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FLOODS IN ALGERIA: ANALYZES AND STATISTICS

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ABSTRACT

The effect of climate change in the world has directly contributed to the increase in the frequency of natural phenomena, including floods. Algeria has suffered from this phenomenon through human and material damage caused by this risk. The objective of this work is to analyze the flood frequency and the number of deaths in Algeria for the period 1969-2022. In this study, 191 events were counted, and 2098 deaths were recorded.

The analysis results of the numbers of deaths showed that the period from 1969 to 2009 was characterized by the presence of devastating floods that left large numbers of victims, while during the period 2010 to 2022, it was characterized by the presence of fewer victims but with a large number of floods; the highest number was recorded in 2015, with 14 floods. The absence of storm drains sometimes and its inability to evacuate stormwater, urban expansion and construction at the edges of wadis (major bed) mainly contribute to increasing the risk of flooding.

For the period 2010-2022, the most significant number of deaths and flood frequency were recorded in August, September and October, which could be explained by the high temperatures during the summer, which increase the impermeability of the soil and thus increase the risk of floods. The distribution of the number of deaths and the flood frequency by province during this period showed that Djelfa, M'sila, Tamanrasset, Tiaret, Batna, Oran and Medea were most vulnerable to flooding.

This work can assist local and national managers in obtaining an overview of the distribution of floods in Algeria and making decisions to mitigate the risk of this phenomenon.

Keywords: Algeria, Floods, Deaths, Frequency, Analysis, Inventory.

INTRODUCTION

Floods are among the most severe and devastating phenomena of natural disasters. In recent decades, cities adjacent to flood-prone areas have played a significant role in increasing the potential adverse effects of flood damage (Madi et al., 2023). Floods in Algeria have become a major risk because they influence the population and the environment. In recent years, this risk has occupied an important place at the local and national authorities. City protection studies, wadi development and flood risk maps have been carried out to minimize and mitigate this risk.

Understanding the causes that affect the occurrence of floods helps to suggest appropriate solutions to reduce flood risk (Hafnaoui et al., 2022). Several factors have contributed to the occurrence of floods. In Algeria, studies have analyzed the factors that contribute to flooding. Hafnaoui et al. (2009) treated the impact of climatic and morphological factors on floods in Doucen City (Algeria). Menad et al. (2012) analyzed the effect of urban land use as an aggravating factor of flooding in the case of Bab El Oued. The simulations obtained using the RuiCells cellular automata modeling witches show that the cumulative amounts of the runoff areas in 2001 increased by (+ 10%) compared to 1986. Hachemi et al. (2019) analyzed the effects of morphometric characteristics on flash flood responses in the El Bayadh region.

Madi et al. (2020) assessed the risk of flooding in Bechar city. Hafnaoui et al. (2022) studied the factors contributing to flood occurrence in El Bayadh city; the effects of land use change, storm drainage systems and morphometric characteristics were analyzed. Bentalha (2023) studied the role of green roofs in reducing the risk of floods using the SWMM. The numerical results show that both intensive and extensive green roofs are very efficient in reducing runoff in most subcatchments.

In addition, some studies on the frequency of floods have also been carried out. The results of the statistical analysis of the annual maximum daily rainfall can be applied to the planning and design of flood infrastructures in the basin (Bong et al. 2023). Hachemi et al. (2016) studied flood frequency analysis (FFA) using the instantaneous flood discharge data of Foum El Gherza station to develop a flood-duration-frequency (QDF) curve. The results showed that the Pearson type III (P3) distribution is more appropriate to fit the considered data. Benameur et al. (2017) estimated the flood events of Abiod wadi at given return periods at the station of M’chouneche; the results showed that the generalized Pareto distribution (GPD) better describes the analyzed series. Bekhira et al. (2018) modeled the annual and monthly scales in the watershed of Wadi Bechar using the rural engineering model (GR). Karahacane et al. (2020) considered complete multivariate FFA on-site case studies in northern Algeria using 11 hydrometric stations; the obtained results help to assess flood risks and water management in the regions studied. Benzater et al. (2021) used the Mann–Kendall method to detect the trends of maximum daily rains at 41 rainfall stations in the Macta watershed (North West Algeria) for a period of 41 years (1970–2010); the results showed that August and September are marked by the most significant increases in the intensity of the rains, justifying the catastrophic floods that hit the region every year. Madi et al. (2023) studied mitigating flood risk events in the El Bayadh region by evaluating the rainfall intensities and their limits for durations from 0.167 to 24 h with return periods from 2 to 1000 years. The results showed that high-intensity rainfall values last for short durations, while high flood risk values last for intermediate durations. Zegait and Pizzo (2023) proposed and dimensioned a damping reservoir to control and protect IDLES cities against floods using a new program created in Visual Basic for Applications (VBA).

