cambio climático. Por otro lado, los patrones espaciales demostraron claramente desigualdades en la distribución de las precipitaciones, donde algunas zonas reciben más lluvia que otras. Estos hallazgos alertan sobre la urgente necesidad de desarrollar métodos de adaptación climática localizada para ayudar a mitigar los efectos adversos de la imprevisibilidad de las precipitaciones sobre los recursos hídricos y la agricultura. Este artículo contribuye a nuestra comprensión de la dinámica climática de Nayaf y demuestra la eficiencia de integrar conjuntos de datos globales con técnicas computacionales avanzadas en el análisis climático.

Palabras clave: Variabilidad de las Precipitaciones; Najaf; Unidad de Investigación Climática (CRU); MATLAB; Análisis Espacial; Tendencias Temporales; Cambio Climático; Cartografía Geoespacial.

INTRODUCTION

Precipitation is one of the basic components of Earth's hydrological cycle and has a particularly significant effect on natural ecosystems, agriculture, water resources, and human survival. Since precipitation is the main source of freshwater supply, understanding variability in rainfall is very important for managing the consequences of climate change-particularly for regions with limited water supply.[1] Over recent decades, there have been significant changes in precipitation patterns all over the world due to the interaction between climate change and anthropogenic activity.[2] Such changes significantly affect the availability of water, agricultural production, and ecosystem sustainability, noticeably in arid and semi-arid regions such as Iraq.[3]

Najaf is a very desert area; therefore, it relies greatly on rainfall as the main water source for agriculture and daily activities. Rainfall in such areas is usually highly variable; thus, its spatial and temporal distribution must be monitored and analyzed.[4] Climate change poses serious challenges to such regions through enhancements in risks of water scarcity, droughts, and extreme weather events.[5] Temporal and spatial variability understanding of precipitation is crucial for sustainable water resource management and climate adaption strategies in Najaf and similar areas.[6]

Global databases, such as the CRU data, provide high-resolution, long-term records of climate variables, including precipitation, which enables analysis of trends and anomalies across a wide range of spatial and temporal scales.[7] These datasets are particularly important in regions where local climate-monitoring infrastructure is sparse or nonexistent. Application of such CRU data allows researchers to gain detailed information on regional rainfall trends, thus helping inform policy decisions on climate adaptation.[8] The current study is based on CRU precipitation data and assesses the variability in Najaf's rainfall over a 40-year period (1980-2020). Temporal variation and spatial patterns of precipitation are pursued in this analysis to identify potential implications for regional water management.

A multitude of studies has investigated rainfall changes both globally and regionally, utilizing diverse datasets and analytical methodologies. Research has demonstrated substantial temporal and spatial alterations in precipitation patterns, underscoring the impact of global warming on regional climates.[9,10] Studies concerning the Middle East and North Africa (MENA) region have revealed escalating issues associated with water scarcity and alterations in precipitation patterns, especially in arid and semi-arid areas.[11,12] Although these studies offer significant insights into overarching regional trends, there is an increasing demand for localized analyses to comprehend the specific effects of climate variability on cities such as Najaf.[3] The distinctive

geographical and climatic attributes of Najaf require targeted investigations into rainfall variability to enhance its water resource management and agricultural sustainability. This work intends to generate high-resolution rainfall maps for Najaf utilizing MATLAB's computational and geospatial capabilities, based on CRU data.[13] The maps offer a distinct visual depiction of rainfall variability over the study period, facilitating the recognition of notable patterns and anomalies. The utilization of nine-year intervals for a thorough analysis of temporal variations, enhancing the comprehension of the city's rainfall dynamics.

Results from this study go beyond the academic domain and give useful lessons to politicians, urban planners, and agricultural stakeholders.[14,15] Findings can be used to devise adaptive strategies to reduce adverse impacts of climate variability by decision-makers, including the realization of enhanced water management systems and shifts toward climate-resilient varieties of agriculture. The approach used in this paper demonstrates how global datasets like CRU can be combined with advanced analytics to provide insights into a replicable framework for other locations facing similar challenges.[16,17]

Related Work

Understanding rainfall variability is crucial for many strategies of coping with climate change, especially in arid and semi-arid regions.[18] Many studies have explored the temporal and spatial characteristics of precipitation using various data sets and methods. Global studies on rainfall variability have involved high-resolution data sets, such as the Climate Research Unit (CRU) data, renowned for their extensive temporal coverage and high spatial resolution. Hulme et al.[1] conducted an analysis of global precipitation changes in the 20th century, focusing on the complex interplay between natural variability and human impact. Dai[8] presented a global perspective on drought and precipitation trends, pointing out the consequences of global warming for hydrological cycles.

