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What Sustainable Strategies Allow the City to Benefit from the Advantages of Rainfall and Protect Itself Against its Risks?

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Abstract
Like many metropolises around the world, Algerian towns and cities are particularly vulnerable to the risk of flooding. This threat has increased in recent years, exacerbated by global warming and other converging factors. The vulnerability of Algerian cities, where major human, material and environmental issues are concentrated, now appears to be increasing in the face of the growing threat of such natural hazards.
Take the town of Batna in Algeria, for example. Situated on a gently sloping site, it is crossed by two major rivers and surrounded by very uneven terrain. This geographical conFigureuration has earned it the status of a 'base city', making it particularly vulnerable to the recurring risk of flooding, and adding to the impermeability of its soil.
With this in mind, our research first set out to elucidate the dialectical relationship between the rapid urbanisation of the Algerian city of Batna in recent years and the risk of flooding. Secondly, our study set itself a pragmatic objective: to identify precisely defined solutions for each area of the city, while avoiding a 'clean slate' approach.
Keywords: *Sustainable strategies; flood; rainfall; risk of flooding; impermeability of soil; permeability of soil.*

1. PROBLEMATIC

Climate change complicates the pursuit of sustainable flood risk management by introducing a new dimension : increased variability in meteorological conditions. Faced with this climatic uncertainty, adapting flood risk reduction strategies becomes imperative.
Algeria is one of the nations affected by flooding, whether as a result of overflowing rivers running through its urban areas or torrential rains. Among the most tragic episodes was the flooding of Algiers (the capital of Algeria) at Bâb El-Oued in November 2001, which caused the loss of 733 lives and considerable material damage, as well as the flooding of the town of Ghardaïa / Algeria in October 2008, which claimed 40 lives and caused considerable material damage.
Batna, Algeria, is no exception to this rule, having experienced significant rainfall in 1983, 1987, 2004 and 2007. These events led to major flooding, the consequences of which are still vivid in the collective memory, underlining the particular vulnerability of this city. It should be remembered that flood risk is defined by the interaction between natural hazards and the sensitivity (vulnerability) of the area to these phenomena.
The control and management of the danger and risk of flooding rests on three fundamental pillars: forecasting, prevention and protection of the town or area. Inappropriate management of these situations, or the adoption of solutions that are unsuited to the specific characteristics of the site, can cause considerable damage that is often irreversible.
Although knowledge and technology have progressed considerably, enabling the development of increasingly sophisticated and precise methods based on topographical, hydrological and hydraulic concepts, no approach has yet succeeded in achieving both a preventive and quantitatively accurate assessment of the risk of flooding.
Against this backdrop, it is becoming imperative to reflect on and think about sustainable strategies to protect urban areas from the harmful consequences of rainwater, particularly flooding, while at the same time exploiting the benefits that this rainfall can offer.

2. INTRODUCTION

According to UN-Habitat, our cities today face demographic, environmental, economic, social and spatial challenges on an unprecedented scale. As a result of the major phenomenon of urbanisation, it is predicted that six out of every ten people in the world will be living in urban areas by 2030.

It is important to note that over 90% of this growth will be concentrated in Africa, Asia, Latin America and the Caribbean. Without effective urban planning and development, the consequences of this urbanisation could be dramatic.

Urban expansion is particularly noticeable in Africa and Asia, especially in medium-sized cities and those with fewer than one million inhabitants. This rapid concentration of population in urban areas is intensifying the process of urbanisation. Although this process generates a range of economic, social and environmental benefits and opportunities, and cities play a key role in development and poverty reduction, this accelerated growth, when not properly planned for, also exposes people to considerable risks.

Disaster management and natural hazards, in both urban and rural areas, are now a major concern for national and local authorities. This phenomenon is tending to intensify as a result of climate change, demographic pressure and the increase in impermeable surfaces in towns and cities.

Floods are a major global hazard, likely to occur in almost every region of the world, with major repercussions for the environment, the economy and society. Many experts and researchers consider them to be the number one natural disaster, due to the high number of victims and material damage they cause each year.

The analysis and in-depth study of the city of Batna, Algeria, gives us the opportunity to identify effective sustainable solutions and strategies to prevent flooding, while making the best possible use of rainfall resources.

3. RESEARCH METHODOLOGY

A theoretical framework encompassing generalities and explanations is essential to clarify in depth and highlight the fundamental concepts inherent in flood risk.

The study and multi-criteria analysis of the city of Batna, Algeria, encompass the topographical and hydraulic dimensions, while closely examining urban development and the urban fabric through its stages of growth.

The aim of this in-depth approach is to establish a precise diagnosis of the areas that are vulnerable and potentially exposed to the risk of flooding.

The aim is to identify sustainable and appropriate solutions and strategies to protect the city of Batna, Algeria, from the harmful effects of rainfall, while making the most of its benefits.

4. GENERAL CONCEPTS

4.1. Flooding (definition)

Flooding occurs when a dry area is covered by water, either suddenly or gradually. This general term encompasses a variety of events: the overflowing of rivers, the rising of groundwater, the run-off of rainwater during violent storms, flooding caused by the breaching of dykes or other protection, and coastal flooding due to high tides combined with storms and river flooding. In short, flooding is the temporary submergence of land, whether natural or man-made. Scarwell H.J., et Laganier R., (2004)

Excessive surface water run-off causes rivers to flood or run off. These phenomena can even lead to flooding.

