The mineralization of urban soils facing the risk of climate change: case of the flooding phenomenon in the city of Annaba

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Abstract. Urbanization exerts changes on the environment and on the ecosystems and it leads to a modification of the nature of the soil or even a soil impermeability via the infrastructures carried out. This impermeability acts as an aggravating factor for the effects of climate change and causes local environmental stresses. These are particularly urban heat island and urban flooding. The city of Annaba (located in the northeast of Algeria) is among these dense coastal cities, which have experienced rapid and abrupt urban development resulting in the expansion of impermeable infrastructure at the expense of the removal of naturaland vegetal cover. The problem of soil sealing in Annaba therefore put it face to face with the direct risk of climate change.Urban flooding is a phenomenon directly linked to soil sealing. The combined effects of climate change, in terms of changes in rainfall patterns and intensities, make some sewerage networks unable to evacuate increasingly large quantities of runoff water from impermeable surfaces causing important material and human damages. In fact, this city has experienced strong periods of heat in recent years, reaching 47°C in summer 2021 [1]. Winter was not so different, intense rainfall causes repeated flooding every year, amplifying the sensitivity and exposure of city dwellers and properties to multiple risks. The present consideration, aims to identify andmeasure sealed surfaces and to determine the areas vulnerable to the impacts of soil sealing.

1 Introduction

The term climate change refers to the way in which the Earth's climate changes over time. Long-term natural processes cause these changes, but currently it refers mainly to human activities. The main change we are facing today is the increase in record temperatures (Figure 1), also known as "global warming", and other changes, notably in precipitation patterns and certain extreme weather events such as droughts, floods and cyclones (Figure 2). According to [2] -World Meteorological Organization (2021), the number of disasters linked to climate change has increased fivefold over the past 50 years, causing widespread material and human damage.

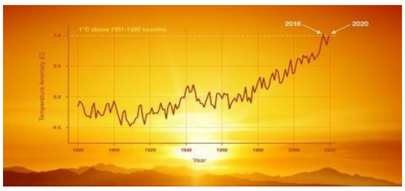

Fig. 1. The global evolution of temperature records(period 1880-2020); Source: Climate NASA (2016) [3].

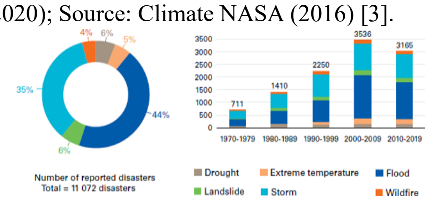

Fig. 2. Distribution of reported disasters worldwide;Source: WMO (2021).

In fact, the toll is heavy in terms of loss of life, material goods, drought and destruction of nature: let's mention thefloods in China in 2020, the droughts of 2011, 2017 and 2019 in East Africa and the forest fires in Australia in 2019 and California in 2021, Canada 2022 and 2023). The Mediterranean has not escaped the phenomenon, and has become a vulnerable and fragile zone as a result of global warming. The Mediterranean Expert Network on ClimateChange [4] warns of the risks expected in the Mediterranean basin. Its report highlights the worrying impacts of climate change on the Mediterranean basin, particularly on urban areas. These risks will be high due to the high concentration of population along the shores. Indeed, accelerated urbanization along the shores is exerting strong pressure on coastal areas, which are particularly sensitive to the effects of climate change, as protective ecosystems such as coastal dunes are increasingly disappearing, placing adjacent cities under greater threat of flooding.

Ongoing urbanization is increasing the intensity and exposure to urban flash floods due to the increased percentage of sealed surfaces and higher building densities. In cities, the mineralization of soils represents the imprint of urbanization on the landscape [5]. These impermeable surfaces prevent the natural infiltration of water into the ground and cause a hydrological imbalance. They are essentially made up of building roofs and urban infrastructures such as pavements, pavements, parking areas, playgrounds, etc. (figure 3).

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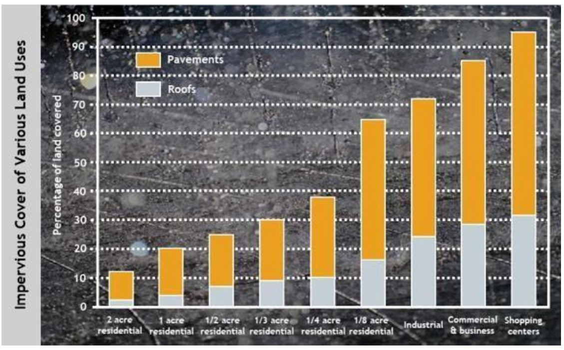


Fig. 3. Coverage rate of impermeable surfaces (pavements and roofs); Source: Frazer (2005) [6].

