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Bioclimatic mapping of temperature dynamics in Northern Iraq

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Abstract. This study investigates the biological and ecological implications of temperature variation in northern Iraq through bioclimatic modeling and temporal-spatial analysis. Using long-term temperature data (1991–2021) from the Kirkuk, Mosul, and Tikrit meteorological stations, bioclimatic indices were derived to assess potential effects on local ecosystems and species distributions. Advanced two-dimensional (2D), three-dimensional (3D), and four-dimensional (4D) temporal-spatial mapping models were developed within a geographic information system (GIS) framework to visualize temperature dynamics and biological relevance over time. The 4D bioclimatic maps revealed clear spatial-temporal gradients linked to potential habitat shifts and environmental stress zones, offering a biologically meaningful perspective on climate variability. The integration of time as the fourth dimension significantly enhanced interpretation accuracy and reduced mapping errors compared to traditional visualization methods. These findings provide a valuable foundation for understanding climate-driven biological processes and support future ecological and biodiversity studies in the region.

1 Introduction

In geographic information systems, there are advanced static applications for the second and third dimensions, they expand on the static two- and three-dimensional theory but deal with the dynamic fourth dimension (4D), which is a step toward the spatio-temporal handling of geographic information systems, i.e., the transition from second dimension and third dimension to fourth dimension to support spatio-temporal modeling and include temporal information in spatial databases, the aim is to process spatio-temporal data for geographical phenomena. The importance of the fourth dimension in representing data in thematic maps is also highlighted in overcoming the problem of the difficulty of representing data for multiple time periods in a single map, as the fourth-dimensional representation method allows for the creation of a single comprehensive map that ensures the representation of more than one time period instead of creating multiple maps, this facilitates comparison between time periods and provides a comprehensive view of the map, time plays an important role in geographical studies because it has been proven that all natural and human geographical data is changed and not stable [1-4]

Research problem

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Two-dimensional (2D) maps are no longer sufficient to meet geographical needs and represent various phenomena, especially changes in geographical phenomena over time, they are less efficient than three-dimensional (3D) models in terms of visual perception and geometric representation, geographic information systems require another solution to support spatio-temporal modeling, which is to use the fourth dimension (4D) to express changes in geographic phenomena over time, the following questions can be asked:

1.Do geographic information systems have the ability to represent the fourth dimension (4D) model of various phenomena with rapid visual perception and geometric representation that traditional methods are unable to achieve?

2.How can four-dimensional maps be designed in a single map where the fourth dimension represents time?

3.Can the elements of temperature be represented by three-dimensional and four-dimensional maps based on the database and the data updates made to it?

Research hypothesis

1.Geographic information systems have the ability to design highly efficient maps in three-dimensional representation of various geographic phenomena with quick visual perception and geometric representation that differs from traditional methods.

2.It is possible to compare time periods and produce two- and three-dimensional shapes based on the database and design a map represented by four-dimensional maps and compare time periods to achieve integration and comprehensiveness in the map.

Research objectives

The research aims to find spatial and temporal databases in geographic information systems (GIS) to support spatio-temporal modeling by including temporal information and using geometrically based spatio-temporal forms to represent reality by combining time layers with place and making the third dimension (3D) a fourth dimension (4D). The research aims to: 1. Selecting third- and four-dimensional models for data in temporal geographic information systems.

2.Applying the fourth-dimensional model according to the temporal geographic information systems framework for temperature in Kirkuk province and nearby stations.

Importance of the research

The importance of the study lies in the role of geographic information systems in representing the temporal dimension, which is one of the important topics that have occupied the minds of geographers, in order to highlight and understand the changes occurring in geographical phenomena over time (4D) and to present them in three dimensions for the studied phenomena in nature (3D), the subject is presented in three dimensions because four dimensions rely on three dimensions to show temporal differences.

Boundaries of the study area

The boundaries of the study area represent the boundaries of Kirkuk Governorate, located in the northern and northeastern parts of Iraq, bordered by Erbil Governorate to the north, Sulaymaniyah Governorate to the east and northeast, and Salah al-Din Governorate to the southwest. The province is confined between latitudes 42.34° and 54.35° north and longitudes 23.42° and 44.48° east

2 Materials and methods

2.1 Concept of the Digital Terrain Model (DTM)

The use of the Digital Elevation Model (DEM) instead of the Digital Terrain Model (DTM) is because the term “ground surface” refers to surface extensions rather than the elevation of these surfaces, despite taking this point into consideration, the term DTM is intended for use because it contributes to the inclusion of the ground surface as a means of improving digital representation [5, 6]. It can be used as a digital model for any surface, which may be a single value, geological horizon, air temperature, or population density. It was defined as a three-dimensional digital representation of the terrain surface and the determination of the spatial dimensions of objects related to that surface. There is a difference between the digital terrain model and the digital elevation model (DEM) because the latter is limited to variations in elevation, while the former is a three-dimensional graphical representation of various phenomena, whether natural or human-made. The use of models in the geographical distribution of phenomena or the trends of various phenomena in three dimensions (X, Y, Z) Thus, the digital terrain model represents the topographic surface system from the data file in the form of a set of coordinates.

