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Socio economic impacts of Hydrological Hazards and Disasters in Tunisia

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Abstract

Tunisia is a water-scarce country and substantial imbalances exist in water resource distribution between the better endowed north and the semi-arid south in regards to water balance, storage, and water distribution. The country has a 90% mobilization rate of water resources through dams, whereas groundwater resources already overexploited. A network of canals and transfers exists to transport water from the north to the south. The country's main permanent watercourse is the Medjerda River, with sources in Algeria and on which Tunisia's largest dam, the Sidi Salem dam, is located. Rainwater also infiltrates the soil and contributes to the country's water reserves for rainfed agriculture, with the remaining water stored in wetlands or flowing towards the sea. While the country has made significant progress in regards to its water supply, sanitation, and water-related health services, significant imbalances and lack of access still remain high. Inequalities persist with regard to service availability, water quality, and access, particularly across different geographies and between urban and rural populations. Understanding natural hazard occurrences as well as historical climate conditions, in relation to development contexts, is critical to understanding a country's historical vulnerability. This tool allows the visualization of different natural hazards or historical climate conditions with socio-economic and development datasets. Climate variability and human activity have critical impacts on the sustainability of natural water resources, which may lead to the over-abstraction and deterioration of water quality. In the context of climate change and an increasing demand for water, it is important to stress the distinction between vulnerability and exposure to dangers. Vulnerability is made clear when exposure to dangerous forces occurs. The latest and current global-level disaster is the COVID-19 (and variants) pandemic. Research and investigations into the cause and potential responsibility for the pandemic are still ongoing (early 2021) and a clear and definitive answer may never be achieved. It seems clear, however, that the virus originated in an animal species.

Key Words*:* Socio economic, Hydrological Hazards, Drought, Disasters, Tunisia

Impacts socio-économiques des aléas et catastrophes hydrologiques en Tunisie

Résumé

La Tunisie est un pays pauvre en eau et des déséquilibres substantiels existent dans la répartition des ressources en eau entre le nord le mieux doté et le sud semi-aride en ce qui concerne l'équilibre hydrique, le stockage et la distribution de l'eau. Le pays a un taux de mobilisation des ressources en eau à travers les barrages de 90%, alors que les ressources en eaux souterraines sont déjà surexploitées. Un réseau de canaux et de transferts existe pour transporter l'eau du nord vers le sud. Le principal cours d'eau permanent du pays est la rivière Medjerda, qui prend sa source en Algérie et sur laquelle se trouve le plus grand barrage de Tunisie, le barrage de Sidi Salem. L'eau de pluie s'infiltre également dans le sol et contribue aux réserves d'eau du pays pour l'agriculture pluviale, l'eau restante étant stockée dans les zones humides ou s'écoulant vers la mer. Bien que le pays ait réalisé des progrès significatifs en matière d'approvisionnement en eau, d'assainissement et de services de santé liés à l'eau, des déséquilibres importants et un manque d'accès restent élevés. Des inégalités persistent en ce qui concerne la disponibilité des services, la qualité de l'eau et l'accès, en particulier entre les différentes zones géographiques et entre les populations urbaines et rurales. Comprendre les occurrences des aléas naturels ainsi que les conditions climatiques historiques, en relation avec les contextes de développement, est essentiel pour comprendre la vulnérabilité historique d'un pays. Cet outil permet de visualiser différents aléas naturels ou conditions climatiques historiques avec des ensembles de données socio-économiques et de développement. La variabilité climatique et l'activité humaine ont des impacts critiques sur la durabilité des ressources naturelles en eau, ce qui peut conduire à une surexploitation et à une détérioration de la qualité de l'eau. Dans un contexte de changement climatique et de demande croissante en eau, il est important d'insister sur la distinction entre vulnérabilité et exposition aux dangers. La vulnérabilité est mise en évidence lorsque l'exposition à des forces dangereuses se produit. La dernière catastrophe mondiale actuelle est la pandémie de COVID-19 (et ses variantes). Les recherches et les enquêtes sur la cause et la responsabilité potentielle de la pandémie sont toujours en cours (début 2021) et une réponse claire et définitive pourrait ne jamais être obtenue. Il semble clair, cependant, que le virus est originaire d'une espèce animale.

Mots clés : Socio économique, Aléas hydrologiques, Sécheresse, Catastrophes, Tunisie

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INTRODUCTION

Tunisia is in North Africa, on the edge of the Sahara desert, at the eastern end of the Maghreb mountain ranges, and on the southern shore of the Mediterranean Sea. With a surface area of about 164 000 Km², and elongated in shape along its north/south axis, it is located in the transition zone between the sub-humid Mediterranean climate and the arid Saharan climate, with a strong overall north/south hydro-climatic gradient of rainfall and evapotranspiration, and hence of hydrological conditions.

Tunisia is situated to the south of the Mediterranean; it is bordered by Libya in the southeast and Algeria in the west (Figure 1). Tunisia's surface area is 164 000 Km², its coastline totals 1300 km, its average altitude is 700 m and its highest point is the Jebel Châambi (1540 m). Tunisia shares many common features in terms of climate, water, and land resources, and development issues. These include arid and semi-arid climates, limited water resources, agricultural development limited by water availability, and the high economic and social value of water (Gaaloul, 2011).

In the arid and semi-arid regions, countries such as Tunisia are facing increasingly more serious water shortage problems. Problems of water scarcity will intensify because of population growth, rise in living standards, and accelerated urbanization which threaten the water supply in general and agriculture in particular and lead to both an increase in water consumption and pollution of water resources. A continuing increase in demand by the urban sector has led to increased utilisation of fresh water for domestic purposes, on the one hand, and the production of greater volumes of wastewater, on the other. Agriculture in competition with other sectors will face increasing problems of water quantity and quality considering increasingly limited conventional water resources and growing future requirements and a decrease in the volume of fresh water available for agriculture (Gaaloul, et al, 2017). The history of Tunisia reveals how the scarcity of water resources forced its inhabitants to deal with the unequal distribution of these resources within the country. As early as 130 BC, the Roman Emperor Adrian constructed a temple of water and a huge aqueduct to transfer water over 123 km from a spring located in the region of Zaghouan to the city of Carthage. In the early eighth century, the Arabic Dynasty of Aghlabides transferred groundwater and stored it in big basins to supply the new founded town of Kairouan (Gaaloul et al., 2021). This concern for water still persists since it is required for development in all social and economic sectors (Gaaloul et al., 2021).

Rainfall in Tunisia is irregular: there are long dry periods and precipitation varies from year to year and from North to South. The average annual rainfall in the north is 500 mm to 1000 mm, 300 mm in the center, and 150 mm in the south (Figure 1). Dry periods lasting several weeks often occur during one season or can last over several consecutive seasons. The annual average rainfall is estimated at 36 billion cubic per year and is ranging from 11 to 90 billion cubic. The rainfall received in the north is highly variable compared to the rainfall received in the south, and often a transfer of water resources is needed from the north to the south. The average annual evapotranspiration is also high and the water deficit is particularly significant from May to October. The annual evaporation varies between 1300 mm in the north to about 2500 mm and even more in the south.

Tunisia's geographical situation, bordering the Mediterranean on the east and north and stretching to the Sahara in the south, gives it an arid, diversified climate. The climate varies from the Mediterranean redundant to semi-arid and arid, ranging from humid in the extreme north to desert-type in the extreme south. The climate is Mediterranean, ranging from humid in the extreme north to desert-type in the extreme south. In the north and along the coast, the climate is Mediterranean; inland and in the south, it is semi-arid to arid (Gaaloul, et al, 2017).

The hottest month is August, with a mean monthly temperature of 26ºC, and a highest monthly temperature of 28.7ºC. January is the coolest month having a mean monthly temperature of 10.7ºC . And a lowest value of 8.4ºC. The mean annual temperature in Tunisia varies between 15ºC in the north to 21ºC in the south (Gaaloul, et al, 2021)

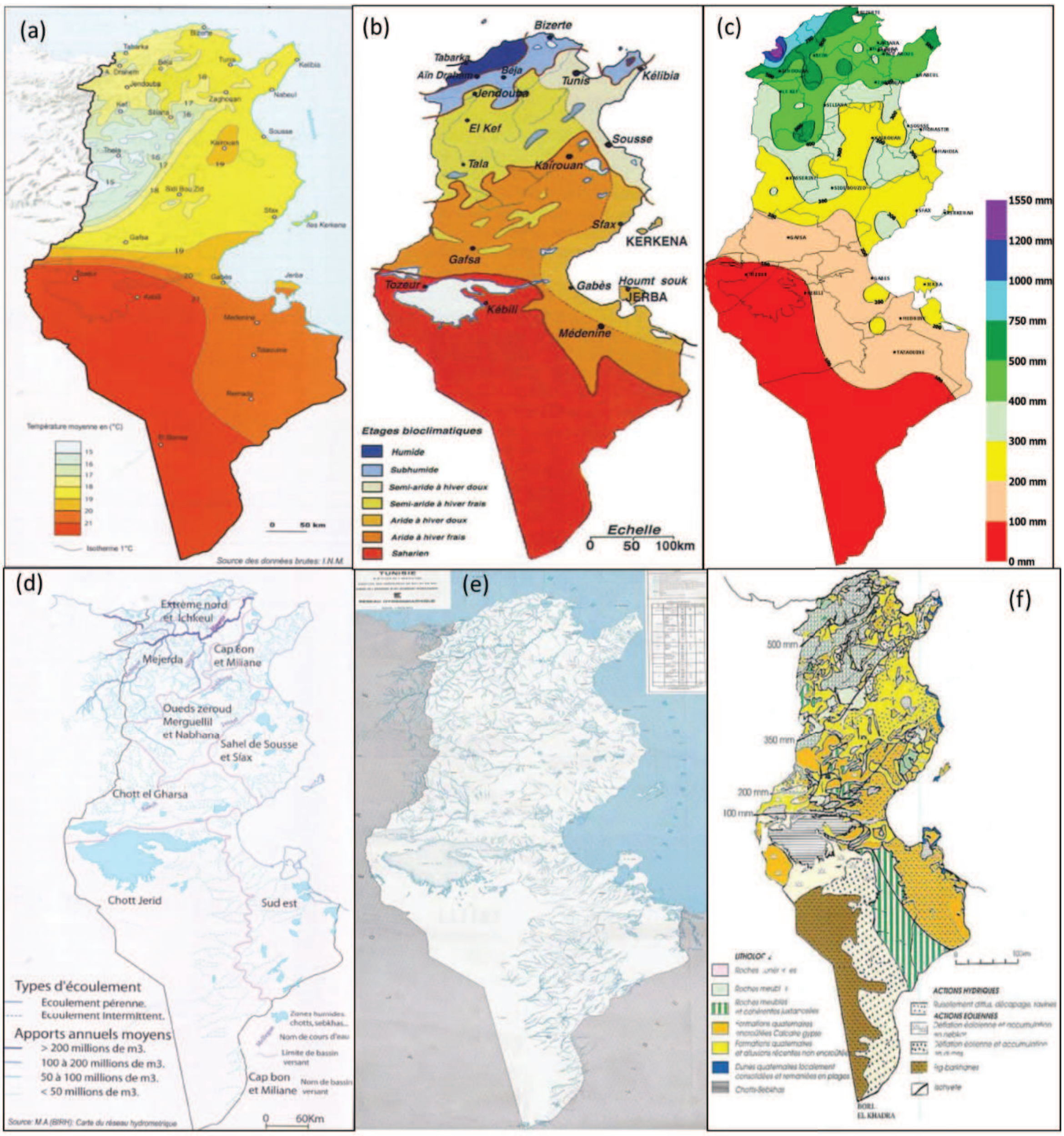

Figure 1. Tunisia situation geographic and the network hydrographical (Gaaloul, et al., 2021)
(a) Temperature; (b) Bioclimatique, (c) Rainfall; (d) Dam, (e) Hydrographic network; (f) Erosion

The climatic and geomorphologic characteristics define three major agro-ecological zones (Gaaloul, et al., 2021):

- The north, constitutes a sylvo-agricultural region (mainly forests and annual crops); its average rainfall is between 400-600 mm and its main topographic features are mountain pasturelands in the northwest and fertile plains in the northeast.