In the specific case of the city of Batna, Algeria, our study focused on flooding due to run-off caused by excessive rainfall (Figure 01). Beloulou L., (2008)

Flooding mainly causes direct damage to people, buildings, economic activities and the environment. According to the Institut Français de l'Environnement (IFEN), the risk of flooding occurs when a natural or man-made event with foreseeable consequences threatens a large number of people, causes considerable damage and exceeds the capacity of local authorities to respond. IFEN, (2002)

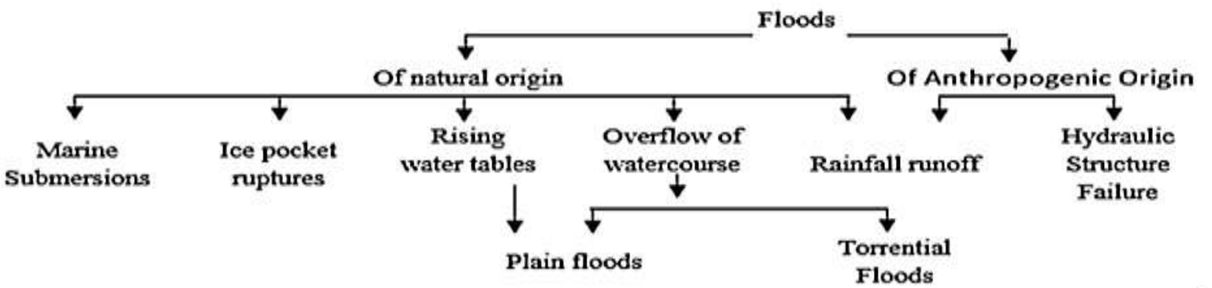

Figure 01. Flooding typology. Source : GUELLOUH SAMI ; (2017).

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There are two types of flooding : those resulting from slow flooding, where rivers gradually overflow their minor beds over an extended period (due to intense rainfall or saturation of the water tables in large basins of more
than 1,000 km²), and those, much more sudden, caused by rapid or torrential flooding.
The slow kinetics of the former mean that they can be better anticipated. Unlike slow-onset floods, torrential floods are characterised by their sudden onset and extremely rapid evolution, lasting only a few hours after often-intense rainfall. GUELLOUH SAMI ; 2017.
4.2. Permanent threat worldwide : flooding
Flooding is the most frequent natural hazard worldwide, accounting for 43% of all natural disasters recently recorded (Figure 02).

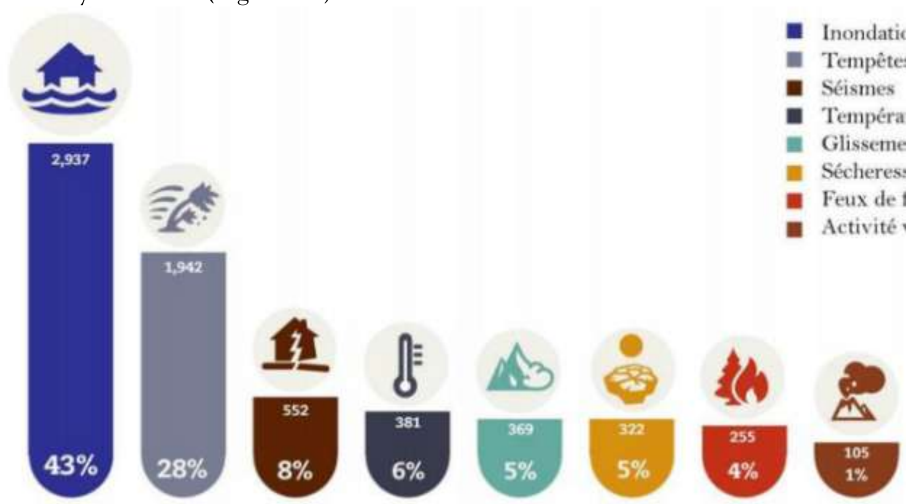

Figure 02. Typology of disasters worldwide (1994-2013) ; ■ : floods ; ■ : storm ; ■ : extreme temperature ; ■ : earthquake ; ■ : landslide ; ■ : drought ; ■ : fire ; ■ : volcanic activity. Source : CRED (Centre de Recherche sur l'Épidémiologie Des Catastrophes). HARKAT Naim (2021)
According to many experts, floods are considered the most devastating and deadly major hazard identified by the United Nations. Over the past few decades, they have caused half of all deaths linked to natural disasters, and are responsible for almost a third of property damage and economic losses worldwide. Pulvirenti L., Pierdicca N., Chini M., Guerriero L., (2011)
4.3. Flooding : Permanent threat in Algeria
Of course. In Algeria, flooding has become the most frequent major hazard. They are mainly due to sudden, unpredictable flooding of the rivers or streams (usually dry) that flow through the cities. These floods, often caused by heavy rainfall, particularly affect medium-sized watersheds and towns located in valleys at the foot of mountains (Figure 03).

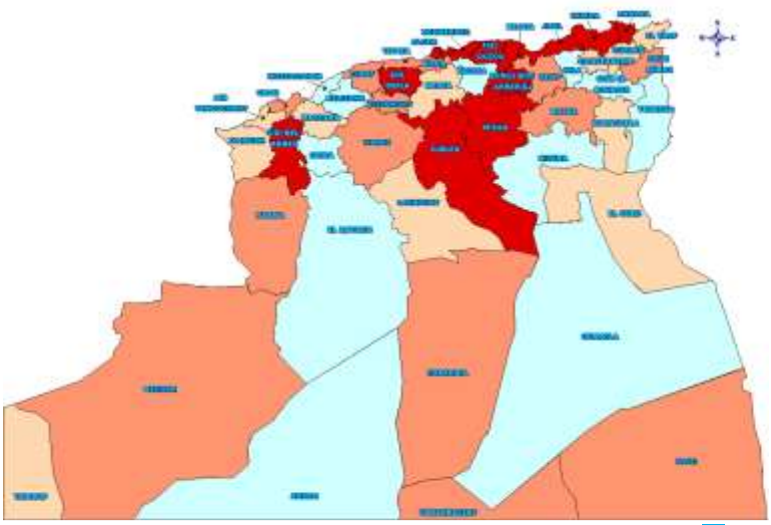

Figure 03. Map of towns at risk of flooding (by risk level) ; ■: low risk ; ■: medium risk ; ■: high risk ■: very high risk. Source : CTL : Comité Technique Local d'après HARKAT Naim ; (2021)

5. CLIMATE AND WEATHER IN ALGERIA

During the summer months, the heat is intense throughout Algeria. Winter frequently brings heavy rain, sometimes causing localized flooding, while snow regularly covers the mountain peaks. Algeria is relatively unaffected by recurrent natural disasters, with the exception of heavy winter rains, which can cause sudden wadi flooding. In desert regions, sandstorms can be a real nuisance.