Among the tools that help to mitigate the risk of flooding is the realization of flood hazard maps. The mapping of areas at risk of flooding has been the subject of several studies in different provinces of Algeria. HEC-RAS software has been used by Yahiaoui (2012), Bekhira et al. (2019), Boukhanef et al. (2019), Bouhellala and Cherif (2020), Kastali et al. (2021), and Zegait et al. (2022) to simulate flood areas. Yamani et al. (2016) and Derdour and Bouanani (2019) used two types of models to determine flood-prone areas: the HEC-HMS hydrological model and the HEC-RAS hydraulic model. The combination of the ArcGIS system using the HEC-GeoRAS application and HEC-RAS software for numerical modeling was used by Hafnaoui et al. (2013; 2020; 2022), Madi et al. (2020), and Madi et al. (2023) to realize a flood hazard map. Atallah et al. (2018) used a 2D numerical model based on the Runge–Kutta discontinuous Galerkin (RKDG) finite element scheme to simulate the flow in the flood-prone area of Sidi Bel Abbes city. Bourenane et al. (2019) used the hydrogeomorphological approach to map the flood hazard of Constantine city based on the interpretation and analysis of floodplain geomorphology. Guellouh et al. (2021) used QGIS and HEC-RAS to realize a flood hazard map of a chemora city. Nezzal et al. (2015) delineated the flood risk map of the Hamiz watershed through a combination of the different classes of hazard and vulnerability. Mapping areas at risk of flooding using multicriteria analysis based on the AHP method and GIS system has been the subject of many studies, for instance, Roukh and Nadji (2018); Guellouh et al. (2020); Faregh and Benkhaled (2021); Hamlat et al. (2021); Loumi and Redjem (2021); Goumrasa et al. (2021); Bouamrane et al. (2022); Abdelkrim and Nouibat (2022); and Hallil and Redjem (2022).

Statistical analysis and bibliographical research on the history of flood risks have been the subject of several studies; we can cite the work of Lahlah (2004), who carried out an inventory of the floods that occurred in Algeria during the period 1970 to 2000. Nouri et al. (2016) studied the history of floods in urban areas in Algeria to create a database on major floods that affected the Algerian territory; this work was based on a classification of site information, date, specified causes (natural or anthropogenic) and human and economic damage of each event for a period from 1852 to 2015. Sardou et al. (2016) presented an inventory of floods in northwestern Algeria with more than 127 documented events from 1847 to 2014. Hadjij et al. (2021; 2022) analyzed flood-related deaths in northwestern Algeria; 52 flood events were discussed for the 1966-2019 period. Boutaghane et al. (2022) synthesized flood phenomena in Algeria based on databases, existing studies, research projects, scientific publications and local technical reports; a flood inventory was also presented from 1965 to 2013.

The objective of this work is to analyze floods in Algeria from 1969 to 2022. This analysis is mainly based on the number of deaths and the frequency of floods. In this study, the events are analyzed at the national, regional and province levels. In this study, 191 events were counted, and 2098 deaths were recorded.

MATERIAL AND METHODS

There are several criteria for determining the severity of floods, including the number of victims, material damage and displaced persons. In our study, we found it difficult to estimate the power of the floods because of the existence of many factors that contribute to the occurrence of floods but do not reflect their severity.

The absence of storm drains sometimes and its inability to evacuate storm water due to its blockage or not designed to be enabled to contain rainstorms other times leads to water accumulation in cities. However, the precipitation amounts are not significant. The sudden character of the flash flood leads people or cars to be swept away in the wadis because of the lack or poor sizing of bridges, although the value of the flow is not considerable. Additionally, the building on the major bed of the wadis leads to a considerable narrowing of its cross-section, which contributes to the overflow of the wadis.

Ketrouci et al. (2012) described the flood power of the Tafna catchment in western Algeria. The authors indicated that most flooding in the study area was devastating, although of varying severity, suggesting that the meteorological phenomenon has been amplified by human activity, including uncontrolled urbanization and development facilities and economic activities in flood-prone areas. Zekouda et al. (2020) analyzed flood indicators in the Wadi Cheliff Basin. The results indicated that precipitation alone could not explain most flood indicator trends. The construction of dams, climate variability and human activities were the main factors causing increasing or decreasing flood trends.

The absence of an accurate assessment of flood severity and the lack of sufficient data on its history through the discrepancy in the date of its occurrence and the number of deaths in some cases made us focus in this study on the most critical floods in Algeria from 1969 to 2022.