Climate models predict significant increases for almost all land areas by the middle and end of this century. [7] showed in a study area in Italy that an average increase of8.4% in impermeable urban areas leads to an average increase in surface runoff equal to 3.5 and 2.7% respectively for return periods of 20 and 200 years, with a maximum exceeding 20% for impermeable coastal areas. Urban flooding is a phenomenon directly linked to soil mineralization. The combined effects of climate change in temperature and rainfall patterns mean that some drainage systems are unable to evacuate the increasingly large quantities of water running off impermeable surfaces, causing considerable material and human damage. [8] showed that the increase in impervious areas caused for a storm duration of 2 hours and an exceedance probabilityof 1%, the peak time increased from 22.01 to 44.95 % The problem of soil mineralization in the city of Annaba has exposed it to the direct risk of these climaticupheavals. The city of Annaba (located in north-east of Algeria) is one of those dense coastal towns that has undergone rapid and abrupt urban development, resulting in the expansion of impermeable infrastructures to the detriment of the suppression of natural and plant cover. (Franzizka, Tugel remind that Bare soils with novegetation tend to develop a surface crust, leading tosignificantly decreased infiltration rates during heavyrainfalls.

2 Case study presentation

In recent years, the city of Annaba has experienced very hot temperatures, recently reaching 47°C in the summerof 2021 (Infoclimat, 2021). Winter has not been sodifferent, with intense rainfall causing repeated floodingevery year, increasing the sensitivity and exposure ofresidents and property to multiple risks. The first flood in Algeria was that of Bab el Oued, in 2001 (4000 deaths) Chelghoum, President of the Algerian Major Risks Club, has stated that over the past ten years, around 25 ofAlgeria's 58 wilayas have experienced flooding, withconsiderable loss of life and property. [9] In 2023, K. Laamache, representative of the National Delegation forMajor Risks at the Ministry of the Interior, Local Authorities and Town and Country Planning, reported "78 damaged roads in six of the wilayas concerned, including 48 completely closed to traffic, and 227 damaged homes in 137 housing estates in these wilayas. In the same vein, modelling is being carried out to assess the future impact of the combination of influences relating to climate change and the increase in urban run-off due to impermeable soils. The urban growth of the city of Can Tho in Vietnam was projected to 2100 based on historical growth models. The results (Figure 4) show that, if the city grows as predicted, the maximum flood depth and area will increase by around 20% [10].

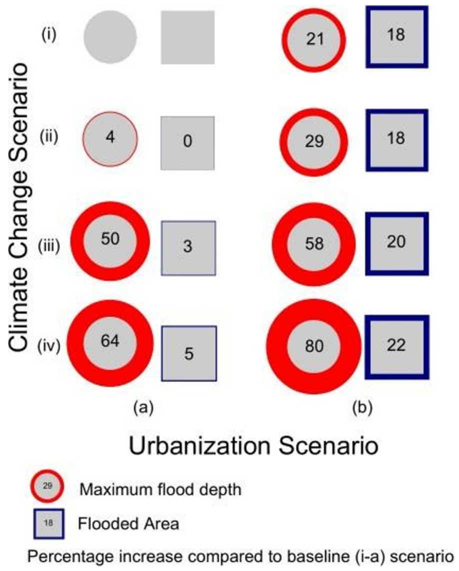


Fig. 4. Results of flood risk simulations in Can Tho, Vietnam; Source: Huong & Pathirana (2011).

3 Objectives

The aim of this paper is to find a way of identifying and measuring impervious surfaces. And to determine the areas vulnerable to the impacts of soil sealing. And finally to choose the most appropriate mitigation strategy.

4 Methodology

The methodology is based on a climatic analysis of the city of Annaba and - an analysis of cartographic data based essentially on the use of Geographic Information Systems (GIS) in order to measure the impact of the sealing of urbanized soils on the local environment of the city and to find means of mitigation. The study is based on the use of the NDII index for extracting and quantifying impervious surfaces in the city of Annaba, with the NDBI urbanization index and the NDVI vegetation index as control indices.

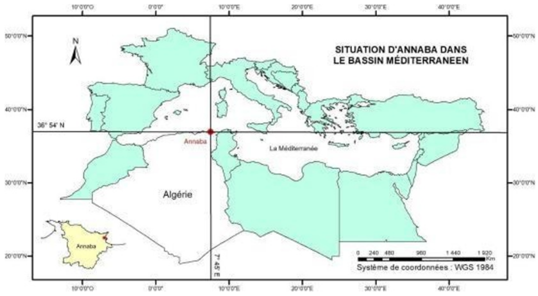
Several studies have made use of remote sensing, given its usefulness for studying areas vulnerable to flooding. Singh et al (2022) used it to estimate the net-flooded area using the NDWI (Normalised Difference Water Index) index. Others have analyzed changes before and after flooding, such as Ahmed & Akter (2017),using the NDWI and NDVI indices.

