Rainfall Data Analysis and Interpolating in ArcGIS: Sudan Case Study

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ABSTRACR- Rainfall has many effects, including, for example, but not limited to, its impact on agriculture, where many countries depend on agriculture, and therefore the amount of rainwater and its management play a direct role in the economy. Also, the lack of study and effective management of rainfall by competent authorities leads to many human and material disasters. This paper was conducted to study rainfall using Geographical Information Systems (GIS) technology and thus enable effective management and prediction of the rainfall amount. Rainfall data were obtained for 41 years, from 1981 to 2021, for 18 stations in the Republic of Sudan, in the form of Excel files from the National Aeronautics and Space Administration (NASA) website. Then, within the ArcGIS 10.8 program, the stations were created, which were randomly selected to cover all the states of Sudan, and the study was conducted on them. By using the geostatistical analyst toolbar, A histogram was obtained that shows the frequency of values and detailed information about them. Also, a trend analysis was conducted, and it became clear that the rainfall increases the more we head south and east. Rainfall prediction maps were generated using inverse distance weighting, local polynomial interpolation, and kriging methods. Finally, a detailed study was conducted on the Khartoum station by creating a graph that shows the variation in rainfall over the 12 months for 41 years.

Keywords: Rainfall Stations, NASA, Histogram, Trend Analysis, Variation in Rainfall

المستخلص- لهطول الأمطار تأثيرات عديدة، بما في ذلك، على سبيل المثال لا الحصر، تأثيره على الزراعة، حيث تعتمد العديد من البلدان في اقتصادها على الزراعة، وبالتالي فإن كمية مياه الأمطار وإدارتها تلعب دورًا مباشرًا في الاقتصاد. كما أن نقص الدراسة والإدارة الفعالة لهطول الأمطار من قبل الجهات المختصة يؤدي إلى الكثير من الكوارث البشرية والمادية. أجريت هذه الورقة لدراسة هطول الأمطار باستخدام تقنية نظم المعلومات الجغرافية وبالتالي تمكين الإدارة الفعالة والتنبؤ بكمية هطول الأمطار. تم الحصول على بيانات هطول الأمطار لمدة 41 عامًا من 1981 إلى 2021 لـ 18 محطة في جمهورية السودان في شكل ملفات إكسل من موقع ناسا، ثم في برنامج ArcGIS 10.8 تم إنشاء المحطات التي تم إختيارها عشوائيا لتغطي كل ولايات السودان وأجريت الدراسة عليها. باستخدام شريط أدوات التحليل الإحصائي الجغرافي تم الحصول على رسم بياني يوضح تواتر القيم والمعلومات التفصيلية عنها. كما تم إجراء تحليل للاتجاه واتضح أن هطول الأمطار يزداد كلما اتجهنا جنوبا وشرقا. تم إنشاء خرائط التنبؤ بهطول الأمطار باستخدام طرق ترجيح المسافة العكسي، والاستيفاء متعدد الحدود المحلي، و كريجينج. أخيرًا، تم إجراء دراسة تفصيلية على محطة الخرطوم من خلال إنشاء رسم بياني يوضح التباين في هطول الأمطار على مدى 12 شهرًا لمدة 41 عامًا.

INTRDUCTION

The objective of rainfall climatology is to measure, understand, and predict the distribution of rainfall across different regions of the planet based on factors such as atmospheric pressure, humidity, terrain, cloud type, and raindrop size, either by direct measurement or by data acquisition by remote sensing.

The importance of studying climatology lies in many matters, the most important of which is to help countries make the right decisions and take the necessary measures to confront any obstacles that may come in the coming period. Also, the ability to study natural disasters in addition to environmental phenomena and problems such as climate change and global warming.

