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Overview of the climate change impact on the environment and humanity

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Abstract
Even on a scientific level, climate change is often confused with the term global warming. However, this term is broader and includes global warming, the rise in sea level, the distinction of animal and plant species, the more intense climatic events, and certain other aspects observed on our planet in recent decades.
The objective of this article is to make known the causes and the effects of climate change to the public in order, to correct their behavior regarding the environment that surrounds them and to take the necessary actions that protect them from the consequences adverse of such change.
It brings to mind the essential causes of global warming which are attributed to the emission of greenhouse gases (GHG) and the poor management of territories, in particular deforestation and agriculture.
Then, it evokes the impacts of climate change on the environment, which are multiple, increasingly frequent, and affect all the world's ecosystems including the world population, and the planetary biodiversity. It also cites case studies and experimental achievements to deal with the negative effects of climate change.
Finally, this overview presents the options and adaptation strategies that would be useful to try in the different countries, each according to its possibilities. These options range from the reduction of greenhouse gas emissions to the implementation of new technologies in agriculture, including the protection of coastal areas and, if necessary, opting for the withdrawal of threatened coastal populations.

Keywords: Climate change, global warming, ecosystems, extreme climatic events, mitigations

Introduction

Global warming is the atmospheric temperature rise, felt and observed in recent decades, and which permanently modifies meteorological balances and ecosystems. It is linked to human activity and in particular to greenhouse gases.
It was noticed that carbon dioxide content in the air retains more solar radiation heat, leading to an increase in air temperature. Recently, scientists definitively proved that the greenhouse gas concentration in the atmosphere influences the air's ability to retain infrared rays and heat [1].
To study the evolution of the global warming phenomenon and its consequences, many scientists grouped together within the Intergovernmental Panel on Climate Change (IPCC) in 1988 and they regularly published reports on the state of the climate and the possibilities of its warming.
This group brings together hundreds of scientists: climatologists, geologists, oceanographers, biologists, but also economists, sociologists, engineers, and other specialists from various fields in order to have a global vision of this phenomenon and put in place strategies to fight these changes or to better adapt to it.
The negative impacts of climate change during the last decades were so severe on all life aspects and they were more severe in hot and dry areas, particularly in developing countries. For example, in North Africa (Particularly in Tunisia), which is on the front line of the consequences of climate change, the weather temperature was rising 20% faster than in the rest of the world. We recorded 50.1C° in July 2005 in Borma city (South of Tunisia), 50.3C° in Kairouan city (Center of Tunisia) in the summer of 2021; and more than 50C° recorded in Ariana city (North of Tunisia) in the summer of 2023. As for rain, we noticed a decrease in precipitation by 23% over the last 43 years. In most cases, we have had one rainy year followed by three dry years.
Therefore, climatic change is a major concern for the world population. Thus, it is important to highlight how climatic change will affect growth, development, water use, food security, and biodiversity in the world.
With this overview, we aim to spread scientific information and to make known the causes, and consequences of climate change to the wide public through concrete examples around the world. We propose solutions, which are necessary tools for decision-makers and the public to take practical action to reduce the magnitude of climate change and adapt to its impacts.

Climate change indicators

1. The first indicator is the increase in the atmosphere temperature, which was noticed a long time ago [2]. In addition, extreme heat episodes were observed worldwide with more intense and severe frequency [3].
2. The ocean temperature increase, which has been measured since the 1950s by commercial ships or oceanographic vessels and more recently by the buoy system, showed a global average increase for a few decades.
3. The reduction of Arctic ocean ice and sea ice area is another strong indicator of climate change acceleration:

from 8.5 million km^2 in the period of 1950-1975, sea ice area fell very rapidly reaching 5.5 million km^2 in 2010 [2].