Following this work, and according to the objectives of this research, the NDWI index is used to extract flooded surfaces or vulnerable surfaces to the risk of flooding in the city of Annaba. The proposed technique for extracting flooded areas and preparing a spatial database specific to the study area consists of using Landsat-8 OLI/TIRS images, taken on a winter day preceded by precipitation during the same month (i.e. the day of 22-12-2021) from the Land Viewer platform. The acquired data are then processed and analyzed using ArcGIS 10.8.1 software.

4.1 Presentation of the climatology of the town of Annaba

Annaba is a coastal town located in the north east of Algeria (at approximately 36°54'N and 7°45'E). Due to its geographical location on the southern shore of the Mediterranean basin (Figure 5), the city of Annaba has a Mediterranean climate. This is defined by hot, dry summers and mild, wet winters with abundant rainfall.

In figures, the average annual temperature in Annaba is 18.2°C and the average annual cumulative rainfall is 741.8 mm, based on climate normals for the period 2010-2021 (Infoclimat, 2022).



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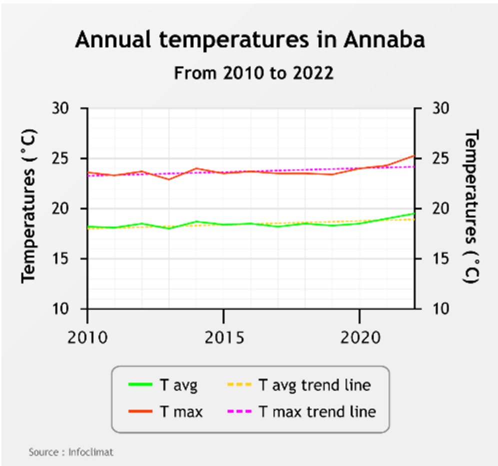
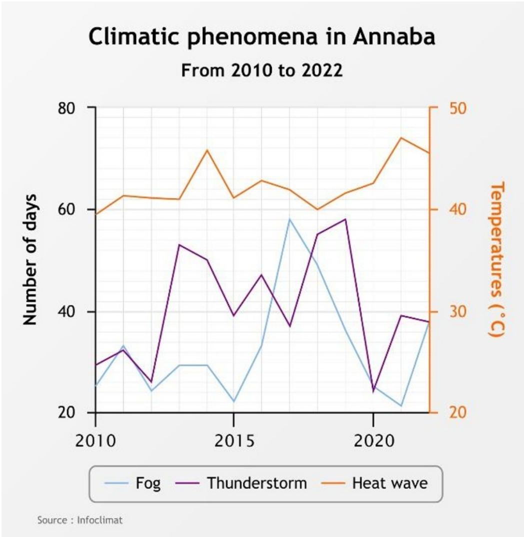


b

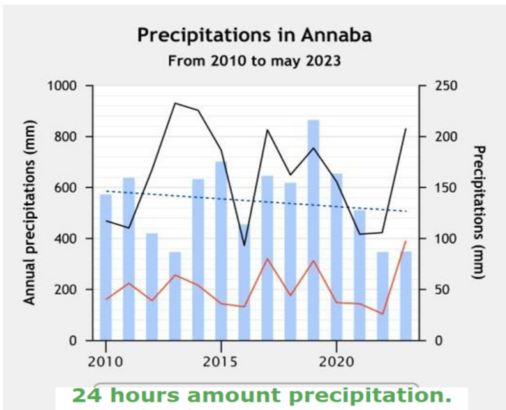
Fig. 5. a/ Geographical location of Annaba,
b/ Annual temperature trends in Annaba (2010-2021);
Source: Infoclimat (2021) [1]

This figure illustrates an increase of 1°C in maximum temperatures and a rise of 0.8°C in average temperatures since 2010 in Annaba.



By observing the graph, we notice the variability of the frequencies of climatic phenomena in Annaba. The effectof climate change is obvious: the number of occurrence of thunderstorms and fog has increased in recent years, reaching the threshold of 58 days per year. Thus, extreme heat records are becoming more intense, reaching the record of 47°C in 2021.