In Algeria, the country's aridity exacerbates a water crisis with serious consequences for daily life, health, employment and development. Paradoxically, although less exposed to flooding than other nations, Algeria is not exempt. The uncontrolled urbanization of at-risk areas, where housing and activities proliferate, and the multiplication of infrastructures, amplify the impact of floods. Actes des journées techniques (2004)

5.1. Severity of floods

According to BELOULOU (2008), water disasters can wipe out decades of progress. Floods are a major obstacle to development, especially in poor and developing countries, where warning systems and risk management experience are inadequate. Beloulou L ; (2008)

Human existence takes place against a backdrop of natural hazards that seem to be intensifying and multiplying. Among them, floods stand out as the world's leading natural threat, with considerable destructive potential for people, property and the environment, often causing irreparable damage. Anh Tu NGO ; (2014)

This means that human populations are living with the reality of natural hazards that seem to be increasing in frequency and strength. Floods, the world's leading natural hazard, can cause considerable loss of life and property, as well as serious and irreversible environmental damage. Eric B. T., Florian G. M., Laffly D., Christelle M., (2009)

5.2. Examples of flooding in Algeria

5.2.1. Flooding in Bâb El oued / Algiers / Algérie

Over the years, Algiers has unfortunately experienced a number of disastrous hydro-meteorological events. Among them, the bad weather of 9 and 10 November 2001, although qualified as remarkable but not exceptional, caused unprecedented human and material losses: 781 deaths, 115 missing and 3,271 buildings destroyed or damaged, largely concentrated in the Bab-el-Oued district. Wahiba Menad, Johnny Douvinet, Gérard Beltrando et Gilles Arnaud-Fassetta ; (2012)

Rainfall on 9 and 10 November 2001, with an estimated cumulative total of 263 mm, caused widespread flooding in the western part of Greater Algiers, making it one of the worst in the Mediterranean basin over the last decade (Figure 04 ; Figure 05 and Figure 06).

Figure 04. Relating to the flood of 09 - 11 November 2001 in Bâb-el-oued Algiers Algeria. Archive of the author.

Figure 05. Relating to the flood of 09 - 11 November 2001 in Bâb-el-oued Algiers Algeria. Archive of the author.

Figure 06. Relating to the flood of 09 - 11 November 2001 in Bâb-el-oued Algiers Algeria. Archive of the author.

5.2.2. Flooding in the town of Ghardaïa / Algérie

Flooding of the Oued M'Zab in Ghardaïa has been marked by several devastating floods. These include the events of 17 November 1980, when four days of rain totalling 98.8 mm caused the river to overflow its banks.

Later, on 3 June 1991, a flood of considerable magnitude, with a discharge of 1120 m^3/s, caused the loss of more than 100 lives and extensive material damage, notably following the partial failure of the dyke at Al Atteuf (a village in Ghardaïa) caused by a violent storm. On 29 and 30 September 1994, another significant flood dumped 151 mm of rain in one hour, generating a flow of 873 m^3/s. On 15 June 2004, a violent flood occurred with only 15 mm of rainfall. However, the floods of 1 and 2 October 2008 were particularly catastrophic. Exceptionally heavy rainfall, reaching 500 mm in over 48 hours in the Ghardaïa region, caused the destruction of the protective dam.

The dam burst, flooding the various waterways of the Oued M'Zab and killing at least 45 people, injuring dozens more, and destroying hundreds of houses and roads. Material losses were estimated at 2.5 billion dinars,

including 2 billion for infrastructure (Figure 07). Yahiaoui Abdelhalim ; (2012) and Berbeche rouwaida et al ;(2025)

Figure 07. In the El-Ghaba district of Ghardaïa. For over a week, the city of Ghardaïa was the scene of catastrophic flooding following the flooding of the Oued M'Zab. Source : website : https://observers.france24.com/fr/20081010-ville-ghardaia-ensevelie-boue-inondations.

5.2.3. Flooding in the city of Batna / Algeria

Batna /Algeria, a basin city and a city vulnerable to flooding. Like many of Algeria's major cities, Batna, a significant regional metropolis, is particularly exposed to flooding, with major floods occurring on average every three to four years. Although risk is a fact of life for any society, Batna's vulnerability to this natural threat seems to be increasing, given its concentration of inhabitants and assets. Batna is situated on a slightly sloping terrain, crossed by several streams (rivers) and bordered by a rugged mountainous terrain, characterised by numerous alluvial fans formed by the flow of water.To illustrate the vulnerability of the city of Batna / Algeria to flooding, it is worth recalling the major floods that have affected it, those of September 1983, September 1986, July 1987, June 2006, September 2007 and July 2008, as well as the more recent floods of March 2014 and August 2015. These events have systematically caused heavy loss of life and significant material damage (Figure 08).

Figure 08. Various views of flooded districts in Batna / Algeria. Source: HARKAT Naim; (2021)

6. CONSEQUENCES AND DAMAGE CAUSED BY FLOODING IN THE CITY OF BATNA, ALGERIA

This data highlights a series of devastating floods that have occurred on various dates, causing loss of life, displacement of populations and considerable material damage. In 1963, a flood affected 12,800 families, causing damage estimated at 456 million centimes. In 1965, 4 people died, 7 were injured and considerable material damage was caused. On 9 October 1969, a flood claimed 27 lives, injured 44 others, left 5,014 families homeless and caused 495 million centimes worth of damage. On 26 March 1973, 4,400 families were left homeless, with material damage totalling 282 million centimes.