- The centre, constitutes an agro-pastoral region (pasturelands and crops); its rainfall is between 200 and 400 mm, and its morphology is composed of a low steppe to the east with fertile plains interrupted by depressions and a high steppe with mountain pasturelands and plains.
- The South, with irregular rainfall of 100-200 mm, is characterised by its aridity and vulnerability of its soils to desertification. This area is pastoral with oases.The total population of the country is 9.6 million inhabitants (2004 census) with 61 % living in urban areas and 39 % in rural areas. The natural growth rate is 1.9 % (2004). Education has always been a priority sector, with a primary school enrolment rate of 100 %. Although the illiteracy rate is still high, it is decreasing progressively. Health standards have much improved as witnessed by the drop in infant mortality from 127‰ in 1970 to 42‰ in 2004 (Gaaloul, et al, 2021)

Tunisia faces many of convergent natural and anthropic factors, which account for the fairly advanced level of soil degradation. The main problems are water and wind erosion, and salinization. The great challenge is to contain these problems whilst preserving the productive potential of the land. Preventive actions aimed at the rational management of land must be combined with curative actions to enable land improvement, rehabilitation, and restoration through adequate management. The combination of Tunisia's varied bioclimate, ranging from humid to Saharan and its geology, offering different types of rock outcrops, generates a fairly rich variety of soils. The soils are well differentiated by their fertility and sensitivity to degradation. Three major regions can be distinguished by the nature of their soils and the related cultivation systems (Souissi, 2001).

Northern Tunisia, a region with sylvopastoral potential, has a diverse range of soils:

- Acid soils on alternating clay and sandstone, shallow but quite rich in organic matter and relatively stable,
- Deep calcareous soils on marl slopes are very sensitive to water erosion;
- Shallow soils on calcareous rock, located on tops of hills;
- Deep, stable and fertile soils of numerous more or less extended plains.

All suffer severe water erosion enhanced by slope cultivation and tillage, overgrazing, and by inadequate rotation of rain fed and irrigated crops where the integration of animal husbandry is virtually absent. The failure to recycle organic matter (manure, straw) accentuates the impoverishment of soils in humus and leads to their physical and chemical degradation. Soils of irrigated plains risk chemical degradation - salinization - due to irrigation with brackish water without sufficient drainage to leach out the salts.

Central Tunisia is an agro-pastoral region dominated equally by the heavy soils of the alluvial plains, which are mostly sodic, by the sealed skeletal calcareous soils of the large fans, and by the deep and light soils, which were in the past occupied by rich pastures.These different units are confronted with several problems: the expansion of tree cultivation on the sandy steppes which triggers wind erosion; the cultivation of natural and esparto grass pastures which leads to the reduction of pasturelands, and as a consequence overgrazing; the excessive development of irrigated agriculture using degraded water derived from overexploited aquifers, which leads to the secondary salinisation of soils.

Southern Tunisia has a pastoral vocation and is characterized by arid, light soils vulnerable to wind erosion, dominated by the presence of gypsum. Olive growing and cereal cultivation in the southern steppes are the causes of desertification of the natural pastures; these, by deflation, become stone deserts, and by accumulation, dunes.

Mean annual rainfall values can be exceeded by factors of two to twelve during short and intensive rainfall events, producing runoff and causing soil erosion (695 to 6050 tons per km² per year) (Gaaloul, 2021). Annual soil losses are estimated at 23 000 hectares, of which 13 000 hectares cannot be recovered (Gaaloul, 2021).

Land suitable for cultivation in the north and center of Tunisia, located north of the 200 mm isohyets, is most threatened by strong and moderate erosion, while the center-east and Cap Bon are somewhat less threatened. In total, 1.2 million hectares are affected by water erosion, representing 25% of the nation's land suitable for cultivation. In the South, an estimated 50% of the land, not included in natural deserts, faces desertification (accumulation of sand, surface scraping).

Despite of the wide range of causes and effects often used to describe it, desertification is a well-defined process. It is triggered by changes in climatic and socio-economic boundary conditions of affected land systems. These changes cause the systems to enter an irreversible positive feedback loop of overexploitation of land. The outcomes are land degradation and the disruption of local economies. Desertification is an acute process that occurs at rates several orders of magnitude faster than purely climate-driven land responses.

Tunisia's physical and climatic diversity has had a great influence on the way in which its natural resources are used, and this, in turn, has had an influence on the risk of desertification. In the south of Tunisia, the steppes are reportedly being destroyed by human pressure at a rate of 1% per year. Alfa grass or plant communities associated with it dominate most of the steppes in the south of Tunisia. Human activities are at the root of the main factors in soil and plant-cover deterioration: overgrazing, cultivation of natural grazing lands, eradication of woody plant species, and irrigation with brackish water accompanied by poor drainage.

The effects of such inappropriate use of natural resources tend to be amplified by physical factors, varying according to region in terms of vulnerability and sensitivity: water and wind erosion, increasing soil salinity.As an arid to semi-arid country, Tunisia is facing water shortages of increasing severity. Most regions in Tunisia have modest rainfall: only one-third of the territory benefits from 400 mm per year, while the other two-thirds receive less than 4 00 mm per year. Rain is concentrated between May and September, with a limited number of days receiving rainfall. Two-thirds of the country, for example, receive an average of less than 50 days of rainfall. Tunisia, like all countries in the Middle East and North Africa (MENA) region, is characterized by overall water scarcity. Even without the impacts of climate change, Tunisia already faces an increasing scarcity of water resources and a number of challenges in the water sector (Gaaloul et al, 2015).

Tunisia is divided into seven river basin districts, which include several river basins:

- Basin 1, which covers the northernmost part of the country;
- Basin 2 consists of the CapBon watershed and the Miliene River,
- Basin 3, corresponding to the Medjerda River watershed, which is the most important river basin in Tunisia;
- Basin 4, which corresponds to the central part of the country (Zeroud, Merguellil and Nebhana rivers);
- Basin 5, which includes Sousse and Sfax in the Sahel
- Basin 6, which extends north of Chot el Jerid from the southern limit of Basin 4 and the Sahel
- Basin 7, which covers the southernmost part of the country, up to the Algerian and Libyan borders.

This is a list of rivers and wadis in Tunisia (Figure 2). This list is arranged by drainage basin, with respective tributaries indented under each larger stream's name:

- *North Coast*: Oued Zouara, Oued Sejenane (Oued Zitoun), Oued Joumine, Oued Tine, Oued Medjerda (Oued Siliana, Oued Tessa, Oued Mellègue (Oued Sarrath), Oued Miliane (Oued el Hamma))
- *East Coast: Oued el Hadjar, Oued Lebna, Oued Chiba, Oued Nebhana, Oued Zeroud (Oued Merguellil, Oued El Hattab Oued el Hajel (Oued el Fekka), Oued el Leben)*
- *Interior*: Oued el Melah (Oeud Sefioune, Oued el Kebir), Oued Jeneien

Figure 2. Hydrological networks and location map of Tunisia (Gaaloul, 2021).

The Current Situation in Terms of Water Resources, Water Use, and Water Reuse in Tunisia

Water resources in Tunisia are characterized by large variability in both time and space. In terms of spatial variability, mean annual precipitation ranges from 1500 mm on the peaks of the Kroumirie mountains in the northwestern corner of Tunisia to less than 100 mm in the south. Variability in time is very high, both within and between years. The mean total precipitation is 36 km3 , of which only 3 km3 could be potentially collected as runoff water in large dams. Renewable groundwater resources are estimated at 1.8 km3. The total water resources are about 4.8 billion cubic meters of which 2.7 billion cubic meters are from surface water and 2.1 billion cubic meters from groundwater. The annual total volume of exploitable water resources in Tunisia is about 4800 million cubic meters of which about 56% (2700 million cubic meters) is surface water and the remaining 44% (2100 million cubic meters) groundwater (Gaaloul; 2021). Tunisia's average rainfall of 230 mm/year represents a total water volume of 36 billion m3 and is highly variable: about 36 percent of this rainfall falls on 3 percent of the land surface in the extreme north, while 6 percent is received by 62 percent of the land surface in the south.

The escalation of urban water demand has led to the increasing use of freshwater for domestic purposes and the production of large volumes of wastewater. In turn, this has a significant impact on the allocation of water for crop irrigation: the agricultural sector is expected to face significant water quantity and quality problems, given that the volume of freshwater that becomes available for crop irrigation is decreasing. Furthermore, there is growing competition over available resources near large urban centers.

In the above context, policy water makers have been compelled to develop additional resources, and to take measures toward water resource conservation. Currently, the main components of the National Water Resources Management Strategy are gradually shifting towards surface water mobilization, soil, and water conservation works, water harvesting, and the use of non-conventional water resources, such as the re-use of treated wastewater for crop irrigation and aquifer recharge.

The water distribution resources in the three geographical regions are quite different (Gaaloul and Eslamian, 2021) :

- Most surface water resources are localized in the Northern region (81.2%), which represents only 17% of the total Tunisian area,
- The majority of ground water resources are concentrated in the south, particularly in deep-lying aquifers containing fossil water,
- The Center is the poorest region for the water resources

Water resources are unevenly distributed across the country, with around 60% located in the north, 18% in the center, and 22% in the south. Water quality, especially salinity, is a serious constraint. Surface water has a generally low salinity (except for the tributaries entering the Medjerda river from the south).

Groundwater is badly affected, with 84% of all groundwater resources having salinity levels of more than 1.5 g/L and 30% of the shallow aquifers having than 4.0 g l-1.

Surface water resources in Tunisia are characterized by problems of quantity and quality. These resources are limited because of the semi-arid to the arid climate found in most of the country, with episodic droughts, and natural deterioration of water quality because of the salty types of rocks found within the country. The average annual rainfall ranges from 1500 mm in the extreme north to less than 100 mm in the extreme south. The annual evaporation varies between 1300 mm in the north to about 2500 mm and even more in the south. The climate is the Mediterranean, ranging from humid in the extreme North to desert-type in the extreme south.

The climatic and geomorphologic characteristics define three major agro-ecological zones:

- The humid account for hardly 6.6 % of the territory.
- The semi-arid zone extends over the mountainous regions of Tell and the Dorsal and of the North east and has moderate rainfall (400 to 600 mm/yr.) but occupies only 16.4 % of the country. These two rainy areas constitute the water reservoir of Tunisia for surface water.
- The rest of the country (77 %) comprises Central and Southern Tunisia, and is part of the arid or desert area where average rainfall varies from less than 100 mm/year to less than 400 mm/year. As these zones are sufficiently arid and generally have permeable soils and little topographic variation, surface rainwater available for use is virtually non-existent, and is stored below ground to form aquifers.