Rainfall is one of the most important factors affecting the environment, agriculture, and the layout of any hydraulic infrastructure [1]. Reports on rainfall predictions are essential for informing and warning the populace in a certain location. Uncertain meteorological conditions frequently result in fear because of flash floods brought on by improper drainage management. The majority of the time, precipitation data is obtained in tables, making it challenging to assess and determine a precipitation pattern. As a result, GIS applications are frequently used to create precipitation patterns using a mix of precipitation data features, which can subsequently be utilized by stakeholders to make the analyzing process easier and precipitation prediction. It is not thought to be overstating the significance of GIS for surface creation and precipitation estimation [2].

In light of the current circumstances that the countries of the world are witnessing in terms of climate change and the fear of its negative effects, GIS technology can be used in effective management in this field and support decision-making in finding appropriate solutions and reducing risks.

Some of the most crucial elements that should be investigated include meteorological variables such as rainfall parameters, temperature, sunshine hours, relative humidity, wind speed, and soil moisture [3]. The availability of water resources is crucial to the economic and social well-being of the inhabitants and significantly affects the socioeconomic circumstances in a nation [4].

Hazard-based planning works to reduce harm to population and property before a catastrophe occurs, but its success in catastrophe reduction necessitates top-tier coordination and cooperation on the political and technical levels, in addition to a dedication on the part of other society stakeholders to work with us toward sustainable development [5]. The lack of effective water resource planning causes a sharp decline in urbanization and population growth [6].

Potential sources of high-quality precipitation are less certain and more changeable in arid areas. Rainfall is a major problem because there are limited resources for managing water [7]. In dryland areas where rainfall is the most important hydrological variable, agriculture is greatly impacted [8]. Rainfall's kinetic energy can erode the top layer of soil, resulting in significant rainfall erosivity [9].

Water scarcity, which poses a threat in many countries, requires a lot of studies, especially on how to conserve rainwater and benefit from it throughout the year and thus ward off flood risks.

The world's population is urbanizing quickly, which has increased the frequency and severity of flood disasters. Floods arise when a normally dry area becomes heavily saturated with surface water. This might happen as a result of rainfall [10]. Water is transported and released more quickly than it would in its natural state as a result of the global tendencies toward urbanization in the twenty-first century. A result of increased runoff volumes and decreased infiltration results in a change in hydrological patterns and an increase in the danger of floods [11].

One of the most crucial of the hydrological cycle's constituents is rainfall, which is significantly impacted by global climate change [12]. Precipitation plays a significant role in the environment and daily life, serving as a supply of water. We can better manage the water system if we can detect or estimate the amount of rainfall [13]. Accurate estimations of rainfall are necessary for hydrological and climate studies since it is a crucial meteorological component in hydrologic processes [14].

Sudan is one of the nations whose economy is heavily dependent on agriculture, supported by rainfall, and which also experiences cyclical periods of drought. Rainfall is thought to be the most significant climatic factor affecting agriculture. As a result, forecasting rainfall is crucial for planning and managing agricultural schemes, water resource management, and ultimately the management of the entire economy [15].

It was vital to study rainfall well in Sudan because it is a large country with many parts that are affected by drought and numerous regions that are also affected by flood disasters.

Sahat et al in 2016 in their study concentrated on identifying the district of Batu Pahat's GIS-based distribution of rainfall patterns. They studied rainfall data collected over ten years and found because of employing GIS technologies, rainfall analysis is effective for learning about rainfall patterns [16].

Ly et al [17] in 2013 conducted a study to examine the techniques for interpolating rainfall data that are typically needed in hydrological modeling. They used a few standard techniques and geostatistical approaches, such as the inverse distance weighting method, and concluded that additional research is required to look into ways of enhancing the goodness of rainfall data.

The authors agreed with the previous studies in the study of rainfall, but their study was unique. The gap was covered in the method of obtaining the data, as the authors used data from the nasa.gov website for 41 years and thus benefited from open-source data. The study was also unique in the methodologies used, as it did not focus on one methodology but rather four methodologies that were conducted to study rainfall, which distinguishes it from previous studies.