This analysis was based on the floods that witnessed victims as well as on those reported by several sources using the declarations of the Civil Protection at each intervention, National Agency of Hydraulic Resources, National Office of Meteorology, media, press, radio, websites, and papers. Some of the papers that were used to collect information include Lahlah (2004), Yahiaoui (2012), Nouri et al. (2016), Sardou et al. (2016), Korichi et al. (2016), Hadjij et al. (2021; 2022), Boutaghane et al. (2022), and Azioune (2022).

We used the old administrative division, which contains 48 provinces, because these data were collected based on the old administrative division.

RESULTS AND DISCUSSION

Flood analysis for the period 1969 to 2022

In this section, the analysis of flood events is based on the number of deaths and the frequency of floods from 1969 to 2022. Fig. 1 shows the distribution of deaths during 1969-2022.

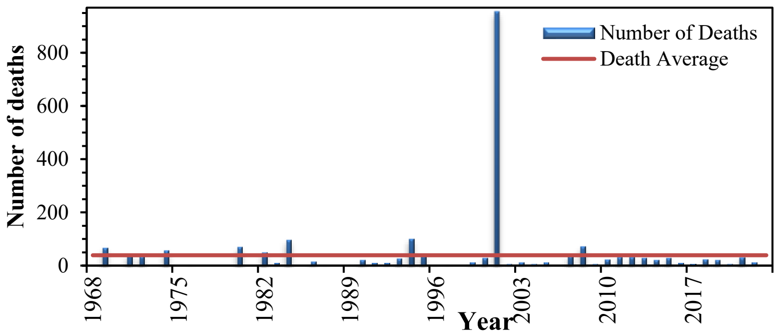


Figure 1: Number of deaths during 1969-2022

The analysis of the number of deaths showed that the highest number of deaths was recorded in 2001, with 900 deaths; this number of deaths corresponds to the disaster of Bab El Oued on November 10, 2001, in Algiers, which represents the worst flood in terms of human losses during this period. The annual average of deaths for this period is estimated at 39 deaths, and several years exceeded this average, for example, 1969, 1971, 1974, 1980, 1982, 1984, 1994, 1995, 2001 and 2008, which experienced disaster floods, including Biskra in 1969 (28 dead), Tizi Ouzuo (Azazga) in 1971 (40 dead), Tizi Ouzou in 1974 (52 dead), Setif (El Eulma) in 1980 (44 dead), Annaba in 1982 (47 dead), Ain Temouchent in 1984 (33 dead), Jijel in 1984 (20 and 29 dead), Bordj Bou Arreridj in 1994 (16 dead), Laghouat in 1995 (40 dead), Chlef in 2001 (40 dead), and Ghardaïa in 2008 (47 dead). The analysis of the number of deaths by province from 1969-2022 is presented in Fig. 2.

Fig. 2 shows that the most significant number of deaths was recorded in the province of Algiers, with more than 900 victims. The range from 51 to 110 included provinces of Tizi Ouzou, with 101 dead; Annaba, with 83 dead; Tiaret, with 73 dead; Chlef, with 69 dead; Setif, with 67 dead; Ghardaïa, with 56 dead; and Biskra, with 56 dead. The 26-50 interval contains the provinces of Jijel with 49 dead; M'sila with 46 dead; Batna with 45 dead; Ain Temouchent with 42 dead; Laghouat with 41 dead; Tamanrasset with 40 dead; Sidi Bel Abbes with 35 dead; Djelfa with 32 dead; Bechar with 32 dead and Relizane with 30 dead. More information on the most important flood events by province can be found in Fig. 3.

To provide more details about the number of deaths, we excluded the number of deaths in the Bab El Oued flood, which is an exceptional event in terms of the number of deaths. Fig. 4 shows the distribution of deaths without the Bab El Oued flood during 1969-2022.