Rainfall throughout the country is equivalent to an average of about 36 billion m^3 per year, or an average of 230 mm. From this quantity, an average of only 2.7 billion m^3 is annually mobilized through a well-developed

hydrographic network, a topography favoring runoff, and an impermeable geological stratum limiting infiltration. There are few aquifers in the North.
The major basins in the north are the Medjerda Basin, in the extreme north, and the Oued Miliane. Most dams are constructed on these Oueds (16 units). Agriculture entirely depends on irrigation from the Medjerda River. It is the only permanent flowing river and carries one million cubic meters of surface water. In the center, three dams have been built on the Zeroud, Merguellil, and Nebhana Oueds. The mobilizable water is collected at 81 % in the northern basins, 12 % in the center and only 7 % in the south. Surface water is considered of great interest for agricultural development since it irrigates nearly 131 500 hectares and during the floods it spreads over 170 000 hectares. This resource is now at risk because of the decline in dam storage capacity, which annually accumulates over 30 million m3/year of silt. Furthermore, surface water is the most affected by variability in space and time. One year out of every two is dry, and out of 2700 Mm3/yr of surface water, 2230 Mm3 is available one year out of every two, 1500 one year out of every five, and 1250 one year out of every ten. One year out of every two is dry, and out of 2700 Mm3/yr of surface water, 2230 Mm3 is available one year out of every two, 1500 one year out of every five, and 1250 one year out of every ten. Of the reduction of their available capacity due to silting (5 to 10% per decade), water losses by evaporation (1 to 2 m per year), and infrastructure. Existing reservoirs are therefore integrated into a complex hydraulic system. Water transfer and spatial redistribution are possible due to the interconnections. Water is piped and conveyed over long distances from inland to the coastal areas (150 km) or from north to south (300 km) through systems of open canals (Canal Medjerda-Cap Bon) and pipelines, reservoirs, and pumping stations. This is to provide drinking water to coastal cities while also preserving agricultural areas such as the Cap Bon (Gaaloul, 2021).
Other smaller structures have been implemented to store surface water: hillside dams and hillside lakes. These are essential to flood control and soil and water conservation and also contribute to groundwater recharge. They may also lengthen the expected life of the dams by reducing reservoir silting. In total, 66 hillside-dams (plus 45 under implementation) and 392 hillside lakes (with a capacity varying from 3300 to 500 000 m3), mobilizing 77 Mm3/yr and around 37 Mm3/yr, respectively, are already in operation. In the next century, 203 hillside dams and 1000 hillside lakes will be in operation. 30% of the volume mobilized by the hillside lakes should contribute to groundwater recharge and 70% to fulfill local water requirements. 23 million cubic meters per year mobilized through floodwater diversion structures are used to irrigate 13 100 ha. These structures are mainly located in the central and southern parts of the country. They are used to recoveingr 47 million cubic meters per year (Gaaloul, 2021).
In 2017, Tunisia had 33 dams, 280 collinear dams, 900 collinear lakes, and more than 9000 deep wells and 150,000 surface wells exploiting 86% of total conventional water resources. These proposed projects will permit the development of 90% of conventional water resources by the year 2030. To order to increase the water potential in the country, the use of non-conventional water resources, such as treated wastewater and desalinated briny water, is being encouraged. At the same time, the exploitation of water resources is being managed by better allocating scarce resource. In addition, the protection of coastal aquifers against the intrusion of salt water is reinforced by regulations (Gaaloul, 2021).

The groundwater resources of the country are about 1.97 billion m^3 of which 650 Mm^3 is nonrenewable and located in the south. 1250 million m^3 are in deep aquifers (267) and 719 million m^3 are in shallow ones (Hamza and Khanfir, 1991). The net rate of development is 93%: 86% from 2400 tubewells pumping into deep aquifers (about 85% of the Boreholes and tubewells are 100-400 m deep) and 106% from 123 000 shallow wells (less than 50 m deep). This number of wells was 60 000 in 1980. In total, 59 Mm^3/yr are provided by springs. Groundwater resource exploitation is more advanced :

- 0.7 billion m^3/year from shallow aquifers, representing 106% of renewable resources
- 1.4 billion m^3/year from deep aquifers, representing 77% of renewable resources (including fossil groundwater)

Groundwater resources are exposed to various types of pollution and deterioration, increasing their vulnerability and scarcity.
Shallow aquifers are already over-tapped. Groundwater resources in coastal aquifers (Cap Bon, Sahel, and Gulf of Gabes) and in the chotts (Nefzaoua and Jerid) suffer from Stalinization problems due to seawater or saline water intrusion. As a result, the quality of these aquifers has deteriorated considerably. Pollution of some shallow aquifers by nitrates constitutes also a major risk for domestic requirements. Generally, deep aquifer composition is rather stable over the year while the shallow aquifers one depends on location and season and is often salt-

affected. The Groundwater of the shallow aquifer is generally over exploited, leading to the lowering of water tables and the deterioration of water quality. The majority of the shallow aquifer are located in the north and the center of the country, while deep aquifers are mostly concentrated in the south. The south of the country includes the fossil aquifer of the Sahara Aquifer System (SAS), shared with Algeria and Libya, with its two components: "Continental Intercalaire"(CI) and "Complexe Terminal" (CT) (Gaaloul and Eslamian, 2021).

Deep groundwater extraction rates are currently at 73% of annual recharge, and shallow groundwater is at 97% in the coastal and central regions. Excessive groundwater extraction in the coastal regions of Cap Bon, Soukra, and Ariana has resulted in saline intrusion in many areas leading to groundwater being rendered unsuitable for further irrigation. Underground water reserves are very important in the south, especially deep water tables that represent 44.7% of the underground water total. Potential fossil reserves represent 605 million m^3 that is 33 %. Given its modest water resources potential and the mediocre quality of most of its groundwater resources, Tunisia has no choice but to try to finding new sources of potable water. The total fresh water demand is expected to reach 877 million m^3 per year by the year 2025. The increase in potable water demand is dictated by the population growth on one hand and the rise in the standards of living on the other. In addition, steady urbanization and industrialization processes contribute significantly to the increase in future water demand (Gaaloul, 2021).

Artificial groundwater recharge is practiced for groundwater protection and underground storage of surface water in rainy years. From 1992 to 1996, 25 aquifers were concerned by recharge practiced in river beds, quarries, using infiltration basins or through well injections (Gaaloul and Eslamian, 2014), 262 Mm^3 have thus been recharged plus 22 million m^3 per year through water and conservation structures. Recharge increased underground water levels (from 1 to 5 m) and improved the chemical water quality (Gaaloul and Eslamian, 2021).

Rainwater, which is not taken into account in the water resources budget, is also a major component that participates to rainfed agriculture and to biomass production in general. These are the main water consumers since 31.3 billion m^3 are evapotranspirated. Soil constitutes an important reservoir which regulates water flows to plants and more attention should be given to these unaccounted water resources.

Water pumped from shallow aquifers is mainly used for irrigation and to a less extent for drinking purposes. Deep groundwater is used for agriculture (74%), for potable water supply (18%), industry (8%), and tourism in the arid and semi-arid parts of the country where surface water is lacking. Water is sometimes transported several kilometers to supply cities such as Sousse, or Sfax.

Groundwater resources are exposed to various types of pollution and deterioration, increasing their vulnerability and scarcity. Shallow aquifers are already over-tapped. Groundwater resources in coastal regions (Cap Bon, Sahel, and Mareth) and in the vicinity of chotts (Nefzaoua and Jerid) suffer from salinization problems due to seawater or saline water intrusion. As a result, the quality of these aquifers has deteriorated considerably. Pollution of some shallow aquifers by nitrates also constitutes a major risk to domestic requirements.

Generally, the deep aquifers composition is rather stable throughou the year while the shallow aquifer depend on location and season and is often salt-affected. Therefore, salinity of 8% from the shallow aquifers is less than 1.5 g l^{-1}, 71% are ranging between 1.5 and 5 g l^{-1}, and 21% are above 5 g l^{-1}. In the deep aquifers, 20% have a salinity of less than 1.5 g l^{-1}, 57% are between 1.5 and 3 g l^{-1} and 23% are above 3 g l^{-1}. In the south, there are three main fossil aquifers with different water qualities (1-7 g l^{-1}),

At present, saline water is mainly disposed of in sebkhas where it evaporates. Assessments conducted so far, which need to be further refined, already indicate significant amounts of available resources. Some experiments have already been conducted such as in south Tunisia using saline water for irrigation of some specific crops. They could be the starting point for the development of biosaline agriculture in these regions (John S. et al, 2006).

Groundwater is sometimes mined as a limited resource. The increasing need for water is prompting agencies to look at various water management scenarios, so that they will be prepared for the future. These scenarios include managing groundwater and conjunctive use, which includes the coordinated management of both surface and ground water. Underground storage via artificial recharge, where possible, may be an efficient, environmentally friendly solution to water storage (ASCE, 2001).

Figure 3 shows a detailed classification of water resources in Tunisia according to their salinity. In Tunisia, 26% of surface freshwater, 91.6% of groundwater (shallow aquifers) and 80% of groundwater (deep aquifers) have a salinity of over 1.5 g l^{-1}. It is clear that a large percentage of these waters need to be desalted before they can be exploited. Of the modest quantities of water available, only a small portion meets the standards for potable water due to high salinity levels. Only 8.4 % of the total shallow groundwater has salinity levels inferior to 1.5 g l^{-1} (Gaaloul, 2021).

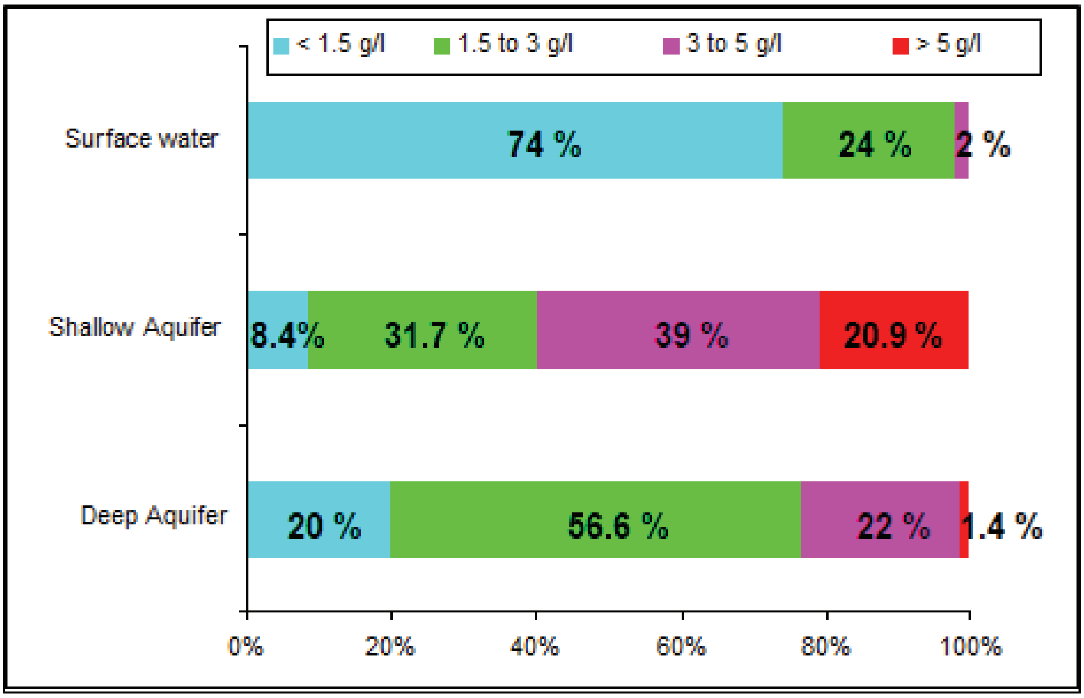

Figure 3. **Tunisian water resources classification according to salinity levels (Gaaloul, 2021).**

On a national scale, water resources are distributed unequally (Table 1, Table 2, and Table 3). In most regions' precipitation is insufficient and unpredictable, and it is unevenly distributed across regions. Groundwater supplies a large proportion of water resources, whether for drinking or agriculture. The country belongs to the so-called variability group of countries in North Africa, which consists of countries that have more or less adequate quantities of renewable water at the national level, but with high levels of variation between different parts of the country and over time. The primary concern is, therefore, internal distribution, both geographically and temporally. Climate change is predicted to increase the natural variability of precipitation regimes in Tunisia, along with a predicted overall decrease in mean annual precipitation, which will make water management increasingly difficult for water and agriculture planners (Gaaloul, 2021).