4. The melting of continental glaciers has been observed almost universally for 3 to 4 decades, in the Himalayas and the European Alps. According to the IPCC, glaciers in northern Asia, central Europe, and Scandinavia will shrink by 80% in volume by 2100 [4].
5. The reduction of the polar ice caps of Antarctica and Greenland, which was observed about ten years ago, has been attributed to the ocean water warming of these regions.
6. The rise of the ocean's average level, monitored since 1990 by altimetric satellites has shown a rise in the sea's global average level by 3.4 mm/year over the period 1993-2016 [5].
7. Biological indicators, such as the migration of earthly or marine animal populations and changes in the dates of seasonal agricultural activities, also showed the occurrence of global warming [2].

The causes of global warming

Many scientists believe that greenhouse gas (GHG) emissions of human origin are causing global warming. Energy and fuel production, cause global warming, and then comes territory management in the second rank (deforestation and agriculture including livestock).

Some experiments conducted in the laboratory have shown that in a gas-rich atmosphere (CO_2, CH_4, N_2O, etc.), the cooling rate of this atmosphere is low compared to a normal atmosphere due to the lower concomitant heat loss to its environment. Which confirms that greenhouse gases contribute to global warming [1].

Greenhouse gases (GHGs) are naturally present in the atmosphere. They form a layer around the Earth, allowing it to retain its heat. Indeed, the sun heats the Earth, which, subsequently, re-emits part of its heat towards space. GHGs in the atmosphere trap some of this heat, preventing it from returning to space. This phenomenon maintains average temperatures of 15°C on our planet [6]. Not all GHGs contribute equally to the greenhouse effect. Indeed, their global warming potential (GWP) and their lifetime in the atmosphere are different.

It is agreed that the development of human activities is responsible for the emission of three main greenhouse gases: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The three gases concentration has increased considerably since the industrial period: by 35% for CO_2, 148% for CH_4, and 18% for N_2O [6]; [7] and [8]. The concentration increase of these gases in the atmosphere is at the origin of the temperature increase on the Earth's surface, causing many adverse impacts on the environment.

Over the past century, an average warming of the earth's surface temperature of 0.74°C has been observed, while the average temperature is expected to increase by only 0.6°C [6]. Forecasts for 2100 are even more alarming, with an expected increase in average temperature of 2 to 4.5°C [9].

The consequences of global warming

The impacts of climate warming on the environment are multiple and increasingly frequent droughts, glaciers and sea ice melting, rising ocean levels, tropical storms, etc. They affect the entire world population and planetary biodiversity.

1. Consequences of global warming on ecosystems and agriculture

Global warming affects the entire global ecosystem (increase in extreme weather phenomena, such as storms, floods, cyclones, and drought) but also fragile ecosystems (coral barrier, Amazon forest) and biodiversity (some plants, insects, and even mammals could disappear).

In certain regions of the world, and because of the extreme and prolonged drought, Mélanie, (2011) [10] mentioned that large water reservoirs (dams) have lost 2/3 of their water capacity, in addition to the decline in their quality (water salinization), causing damage not only to agriculture but also to the ecosystems that depend on it.

Brazil's National Institute for Space Research (NISR) avowed that deforestation in the Brazilian Amazon ecosystem has increased by almost 22% in one year. According to the same institute, some fires are triggered voluntarily to transform forest areas into crop and livestock areas.

Another major ecosystem, the Great Barrier Reef located along the Australian northeast coast is one of the most biodiverse ecosystems on the planet. This coral reef could disappear in a few years due to climate change. Such changes would have dramatic consequences for humans and other species that depend on these habitats.

Indeed, corals are sensitive to the increase in the surface water temperature, which exceeds their ability to adapt to climate change. Ainsworth *et al*., (2016) [11] pointed out that since the beginning of 2016, 93% of the Great Barrier Reef has been affected by a massive episode of bleaching, a phenomenon corresponding to the departure of microalgae living in symbiosis with corals, due to too high water temperature.