Regional analyses in the Middle East have indicated significant issues with water shortage and variable precipitation. Lelieveld et al.[3] studied climate change effects on the MENA regions' water resources, where the projection for increased aridity is highly anticipated due to reduced precipitation and increased evaporation rates. Al-Ansari[9] investigated Iraq's water management problems by relating reduced rainfall to lower river flows and agricultural production. These findings highlight the need for regional analyses to further understand the regional precipitation mechanisms.[19]

While these provide useful information on the regional and national precipitation characteristics, few studies have focused on the urban level. Najaf being a dry region has been given less consideration despite its vulnerability to anomalies in precipitation amounts. The current study focuses on the spatiotemporal rainfall dynamics of Najaf based on the CRU dataset. Modern MATLAB methods are utilized herein to improve earlier approaches with high-resolution precipitation maps and their trends over a 40-year period from 1980 to 2020.[20,21]

Recent research has increasingly relied on the use of global climate datasets in combination with geospatial analysis techniques. Studies have demonstrated the feasibility of using MATLAB and other tools to produce high-resolution precipitation maps and analyze spatial patterns. For example, Soltani et al.[5] used CRU data to investigate rainfall variability in the Middle East, which demonstrates the value of these datasets for identifying long-term trends. The work of Luhunga[14], though on rainfall trends over Tanzania, also used geospatial approaches and thus presents a methodological framework relevant to the present work.

METHOD

Study Area

Study Area Najaf is an ancient city in south Iraq, about 160 km southwest of Baghdad. It is situated in a semi-arid and arid climatic region, which is normally characterized by low and variable rainfall, high temperatures, and limited supplies of water, according to Hashim et al. in 2011. The entire city covers an area of about 28,824 square kilometers, mostly metropolitan areas, agricultural areas, and vast expanses of deserts. It borders along the Euphrates River, which provides the necessary supply of water to maintain agricultural activities, as well as the inhabitants of the city, according to Al-Ansari, 2013. Najaf has great cultural and religious importance, with the Imam Ali Mosque, one of the most sacred sites in Islam, attracting millions of pilgrims annually. Despite its importance, the region faces challenges such as water scarcity and climatic unpredictability, which have direct impacts on agricultural production and the livelihood of its people. The identified variables make Najaf a highly relevant region to understand the impact of rainfall variability and climate change, particularly in terms of managing water resources for sustainable development. Figure 1 show location map of study area.

Figure 1. Location map of study area

Data

This study utilizes CRU dataset precipitation data, specifically the version entitled CRU TS4.06, which is gridded at 0,5° × 0,5° latitude and longitude for the period 1901–2023. The CRU dataset is prized for its long temporal record with reliable interpolation methods, especially for regions with very little observational data. The precipitation data regarding Najaf was acquired for the period 1980–2020 to analyze spatiotemporal trends in rainfall.

Data Description

The CRU TS4.06 dataset provides high-resolution global climate data encompassing precipitation, temperature, and more variables. The precipitation variable (in mm/month) is a major means of understanding hydrological cycles and recognizing temporal and geographical variability. The main dataset characteristics are presented below:

- Temporal Resolution: monthly.
- Spatial Resolution: 0,5° × 0,5°
- Temporal Coverage: 1980-2020 (dataset subset).
- Variable Used: Precipitation (mm/month).

Preprocessing

Preparation of the CRU data consisted of the following steps:

AOI Extraction: the geographical boundaries of Najaf were determined through the use of latitude and longitude. This specific area's precipitation dataset was retrieved from the global dataset:

$$P_{\text{region}}(t,x,y) = P(t,x,y) \text{ for } (x,y) \in \text{ROI} \quad (1)$$

Where P(t,x,y) is the precipitation at time t and coordinates (x,y).

Temporal Aggregation: monthly precipitation data was aggregated to calculate annual averages for the long-term pattern analysis. It is calculated as:

$$P_{\text{annual}}(x,y) = \frac{1}{12}\sum_{m-1}^{12} P_{\text{monthly}}(m,x,y) \quad (2)$$

Where Pmonthly(m,x,y) represents monthly precipitation for each grid cell.

Interval Averaging: to capture periodic fluctuations, data were also averaged over nine-year periods, for example, in 1980, 1985, 1990, etc. The nine-year average was computed as:

$$P_{\text{interval}}(x,y) = \frac{1}{5}\sum_{y-k}^{k+4} P_{\text{annual}}(x,y) \quad (3)$$

Where k is the starting year of each interval.

Spatial Interpolation: spatial interpolation was employed to obtain more refined precipitation maps and thereby enhance the clarity of rainfall distribution visualization. Interpolation functions in MATLAB, including those involving grid data, were used to fill the gaps between grid points.