Table 1. Geographical distribution of different categories of water in Tunisia

Basin	North	orth	nter	outh	otal
Regional surface (%)	30	7	1	62	00
pply of surface water (million m^3)	970	230	20	80	700
Groundwater (million m^3)		95	16	08	19
Deep Groundwater (million m^3)		69	26	322	417
tal potential resource (million m^3)		354	62	120	336
Percent		9	8	23	

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unisia, like any Mediterranean country, is subject to the vagaries of the climate, with droughts becoming more frequent, forcing them to focus on water resources. Indeed, it has for decades, public facilities for the storage, transfer, and distribution of water, allowing him to regulate water resources and the needs of all economic and social sectors over a multiyear period. Surface water intakes from four distinct natural regions by their climatic, hydrological, and geomorphological, and geological aspects; these are:

- The extreme north: Although its area presents only 3% of the total land area, it provides surface water intakes estimated on average to 960 million m³, 36% of the total potential of the country.
- The North: represented by the basins of the Medjerda Cap Bon and Méliane, and provides an average of 1,230 million, 46% of the total potential surface water.
- The center: it includes the watersheds of Nebhana, Marguellil, Zeroud and Sahel and presents annual resources estimated at an average of 320 million m³, or 12%.
- The South: it accounts for about 62% of the total land area. It is the poorest region in surface water and has only very irregular resources, assessed at 190 million m³, or 6% of the total potential.

Access to drinking water reached 100 % in urban areas in 2011 and 93.5 % in rural areas, connection rates that are close to those observed in the Organisation for Economic Co-operation and Development (OECD) countries and very high compared with the average for the North african region (Gaaloul, 2021).

Table 2. Water resources in Tunisia

Renewable freshwater resources	
Precipitation (long-term average) (mm/yr)	207
Precipitation (long-term average) (million m³/yr)	33 870
Internal renewable water resources (long-term average) (million m³/yr)	4 195
Total actual renewable water resources (million m³/yr)	4 615
Dependency ratio (%)	9
Total actual renewable water resources per inhabitant (m³/yr)	419.7
Total dam capacity (million m³)	2 677

Most residents of large urban centers have access to adequate sanitation systems, and wastewater treatment facilities generally follow conventional designs. The sanitation coverage in sewered cities is about 78%; this rate, related to the whole urban population (5.8 million), is 61%. Concerning industry, compliance with the Tunisian standards (INNORPI, 1989) fulfill the discharge requirements stated in the regulations must be implemented. Subsidies were given to equip industrial units with pre-treatment processes (Gaaloul, 2021).

Of the 240 Mm³ of wastewater discharged annually, 140 Mm³ (58%) are treated in 61 WasteWater Treatment Plants (WWTPs), of which around 41 have a daily capacity of less than 3500 m³ and 10 above 10 000 m³, Choutrana being the largest with 120 000 m³/d. Five treatment plants are located in the Tunis area, producing about 62 million m³ per year or 54% of the country's treated effluent. Several of the plants are located along the shoreline to protect coastal resorts and prevent sea pollution. Municipal wastewater is mainly domestic (about 88%) and processed biologically up to a secondary treatment stage. The treatment processes vary from plant to plant depending on the origin of the wastewater and local conditions. Out of 61 treatment plants, 44 were based on activated sludge (medium or low rate), 3 on trickling filters, and 14 on facultative or aerated ponds. Sanitation master plans have been designed for several towns. The annual volume of reclaimed water is expected to reach 290 Mm³ in the year 2020. The expected amount of reclaimed water will then be approximately equal to 18% of the available groundwater resources and could be used to replace groundwater currently being used for irrigation in areas where excessive groundwater mining is causing salt-water intrusion in coastal aquifers (Gaaloul, 2021).

Like most countries affected by aridity, particularly within the Maghreb region, water resources represent Tunisia the most precious environmental good. The climate varies from the Mediterranean to semi-arid and arid; it is characterized by hot and dry summers and mild winters, receiving the major partof the annual precipitation.

Table 3. Water use in Tunisia

Water withdrawal	
Total water withdrawal (million m³/yr)	3 305
Irrigation + Livestock (million m³/yr)	2 644
Municipalities (million m³/yr)	463
Industry (million m³/yr)	165
Tourisme ((million m³/yr)	33
per inhabitant (m³/yr)	307
Surface water and groundwater withdrawal (million m³/yr)	3 217
as % of total actual renewable water resources (%)	70
Non-conventional sources of water	
Produced wastewater (million m³/yr)	287
Treated wastewater (million m³/yr)	226
Reused treated wastewater (million m³/yr)	68
Desalinated water produced (million m³/yr)	
Reused agricultural drainage water (million m³/yr)	19.7

Most residents of large urban centers have access to adequate sanitation systems and the wastewater treatment facilities generally follow conventional designs. The sanitation coverage in the cities is about 78%; this rate, related to the whole urban population (5.8 million), is 61%. Concerning industry, compliance with the Tunisian standards (INNORPI, 1989) to discharge wastewater into the sewerage system is required. So, preliminary treatment plants to fulfill the discharge requirements stated in the regulations must be implemented. Subsidies are given to equip industrial units with pre-treatment processes (Gaaloul, 2021).

Reclaimed water is now a part of Tunisia's overall water resources balance. It is considered an additional water resource and as a potential source of fertilizers elements (Gaaloul, 2011). Water reuse has been made an integral part of the overall environmental pollution control and water management strategy. Consequently, it is also considered a complementary treatment stage and consequently,-a way of protecting coastal areas, water resources, and sensitive receiving bodies.

Water resources in Tunisia are characterized by scarcity and a pronounced irregularity. By adopting an integrated strategy for the use of water based on scientific and technical studies. Tunisia has been able to develop a complex and diverse water infrastructure, allowing the country to mobilize and exploit available water resources. At the same time, Tunisia has put in place systems and legislation to ensure access to drinking water for the majority of the urban and rural population and to provide supplies for agricultural irrigation, as well as the industrial and tourism sectors.

A lot has been accomplished in the field of water resources planning and management in Tunisia and the data generated for the next 30 years constitutes a good basis. The water security of the country requires the tapping of all water resources to the extent permissible by economic feasibility and by social and environmental impacts, and optimal, economic, and sustainable use. Planning was therefore first based on water supply because of water availability and low demand. The continuing increase in demand by the different sectors and the scarcity of resources is leading to an approach essentially based on demand management. The water issue requires innovative actions in the matter of water resources development, assessment, planning, conservation, management, and utilization. In terms of demand and pollution, as well as public health and the environment, better coordination is required between irrigation, water supply, and sanitation. In terms of demand and pollution, as well as public health and the environment, better coordination is required between irrigation, water supply, and sanitation

In such countries, the sustainability of the development system can only be achieved through the adoption of a long-term strategy, that brings together physical, economic, and social factors. This strategy must be based on a dynamic evaluation of underground and surface water resources by analyzing their regimes and behaviors. This evaluation must take into account occurrence of exceptional droughts. National water policy should be prepared to guide the harnessing and use of water by comparing short and long-term resources, adopting several hypotheses, and putting forward several alternatives. The recycling of used water could lead to a great deal of progress but is still limited by the lack of research in this field. This approach appears to have a great future and will enable the impact of scarcity to be minimized in times to come.

Several studies enabled an assessment of saline water resources in Tunisia, both surface water and groundwater. As the management of surface water is based on the mixing-up of fresh water and saline water, there is no saline water available as such for use in biosaline irrigation. At the level of groundwater, several phreatic and deep aquifers with saline water resources are presently used in agriculture, industry, or -desalination for the production of fresh drinking water.

Flood protection in Tunisia dates back to the Middle Ages. In recent decades, the cities of Tunis and Gabès have emerged as examples (ONAS, 2020) of modern flood control, which includes the use of dikes along wadis such as the Medjerda Oued.

These projects have complemented socio-economic development in recent decades, and while data sharing between stakeholders lags (UNESCWA, 2019), professionals are aware of the challenges and competencies required to manage water resources and infrastructure.

Nonetheless, Tunisia remains vulnerable to severe events, and to conflicts and tradeoffs between objectives, regions, and stakeholders, some of which played a role in the 2011 revolution. Challenges include the conflicting needs of upstream users and downstream consumers such as cities and the tourism sector, crop irrigation needs, groundwater exploitation, infrastructures, siltation, and sedimentation. The following findings and references (WMO/GFCS, 2014; WB/GFDRR, 2018; Perera et al., 2019; Dixon et al., 2020) indicate the need to modernize hydroclimatic services.

To this end, Tunisia has conducted two national strategic studies Eau 2000 and Eau 2030 (UNESCWA, 2019), and is developing a participative 2050 Water Strategy with the MARHP which is part of a wider national policy regarding Agenda 2030 and its Socio Development Goals (SDGs), architecture, targets and indicators (République Tunisienne, 2019).

Climate and Hydrological Related Hazards and Risks

Why Studying Natural Hazards is Important

Since 1995, the world has experienced the deadliest tsunami in recorded history, caused by a massive Indian Ocean earthquake; another devastating tsunami in Japan caused by one of the largest and costliest earthquakes in recorded history; catastrophic flooding in Pakistan, Venezuela, Bangladesh, Thailand, and central Europe; a volcanic eruption that shut down international airports for more than a week; and deadly earthquakes around the world. At the same time, North America has experienced catastrophic hurricanes on the Gulf Coast, along the Atlantic Coast, and in Guatemala and Honduras, record setting; wildfires in western Canada, Arizona, Colorado, Utah, California, and the high plains of Kansas and Texas; the worst outbreak of tornadoes in U.S. history; a record-matching series of four hurricanes within six weeks in Florida and the Carolinas; a paralyzing ice storm in New England and Quebec; record-setting hail in Nebraska; and rapid warming of the climate, especially (but not limited to) Alaska, northern Canada, and Arizona. These events are the result of enormous forces that are at work both inside and on the surface of our planet. In this book, we will explain these forces, how they interact with our civilization, and how we can better adjust to their effects. Although we will describe most of these forces as natural hazards, we can, at the same time , be in awe of and fascinated by their effects (Edward and Duane, 2019)

A natural hazard is a natural process of event that is a potential threat to human life and property. The process and the events themselves are not a hazard but become so because of human use of the land. A disaster is a hazardous event that occurs over a limited may be redundant within a defined area. The criteria for a natural disaster are (1) 10 or more people are killed, (2) 100 or more people are affected, (3) a state of emergency is declared, and (4) international assistance is requested. If any one of these applies, an event is considered a natural disaster (Hoyvis, et al., 2007).

A catastrophe is a massive disaster that requiresa significant expenditure of money and a long time (often years) for recovery to take place. Hurricane Katrina, which flooded the city of New Orleans and damaged much of the coastline of Mississippi in 2005, was the most damaging and most costly catastrophe in the history of the United States. Recovery from this enormous catastrophe has taken years and continues in parts of New Orleans (Hoyvis et al, 2007).