2.2 Temporal-spatial changes

Temporal changes represent changes that occur at different points or points in time and can be identified through attributes or location from one time to another. Although most phenomena change over time, there have been attempts to model real-world phenomena and diagnose changes over this time period. Spatial changes occur across space or over a specific period of time. Spatial data can be classified into static and dynamic data.
Static spatial data: This refers to data that is constant or changes very slowly in terms of geographical phenomena at a given layer, i.e., data that may not change over a short period of time. All of these things change after a long period of time.
Dynamic Spatial Data: this spatial data relates to geographical objects and phenomena that change over a short period of time and compares the occurrence of the phenomenon from different locations. Spatial changes may occur in characteristics from time to time, and several mathematical methods are used to detect changes between one layer and another.

2.3 Thematic maps

The maps that focus on a single topic, which is why they are sometimes called special maps. They include geological maps, geomorphological maps, and most branches of geography, such as city maps, industrial maps, rural and urban land use maps, political maps, weather maps, climate maps, historical maps, population maps, educational maps, health maps, distribution maps, topographic maps, and other topics. They are drawn to a small scale. Thematic maps are one of the traditional functions for processing and analyzing spatial data and displaying features or descriptive data in an illustrative style, using visual variables such as colors and shadow values.

2.4 Methods of representing time in geographic information systems

It is well known that the world we live in consists of three dimensions (length, width, and height). while the temporal-spatial dimension is the movement of any object at different time intervals between two or more specific points. One of the problems faced by temporal-spatial maps is that the regions in the foreground with higher values cover and obscure the regions in the background when the map is tilted flat, making them invisible, although it is possible to rotate the map to bring the lower region to the front, this does not always work in highlighting some hidden regions behind larger areas, rotation causes the map to lose its basic northward orientation as well as its coordinates [7, 8].

Geographic information system software can easily build three-dimensional models by requesting data on the location and elevation (X, Y, Z) of points. The coordinates values (X, Y) for this point represent the location of the point on the horizontal plane, i.e., the two-dimensional plane while the (Z) value represents the height of the point above a reference level, which is usually taken to be sea level. There are several ways to represent time in geographic information systems for temporal modeling in GIS, including the following methods:

Layers in GIS software:

Layers can be defined in geographic information systems as a set of maps, each layer or map having a specific theme, called a thematic map. These layers are transparent and can be placed on top of each other to store data in more than one layer to facilitate management and overcome technical problems caused by processing large amounts of information at once. It is better to overcome a problem in a specific layer than to process an entire system. Each layer consists of homogeneous time units, and when the two layers are merged, a new layer is created and the time of changes in production quantity is added to the new layer.

Time series analysis:

The traditional method (graphs and histograms) for analyzing sequential events that occur over a period of time by using a time series of graphs and equations to illustrate changes in characteristics over a period of time or at a specific time in the sequence. Geographic information systems use time series analysis as a preparatory step to summarize characteristics over a period of time.

Cartographic methods are usually used to show temporal changes and represent specific data and characteristics that change slowly over time. The use of land and maps may depend on surveys conducted over several years, as the dynamic process changes continuously over hours or days, and it is impossible to put maps by using traditional cartographic methods. A four-dimensional model was designed for temperature, dividing the time period into three periods of 10 years each, based on climate data for the period 1991-2020, as shown in Table (1).

Table 1. Temperature rates for weather stations for the period 1991-2020

Temperature averages for weather stations from 1991 to 2020			
Third period 2010-2020	Second period 2001-2010	First period 1991-2000	Station name
23.2	22.5	22.2	Kirkuk
22.7	22.6	21.9	Mosul
30.4	29.8	29.1	Tikrit

3 Results

The map is an expression of visual language, and the goal of map design is to make it easy to read and understand so that it is useful to the reader. This is because any useful map or graphic provides quick answers to the reader's questions. Since the content of the map requires knowledge of all the details because it is subject to the process of perception, as in Figure 1, which shows the representation of temperature rates for the first period and the second dimension 2D)