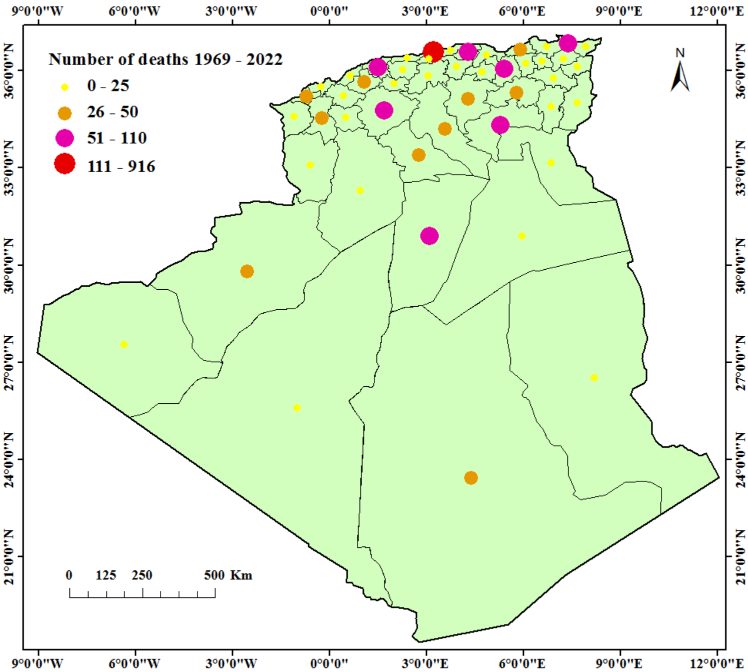


Figure 2: Total number of deaths for the period 1969-2022

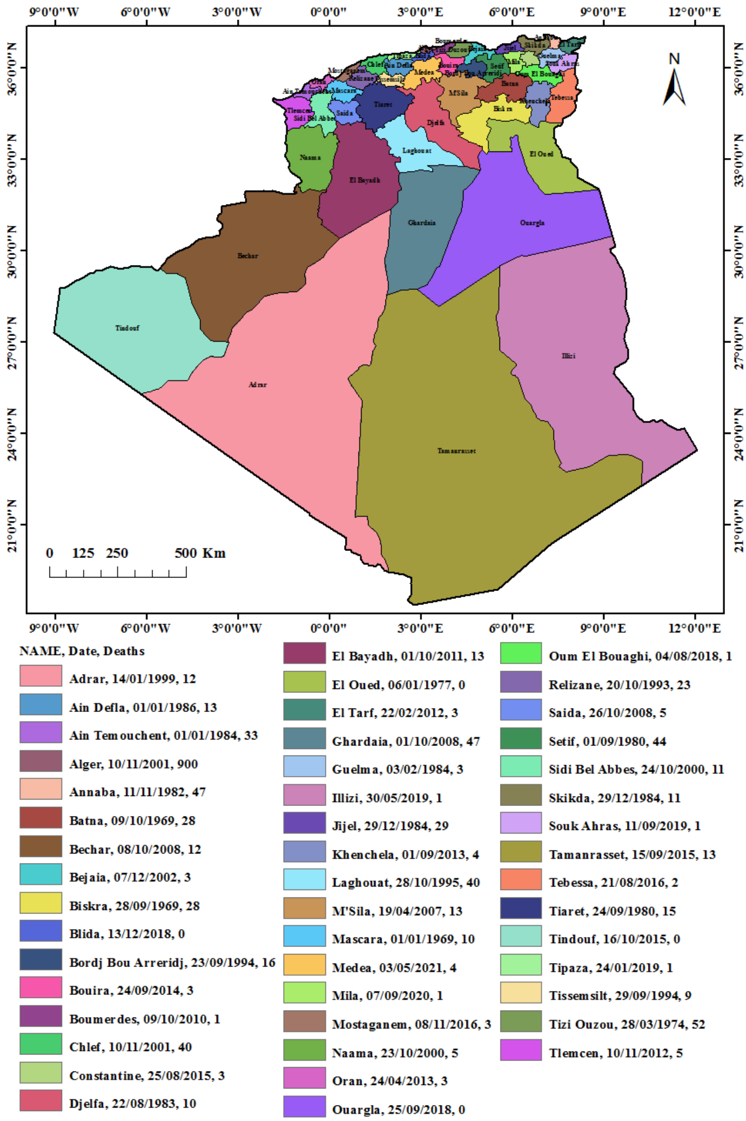


Figure 3: Most important flood events by province with number of deaths during 1969-2022

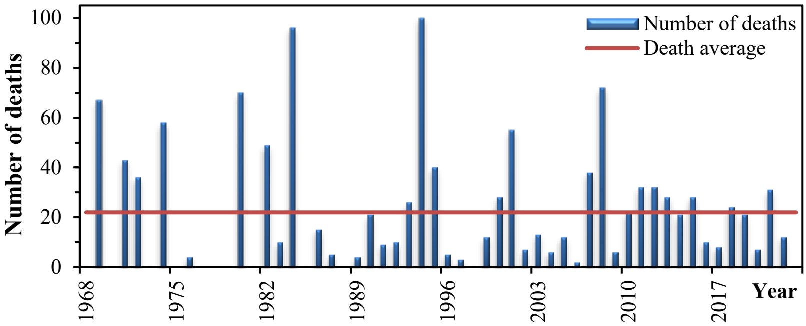


Figure 4: Number of deaths during 1969-2022 without the flood of Bab El Oued

The annual average number of deaths has decreased to 22; in recent years, specifically since 2010, there have been many years in which the new death average has been exceeded. The period from 1969 to 2009 was characterized by devastating floods that left large numbers of victims, while fewer victims characterized the period from 2010 to 2022, but with many floods. The latter leads us to analyze the flood frequency; the flood frequency distribution during 1969-2022 is represented in Fig. 5.