Though the terms natural hazard and natural disaster are often used interchangeably, there is a recognized distinction between the two. Natural hazards are threats to people and have the potential to kill and injure them as well as cause considerable damage to their property and environment. In contrast, natural disasters occur when the potential turns into reality (Alexander, 2000). But not all hazards necessarily become disasters. If the actual event is not large enough and/or does not affect (harm) people, it is not considered a disaster, but rather remains a hazard. For example, an earthquake of considerable strength that occurs on an uninhabited island cannot be classified as a disaster because it does not affect people.

Natural hazards and disasters may not happen just to us but often happen because of us. Recent definitions of natural hazards and disasters directly acknowledge the role of humans in causing and exacerbating such events (Montz et al., 2017).

Reducing the intensity of disasters : From 1996 to 2015, natural disasters such as earthquakes, floods, and hurricanes have killed about 1.3 million people worldwide, an average of about 65,000 people per year. Earthquakes and tsunamis killed 57% of people; storms killed 18%; extreme temperatures (hot or cold) killed 12%; and floods killed 11% (Edward and Duane, 2019). During the last few decades, there has been a significant increase in the number of catastrophes and disasters worldwide (Figure 4: Disasters and catastrophes from 1980 to 2015; also shown are the events, by name and location, with the largest economic damage).

Although there are several hundred disasters from natural hazardous events each year, only a few are classified as a great catastrophe—one that results in deaths or losses so great that outside assistance is required (Center for Research on the Epidemiology; 2016). In disasters since the 1990s, flooding and storms caused about 61 percent of disasters and about 56 percent of the total number of people affected by disasters, while earthquakes caused about 57 percent of the deaths, and, over the same period, countries with medium to low income suffered most from floods and storms. High income countries suffered some of the greatest economic losses but the lowest number of deaths. The losses could have been even greater were it not for improvements in warning systems, disaster preparedness, and sanitation following disasters (Center for Research on the Epidemiology, 2016; Crossett, et al., 2004).

Nevertheless, economic losses have increased at a faster rate than the number of deaths. Figure 1.6 shows the disasters in 2015. In comparison, the United States, with a population of approximately 0.33 billion people, experienced approximately 6% of the disasters (Center for Research on Epidemiology, 2016; Crossett et al., 2004).

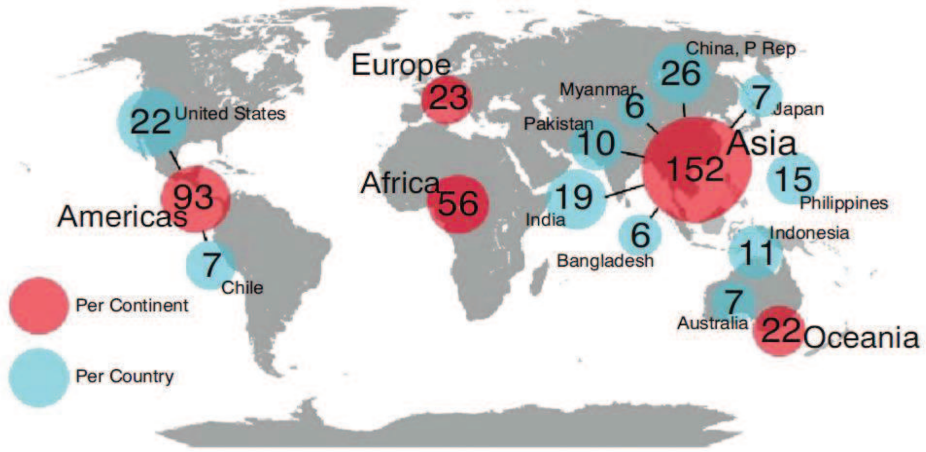

Figure 4. Number and locations, by continent and country, of natural disasters in 2015 notice that about half are in asia. (center for research on the epidemiology, 2016).

In fact, only an operational definition of drought helps hydrologists or water resources researchers and practitioners to identify the beginning, end, and degree of severity of a drought. This definition is usually made by comparing the current situation to the historical average, often based on a 30 year period of record (according to World Meteorological Organization recommendations).

Drought is one of the most difficult natural hazards to quantify, monitor, and predict (Wilhite, 2000; Wilhite and Pulwarty, 2017). This is simply because drought cannot be directly measured using specific instruments in the field. The diverse impacts of drought on natural systems and economic sectors, including meteorological, hydrological, agricultural, and ecological droughts, add further challenges and complications to drought quantification (Wilhite, et al., 2007; Vicente-Serrano, 2016). Given all these constraints, it is quite difficult to determine the onset and cessation of a drought event, as well as its severity and spatial extent. Drought has a wide spectrum of environmental and socioeconomic impacts in the Mediterranean region, including crops (Pa´scoa, et al., 2016), soil moisture (Scaini, et al., 2015), surface water resources (Giuntoli, et al., 2013; Caillouet, et al., 2017; Lorenzo-Lacruz, et al., 2013), and groundwater (Lorenzo-Lacruz, et al., 2017). These impacts extend to biosystems, particularly forests (Carnicer, et al., 2011; Rubio-Cuadrado, et al., 2018; Pasho, et al., 2011; Camarero, et al., 2015) and wildfires (Pausas and Fernandez-Munoz, 2012; Ruffault, et al., 2018).

Drought is one of the most common and recurrent natural risks that, if not dealt with effectively, turns into a disaster such as famine, with long-term negative impacts on nations and communities. The available statistics show that the number of drought impacts increased from 15 in 2004 to 22 in 2005. In 2005, some 22,788,083 people were affected by drought, as compared with 11,541,000 people in 2004. A recent International Strategy for Disaster Reduction (ISDR) survey concludes that droughts are a natural, recurrent component of the climate system and also that drought-related hazards are expected to increase in the future as society places ever growing pressure on the natural resource base. This increase in the drought hazard may result from an increased frequency and severity of meteorological drought, increased societal vulnerability to drought, or a combination of both. More than other natural hazards, the risk of drought depends on the effectiveness of governance and the management of responsible national and local mechanisms, as well as on the degree of vulnerability. To prevent drought from becoming a disaster, as in the case of famine, the involvement of all stakeholders with a strategic vision that involves empowering communities should be developed by governments (Cathy and Thomas, 2016).

Although mechanisms to cope with drought have been developed over recent years, challenges remain that require our collective attention. Appropriate policies, information management, and monitoring, prediction models, science, technical and technological development, methodologies for early assessment and impact analysis, and the relationship between vulnerability and impact on communities are only some of the areas that must be better addressed to cope with drought (Cathy and Thomas, 2016).

Drought is one of the most serious transboundary and regional natural risks. Several countries are often at risk of drought and famine when hit by severe climate variability. The threat of more severe climate change only increases the need to reduce risk and vulnerability as rapidly as possible. There is a need for close regional and international collaboration on various aspects and phases of reducing the risk of drought and better preparedness to face its negative impacts (Cathy and Thomas, 2016).

Also, since 1900, the third-most deadly flood frequency has been inAfrica, followed by Europe. With four floods, South Africa is most prone to deadly floods. Meanwhile, Algeria, Kenya, and Nigeria, have each experienced two deadly floods, while Burkina Faso, Ethiopia, Ghana, Malawi, Mozambique, Morocco, Sudan, Somalia, and Tunisia have each experienced one deadly flood. Finally, the fewest deadly flood events have occurred in Europe, and nonehave occurred in Oceania. Italy and Spain are the European countries with the deadliest flooding, followed by the United Kingdom and Russia, each having experienced two events. Other European countries that have experienced one deadly event are Belgium, Bosnia, Croatia, the Czech Republic, France, Germany, the Netherlands, Portugal, Poland, and Serbia.The number of deadly flood events is somewhat consistent with the number and percentage of flood events reported by the continent. (IFRC, 2006 and 2016).

Although there are many definitions of flood, most are restrictive in nature because they refer only to the overflow of major rivers that spread water onto the floodplains. Such definitions exclude floods occurring beyond floodplain areas. However, floods also occur in coastal areas due to daily tidal activity, storm surges, and tsunami waves. Thus, a flood is a hazard that causes water to overflow and submerge land that is normally dry. This resonates with Ward's definition,"A flood is a body of water which rises to overflow land which is not normally submerged" (cited in Smith and Ward, 1998). The Center for Research on the Epidemiology of Disaster (CRED) defines a flood as a significant rise of water level in a stream and includes lakes, reservoirs, and coastal regions (Jonkman and Kelman, 2005). The Federal Emergency Management Authority (FEMA) in the United States considers a flood to be a general or temporary condition where two or more acres of normally dry land are partially or completely inundated. The inundation can be derived from overflow of inland or tidal waters, unusual and rapid accumulation of runoff surface waters, or the collapse or subsidence of land along the shores of a water body (FEMA, 2017).

Historic hydrometeorological Hazards in Tunisia

Tunisia has witnessed severe drought events that broadly impacted human activities, leading to bad harvests, failure of crops, increases in food prices, shortages, livestock mortality, hunger, epidemics, and famine. To cope with this situation, early civilizations in Tunisia endeavored to mitigate the negative impacts of these events by constructing water infrastructures.

Tunisia's climate records began in the Middle Ages, and include hydology events in the country's recent history. These records attest to the spatio-temporal variability of such events, their frequency, important processes and variables, and the heterogeneity of Tunisia's natural systems, factors increasingly shaped by recent climatic and landscape changes. Drought is a normal, recurrent feature of THEclimate, although it is erroneously considered a rare and random event. It differs from aridity, which is restricted to low rainfall regions and is a permanent feature of THEclimate. Drought should be considered relative to some long-term average conditions of the balance between precipitation, and evapotranspiration (i.e., evaporation +transpiration) in a particular area. It is also related to the timing (principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness (i.e., rainfall intensity, number of rainfall events) of the rains. However, these are only conceptual definitions that are unable to give an operational definition of drought (Gaaloul, 2008).

Many definitions of drought are adopted in various fields, Consider changing the wording the components of the hydrological cycle considered in the analysis and to the different impacts on water users and ecosystems. The following categories of drought are usually considered (Gaaloul, 2008):

- **Meteorological drought** is usually defined on the basis of the degree of dryness (in comparison to some "normal" or average amount) and the duration of the dry period. Definitions of meteorological drought must be considered specific to a region since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region.
- **Agricultural drought** links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth.
- **Hydrological drought** is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply (i.e., stream flow, reservoir and lake levels, groundwater). The frequency and severity of hydrological drought are often defined on a watershed or river basin scale.

Although climate is a primary contributor to hydrological drought, other factors such as changes in land use (e.g., deforestation), land degradation, and the construction of dams all affect the hydrological characteristics of the basin.

Drought is a frequent climatic event in Tunisia. Except for the south, which had a rather dry decade, the decade from 1990 to saw a predominance of drought (globally: four dry years, one humid year: 95-96 for the body of the country, three comparatively humid years, and two average years). According to the frequency of dry periods and floods since the spelling century, Tunisia experienced 30 inundations and 49 periods of drought. During the twentieth century, characterized by a following uniform of rainfall, 17 inundations alternated with 20 drought periods (Figure 5).

From which a rather dry Character that humid of the Tunisia, this that necessitated the placement, some places of a guiding plan of management of the drought (Scarcity) during the abundance periods (inundations). In Tunisia, the drought is particularly affecting the arid and semi-arid regions characterized by unfavorable climatological and hydrological conditions. Low and erratic rainfall results in frequent periods of serious drought, alternating with periods of floods causing major damage and soil erosion. A strong drought phenomenon is living in Tunisia. A very dangerous natural phenomenon. It concerns the population and all the economic systems of the country. It is not predictable and not easy to manage negative impacts on aquatic and land ecosystems. The negative influence on the quantity and quality of surface and groundwater is salinization (Cary et al., 2013).