The reefs, by offering numerous ecological niches, also shelter thousands of other animals, plants, and bacterial species, which makes it one of the richest ecosystems on the planet, along with the tropical forests. It is estimated that around 30% of the marine biodiversity currently listed is found in reefs. Therefore, it is easy to imagine that the current global warming can have repercussions on coral reefs. If the damages were moderate and light then a rapid return to normal would be possible, but if the damages were severe, there would be a much greater risk of coral mortality.

In this context, the Australian Research Council's Center of Excellence for Climate System Science (ARCCSS) published in 2016 a press release estimating that the rise in temperature at the origin of coral bleaching could become the norm by 2034. If greenhouse gas emissions continue to rise and nothing will be done, much of the Great Barrier Reef could be gone by the mid-2030s.

On the agricultural level, it is known that plants respond to CO_2 concentration increase in the atmosphere with the photosynthesis increase and stomatal water vapor conductance reduction [12]. As the concentration of atmospheric CO_2 increases, the partial pressure of CO_2 in the leaf increases, allowing for higher rates of net leaf photosynthesis, reduced photorespiration, and improved water use efficiency [13]. However, the increase of CO_2 content in the atmosphere is generally accompanied by a rise in temperature, which could have both negative and positive impacts on agriculture.

In general, an increase in average temperature and a lengthening of the growing season should lead, with certain

limits, to a potential increase in crop yield in cold countries. Similarly, these modifications should make it possible to produce crops adapted to higher temperatures [14].

Conversely, combinations of high CO_2 and high temperatures of more than 4°C or 6°C above ambient temperature did not improve biomass and grain yield of plant species but tended to reduce them [15]. In hot countries, an increase in ambient temperature leads to the abortion of plant flowers and consequently, a reduction in agricultural production and yields, resulting in a considerable reduction in carbon stored by biomass. In these countries, due to the temperature increase, high heat, and water stress, plants adopt defense mechanisms that slow down photosynthesis. Thus, vegetation will be less effective in absorbing CO_2 and limiting the greenhouse gas effect.

In the same way, the risk of insect pest invasion could increase and the species distribution could be modified in the coming years, due to more favorable climatic conditions [16].

Schneider *et al.*, (2022) [17] mentioned that the impacts of climate change on crop, insect, and pest species depend mainly on temperature. While their consequences can be both positive and negative for pest species, most scenarios of climate change tend to favor pest proliferation worldwide [18]. This is particularly valid in temperate regions, where the cold season currently remains a limiting factor for pest development.

Under warmer climates, we generally observe a movement toward the poles or toward higher altitudes of animals or plants for which we have regular monitoring or repeated observation campaigns over time (insects, plants, birds, fish, etc.). Therefore, high altitude and high latitude environments are affected due to their accessibility by species with strong dispersal capacity, coming from environments that are more temperate. However, species with low dispersal capacity are exposed to increased risks of local or global extinction.

It is known that plant development cycles essentially depend on thermal conditions. Due to this strong environmental control, the warming observed over the last few decades has already resulted in notable phenological changes. Thus, the advancement of bud burst dates and the delay in autumn coloring correspond to an extension of the length of the growing season from one to two weeks since the 1980s.

The adaptation of agriculture to the new conditions of climate change will be necessary. Of course, many challenges await producers, but they have the possibility of adapting their production to climate change by introducing new crop varieties or new product types, ensuring better high-temperature protection and better water use efficiency.

2. Consequences of global warming on the oceans

According to the Intergovernmental Panel on Climate Change (IPCC) studies, the average surface temperature of the earth has increased by 0.6°C over the past 100 years. The Max Planck Institute for Meteorology in Hamburg predicts that global warming will be between 4.1° and 5.8C° and will result in sea level rise between 2025 and 2100.

Along with rising ocean levels, scientists believe that there will be acidification and deoxygenation of oceans that could limit the ability of the planet's seas to produce the necessary oxygen for the life of several living aquatic organisms.