On 5 September 1979, 4 people died, 144 families were left homeless and 130 million centimes worth of damage was caused. Flooding continued to affect the region, with 37 families affected on 10 November 1982, 76 families affected and 412 million centimes worth of damage on 13 September 1983, and 66 families affected and 77 million centimes worth of damage on 19 September 1986. On 5 July 1987, another flood caused 2 deaths, 167 families affected and 175 million centimes worth of damage. The following years were also affected, with 38 families affected on 22 January 1990, 89 families affected on 13 May 1990, the destruction of 25 homes and 30 families affected on 6 September 1990, and the destruction of 10 homes and 10 families affected on 1 October 1994.

On 31 August 1997, flooding destroyed 23 homes and left 23 families homeless, and damaged 3 bridges and 6 kilometres of roads and pavements. On 4 May 2006, a rise in water levels led to the flooding of 40 homes. On 16 July 2008, a violent flood caused 3 deaths, 27 injuries, the destruction of a dozen buildings and swept away a large number of vehicles. More recently, on 13 and 14 March 2014, 2 people died, 19 homes were flooded and several roads were cut off. Finally, on 24 August 2015, a flood caused 1 death and extensive material damage. CTL ; rapport 2014 ; d'après : Source : HARKAT Naim ; (2021)

7. CASE STUDY, THE CITY OF BATNA / ALGERIA

7.1. General presentation of the city of Batna / Algeria

Batna, located in the east of Algeria, the wilaya of Batna, situated in the north-east of Algeria, between 4° and 7° East longitude and 35° and 36° North latitude, covers an area of 12,038.76 km². Its geography is marked by the meeting of the Tellian and Saharan Atlas mountains, making it a mountainous region (Figure 09).

Mount Chélia (town of Batna), at over 2328 metres, is the second highest peak in Algeria after the Hoggar. The wilaya lies at an altitude of over 1,000 metres, in the heart of a natural basin bounded by Mounts Azeb to the north-east, Ichali to the south and Touguert and Boumezroug to the west. Administratively, it borders the wilayas of Oum El Bouaghi, Mila and Sétif to the north, Kanchela to the east, M'sila to the west and Biskra to the south (Figure 09 and Figure 10). Bendib Karima ; (2019) and Berbeche rouwaida et al ; (2025)

Figure 09. The image on the left shows the geographical location of Batna / Algeria and the image on the right illustrates the administrative division of the whole of Eastern Algeria, with the wilaya of Batna highlighted in red. Source : LAKHDARI Somia ; (2022)

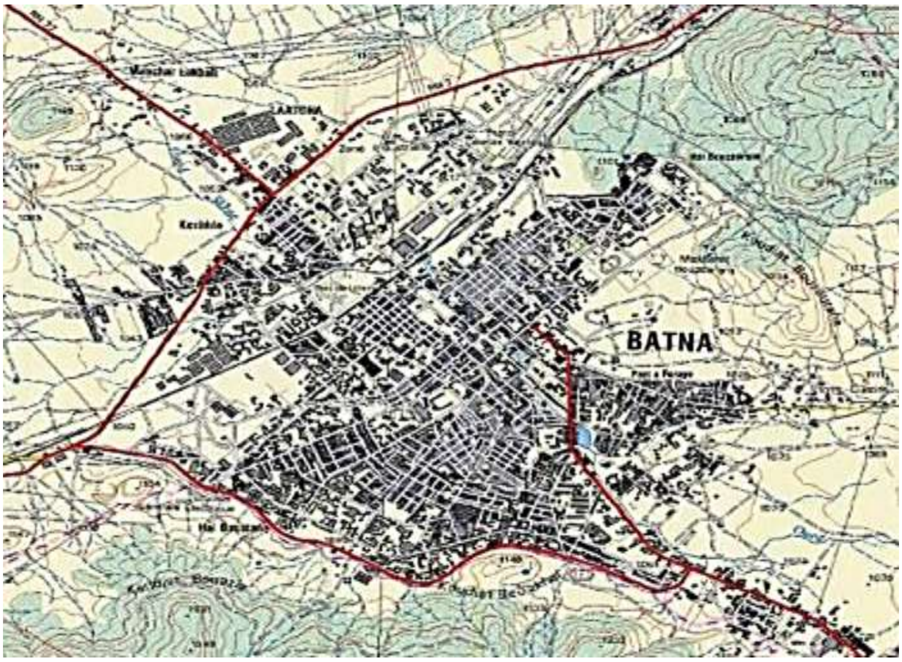

Figure 10. Cadastral map of the town of Batna, Algeria. Source cadastre de Batna.

Historically, Batna is known as the capital of the Aurès. The main town of Batna occupies the central part of the wilaya and covers an area of 11,641 hectares. It is bordered by the communes of Tazoult to the south, Fesdis to the north, Ouyoun El Assafer to the east and Oued Chaâba to the west. Bouha Imen ; (2012)

7.2. Physical data for the town of Batna / Algeria

Batna's climate is characterised by warm, moderate temperatures, with heavy rainfall throughout the year, even in the driest months. According to the Köppen-Geiger classification, Batna's climate is of the Cfa type.

The average annual temperature is 13.5°C and the average annual rainfall is 496 mm.

Situated in the northern hemisphere, Batna has a summer that starts at the end of June and peaks in September, covering the months of June, July, August and September. To make the most of your stay, we strongly advise you to plan your visit during these summer months (Figure 11; Figure 12; Figure 13 and Figure 14). Website: https://fr.climate-data.org/afrique/algerie/batna/batna-3686/