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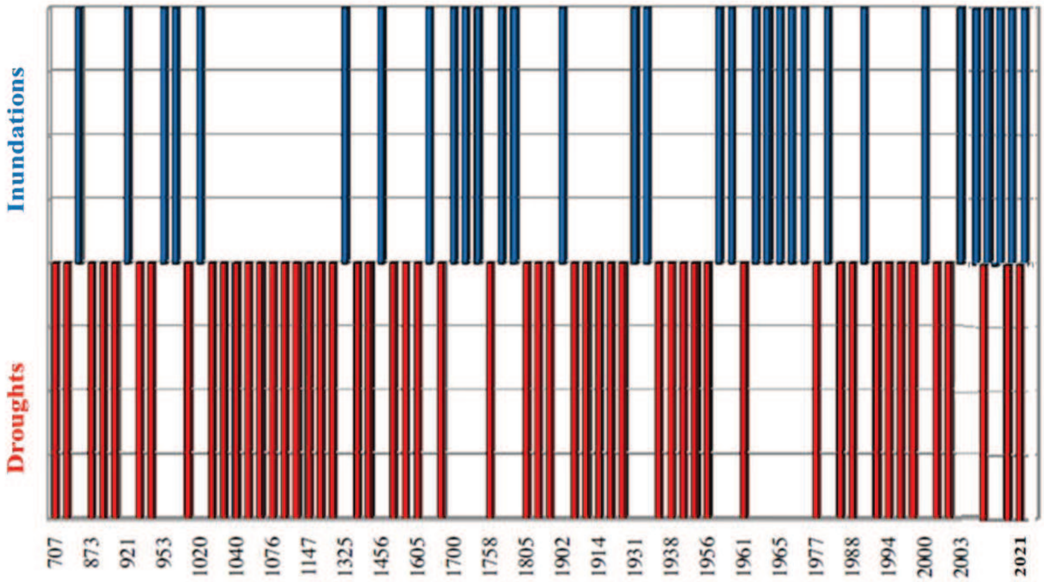

Figure 5. Historic provision of Droughts and Inundations in Tunisia (707-2021) (Gaaloul, 2021)

- 707 à 1640 : 25 Droughts and 8 Inundations
- 1640 à 1758 : 0 Droughts et 3 Inundations
- 1758 à 1900 : 4 Droughts s et 2 Inundations
- From 1900 : 20 Droughts s et 17 Inundations

The rainfall from 25 to 75% is inferior to the seasonal average in a large part of the country.The increase in the minima of temperatures and decrease of food production 10 to 40% compared to the average in the last ten years. The irrigated areas constitute the solution and new water harvesting techniques have to be adopted. Some strategies to manage drought in Tunisia are as follows:

- Reinforcement of hydraulic equipment (dams, small dams, and recharge aquifer's)
- Institutional reinforcement
- Research.

The probability of drought in three successive years varies from 11% to 34% in Tunisia. The probability of the apparition of a drought succession is resumed in table 4.

Table 4. Probability of apparition of a drought

Region	Prob. no drought / Yno Drought (%)	rob. drought / Drought (%)	Prob. 2Y / rought (%)
Tunis 127years	22	15	14
North West	19	11	11
North East	19	23	22
Center	23	24	23
Sahel (sea)	28	23	22
South West	25	35	34
South East	26	21	21

In Tunisia, over the last 50 years, floods have caused huge damage and serious socio-economic risks. In fact, between 1959 and 2015 (floods of 1959, 1962, 1969, 1973, 1979,1980, 1982, 1990, 1995, 2003, 2007, 2011, 2015), at least 815 people were killed by floods, thousands were injured, and 76,300 people were dislocated because of habitat destruction.

The autumn flood of 1969 was one such event (Boudhraâ et al., 2015), predating the advent of major dams, and affecting a large part of the country. The flood caused 542 fatalities, destroyed 70540 houses and left 340,000 people homeless. A discharge of 1,92 l/s/Km² for an 8,950 km² basin was a record for Northern Africa, and the

Medjerda wadi flowed permanently for a few months. The autumn 1969, extremely severe synoptic event is a milestone as it covered a large part of the country, hit Tunisia before the setting up of the major hydraulic infrastructures that exist nowadays, and was extremely severe in terms of hydrometeorological processes and impacts. In September, the National Institute of Meteorology (INM) recorded 10-day accumulated raifall of up to 400 mm in certain regions, and 30-day accumulated rainfall in October up to 500 mm over large areas, with measured intensities up to 80 mm /h. Some direct hydrometric observations have been made, especially in the Zeroud wadi basin.

The Medjerda wadi is permanently flowing, which is quite unique in Northern Africa (except the Nile), and has made it a strategic basin for human settlements and agriculture since antiquity. The setting up of modern hydraulic infrastructures (dams, dykes) for local and remote uses (through dam), sometimes in a multiobjective rationale (especially the Sidi Salem dam), has changed the hydrologic (including sedimentary) functioning and the vulnerability to hazards over the last decadesand has a strong upstream-downstream interdependency. Depending on the rainfall (and snow) regime and the geographic-hydrographic organization, slow floods essentially occur upstream and from northern tributaries in winter, and rapid floods essentially occur from southern tributaries in spring and autumn (GoG and GoT 2016; Rodier et al., 1981). Floods in Medjerda wadi from the various tributaries contribute differently to the shape of the main hydrograph depending on the space-time dynamics of rainfall, which induces difficulties for operational management.

Between 27 and 31 March 1973, floods with a maximum discharge of about 3,000 m^3/s were recorded, and these were followed frequently by others. Between 16 and 20 January 1990, over 500mm of unseasonal rain caused widespread floods in the south and central regions. The volume of sediments transited by the El-H'tab wadi (central Tunisia) at its exit from the Kharroub djebel (Khanguet Ezzazia) due to this event, was estimated at 355,010 m^3 for a watershed of 2,200 km^2 , which represents a specific degradation of about 161 m^3/km^2 (1.61 m^3/ha). Localized heavy rainfall and floods, especially over coastal cities, define risks at smaller spatio-temporal scales. In September 2017, rain over the Gulf of Gabes and Matmata escarpment flooded wadis flowing toward the Gabès gulf and Jeffara valley, with flows of up of 350 m^3/s, causing erosion, geomorphic changes, and damage to infrastructure.

The "Grand Tunis" area regularly experiences intense rainfall, and is vulnerable because of its position at the base of a major watershed and a historic drainage system that has not kept pace with city growth. Between 16–24 September 2003, heavy rains in Tunis-Carthage inundated large areas of Tunis, and floods re-occurred in October 2007 and September 2019 (MARHP, 2019).

In September 2018, catastrophic flash floods in the Cap Bon region caused six deaths and major damage to Nabeul city (GoT et al., 2018; DGRE 2018, 2019) following historic rainfall. Analysis showed that the discharge potential of certain wadis had been amplified by installments, hydraulic defenses were undersized and un-maintained, and that coastal urban zones were vulnerable to extreme runoff, coastal geomorphology and coastal-oceanic weather systems.

Following the disaster, post-disaster analysis revealed that installments in some wadi valleys increased vulnerability and discharge potential, that some preferential flow paths had been overlooked, and that some local hydraulic infrastructure and equipment were under-sized and lacked cleaning routines. Especially, the analysis confirmed the possibility of extreme local rainfall-runoff events enhanced by particular meteorological-oceanic circumstances, particular coastal geomorphology, and the vulnerability of a dynamic coastal urban zone.

Photo1. Inundations of the Grand Tunis" area in Tunis (September 16th, 2003) (Gaaloul, 2011)

Photo 2. Torrential rains in Tunis (October 13th, 2007) (Gaaloul, 2011)

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Tunisia also has a history of 20th century droughts (Mouelhi and Laatiri, 2014; OSS, 2013), and experienced severe droughts in the 1920s, 1940s, 1960s and 1980s (Hénia, 2001); in the 1940s and 1980s droughts persisted for many years, with the 1940s drought the most severe of the century with below-average rainfall for up to eight successive years in some areas; the drought at the end of the 1980s was severe and country-wide in impact. These droughts have an impact on agriculture and health, and may also cause locusts to swarm.
Some stations experienced 6 to 8 successive dry years. During four successive years (from 1944-45 to 1947-48), the 400 mm isohyet remained north of the middle and lower Medjerda valley, i.e., more than 150 km north of its average position, south of the Dorsale (Hénia, 2001).
During the 1980s, years with below-average rainfall prevailed for many years. The end of this decade (1987-88 to 1988-89) experienced a severe drought with an intense deficit in rainfall that affected the whole country. These events seriously impact various socioeconomic and environmental sectors in the country, spanning from agriculture to health. An individual peculiar event of locust invasion happened in Tunisia in March 1988 as a result of 2 consecutive drought years.
Droughts are slow-onset disasters and less dramatic than other extreme natural events; however, they can last for considerable periods, even for several years or decades, as in Tunisia: 49 Droughts (Figure 5).. Because of its long duration, climatologists call drought a "creeping disaster." Effects of this natural event are not felt at once, but they slowly take hold in an area and tighten their grip over time. Others compare drought to a python, which slowly and inexorably squeezes its prey to death. Such a drought is generally defined in terms of its impact rather than its genesis. Droughts occur in nearly every part of the world as well as in almost all climatic regimes, but with varying frequency. They also occur in both dry and wet seasons and thus are a much more complex phenomenon than a routine dry season. However, droughts should not be confused with aridity. In desert or arid regions, rain is rare, and temperatures are high.
Therefore, the lack of rain is the characteristic feature of the climate of such a region. Drought is thus an occasional phenomenon in the region. Droughts are more widespread in terms of area than other natural disasters such as earthquakes and tornadoes, so they affect more people over a larger area. With agrowing population, people are increasingly forced to settle on marginal land, and thus, areas subject to drought are expanding over time. Since the 1970s, areas affected by droughts have doubled. Although droughts may begin any time of the year, they are seasonal in certain places. Their impacts may range from mere local inconveniences to the economic and political breakdown of a nation (WMO, 2014). Often, droughts are broken by heavy rainfall and floods, particularly in semiarid and arid regions.
Floods are the most common natural disaster, affecting nearly the entire country from 707 to 2021 (Figure 5).They are the costliest natural disasters in Tunisia.
Tunisia has frequently experienced torrential rains, which may be considered an effect of climate change. In 2000, 2001, and 2003, particularly large floods triggered by heavy rains broke out in the greater Tunis area of northern Tunisia and the nearby lower river regions, causing widespread inundation damage. Additionally, as a result of rapid urbanization and the accelerated pace of development, as reflected in the reclamation of wadis for road development, housing construction in flood-prone districts, and so on, more and more areas are likely to be hit by flood damage. The torrential rains that occurred in September 2003 devastated the greater Tunis area. These probable torrential rains with a 100-year return period resulted in the deaths of four people and damage valued at around 45 billion yen. An area along a vast lakefront was inundated and traffic was cut off as roads became covered with water, paralyzing Tunisia's capital functions for more than two days (Gaaloul et al., 2015).

Photo 3. Inundations of the Medjerda wadi in the North of Tunisia (February 26th, 2015) (Gaaloul, 2011)

Photo 4. Inundations of the Medjerda wadi in Medjez bab City (February 26th, 2015) (Gaaloul, 2011)

Socio economic Impacts of Hydrological Hazards and Risks

Tunisia is highly vulnerable to natural hazards and climate change, with impacts felt across key sectors of the economy. Between 2011 and 2018, Tunisia recorded over 2,550 fires, which devastated about 34,000 hectares of forest. In 1957, an earthquake in the Jendouba governorate with a magnitude of 5.6 on the Richter scale caused the loss of 13 lives and the collapse of buildings (WB/GFDRR, 2022).