This paper aims to study rainfall in terms of knowing the values frequency, and trends of increasing and decreasing rainfall and also using the interpolation methods to generate prediction maps based on average rainfall for 41 years from 1981 to 2021 for 18 stations, one in each state of the Republic of Sudan. It also aims to conduct a detailed study on one of the stations (for example, the Khartoum station) to find out which months have the highest and lowest rainfall amount by creating a graph.

MATERIALS AND METHODS

The Republic of Sudan was chosen as a study area, its spans 9° to 22°N in north-eastern Africa, and borders South Sudan, Ethiopia, Eritrea, Egypt, Libya, Chad, the Central African Republic, and the Red Sea. Despite being in the tropics, the region has a range of climates, from a desert climate in the north to a summer-rain climate in the south. Rocks and soil cover about half of the country, mostly in the northern states. In the southern sections, trees, bushes, and herbaceous land cover predominate in agricultural areas [18].

Agriculture, industry, and service sectors make up the bulk of the Sudanese economy. According to statistics from 2004, the contribution of the agricultural sector to the overall economic output was about 39.2 percent, while that of the services and industrial sectors was about 32.8 and 28.0 percent, respectively. In Sudan, rainfall is considered to be the primary supply of water for agriculture. According to estimates, Sudan receives 1094 million cubic meters of rain per year, which is needed for crops, cattle, forests, and pastures [19].

In light of the conditions of climatic changes and their impact on the environment, especially regarding rainfall and the physical and human disasters that it causes, it was necessary to study rainfall and reach results that help support decision-making to reduce human and environmental problems.

The data used in the study was obtained from the website https://power.larc.nasa.gov/data-access-viewer/ by spatial resolution is 0.1° x 0.1° (or roughly 10km x 10km) with a 30-minute temporal resolution [20]. NASA has a strong track record of archiving and providing universal access to science data products from its science missions and programs.

Astrophysics Science archives have been established in a wavelength-specific structure alongside the Astrophysics Great Observatories. The evolving heliophysics data environment provides access to data and physics-based models that facilitate a system-level understanding of the sun and its impact on our solar system. Perhaps the most notable endeavor in this regard is the Earth Observing System Data and Information System (EOSDIS), which processes, archives, and distributes data from a large number of Earth-observing satellites and represents a crucial capability for studying the Earth system from space and improving prediction of Earth system change. EOSDIS consists of a set of processing facilities and data centers distributed across the United States that serve hundreds of thousands of users around the world [21].

The data are an average of rainfall data from January to December for 41 years, from 1981 to 2021, in an excel file for each of the 18 stations. The stations are Port Sudan, Al Dammer, Dongola, Al Fasher, Al Geneina, Al Daein, Nyala, Zalingei, Al Fula, Kadugli, Al Abiad, Khartoum, Wdmadany, Rabak, Singa, Al Damazin, Al Gedaref and Kassala, where each station was selected in each state of Sudan. A new excel file was prepared that contains the longitude and latitude of each station, which were obtained from NASA data, as well as the rainfall average for 41 years (see Table I), which was obtained by adding the average rainfall for each year and then dividing by 41 for each station.

By using the study data from the NASA website, the maximum benefit was obtained from open sources in obtaining data instead of collecting it manually by traditional methods or from relevant authorities, as sometimes it is difficult and time-wasting to obtain such data, especially as it includes monthly data for 41 years.

Within the ArcGIS 10.8 program, many procedures were performed (Figure 1). The stations were created by adding an excel file and exporting it to a feature class.

The Sudan states shapefile was created from the OpenStreetMap base map instead of commonly used methods such as satellite images, to take advantage of the capabilities available in the program instead of using other programs to obtain a satellite image, especially since the study area is very large and it is difficult to obtain a satellite image of it with clear details.