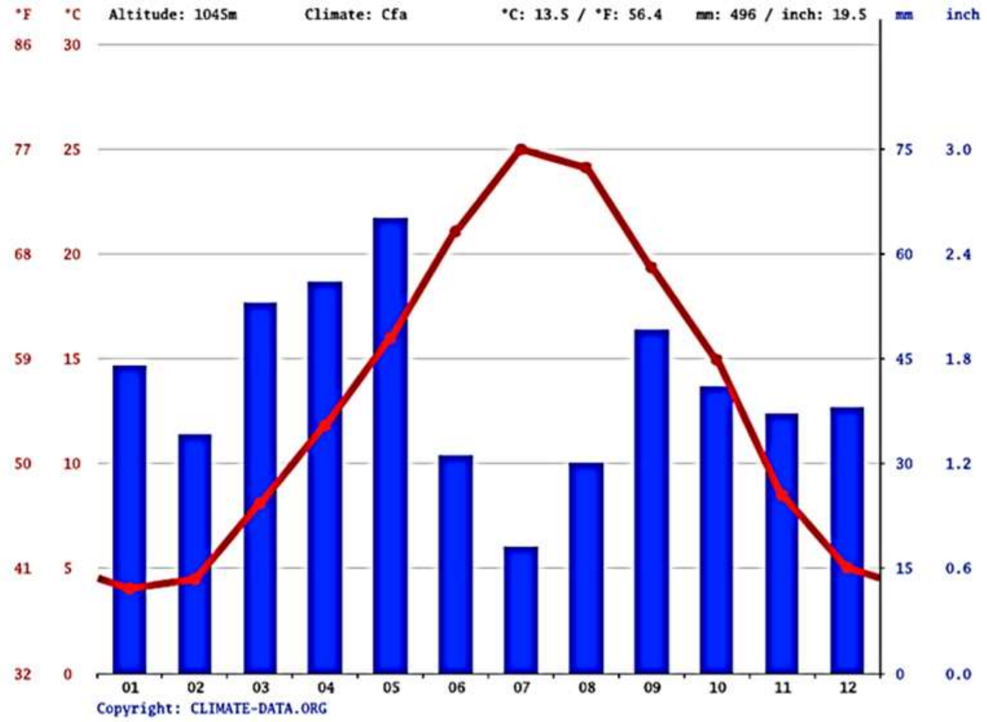

Figure 11. Graph of the OMBROTHERMAL diagram Batna Algeria. Source: webSite: https://fr.climate-data.org/afrique/algerie/batna/batna-3686/ consulted 10/02/2025.

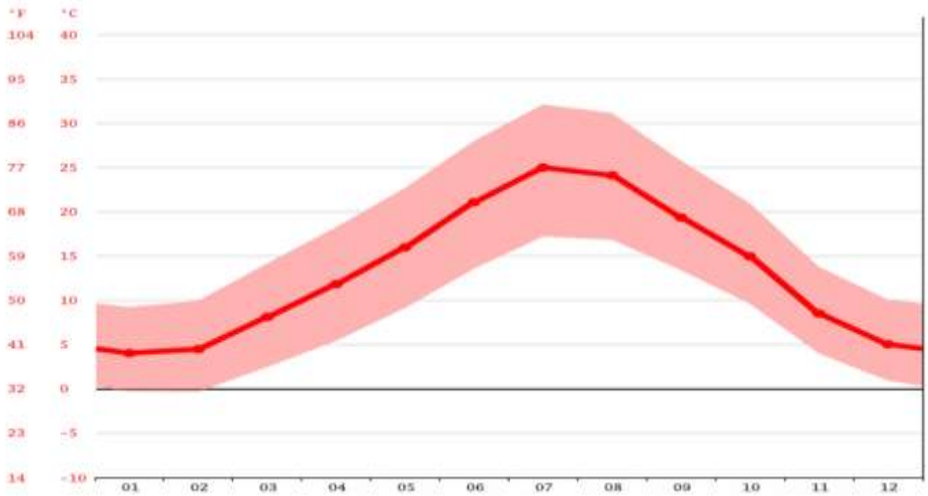

Figure 12. Graph relating to BATNA / Algeria TEMPERATURE CURVE. Source: webSite: https://fr.climate-data.org/afrique/algerie/batna/batna-3686/ consulted 10/02/2025.

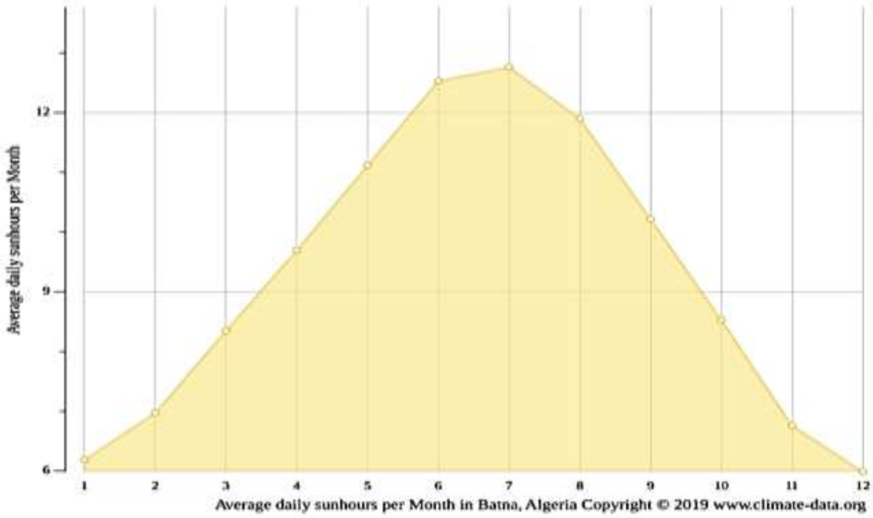

Figure 13. Graph of sunshine hours in Batna / Algeria. Source: webSite: https://fr.climate-data.org/afrique/algerie/batna/batna-3686/ consulted 10/02/2025.