Tunisia has a more diverse economy than other Maghreb countries, with agriculture, industry, mining, and tourism as important sectors. Climate change will significantly affect two of these sectors – agriculture and tourism (and related services). Tunisia's agriculture is primarily rainfed and is thus highly vulnerable to rainfall variability, long droughts, and increasing temperatures (Verner, 2013). The agricultural sector contributes 11–12 percent of GDP, generates around 6 percent of export earnings, and employs an estimated 16 percent of the labor force (Resolve and GIZ, 2013; Van des Gaast, 2018). The droughts caused by climate variability and change will particularly affect rainfed cereal farming, with an anticipated reduction of approximately 30 percent in agricultural land area and lower production of crops such as wheat and barley (SNC, 2013; Verner, 2013).

However, climate change will also impact Tunisia's agricultural exports. Tunisia is a major world producer and exporter of olive oil and dates (accounting for 24 percent of global trade) (Ben Ahmed Zaag, 2017; Jacobs and Klooster, 2012) Currently, about 40 percent of all cultivated land is used to grow olives (Van des Gaast, 2018). It is predicted that climate change will cause olive production to drop by 50 percent and that land area suitable for olive cultivation will decrease by 42 percent in the southern part of the country (Resolve and GIZ, 2013). Similar trends are expected for other crops as a result of the rising temperatures and decreasing rainfall causing climate change. Together, higher global food prices and lower local yields will reduce economic growth in Tunisia. Farm incomes are projected to fall by 2–7 percent annually on average from 2000–2030. While farming households will be hardest hit by climate change, rural, non-farm, and urban households will also be affected by rising global food prices due to climate change.

Heavy rainfall began on September 12th, 2020, when Monastir, the capital of the Monastir Governorate in the center of the country, and many other towns around recorded 47.8 mm of rain in 24 hours, and Sidi Bouzid and many other towns of this governorate had 58 mm. During the same period, Mahdia and localities belonging recorded more than 40 mm of rain in 24 hours during 3 separate days. Kairouan recorded 89 mm of rain. Kef governorate registered similar amounts of rain, especially in the Sers locality. During that period, almost an average of monthly rain was registered (WB/GFDRR, 2022).

According to the country's Civil Protection Agency, flooding and related fatalities were reported in the governorates of Monastir, Sousse, Mahdia, Sfax, and Tunis. Floods struck several districts of the capital, Tunis. Some areas were under 1 meter of water, leaving roads impassable and buildings damaged. The orthopedic hospital in the governorate of Manouba was flooded; water reaching archives and hospitalization rooms. The national Institute of Meteorology (Institut national de la météorologie) of Tunisia issued warnings for further heavy rainfall on 13th and 14th of September. Consequently, floodwater surged through many different districts, damaging infrastructure, houses, properties, and livelihoods of the community members (WB/GFDRR, 2022).

During this period, media reports said at least six people died in floods after days of torrential rainfall in Tunisia, hundreds were rescued and thousands of homes damaged. More than 40,000 people have been affected by the floods. Some of them fled their homes seeking shelter in neighboring high-ground houses and communities. Water supply through pipelines is limited, and the water available in some areas is contaminated. Electricity has been cut off in certain districts to avoid risk to people and electrical damage (IFRC, 2018).

Losses incurred as a result of floods, droughts, and fires were estimated to be $541.3 million between 2011 and 2018, with 94 percent of deaths attributed to floods and earthquakes (Figure 6).

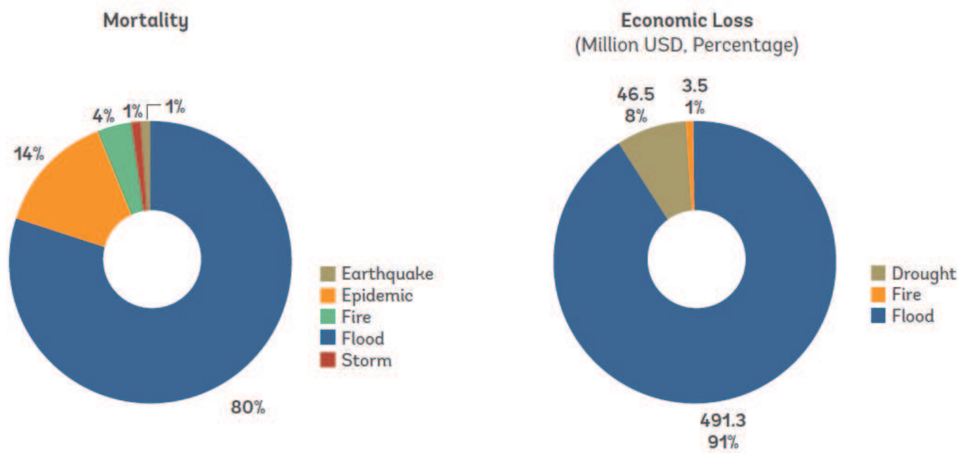

Figure 6. Mortality and Economic Losses (2011–2018), (WB/GFDRR, 2022).

The Tunisian coast hosts two thirds of the country's population, over 70 percent of its economic activities, including tourism, and most of its irrigated agriculture. By 2100, the anticipated sea level rise will directly affect 5 percent of the Tunisian population, its water resources, natural ecosystems, coastal infrastructure, agriculture (e.g. reduction of 10 percent of irrigated areas) and tourism. Due to the importance of coastal tourism, such a rise may have a significant impact on the economy. Droughts, floods, heat waves, and strong winds, in combination with climate-induced decreases in water availability and increased water costs, are likely to have negative effects on tourism in coastal areas. Climate change will intensify the pressure on Tunisia's water resources to meet the demands of a growing urban population and the agriculture, industrial, and tourism sectors (World Bank, 2018).

On Saturda, September 22, torrential rain hit north-eastern Tunisia's Cap Bon Peninsula, causing water levels to rise 1.7 meters. The storm dumped approximately 200 millimeters (7.9 inches) of rain on Nabeul and up to 225 millimeters in the city of Beni Khaled, in the peninsula's center, according to Tunisia's National Institute of Meteorology. This was the heaviest rainfall since the institute began keeping records in 1995. A warning for the storms was issued on September 21st. Floodwater surged through villages, resulting in the loss of 6 lives and damaging infrastructure, houses, properties, and livelihoods of the community members. More than 6,000 families have been affected by the floods. Some of them fled their homes, seeking shelter in neighboring high-ground houses and villages, while others chose to stay in their damaged houses moving to rooftops rather than risking crossing flooded areas to reach evacuation points. Water supply through pipelines is limited, and the water available in some areas is contaminated. Electricity has been cut off in certain districts to avoid risk to people and electrical damage. (IFRC, 2021).

A Rapid Needs Assessment (RNA), conducted by the Government of Tunisia in partnership with the World Bank (WB), the United Nations and the European Union estimated recovery needs at approximately US$100 million. Most of these needs were in the transport, agriculture, and housing sectors, which were significantly impacted by the flooding. The Nabeul disaster flagged Tunisia's exposure to the growing risks of climate change.

The COVID-19 pandemic that began in early 2020 essentially locked down North America, Europe, China, India, and other countries (Gaaloul, 2022). Individuals were advised, sometimes ordered by government agencies, to stay home in order to reduce person-to-person transmission of the virus and to wear a face mask when near other people. The policy of social isolation resulted in far fewer motor vehicles traversing streets and highways, fewer commercial activities such as sporting events, bars and restaurants, and large group activities, all actions that influence climate change dynamics. A further impact of COVID-19 on climate change dynamics was the decline in ridership on buses and trains. A year into the coronavirus pandemic, public transit has experienced a dramatic, dire loss of ridership. Riders remain at home or they remain fearful of boarding buses and trains.. As to climate change, public transit offers a relatively simple way for cities to lower their greenhouse gas emissions because fewer automobiles are utilized, resulting in fewer emissions of greenhouse gases (Gaaloul et al., 2022).

The impact of climate on mental health has been the subject of an investigation. One set of researchers commented on published literature that found exposure to hurricanes and foods is associated with symptoms of acute depression as well as posttraumatic stress disorder, Psychiatric hospital visits increase during hotter temperatures, and both heat and drought amplify the risk of suicide. Further, people with preexisting mental health conditions and lower socioeconomic status are among the most vulnerable to these adverse environmental conditions, commented the researchers (Obradovich et al., 2018).

Assuming that the projections of the dire portent of climate change are true, interventions to mitigate climate change go beyond the necessary to the level of vital. Some people might argue that interventions would be extraordinarily costly, burdensome to global societies, and a misuse of resources needed for use by an increasing global human population. But upon reflection of what can already be observed and attributable to climate change (e.g., rising sea levels, melting polar ice, shrinking glaciers), the question must be asked, "Can humankind afford to be wrong about mitigating climate change?" Given this question, interventions must be implemented. Some of the interventions to lessen the hazard posed by climate change are the following:

- On a global scale, support through sociopolitical means, those policies that are based on consensus science, presented in transparent reports, and implemented through diplomatic dialog and resolution.
- On a national scale, support through sociopolitical means those policies and policymakers that advocate for the development and promulgation of policies for climate change mitigation.
- On a personal scale, use objective, transparent sources of climate change information as the basis for personal decisions and policies. This could include choosing consumer products manufactured by sources that have a neutral carbon impact on the environment. Other individual policies might include selecting energy sources that are not carbon-based, e.g., solar power, wind, and geothermal.
- Industrial entities should understand their role in mitigating climate change and redesign or replace carbon-dependent manufacturing processes and products.
- Research on the control of CO_2 emissions should be encouraged. For example, researchers have discovered a new iron-based catalyst that converts CO_2 into jet fuel. If CO_2, rather than oil, were used to make jet fuel, it could reduce the air travel industry's carbon footprint.

Photo 5. The September 2018 flash floods in the Nabeul governorate (Gaaloul, 2021)

Climate Related Natural Hazards

The phenomenon of climate change is now a reality because of its impact on many areas of our life. The important task of an expert today is to call the attention of humanity to the management of the natural resources that are subjected to disappearing, significant reduction or loss in their quality. The influence of the spatial variability of rainfall on hydrological rain-flow modeling is an active research topic, as evidenced by the abundant literature published in recent years. A proper understanding of rainfall patterns and trends may help water resource development to make decisions about the development ctivities of that region. The bioclimate of Tunisia varies from sub-humid (North) to Saharian (South). The precipitation, in the North of Tunisia, are very variable in time and space. The valley of Medjerda belongs to this category where the flooding is very frequently given the relief, the climate, the river morphology, the land cover, etc. The quantification of the various components of hydrological processes in a watershed remains a challenging topic as the hydrological system is altered by internal and external drivers. Watershed models have become essential tools to understand the behavior of a catchment under dynamic processes.

Tunisia has a high degree of risk to natural hazards. The country experiences disasters such as flash flooding, droughts, storms, sandstorms, and earthquakes; sea-level rise also poses a significant threat to the country's coastline, not only due to inundation and salinization but also from increasingly harmful storm surges. The region has also been impacted by an increase in frequency and intensity of extreme weather events such as heavy rainfall, landslides, and flooding, as well as droughts. An increased frequency of extreme events, such as droughts, soil erosion, and desertification. The country is expected to become generally hotter and drier in projected future climates, and as such, Tunisia is increasingly severely impacted by and susceptible to drought. While drought conditions are generally a common occurrence, Tunisia has experienced increasingly frequent occurrences of aridity and drought in recent years (UNISDR, 2013). Sea level rise is projected to lead to the loss of a sizable proportion of the northern and eastern coastlines due to a combination of inundation and erosion, with consequential loss of agricultural land, infrastructure, and urban areas. (Reimann et al., 2018).