Quality Control: gaps and inconsistencies in the data series were treated by linear interpolation in order to guarantee continuity. The missing values of monthly precipitation data, , were calculated by means of the expression:

$$P_{\text{missing}}(m) = \frac{P_{\text{prev}} + P_{\text{next}}}{2} \quad (4)$$

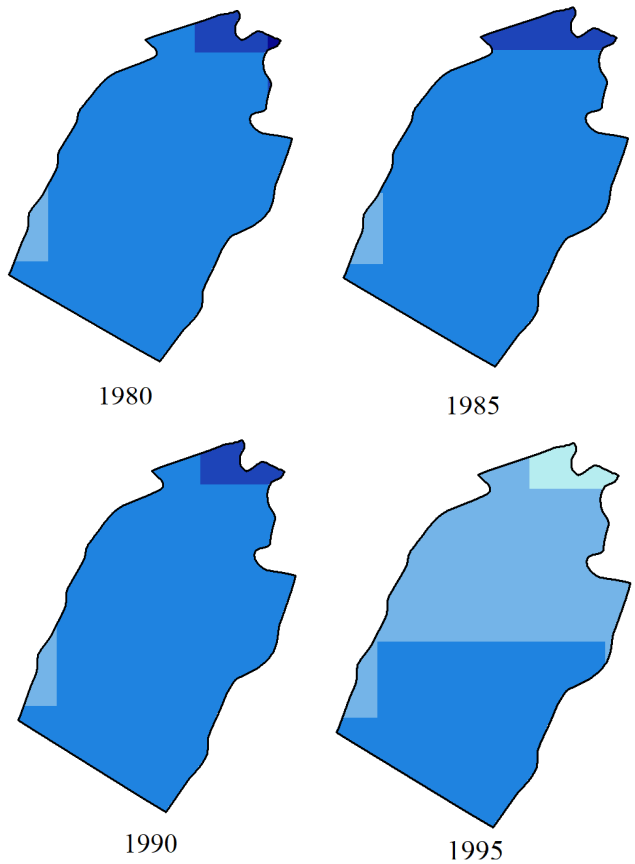
Where Pprev and Pnext are the precipitation values of the previous month and the subsequent month, respectively.

RESULTS

The precipitation maps for Najaf from 1980 to 2020 reveal a high variation in the characteristics of rainfall, both geographically and temporally. The maps are colored using a gradient that varies from light colors, such as light blue, for low precipitation, to dark colors, such as dark blue, for high levels of rain.

In 1980, the region got no precipitation, with a general light blue coloration dominating on the map, characterizing the normal arid conditions of Najaf. By 1985, there were slight increases in the intensity of precipitation in the northern areas, depicted by the introduction of darker shades of blue, which indicate localized rainfall variation. In 1990, precipitation amounts returned to lighter shades of blue, depicting less rain than in 1985, but the pattern remained generally consistent over the region.

By 1995, a slight proliferation of somewhat darker blues in the north made an appearance, showing that some areas locally experienced increased precipitation, while the middle and southern areas retained their lighter blues, reflecting low rainfall. The year 2000 showed continued decreases in rainfall, as the dominant colors across the state are lighter shades, whereas the deeper hues became less dominating on the map.