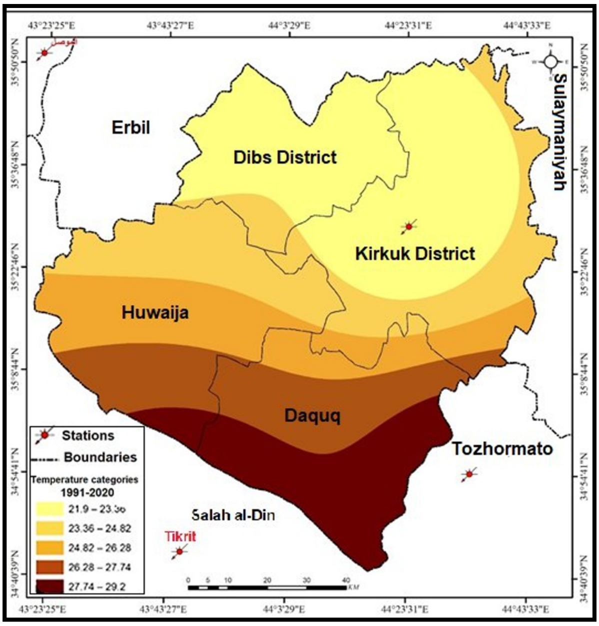

Fig.1. Temperature degrees from 1991 to 2020, 2D. Source: Based on data from Table (1), using ArcGIS 10.3 software

The choice of the direction of the three-dimensional (3D) map depends on the clarity of the perspective and the accuracy of the visibility of geographical features for the map reader, as well as on the direction of the shadow and the angle of the shadow direction. As shown in Figure 2, based on Table (1) of temperature averages for stations in the study area, the temperature categories for the period (1991-2000) are shown, with dark red areas indicating the highest temperature averages

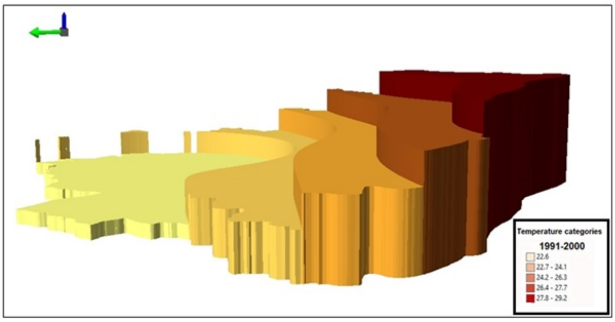

Fig.2. Temperature degrees from 1991 to 2020, 3D. Source: Based on data from Table (1), using ArcGIS 10.3 software.

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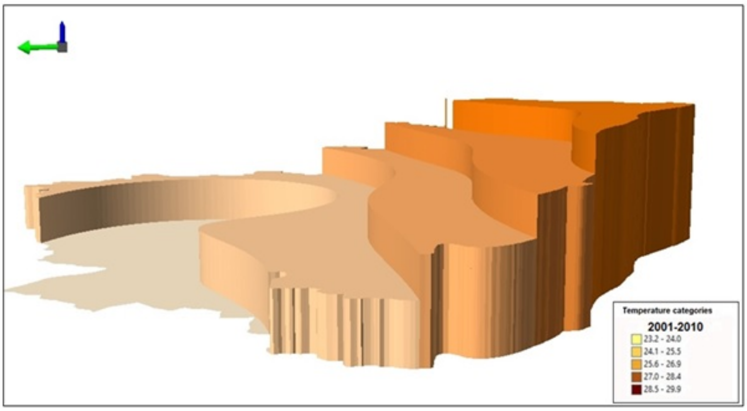

Fig.3. Temperature degrees from 2001 to 2010, 3D. Source: Based on data from Table (1), using ArcGIS 10.3 software.

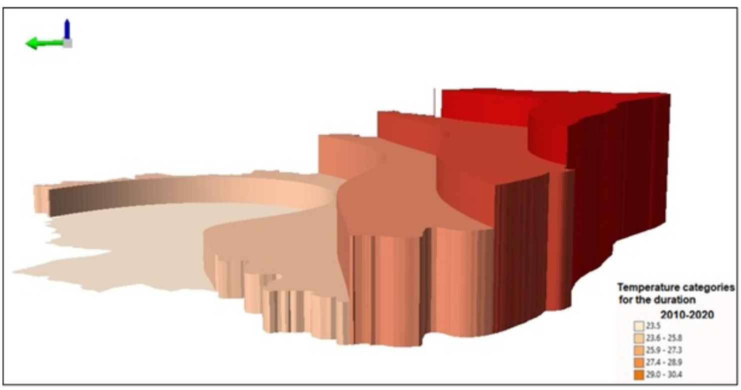

Fig.4. Temperature degrees from 2010 to 2020, 3D. Source: Based on data from Table (1), using ArcGIS 10.3 software.