TABLE I: RAINFALL DATA OF STATIONS

Station	X	Y	Rainfall (mm)
Port Sudan	29.7138	10.9968	2.257
Al Dammer	26.1487	11.444	1.419
Dongola	28.6074	11.7159	1.846
Al Fasher	34.3217	11.7331	2.205
Al Geneina	24.9072	12.0571	1.365
Al Daein	23.5538	12.9112	1.514
Nyala	33.9262	13.1278	1.232
Zalingei	30.2191	13.1775	1.126
Al Fula	32.8166	13.1813	1.19
Kadugli	22.4243	13.4715	1.429
Al Abiad	25.3357	13.6423	0.695
Khartoum	35.3799	14.045	1.571
Wdmadany	33.5617	14.4018	1.132
Rabak	36.3742	15.4315	1.06
Singa	32.5249	15.6445	0.444
Al Damazin	33.9957	17.575	0.158
Al Gedaref	30.4855	19.1844	0.016
Kassala	37.2023	19.5925	0.172

A histogram showing the frequency of the values and detailed information about the stations was obtained.

A trend analysis was conducted for the values of the rainfall average, which shows the trends in which the rainfall increases and decreases.

Rainfall prediction maps were generated using inverse distance weighting, local polynomial interpolation, and kriging methods.

Inverse distance weighting is a fast, precise, deterministic interpolator. Making decisions on model parameters is not common. It might be an effective approach to get a glance at an interpolated surface. However, inverse distance weighting might create "bulls' eyes" around data locations, and there is no evaluation of prediction mistakes. The data doesn't need to be predicated on anything [22].

Local polynomial interpolation is a smooth, somewhat fast interpolator (inexact). The process produces forecast, forecast standard error, and surfaces of the condition number, which are comparable to ordinary kriging with measurement errors. Local polynomial methods are less flexible and more automatic than kriging because you cannot study the autocorrelation of the data with them. The data doesn't need to be predicated.

Kriging is an interpolator that, relying on the measurement error model, can be precise or smooth. It is pretty adaptable and enables you to look into spatial automatic and cross-correlation graphs.

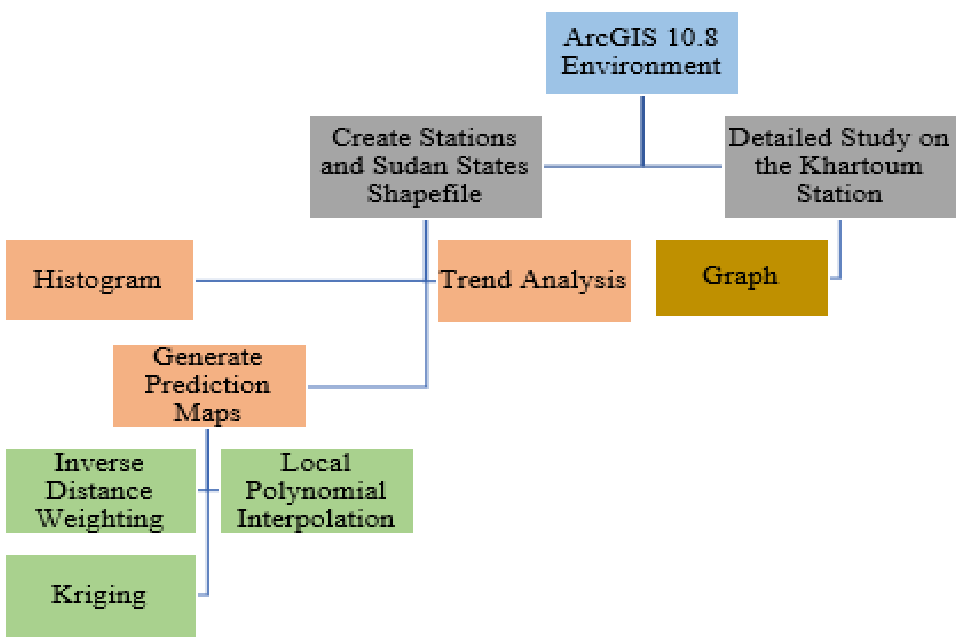

Figure 1: Procedures in the ArcGIS Program

TABLE II: AVERAGE RAINFALL DATA OF THE KHARTOUM STATION

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	0	0.006	0.039	0.186	0.231	1.589	2.063	0.817	0.313	0.011	0.007