Climate change is causing the melting of ice; the rhythm of melting has accelerated in recent years. The United Nations Office for the Coordination of Humanitarian Affairs and the International Displacement Tracking Center confirmed the massive ice melting leading to an increase in the mass of water and causing a rise in sea level. Predicted rises are 9 to 88 cm between 1990 and 2100. This would be very dangerous for the coastal areas of the world where millions of people live. According to the same source, climate-related disasters caused the displacement of 20 million people in 2008.

Furthermore, drinking water resources in the world will be affected by the temperature increase, which cause greater evaporation and therefore a considerable drop in the water level of the lakes and rivers around the world. Moreover, the scarcity of fresh water could be a major cause of conflict between neighboring countries: the most striking case is the conflict between Ethiopia on one side and Sudan and Egypt on the other side.

3. Impacts of global warming on extreme climatic events

Since the last century, several countries have adopted indicators to monitor the evolution of climatic events in their countries. An indicator is a piece of information, associated with a phenomenon, making it possible to indicate its evolution over time and be able to explain the reasons for this evolution.

3.1. More intense and irregular precipitation

The climate changes observed in recent decades have affected the frequency and intensity of extreme climatic events: droughts, floods, heat waves, heavy and abundant rains, tornadoes…

Bourque and Simonet, (2007) [19] suggested that precipitation in the North of the globe could increase by 2050 but some other regions might become drier.

Sudmeyer *et al.*, (2016) [20] working in Australia claim that over the past 100 years, the average annual temperature in Western Australia has increased by around 1°C, while rainfall has increased slightly in the north and interior, but decreased considerably along the west coast and in the south-west of this country.

In North Africa (Tunisia), [15] mentioned that over the past 43 years, rainfall has decreased by about 23%. In West African countries, the long-term variability of rainfall in all is decreasing over the period 1901-2013 [21]. This decrease could have negative impacts on agriculture, water availability, and ecosystems and could cause famine and crises in West African countries [21].

According to the German Center for Climate Services analysis, the precipitation reduction observed over the past 30 years is expected to continue until the end of the century due to human activity, which is constantly increasing and contributing to these climatic changes observed around the world.

Precipitation monitoring is essential for the management of aquatic environments and water resources. This is an essential aspect of preventing floods and droughts.

The National Center for Atmospheric Research (United States) mentioned that a warmer atmosphere on the ocean's surface causes greater evaporation and leads to more intense precipitation. Hence, the greatest increases in precipitation would occur over land in the tropics where the air is water-saturated.

The researchers pointed out that in the Mediterranean and the southwestern United States, although rainfall intensity is

expected to increase, average rainfall would decrease. Tabari, (2020) [22] supported these precipitation changes and mentioned that climate change will affect precipitation patterns around the world: In high latitudes, precipitation is likely to increase, while it is expected to decrease over large parts of the subtropics. Globally, during the last century, trends in temperature and precipitation have been observed to differ in sign and magnitude from region to region around the globe [23].

3.2. Longer and more intense droughts

Global warming leads to significant changes in annual rainfall in different regions of the world. Consequently, some places will become drier and more prone to drought while others will become wetter and more susceptible to flooding [10]. The most visible example is that cited by Lippsett (2012) [24] where, certain regions have experienced longer and more intense droughts, including the scorching drought that swept across the continental United States in 2012 which led to crop failures and soaring food prices.

NASA satellite observations showed that droughts could be getting worse around the world and some places could experience more frequent and severe wildfires.

In Europe, the extreme weather events that took place in 2020, accounted for 85,000 to 145,000 human fatalities, over the past 40 years. Over 85% of those fatalities were due to heatwaves (https://www.eea.europa.eu/publications/economic-losses-and-fatalities-from)

The influence of global warming on extreme events has been underestimated and the real events increase was much greater than predicted.

In Tunisia, the weather is warming 20% faster than the rest of the globe, and more than 50°C was recorded in many cities (Borma, Kairouan, and Ariana Cities); endangering agricultural production, country's food security and water reserves.