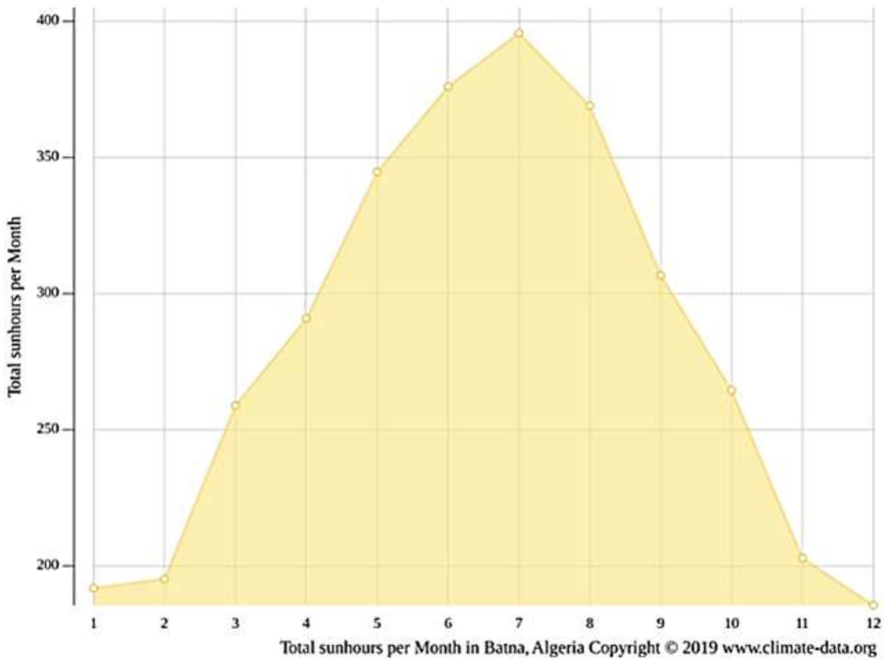

Figure 14. Graph of monthly sunshine hours Batna / Algeria. Source: webSite: https://fr.climate-data.org/afrique/algerie/batna/batna-3686/ consulted 10/02/2025.

In Batna, the month of July stands out for its maximum daily sunshine, averaging 12.76 hours, giving a total
of 395.57 hours for the month as a whole. Conversely, it was in January that the city recorded the least amount
of daily sunshine, with an average of just 5.98 hours, giving a monthly total of 185.49 hours. Over the year as a whole, Batna enjoys a total of around 3,381.16 hours of sunshine, corresponding to a monthly average of around 281.76 hours (Tab 01). https://fr.climate-data.org/afrique/algerie/batna/batna-3686/ consulted : 10/02/2025.

The difference in rainfall between the driest and wettest months in Batna is 47 mm. Over the course of the year, average temperatures vary from 20.9°C. December has the highest relative humidity (70.89%), while July has the lowest (34.02%). May has the most rainy days (9.80 days), while July has the least (4.93 days)
(Tab 01). https://fr.climate-data.org/afrique/algerie/batna/batna-3686/ consulted 10/02/2025.

Tab 01. Data : 1991 - 2021 Mean minimum temperature (°C), Maximum temperature (°C), Precipitation (mm), Humidity, Rainy days. Data: 1999 - 2019: Sun Hours.
Source : WebSite : https://fr.climatedata.org/afrique/algerie/batna/batna-3686/ consulted 10/02/2025.

Designations	January	February	March	April	May	June	July	August	September	October	November	December
Average temperature (°C)	4	4.5	8.1	11.8	16	21.1	25	24.1	19.3	14.9	8.5	5
Average minimum temperature (°C)	-0.3	-0.3	2.5	5.4	9.1	13.6	17.2	16.8	13.4	9.6	4	0.9
Maximum temperature (°C)	9.2	10	14.2	18.3	22.7	28	32.1	31.1	25.6	20.9	13.8	10.1
Precipitation (mm)	44	34	53	56	65	31	18	30	49	41	37	38
Humidity (%)	69	66	59	54	51	42	34	37	51	56	66	71
Rainy days	6	6	7	7	7	5	4	6	7	6	5	5
Hours of sunshine (h)	6.2	7	8.4	9.7	11.1	12.5	12.8	11.9	10.2	8.5	6.8	6.0

7.3. The Algerian state faced with flooding in the city of Batna Algeria: Initiatives and Treatments.

Therefore, in order to solve the problem of flooding in the city of Batna / Algeria, the local authorities undertook a major project to divert the main rivers: the Tazoult river, the Bougdane river and the Azzeb river, which flowed through the city centre. The project, aimed at the southern exit of the city of Batna / Algeria and costing
over 2.6 billion Algerian dinars, was designed to protect the city from flooding.

With this in mind, the wilaya's local technical committee, including civil protection, has implemented a series of operations including the construction of two galleries. The first, mainly rock, is around 2,620 metres long and has a diameter of eight metres. The second, built of reinforced concrete, is 475 metres long and measures
8 x 4 x 2 metres (Figure 15).

Figure 15. Map of the town of Batna / Algeria. Flood control treatments. Source: GUELLOUH SAMI ; (2017)

7.4. Constat / Report
Despite the improvements that have been made, the exceptional floods have continued to hit the city of Batna / Algeria in disappointing fashion. Researchers point out that one essential factor seems to have been underestimated, and that is the particular topography of the city of Batna. Situated in a valley at the foot of steeply sloping mountains, it forms a vast catchment area.
The city of Batna has had to cope with large quantities of torrential rain in a short space of time, and the results are clear: experience shows that the protective structures put in place did not anticipate the power of the torrential flows passing through the city.

8. OPTIMISATION OF STORMWATER MANAGEMENT FOR THE PROTECTION OF THE CITY OF BATNA / ALGERIA AGAINST FLOODING : SUSTAINABLE STRATEGIES.

By recognising the reality of the city of Batna /Algeria, it is imperative to initiate in-depth reflection and develop sustainable solutions and strategies for stormwater management, adapted and feasible for each specific area.
These approaches must be intrinsically applicable, feasible and implemented on the ground. In order to determine the precise location of our study area, the town of Batna in Algeria, we have adopted three fundamental criteria. -Firstly, an administrative criterion, which will enable us to situate the town accurately within the Algerian territorial organisation.
Secondly, a physical criterion, based on the distribution of the country's main morphological and topographical units, will shed light on its general geographical context. Finally, a hydrological criterion will illustrate the integration of this city within the major Algerian watersheds.
According to BOUCHEMAL Fatome (2020-2021), effective stormwater management is based on restoring natural runoff processes, in particular by reducing soil sealing. Although soil artificialisation is sometimes unavoidable,
it can be offset by planting green roofs with water retention capacity, using porous pavements for car parks and terraces, using low-toxicity or non-toxic materials for a healthy environment, and limiting sources of pollution linked to surface maintenance.
The sustainable solutions and strategies presented below apply to the entire territory of the city of Batna / Algeria. Each sustainable solution and strategy can be adjusted and adapted to a specific zone: zone 1, zone 2, etc., with the aim of minimising the risk of flooding. The measures adopted concern the development of public spaces, in particular roads and public squares ... etc. (Figure 16).