4.2 Analysis of rainfall variations in Annaba (Period 2010- 2023)



24 hours amount precipitation.
05/20/2023 at 12:00 UTC
(10 of 64 stations)

1	Annaba (Algeria)	97.0 mm
2	Medea (Algeria)	45.0 mm
3	Souk Ahras (Algeria)	43.5 mm
4	Jijel- Achouat (Algeria)	39.0 mm
5	Skikda (Algeria)	34.4 mm
6	Guelma (Algeria)	31.6 mm
7	Constantine (Algeria)	28.0 mm
8	Tizi-Ouzou (Algeria)	23.0 mm
9	Dar-El-Beida (Algeria)	21.0 mm
10	Batna (Algeria)	20.4 mm

Fig. 7. Change in annual rainfall in Annaba (1982-2021); Source: Infoclimat (2022)

A strong irregularity in rainfall amounts marks the graph: precipitation oscillates from one year to another, whether in 24 hours, in a month or even during the whole year. Based on the data collected, there is a rainfall deficit of 9.8%, as reflected by the decreasing trend line of annual precipitations. Although there is a remarkable decrease, this disruption of precipitation rates is not without significant consequences, because it participates in the advent of extreme events that occur just after a dry period, thus causing floods. Indeed, Annaba was recently exposed to heavy rains in May 2023 reaching the record amount of 97mm in 24 hours, which remains the highest since 2010.

5 Results' Analysis

5.1 Application of GIS to determine impervious surfaces

5.1.1 Location

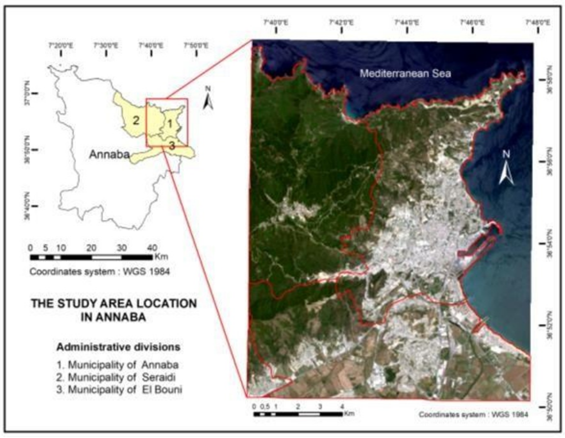


Fig. 8. Location of the study area.

5.1.2 Extraction of the NDII

Figure 9 illustrates the result of extracting the NDII. The presence and concentration of impervious surfaces can be seen in the urban agglomerations. The urban centre of Annaba seems to be more affected by this sealing, as the sealed surfaces in this region cover almost all of the urban land.

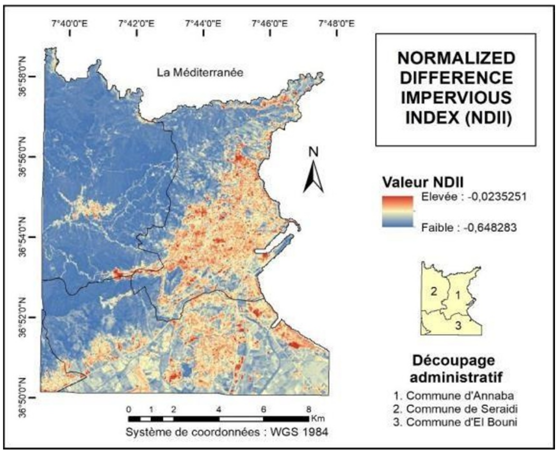


Fig. 9. Map of impermeable surfaces in the study area NDII index extraction.

5.1.3 Determining the relationship between NDII, NDBI and NDVI

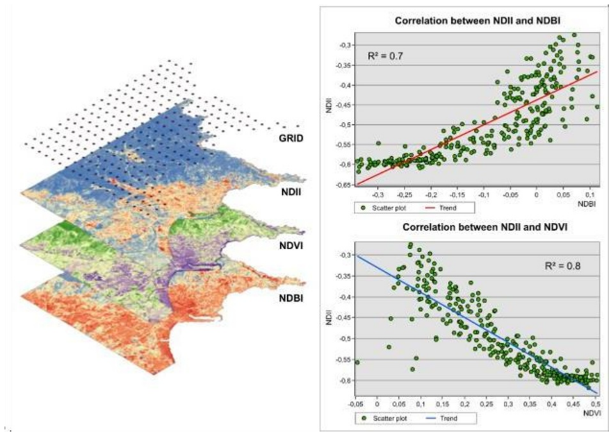


Fig. 10. The relationship between existing impervious surfaces, built-up areas and vegetation in the study area.