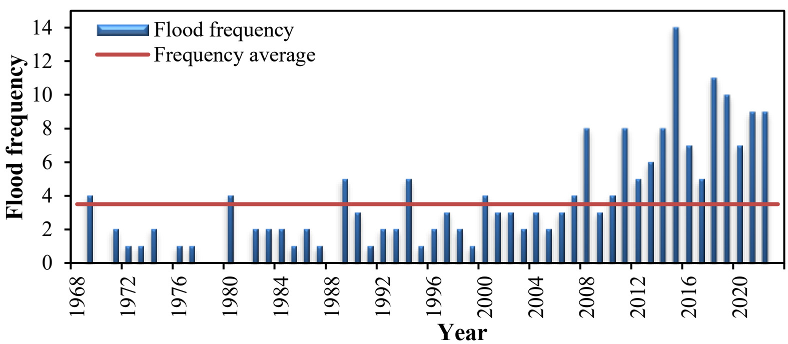
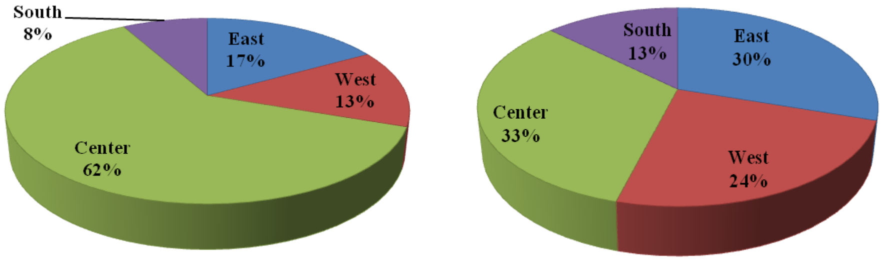


Figure 5: Flood frequency during 1969-2022

The flood frequency analysis showed that the number of floods has increased in recent years; the highest number of floods was recorded in 2015, with 14 floods, followed by 2018 and 2019, with 11 and 10 floods, respectively. The increase in the number of floods in recent years does not necessarily indicate the strength of the precipitation. However, this can be explained by several factors, including urban expansion and settlement on the edges of wadis.

Another analysis based on the regional distribution of deaths and the frequency of floods from 1969 to 2022 was performed, and this distribution is presented in Figs. 6 and 7.



a) with Bab El Oued flood b) without Bab El Oued flood

Figure 6: Percentages of the number of deaths by region for the period 1969-2022

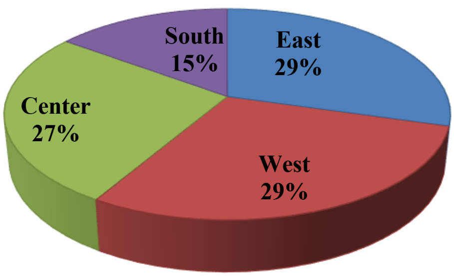


Figure 7: Percentages of flood frequency for the period 1969-2022

The distribution of the number of deaths (Fig. 6) showed that a large percentage of deaths was recorded at the country's center, with a percentage of 62%, followed by the east and the west with 17% and 13%, respectively. The high percentage of deaths in the center of the country is due to the large number of victims of the Bab El-Oued flood on November 10, 2001, representing 43% of the total number of deaths recorded during this period, representing 2098 victims. This percentage decreased after excluding the Bab El-Oued flood to be somewhat balanced between the center and east and then west, with percentages of 33%, 30% and 24%, respectively.

The distribution of flood frequency (Fig. 7) also showed a balance in the number of floods between the east and west during the studied period, with percentages of 30% and 29%, respectively, followed by the center, with a percentage of 27%.

Flood analysis for the period 2010 to 2022

After observing the increase in the number of floods during the period 2010-2022 and to provide more explanation on the distribution of deaths and the flood frequency, in this part, we will focus on the analysis of the monthly, regional and provincial distribution of the number of deaths and the frequency of floods for the period of 2010 to 2022. Fig. 8 represents the monthly distribution of the number of deaths and the frequency of floods during the period 2010-2022.