Figure 16. Map of different stages of growth in the city of Batna / Algeria. In addition, the city of Batna in Algeria is divided into homogenous zones according to its urban fabric and flood risk. These zones are as follows:

Zone 01: Quartier Kechida; Zone 02: Cités Hamla 1 and Hamla 2; Zone 03: Cité Hamla 3; Zone 04: Zone d'équipement; Zone 05: Centre-ville; Zone 06: Quartier Tamchite; Zone 07: Quartier Bouakal and Zone 08: Quartier Bouzourane. Source : PDAU 2012.

9. SUSTAINABLE SOLUTIONS AND STRATEGIES

The sustainable solutions and strategies proposed for each zone of the city of Batna / Algeria (zone 01, zone 02 ... etc.) allow the city of Batna, Algeria, to take advantage of the benefits of rainfall while guarding against its dangers.

9.1. S 01 : Rainwater treatment at source (valid for all areas of the city)

Managing rainwater at source means controlling it as close as possible to where it falls, particularly in urban areas such as towns and cities. Treating rainwater at source means acting on its quality before it reaches a discharge point or a treatment plant. This approach is particularly effective for treating dissolved or particulate pollution. It aims to protect the natural water cycle by avoiding soil sealing, maintaining the natural recharge of groundwater through infiltration, and preventing the concentration of stormwater flows in a single drainage basin.

This management strategy aims to control water flows from surface run-off in two ways: firstly, to prevent the contamination of watercourses, by preventing the concentration of polluting substances from sealed surfaces; secondly, to mitigate flooding, by reducing the phenomena of overloading and overflowing of rainwater drainage networks in urban areas. Source : 20. Website : www.essonne.fr ; Eaux pluviales urbaines, Une gestion à la source contre les inondations et les pollutions / Plaquette téléchargeable.

9.2. S 02 : The use of permeable floor coverings (valid for all areas of the city)

This innovative solution favours the infiltration of rainwater directly into the ground, as opposed to management at source, which would direct rainwater towards slopes or outlets. In other words, instead of evacuating rainwater on the surface, we encourage its gradual penetration into the subsoil, thus replenishing the water table.

The use of permeable surfacing plays a fundamental role in this process, thanks to its triple capacity to infiltrate, retain and store rainwater. The water collected in this way is then returned either to the groundwater table, made available to plants or channelled to a specific outlet. The widespread adoption of permeable paving on an urban scale has a number of advantages: it respects the natural water cycle, significantly reduces the risk of flooding, reduces rainwater run-off, collects water from impermeable areas and improves the aesthetics of public spaces, as illustrated by the design of car parks with grassed honeycomb slabs. What's more, this approach offers a variety of functions that can be combined to create multifunctional, adaptable spaces.

9.2.1. Linked / permeable floor coverings (valid for all areas of the city)

The same type of concrete is known by different names : concrete without fines (or without sand), cavernous concrete, porous concrete or pervious concrete. Its main characteristic is its ability to allow rainwater to infiltrate.

This property gives it its name, which refers to the numerous internal voids, similar to small caverns, generally between 10 and 30 millimetres in size. Its composition is simple, limited to cement, coarse aggregates and water (Figure 17).

Figure 17. The use of permeable flooring: porous concrete. Source: author's archive.

9.2.2. Porous asphalt (suitable for all areas)

Porous asphalt is a material with an open grading that allows water to seep directly through its structure. It is poured in situ and is generally used for secondary roads, low-traffic areas and car parks (Figure 18). (BOUAZZA Mohamed Seyf Eddene et MELLAKH Abdelhafid ; 2018)

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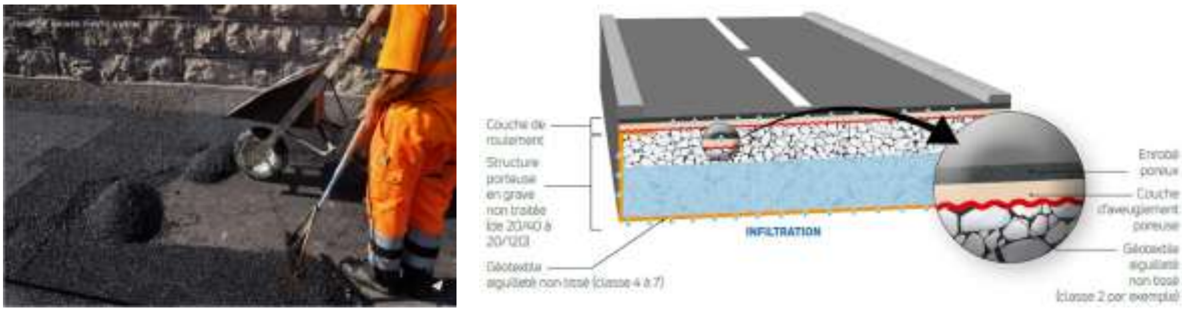

Figure 18. Application of porous asphalt and diagram showing the different layers of pavement. Source : BOUAZZA Mohamed Seyf Eddene and MELLAKH Abdelhafid ; (2018)

9.3. S 03 : Treatment and management of stormwater by storage (valid for zone 02 and zone 03)

The treatment and management of stormwater by storage involves the use of various solutions such as settling basins, retention basins, stormwater basins, landscaped valleys, floodable public spaces, drainage trenches with reservoir structures, as well as combined storage/infiltration (Figure 19). Hanafi A ; (2024)

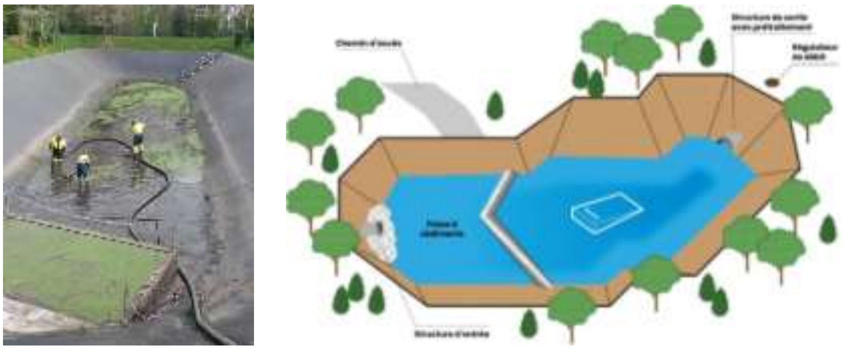

Figure 19. Photo and diagram of a settling tank. Hanafi A; (2024).