The NDBI and NDVI indices are used to correlate and determine the rate of impervious surfaces in built-up areas. Figure 10 confirms the existence of a strong positive correlation between the NDII and NDBI indices of around 70%, and a strong negative correlation of 80% between NDII and NDVI.

5.1.4 Extraction of the waterproofing index (NDWI)

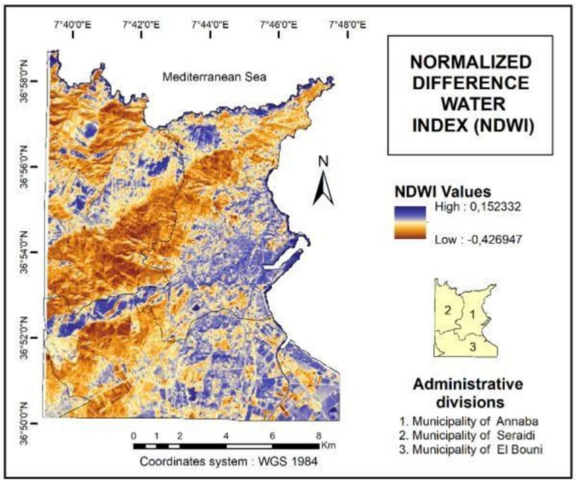


Fig. 11. Map of flooded areas in the study area, NDWI index

5.1.5 Determination of the relationship between NDWI, NDBI and NDVI

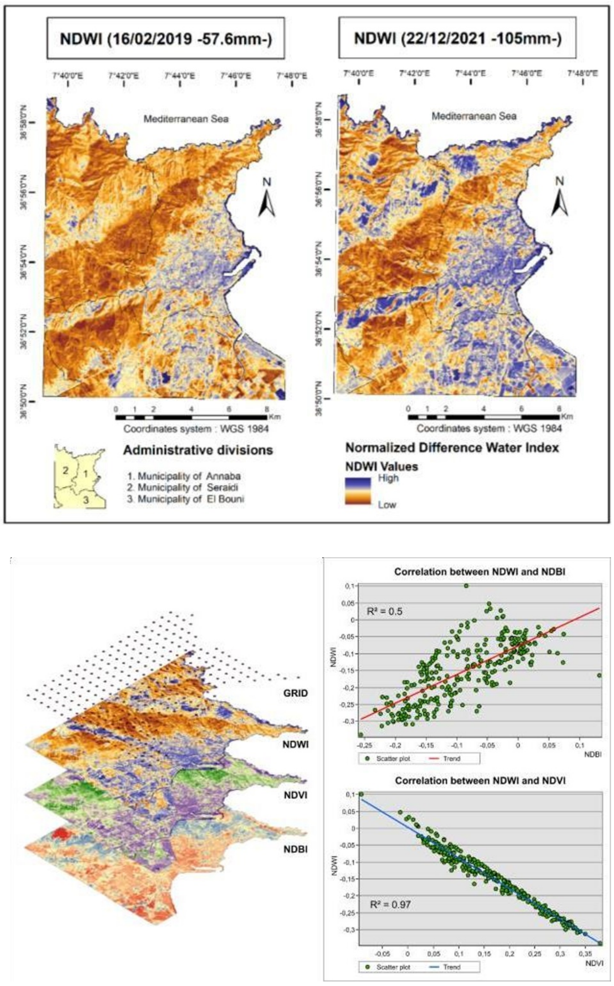


Fig. 12. Relationship between flooded areas, built-up areas and existing vegetation in the study area.

A correlation analysis was carried out between NDWI, NDBI and NDVI on 22-12-2021. The result of the statistical analysis was a positive trend relationship of 50% between NDWI and NDBI (Figure 12) (weakened bythe limitation of NDBI in distinguishing between built-upand bare land). A negative trend of 97% was attached to the relationship between NDWI and NDVI (Figure 12), making vegetation a genuine means of avoiding the risk of flooding.

The results established in this analysis clearly demonstrate the impacts of urbanization and soil sealing on the study area through the various correlation relationships derived from the chosen indices. The study area is therefore vulnerable to the risk of flooding.

6 Conclusion

The urbanisation process in this city has continually led to the development of impermeable infrastructures through the removal of permeable vegetation cover. Aggravated by the effects of climate change, the problem of soil sealing in this city has developed a series of negative impacts on the local climatic environment of the region, making it vulnerable to repeated flooding in both winter and early summer. According to the results of the analyses carried out in this study, the impact of soil mineralisation on the climatic environment of the city of Annaba was well established, and vegetation cover constitutes a rapid and effective solution that can mitigate it.

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