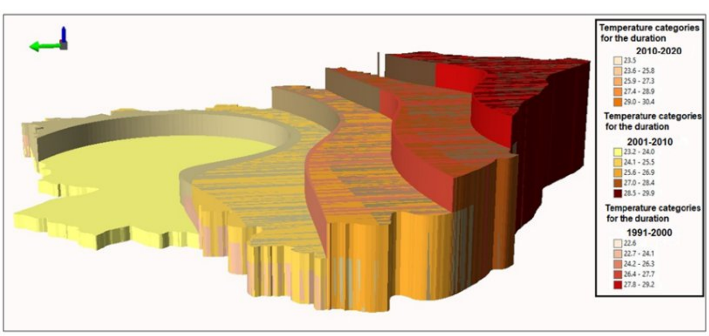

Fig.5. Temperature degrees from 1991 to 2020, 4D. Source: Based on data from Table (1), using ArcGIS 10.3 software Source: Based on data from Table (1), using ArcGIS 10.3 software.

These maps are drawn using the same steps as before, but with a gradient of colors or shades, but what distinguishes the temporal-spatial maps is their high visual perception and the distinction between warmer and cooler periods, as shown in Figure 5. Temperatures are represented for three time periods: 1991-2000, second period 2001-2010, and third period 2010-2020, this method is considered the best way to represent temperature on a map over a period of time, as it is quick and easy for the reader to understand and perceive. It shows that there is a difference between the three periods in terms of temperature averages between weather stations.

The ARC SENCE program does not contain GRID, but is interconnected with other programs that modify images, although they are not accurate, in this regard, the ARC MAP program was used to create the map elements to become in this shape

4 Conclusions

1.Fourth-dimensional maps are more quickly understood and perceived than maps drawn using traditional methods, as the fourth dimension provides a comprehensive composite map that shows changes in data over time, facilitating comparisons between time periods.

2.The digital method of drawing and producing maps is better than traditional methods because it provides ease of perception, accuracy in expressing phenomena, and accuracy in measurement.

3.The error rate in traditional maps is high because they use traditional tools for mapping, while the error rate in digital maps is low because they use computers and geographic information system software for mapping.

4.The benefits of digital maps increase over time, while the benefits of traditional maps remain constant.

Recommendations:

1.Adopting digital methods for producing maps instead of traditional methods, due to their usefulness, accuracy, and speed of perception.

2.The need to rely on geographic and engineering mapping software to draw and update maps for various subjects.

3.Providing a database and information for all departments and institutions and producing modern atlases, unlike those currently available.

References

1. F. Lehmkuhl, et al. Loess landscapes of Europe – Mapping, geomorphology, and zonal differentiation. Earth-Science Reviews. **215** (2021), https://doi.org/10.1016/j.earscirev.2020.103496
2. F. Fanti, et al. High-resolution UAV maps of the Gobi Desert provide new insights into the Upper Cretaceous of Mongolia. Cretaceous Research, **161** ,(2024) https://doi.org/10.1016/j.cretres.2024.10591
3. Yu. Bai, et al. Dynamic analysis of carbon emissions from construction and demolition activities in Japan: Revealed by high-resolution 4D-GIS modeling. Journal of Environmental Management, **361** (2024), https://doi.org/10.1016/j.jenvman.2024.121099
4. M. Cheng, et al. MAPS: A new model using data fusion to enhance the accuracy of high-resolution mapping for livestock production systems. One Earth, **6(9),** 1190-1201 (2023) https://doi.org/10.1016/j.oneear.2023.08.012
5. D. Krdžalić, et al. Evaluating the accuracy of the digital elevation models (DEMs) within the territory of Bosnia and Herzegovina. Remote Sensing Applications: Society and Environment, **34**, (2024), https://doi.org/10.1016/j.rsase.2024.101187
6. M. Habib, A. Habib, M. Abboud. Multi-Aspect Critical Assessment of Applying Digital Elevation Models in Environmental Hazard Mapping. Revue Internationale de Geomatique, **33**(0): 247-271 (2024), https://doi.org/10.32604/rig.2024.053857

7. Nazgol Bagheri, Using mixed methods research with Geographic Information Systems (GIS), Editor(s): Robert J Tierney, Fazal Rizvi, Kadriye Ercikan, International Encyclopedia of Education (Fourth Edition), , Pages 645-654, (Elsevier, 2023) https://doi.org/10.1016/B978-0-12-818630-5.11065-6
8. K. Kryniecka, Implementing Geographic Information System (GIS) tools: Algorithm and Quantum Geographic Information System (QGIS) plugin for automatic detection of riverbed forms. MethodsX, **13** (2024), https://doi.org/10.1016/j.mex.2024.103041