9.4. S 04 : Landscaped ditch (applies to zones 02 and 03)

The landscaped ditch is a linear urban development designed for integrated stormwater management in an urban environment. It consists of a longitudinal depression in the ground, with variable slopes, the purpose of which drainage point. Water is supplied to the ditch either by rainwater run-off from neighbouring surfaces, or artificially via a conduit, drain or pipe.

These linear structures offer the possibility of draining and storing water in the open air. They are characterised
by their shallow depth and wide width, which encourages the storage of rainwater and its infiltration into the ground. It can be vegetated with grass and/or planted with trees, shrubs and perennials capable of tolerating alternating periods of wet and dry weather, such as willows, helophytes and grasses (Figure 20). Degrave Marie (Cerema)

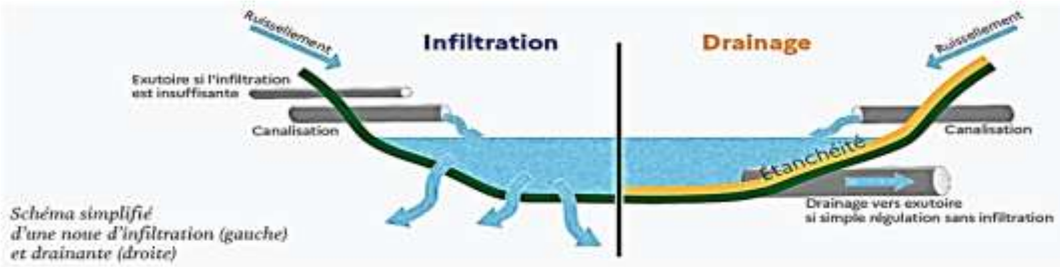

Figure 20. Illustrative diagrams. On the left, an infiltration channel; on the right, a drainage channel. Infiltration channels play a key role in controlling flooding and retaining macro-pollutants. They are also an excellent way of raising awareness of stormwater management. Source: Degrave Marie (Cerema).

9.5. S 05 : Public areas subject to flooding (valid for zones: 02, 03 and 08)

This is a facility designed to temporarily store rainwater by flooding a public area, such as a square, playground
or sports field. The water enters by direct run-off or via downspouts, and is then discharged by infiltration into the ground or by a flow-controlled drainage system into the downstream stormwater network (Figure 21).

Figure 21. For example, flood plots in Villemoisson-sur-Orge. Source website : https://www.villemoisson.fr/urbanisme-environnement/urbanisme-habitat-et-reglements/risques-naturels

10. CONCLUSION

Over the last few decades, cities have tragically suffered the repeated onslaught of various natural disasters, bringing to the fore the crucial issue of how to manage recurring natural risks. These highly vulnerable urban areas are particularly exposed to concentrations of major risks, such as flooding.

Precipitation, and more specifically rainfall, has a dual influence on human existence, manifesting itself as both a source of benefits and a potential threat. On the positive side, it provides essential irrigation for crops and helps to fill dams, vital resources for a wide range of uses. However, they also represent a significant risk, causing devastating floods, encouraging the spread of pollution and causing a variety of nuisances.

Contrary to popular belief, Algerian cities are characterised by the absence of perennial watercourses, i.e. those that maintain a constant flow throughout the year. As a result, the majority of flood-related disasters in these urban areas are mainly due to intense and rapid run-off. This phenomenon is caused by sudden, stormy rainfall, which suddenly submerges entire neighbourhoods.

With this in mind, this research has sought to gain a deeper understanding of the urban vulnerability of Algerian cities to the risk of flooding caused by precipitation, and more specifically by rainfall. The study of the problems in the city of Batna, Algeria, is the central focus of this investigation.

This research addresses the natural risk in its two fundamental dimensions : the natural hazard, represented here by rainfall, and the specific vulnerability of the urban area of the city of Batna / Algeria. The combined analysis of these two aspects then enables us to assess the risk of flooding in this particular context.

It should be emphasised that the entire city of Batna, Algeria, is potentially affected by the threat of flooding,

and no-one is really immune. Although the residential areas made up of individual dwellings are particularly exposed to this phenomenon - especially those in the Erriadh housing estate - they are not the only ones affected. The majority of facilities, administrations and services, often concentrated in the town centre, are also likely to be submerged in the event of flooding. What's more, Batna's university hospital is located on a flood-prone stretch of the Tazoult road, adding another significant vulnerability.

Flooding in the city of Batna, Algeria, would inevitably cause major disruption to essential networks such as electricity, gas and drinking water. It would also cause significant disruption to traffic routes and roads.

In order to propose sustainable solutions and strategies adapted to each specific situation, the city of Batna, Algeria, was divided into different zones (zone 1, zone 2, etc.) according to the nature and homogeneity of its urban fabric, as well as the predominant types of housing (individual, collective, semi-collective, etc.).

The sustainable solutions and strategies selected and presented earlier in this article are appropriate for each of the areas identified and can be implemented with relative simplicity, while guaranteeing verification of their effectiveness. The sustainable solutions and strategies selected are Treatment of rainwater at source ; Use of permeable pavements; Treatment and management of rainwater by storage; Landscaped valleys; Floodable public spaces and others.

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