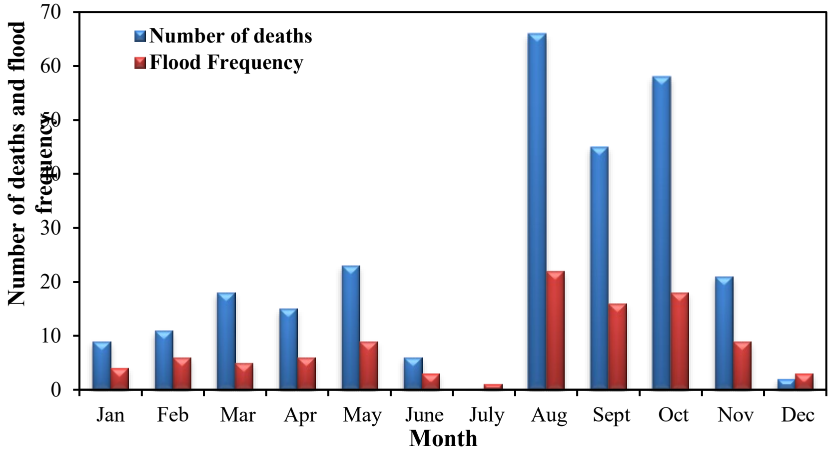


Figure 8: Monthly distribution of the number of deaths and flood frequency during 2010-2022

Fig. 8 shows that the most significant numbers of deaths and floods were recorded in August, October and September, with 66, 58 and 45 deaths and 22, 18, and 16 floods, respectively. The increase in the number of floods, especially in August and September, could be explained by the high temperatures and heat waves during the summer, which increase the impermeability of the soil and thus increase the risk of floods.

The lowest number of floods and deaths was recorded in July. The decrease in floods in July can generally be explained by the lack of precipitation during this month.

Another analysis of the deaths and flood frequency for the annual regional distribution during the same period is presented in Figs. 9 and 10.

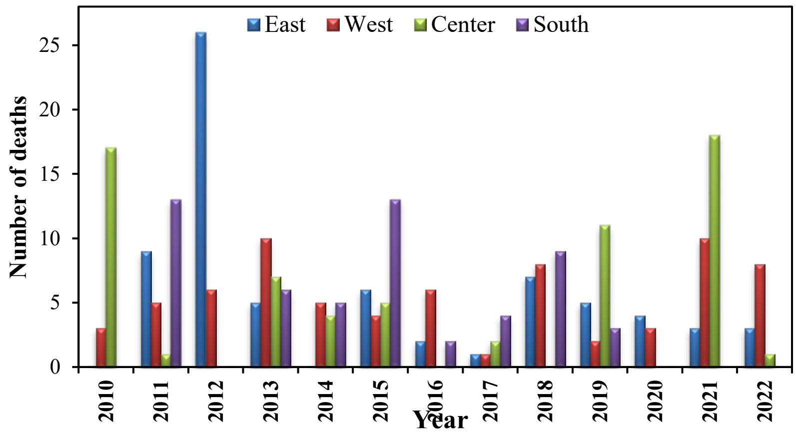


Figure 9: Regional distribution of the number of deaths for the period 2010-2022

The annual regional distribution of deaths showed that the most significant number was recorded in eastern Algeria in 2012, followed by the center in 2010 and 2021, the south in 2011 and 2015, and the west in 2021.

In 2010, two large floods hit several places in the country, leaving many victims, particularly in the country's center. This is related to the flood of 17/08/2010, which was concentrated in the cities of M'sila (04 dead), Djelfa (03 dead), and Medea (02 dead), and the flood of 10/09/2010, which hit the cities of Djelfa (05 dead), Algiers (01 dead), Boumerdes (01 dead), Medea (01 dead), M'sila (01 dead), and Bouira (01 dead). In 2012, the country's eastern regions witnessed large floods on 31/08/2012, leaving 20 deaths. On 01/10/2011, El Bayadh city in southern Algeria experienced a flood that killed and lost 13 people. On 06/03/2021, Chlef City in western Algeria suffered a flood that killed ten people. From 03 to 05/05/2021, numerous floods hit several places in Algeria, especially the country's center, leaving more than 15 deaths; we can mention the cities of Medea, M'sila, Djelfa, Batna and Biskra.

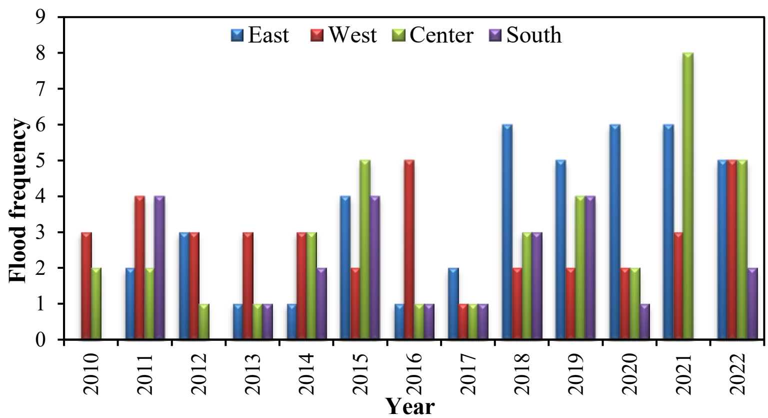


Figure 10: Regional distribution of flood frequency for the period 2010-2022

The annual regional distribution of flood frequency showed that the highest number of floods was recorded in the center of the country in 2021, with 8 floods, followed by the east for 2018, 2020 and 2021, with 6 floods, which indicates that the center and east of the country are more vulnerable to floods.