Kriging employs statistical frameworks to provide a range of output surfaces, including forecast, forecast standard error, likelihood, and quantiles. Kriging can involve a lot of decision-making due to its flexibility. Kriging presupposes a fixed stochastic operation for the data, and some methods presuppose normally distributed data.

A detailed study was conducted on the Khartoum station, where from the data obtained from the nasa.gov website about the station in question, an excel file was created in it the average rainfall from January to December for 41 years (see Table II), which was obtained by adding the rainfall data for each month for all years and then obtaining the average by dividing by 41. The data was added to the Khartoum station, and then a graph was created showing the months with the highest and lowest rainfall amount.

RESULTS AND DISCUSSIONS

After the data was obtained from the nasa.gov website, it was placed the longitude, latitude, and rainfall average for each station in an excel file, and was added to the ArcGIS 10.8 program in the WGS 1984 coordinate system. After that, it was exported to feature class, and thus a layer was obtained with spatial and attribute data for 18 stations within the Republic of Sudan for the rainfall average for 41 years.

The Sudan states shapefile was created from the OpenStreetMap basemap to generate rainfall prediction maps on its extent.

From the geostatistical analyst toolbar, a histogram (see Figure 2) was created showing the frequency of the values and information about the stations. For example, a count of 18 stations, the minimum value is 0.016, the maximum value is 2.257, and other information.

A trend analysis (see Figure 3) was performed of the rainfall average. It was found that the rainfall increases the more we head south and east.

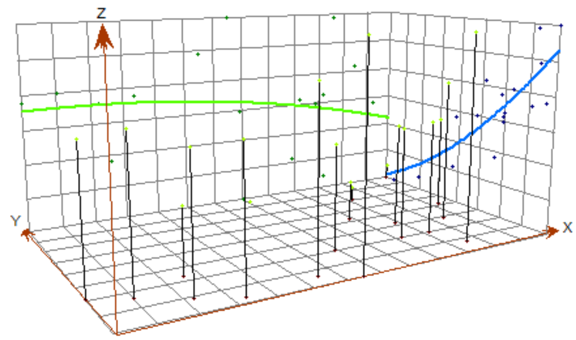

Figure 3: Rainfall Trend Analysis

Interpolation was done to generate rainfall prediction maps (Figures 4 to 6) on the extent of the Sudan states using inverse distance weighting, local polynomial interpolation, and kriging methods.

A symbology was made for the maps, as the rainfall amount is consistent with the color gamut, which means that the darker the color, it shows that the number of rainfall increases. It is clear from the figures above and the clarification in the materials and methods paragraph that the kriging method is the best.

From the rainfall prediction maps, it is possible to predict the rainfall amount at any station other than the stations entered. This is made by the identify tool, and this is useful in case it is difficult to obtain data of rainfall amounts at certain stations.