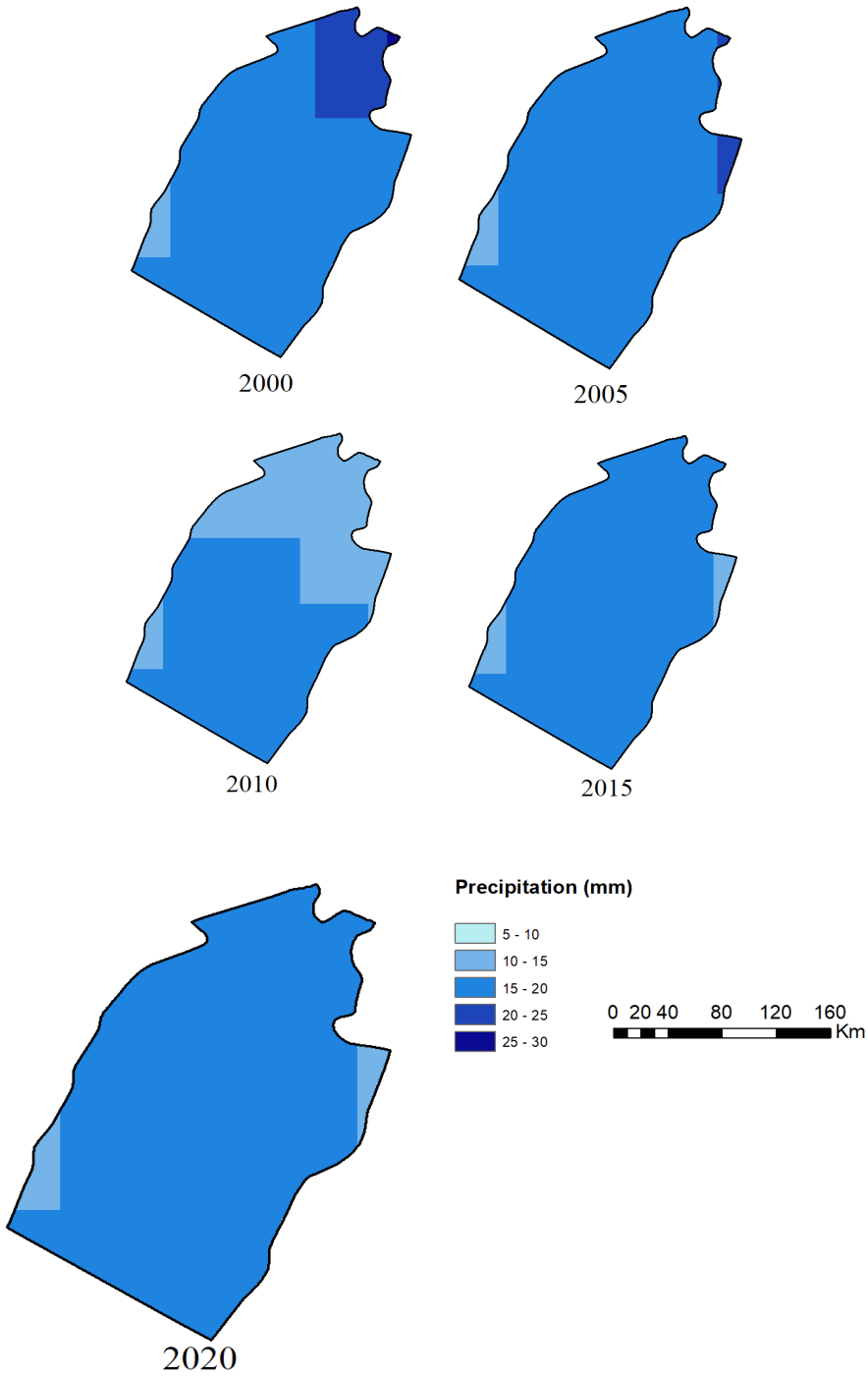


Figure 2. Show the rainfall maps change in Najaf in January from 1980 tell 2020 for nine times different periods

In 2005, rainfall reached some of the lowest levels, represented almost consistently by the pale blue color throughout the area, which showed a significant decrease in rainfall. The 2010

maps showed similar trends but had slight upticks over certain areas; the prevailing light shades of blue, however, showed the continued dryness. By 2015, almost no change was recorded, though small patches of dark blue could be seen in the northern areas, indicating a moderate increase in rain.

The 2020 chart had a mix of light and dark blue colors, indicating an overall modest increase in precipitation compared to the previous decade. Yet, the colors reflected mostly arid conditions similar to Najaf, reinforcing the consistent trend of low and unreliable precipitation in the region. Color changes in the maps reflect changes in rainfall over a 40-year period, showing reductions both in time and geographically. Figure 2 shows the changes in maps of rainfall for Najaf during January from 1980 to 2020 over nine different time intervals.

CONCLUSIONS

The spatiotemporal analysis of the precipitation in Najaf from 1980 to 2020 shows main trends and patterns that are important in understanding the region's evolving climate. The analysis also showed a continuous reduction in precipitation levels across time, with minimum rainfall in the 2000s, in concurrence with global patterns in increasing aridity in arid and semiarid regions. Some northern subregions, however, at certain points in time recorded marginally more rainfall as compared to the center and southern parts of the region; this reflected localized climatic variability.

Results have pointed out the increasing problems of water scarcity in Najaf, which is highly dependent on limited rainfall for crops and livelihood. The reduction of rainfall amplifies ongoing stresses on the water supply, for which adaptive measures will be needed to address such problems. Policymakers and stakeholders need to focus on sustainable water management strategies and look into alternatives for water supply to mitigate the impacts of reduced rainfall.

This work demonstrates the efficiency of integrating high-resolution CRU data with advanced computational tools like MATLAB to accomplish full-scale rainfall mapping and analysis. The methodologies here can be replicated in other arid regions to support climate adaption strategies and resource management. Future studies should stress the use of additional meteorological variables such as temperature and evaporation to enhance knowledge of the evolving climate dynamics in Najaf.

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