To obtain an idea about the provinces most vulnerable to flooding in recent years, we created maps of the distribution of flood frequency and number of deaths in Algeria by province from 2010 to 2022, as shown Figs. 11 and 12.

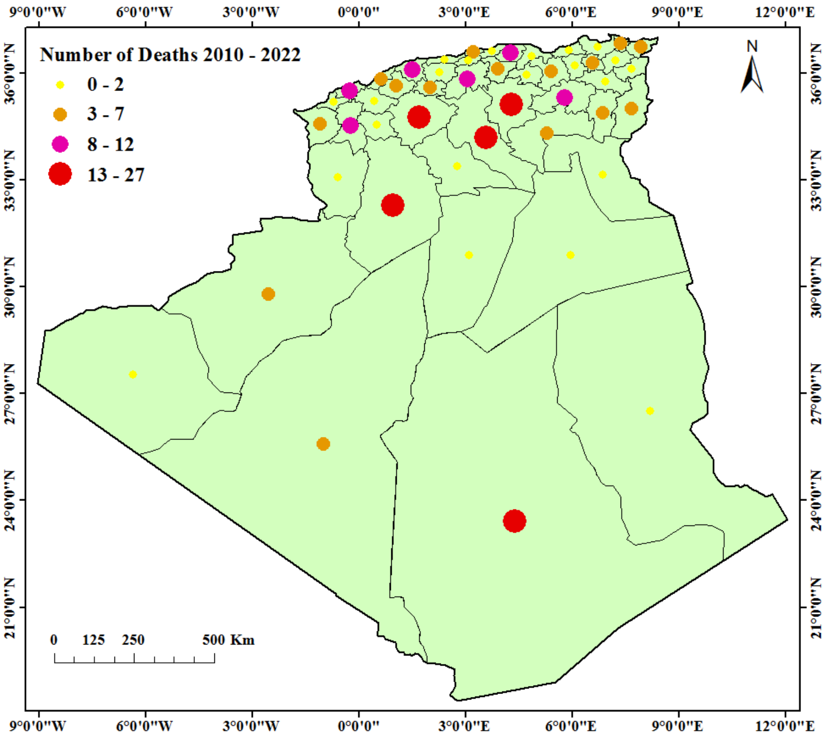


Figure 11: Total number of deaths for the period 2010-2022

Fig. 11 shows that the highest number of deaths was recorded in the provinces of Tamanrasset, with 27 deaths; Djelfa, with 20 deaths; Tiaret, with 19 deaths; M'sila, with 17 deaths; and El Bayadh, with 16 deaths. The most critical floods were recorded in Tamanrasset on 15/09/2015, with 13 deaths, in El Bayadh on 01/10/2011, with 13 deaths, and in Tiaret on 24/04/2018, with 8 deaths. The range from 8 to 12 included the provinces of Chlef, with 12 dead; Batna, with 12 dead; Oran, with 11 dead; Tizi Ouzou, with 9 dead; Sidi Bel Abbes, with 8 dead; and Medea, with 8 dead. In this range, the crucial floods are the floods of Chlef on 06/03/2021 with 10 dead, Batna on 28 and 29/10/2011 with 9 dead and Tizi Ouzou on 01/09/2019 with 07 dead.

The number of deaths in the provinces is distributed between the south, the center and the west. For more understanding, we will analyze the flood frequency shown in Fig. 12.

In this part, the data were collected mainly on civil protection declarations through television channels, national radio, and newspapers, as well as websites such as https://floodlist.com/tag/algeria and https://www.gdacs.org/Alerts/default.aspx.