Data from the Emergency Event Database: EM-Dat database, presented in Table 5, shows the country has endured various natural hazards, including floods, landslides, epidemic diseases, and storms.

Table 5. Natural disasters in Tunisia, (EM-DAT, 1900–2020)

Natural Hazard 1900–2020	Subtype	Events Count	Total Deaths	Total Affected	Total Damage ('000 USD)
Drought	Drought	2	0	31,400	0
Earthquake	Ground Movement	1	13	0	0
Flood	Flash Flood	5	69	37,508	36,000
	Riverine Flood	4	49	180,500	242,800
Insect Infestation	Locust	2	0	0	0
Wildfire	Forest Fire	1	0	2,000	0

Disaster risk from increased temperatures and reduced precipitation is expected to exacerbate existing tensions for water resources between agricultural, livestock, and human needs, especially during periods of high aridity and drought. The existing quality of available water from surface water and groundwater is also likely to be altered. Water scarcity and changing rainfall patterns will play a significant role in the agricultural sector (Tunisia, 2019).

Currently, the growing need for fresh-water supplies in the coastal aquifers is rapidly increasing due to steady population growth and intensive economic activity. However, this resource is especially susceptible to deterioration owing to its closeness to seawater, in addition to the excessive water needs that accompany higher population densities and agricultural activities. Increased temperatures and degraded agricultural conditions are expected to adversely impact the livelihoods and economic resilience of vulnerable groups, as well as increase the risks of wildfires. Most of the country's population and infrastructure are concentrated along the Mediterranean coast, making the country additionally vulnerable to the impacts of sea level rise and coastal erosion, particularly inundation and saltwater intrusion. Figure 7 presents the risk of coastal flooding and wildfires in Tunisia (European Commission, 2018).

Climate change is expected to increase the risk and intensity of water scarcity and drought across the country. The primary sectors affected are water, agriculture, forestry, human health, and livestock. Additionally, the increased frequency of intense precipitation events will lead to a heightened risk of flooding, river bank overflow, and flash flooding. Flooding may also result in soil erosion and water logging of crops, thus decreasing yields with the potential to increase food insecurity, particularly for subsistence-scale farmers. Higher temperatures with increased aridity may also lead to livestock stress and reduced crop yields. This is likely to result in significant economic losses, damage to agricultural lands and infrastructure, as well as human casualties. Furthermore, land degradation and soil erosion, exacerbated by recurrent flooding and drought adversely impacts agricultural production, further affecting the livelihoods of the rural poor. Small rural farmers, are more sensitive to the impacts of these types of disasters (floods, dry periods) because they have limited resources with which to influence and increase adaptive capacity (Tunisia, 2019).

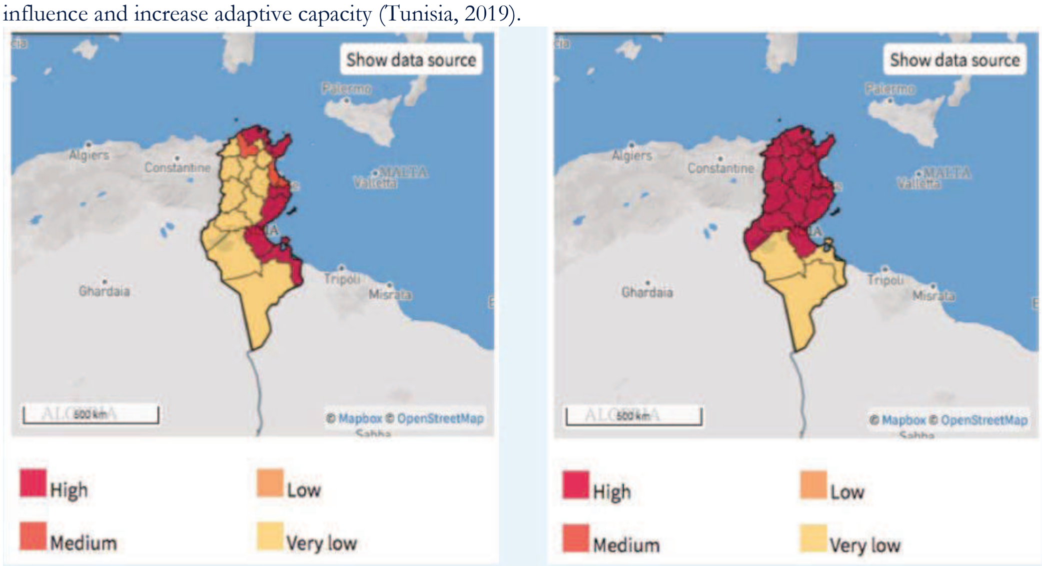

Figure 7. Risk of Coastal Flood (left) (ThinkHazard; 2019a); Risks of Wildfires (right) (ThinkHazard, 2019b)

Tunisia is projected to experience decreases in average rainfall, resulting in increases in the intensity and frequency of dry periods and water scarcity. Increases in temperature should reduce soil moisture, surface water, and underground water storage. These are likely to worsen the increasing water needs, notably for human use, but more particularly for agriculture, given the increase in evapotranspiration and the decrease in soil humidity. Most of the country's groundwater comes from deep aquifers in the south, among which the largest resources are non-renewable fossil groundwater. Currently, the country is undergoing intensive exploitation of underground resources, which provide around 81% of the water needs of the irrigated sector (Republic of Tunisia, 2016).

Tunisia is also expected to experience a decrease in water availability, with greater decreases in water stocks experienced in the northern areas of the country, where ground water is the primary source for agriculture and human consumption. The country's water resource scarcity by the 2050s is expected to be significant and is likely to result in further drying of key water sources, especially for rural communities and in central and southern areas. Water use conflicts are already occurring and are becoming more severe in Tunisia, particularly during drought periods rural areas relying on springs for drinking water will be the most affected, given the drying up of these springs. Women are likely to be even more vulnerable, considering that they are often responsible for water supply and hygiene in the household. The poorest people, including crisis between different regions of the country (Tunisia, 2019).

Rainfall and evaporation changes also impact degrees of surface water infiltration, and recharge rates for groundwater, and low-water storage capacity increasing the country's dependence on unreliable rainfall patterns. Changes in rainfall and evaporation translate directly to changes in surface water infiltration and groundwater recharge. This has the potential for further decreased reliability of unimproved groundwater sources and surface water sources during droughts or prolonged dry seasons. Increased strain on pump mechanisms can lead to breakdowns if maintenance is neglected, and the potential for falling water levels near wells or boreholes, particularly in areas of high demand. Additionally, temperature increases have the potential to result in increased soil moisture deficits even under conditions of increasing rainfall.

Tunisia has already lost more than 90 km of beaches due to erosion or due to the construction of artificial defense structures. Of the 570 km of existing beaches, 190 km are classified as very degraded and likely to disappear. Tunisia is also expected to experience loss through the submersion of approximately 16,000 ha of agricultural land in low-lying coastal areas and approximately 700,000 ha of built-up areas. Salinization is expected to impact up to 50% of the resources available in coastal aquifers, with the potential to indirectly jeopardize the sustainability of 38,000 ha of irrigable land by the 2050s (10% of currently irrigated land). The country's burgeoning tourism industry is expected to see a decline in activity due to retreating beaches, with losses estimated at USD 2 billion, approximately 0.5% of annual GDP. Losses are expected to occur primarily in the tourism sector (55%) and agriculture sector (45%), with the further loss of an estimated 36,000 jobs in the tourism and agriculture sectors.

However, for the Tunisia region, a comprehensive analysis of water demand and scarcity over the next 50 years has been conducted using a combination of hydrological and water resource models, remote sensing, and socioeconomic changes. Studies published so far have not been able to reveal the full picture as their focus has been on a limited number of aspects only. Outstanding issues with previous studies include the following (Gaaloul, 2011):

(i) They focus only on climate or agriculture;
(ii) They are based on statistics rather than a thorough hydrological analysis;
(iii) they are based on annual or monthly approaches rather than on the required daily approach to capture hydrological processes;
(iv) they use only a limited number of GCM realizations;
(v) They use coarse spatial resolution to model the hydrology;.
(vi) they do not include socio-economic aspects.

Conclusion

Tunisia is a water-scarce country and substantial imbalances exist in water resource distribution between the better endowed north and the semi-arid south in regards to water balance, storage, and water distribution. The country has a 90% mobilization rate of water resources through dams, whereas groundwater resources already overexploited. A network of canals and transfers exists to transport water from the north to the south. The country's main permanent watercourse is the Medjerda River, with sources in Algeria and on which Tunisia's largest dam, the Sidi Salem dam, is located. Rainwater also infiltrates the soil and contributes to the country's water reserves for rainfed agriculture, with the remaining water stored in wetlands or flowing towards the sea. While the country has made significant progress in regards to its water supply, sanitation, and water-related health services, significant imbalances and lack of access still remain high. Inequalities persist with regard to service availability, water quality, and access, particularly across different geographies and between urban and rural populations.

Understanding natural hazard occurrences as well as historical climate conditions, in relation to development contexts, is critical to understanding a country's historical vulnerability. This tool allows the visualization of different natural hazards or historical climate conditions with socio-economic and development datasets.

Climate variability and human activity have critical impacts on the sustainability of natural water resources, which may lead to the over-abstraction and deterioration of water quality. In the context of climate change and an increasing demand for water, it is important to stress the distinction between vulnerability and exposure to dangers. Vulnerability is made clear when exposure to dangerous forces occurs. However, people who are more exposed can, in fact, be less vulnerable if provided with adequate protection. Limited exposure may offset unusual weaknesses – what might be termed the trade-offs of frontline responders, firefighters, or lighthouse keepers. Then again, those whose losses stand out in disasters tend to exhibit both adverse exposure and multiple vulnerabilities. In the 2020 covid-19 pandemic, for example, social inequities, indifference, or neglect were the scandalous partners of the plague. Greater concentrations of infections and mortality affect people and groups already disadvantaged. Frontline workers were widely denied adequate protection and support – though called 'essential'. People with preexisting health-related weaknesses and insecure livelihoods have proved more at risk. They include, especially, women, racialized groups, migrant workers, needy children, and the uncared-for elderly. When students of disaster take power seriously, they can contribute to a critical assessment of policies that disregard, condone, or are complicit in displacement and risk creation. Disaster studies can also help to understand increasing citizens resistance to the systems of power that have brought the planet and humanity face to face with increasing daily risk for some, and existential risk for all.

The latest and current global-level disaster is the COVID-19 (and variants) pandemic. Research and investigations into the cause and potential responsibility for the pandemic are still ongoing (early 2021) and a clear and definitive answer may never be achieved. It seems clear, however, that the virus originated in an animal species.

Growing salience among a range of underlying factors and root causes are climate change, pandemics, and economic and technical globaliZation. Long gone are the days when it seemed reasonable to refer to 'natural' disasters because the disasters in question were caused by extreme natural events. It has come to be understood, after many decades of debate, that disasters are the result of human choices which help to create and perpetuate local and personal vulnerability. With the advent of climate change, the role of climate change in destabilising atmospheric processes, increasing the frequency and magnitude of extreme events, and the emergence of epidemics and pandemics, it is now apparent that the underlying causes of disasters include the whole global system of economic growth and development. Vulnerability is no longer only, or mainly, localised, it is widespread and global.

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