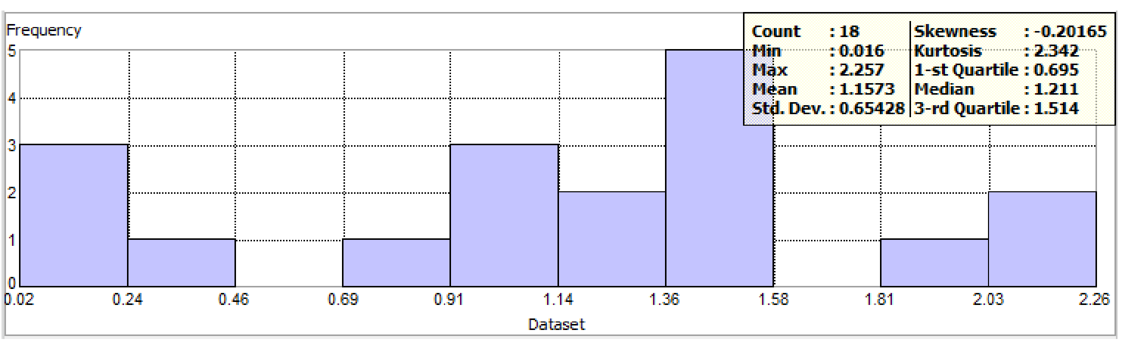

Figure 2: Rainfall Histogram

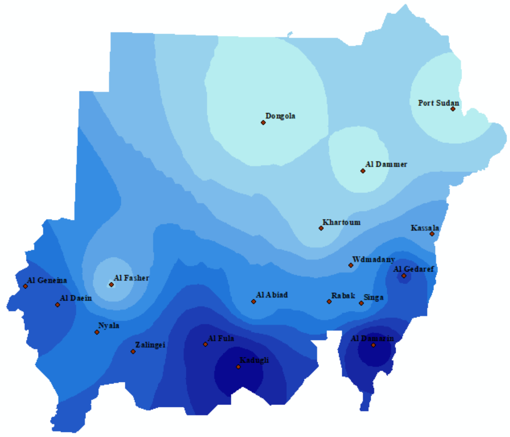

Figure 4: Rainfall Prediction Map using the Inverse Distance Weighting Method

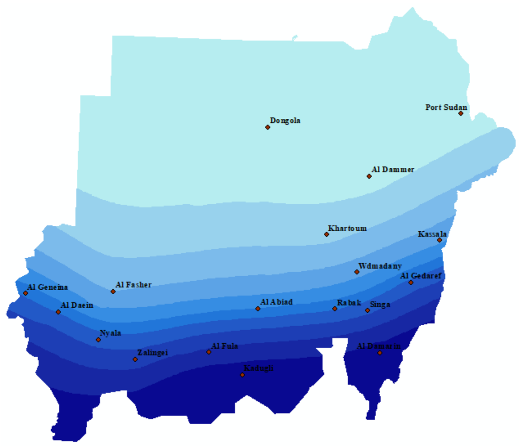

Figure 5: Rainfall Prediction Map using the Local Polynomial Interpolation Method

The detailed data for the Khartoum station, represented by the rainfall average of 12 months for 41 years from 1981 to 2021, was added, and then a graph (Figure 7) was created showing the variation in the rainfall amount, as it was found that the August had the highest amount of rainfall.

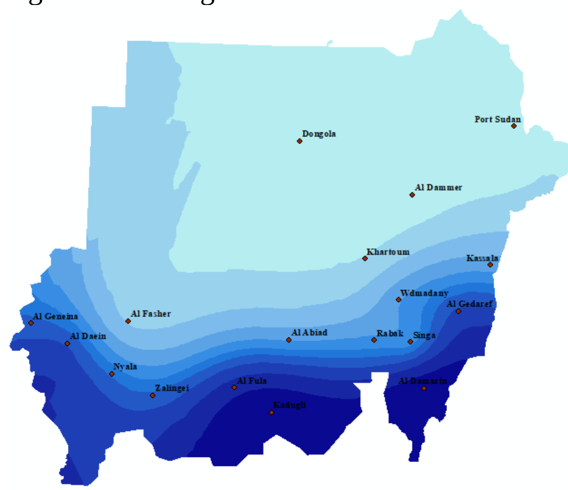

Figure 6: Rainfall Prediction Map using the Kriging Method

In this study, the authors used four methodologies, where a histogram was obtained that contained much information about the rainfall stations data in terms of count, minimum and maximum value, mean, standard deviation, and so on; all of this information can be obtained simply by looking at the histogram without having to refer to the tables of data used.