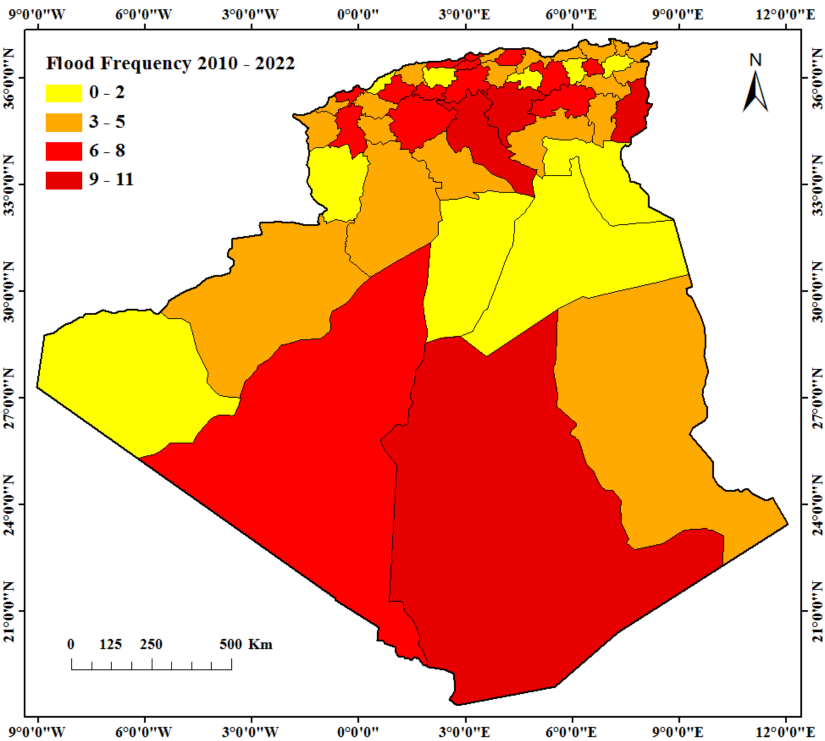


Figure 12: Total flood frequency for the period 2010-2022

The flood frequency analysis showed that the most considerable frequency was recorded in M'sila, Djelfa, and Tebessa, with 11 floods, followed by Tamanrasset, with 9 floods. Eight floods were recorded in Batna, Tiaret, Alger, Medea, Oran, and Tissemsilt, and 7 were recorded in Constantine and Adrar. The maximum frequency per year is recorded in the province of Chlef, with four frequencies in 2021.

The analysis of the distribution of the number of deaths and the flood frequency by province during the years 2010-2022 showed that the provinces of M'sila, Djelfa and Tamanrasset are most vulnerable to the risk of flooding. Frequent floods in these areas can be explained by the lack of vegetation cover, which increases the intensity of floods.

By observing Figs. 11 and 12, we can say that the provinces vulnerable to the risk of flooding are Djelfa, M'Sila, Tamanrasset, Tiaret, Batna, Oran and Medea.

CONCLUSION

This work contributes to the analysis of flood history in Algeria. It was divided into two phases. In the first phase, we analyzed the number of deaths and flood frequency from 1969-2022. Then, in the second phase, we focused on 2010-2022.

For the first part, the analysis of the number of deaths showed that the period from 1969 to 2009 was characterized by the presence of devastating floods that left large numbers of victims, while the presence of fewer victims characterized the period from 2010 to 2022, but with a large number of floods; the highest number was recorded in 2015, with 14 floods. The increase in the number of floods in recent years does not necessarily indicate the strength of the precipitation. However, this can be explained by several factors, one of which is urban expansion and construction on the edges of Wadis.

The flood frequency distribution showed a balance in the number of floods between the east and west for the studied period 1969-2022, with percentages of 30% and 29%, respectively, followed by the center with 27%.

For the second period, 2010-2022, the annual regional distribution of the number of deaths showed that the most significant number was recorded in eastern Algeria, followed by the center and then the south. The annual regional distribution of flood frequency showed that the highest number of floods was recorded in the country's center, followed by the east, indicating that the country's center and east are more vulnerable to floods.

The most significant deaths and flood frequencies were recorded in August, September, and October. This increase could be explained by the high temperatures and heat waves during the summer, which increase soil impermeability and thus increase the risk of floods.

By observing the distribution of the number of deaths and the flood frequency by province during the years 2010-2022, we can say that the provinces most vulnerable to the risk of flooding are Djelfa, M'Sila, Tamanrasset, Tiaret, Batna, Oran and Medea.

Through this study, we can classify floods into three levels. The first is characterized by relatively heavy precipitation that leads to water accumulation due to the blockage of storm drains or their inability to evacuate rainwater. This type requires an accurate study of the maximum flow of rainwater and storm drain cleaning. The second level of floods in which there is heavy precipitation leads to the overflow of wadis due to not respecting the construction standards through the construction at the edges of wadis (major bed), and as a solution to this type of flooding in addition to the previous solution, wadis should be developed, and construction in the wadi floodplain (major bed) must be avoided using flood hazard maps. The third level of floods concerns extreme events characterized by heavy and intense precipitation that lead to catastrophic flooding and that, as solutions in addition to the two previous solutions, require the construction of protective facilities upstream of cities, such as dams and dikes; it should be noted that the construction of dams in recent years has contributed significantly to protecting cities and reducing the risk of flooding.

This work provides an overview of the distribution of floods in Algeria, which are not necessarily due to precipitation intensity, but to several factors, the most important of which are related to anarchic constructions such as building on the wadi edges and the climate change impact through heat waves and droughts that affect soil permeability in addition to vegetation cover.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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