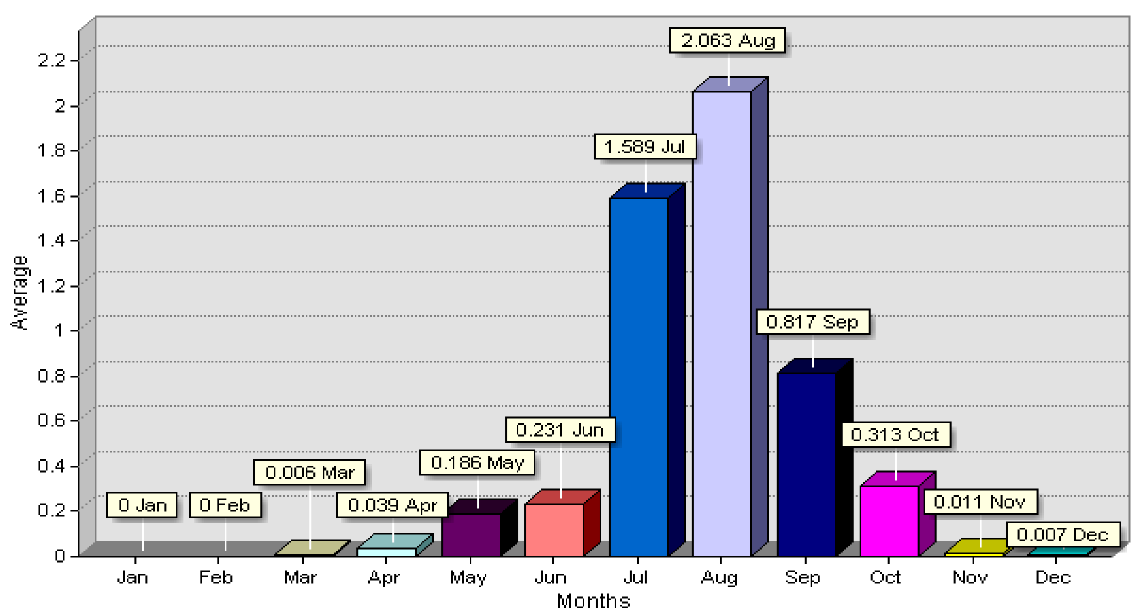

Figure 7: Rainfall Average Graph of the Khartoum Station

Also, by looking only at the result of the trend analysis, it was known that the rainfall increases as we head south and east, as it is difficult to understand this directly through the data tables.

Even a non-specialist can tell from the color gradient the regions where the rainfall increases, where the darker regions are the regions where the rainfall increases, by looking at the obtained prediction maps.

Through the graph obtained for the Khartoum station over 12 months for 41 years, it is easy to know which months have the highest and lowest rainfall.

This study is significant because it focused on multiple methodologies, in contrast to previous studies, one of which Sahat et al., in [16] focused solely on the IDW method for interpolation and concluded the effectiveness of GIS application in the study of rainfall, and the other Ly et al., in [17] dealt with conducting spatial interpolation and concluded the need for new research in the study of rainfall.

CONCLUSIONS

The furthest benefit from GIS technology in the study and management of rainfall was made, and thus the direct contribution to increasing the economy of societies and warding off human and material disasters. It is difficult to obtain such results manually because the data on which the study depends is an average data of 492 months (41 years), not to mention the simplicity of the available methods for analysis within the GIS program, which can be used to support decision-making in the least amount of time at the lowest cost.

To study rainfall, data were obtained for the average rainfall for 41 years, from 1981 to 2021, for each station out of 18 stations. Within the ArcGIS 10.8 program, the stations were created, and then the histogram, trend analysis, and prediction maps were created. Finally, the Khartoum station was thoroughly investigated.

We recommend conducting more studies related to rainfall using various GIS applications and benefiting from them in support of decision-making, particularly in terms of conducting more detailed studies on all stations and benefiting from them in disaster prevention.

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