3.3. Stronger hurricanes

Webster *et al*., (2005) [25] mentioned that hurricane formation requires the combination of several factors including water temperature above 26°C at a depth of 60 meters, a sufficient quantity of humidity in the atmosphere, and a disturbance producing swirling winds. This is why such phenomena are mainly observed in tropical and subtropical waters. The study carried out by [25] over 35 years showed that in warmed climate, cyclone number and duration has been globally stable, but their intensity is more amplified. This finding was confirmed by researchers from the Reading and Academics University of the United States where the rising temperatures and high humidity in the atmosphere provide the right conditions for storms to become dangerous hurricanes [26]. These conditions were met in the Philippines at the end of 2021 where Typhoon Rai rapidly intensified and caused the death of more than 400 people.

Similarly, theoretical work published many years ago by Emanuel, (2005) [27], predicted that climate change would increase the upper thermodynamic limit of tropical cyclone winds and will lead to a higher frequency of intense storms. A recent study published in the journal Nature, using data collected by thousands of scientific instruments scattered across the world's oceans, shows that hurricanes are becoming stronger as the climate warms and more of them will develop into major storms.

In tracking hurricane activity around the world, satellites have played an invaluable role over the past 40 years, but they have their limitations since they are less reliable when it comes to accurately measuring their intensity.

Consequences on human health and society

Most scientists recognize that climate change will have serious consequences for human health. Several impacts on health have been identified all over the world, including an increase in respiratory syndromes such as asthma, skin cancers, and deaths related to intense heat. The deterioration of environmental conditions may implicate the transmission of vector-borne and infectious diseases [28].

Furthermore, Camirand and Gingras, (2011) [16] suggested that climate change can amplify the heat waves phenomenon in urban areas, which has impacts on health, ranging from heat cramps to heat syncope, and from heat exhaustion to heat blow. Moreover, an increase in diseases transmitted by insects and animals is to be expected.

It is admitted that global warming obviously leads to an increase in extreme phenomena (heat waves, intense rainfall, floods, and droughts); which cause either illnesses and deaths or various epidemics linked to floods. In this context, Mojahed *et al*., (2022) [29] mentioned that global warming would expand the areas conducive to the spread of so-called vector-borne diseases. Diarrheal diseases resulting from water contamination, meanwhile, could increase by 10% in the next 15 years. The consequences of these disturbances should therefore result in the multiplication of the number of “climate refugees” and in the increase of geopolitical instability.

Global warming will have repercussions on the health of populations living in tropical regions. In Africa, for example, rising temperatures favor the proliferation of mosquitoes making populations more exposed to diseases such as malaria, dengue fever, and other insect-borne infections. In addition, people with heart problems or the elderly and the sick are more vulnerable to rising temperatures, especially those who already live in hot regions.

Another example has already happened in Europe during the heat wave of 2003, which killed around 35,000 people [30].

Other indirect effects may occur when global warming could have a significant impact on rainfall patterns, food security, and water supply for millions of people. Boko *et al*., (2007) [31] report mentioned that between 75 and 250 million people living in Africa would no longer have access to an adequate supply of water and would face food and water shortages. That would increase the risk of conflict between local populations and/or between neighboring countries for water and food. The agricultural production in these regions is mostly subjected to food shortage and insecurity in years with low rainfall [32]. Food insecurity would, in turn, increase the illness and death of vulnerable groups including women and children [33].

Global warming can have several consequences on society: Indeed, populations must adapt to a new climate, and adapt their infrastructures, in particular medical ones, but also their buildings, their public health, and their food capacity.

The climate change impact would be particularly strong on the African continent, where global warming could lead to rising food prices. This increase could reach 12% within

fifteen years, explained the World Bank in its report in (2015). It would be a hard blow for African households where food consumption represents more than 60% of their expenditure.

The territories and the infrastructures could not withstand floods and other disasters (fires, etc.). A warming of 2 to 3°C would be enough to increase by 5%, the number of inhabitants exposed to malaria. Moreover, by 2080, the World Health Organization (WHO) estimated that an additional two billion people could be at risk of transmission of dengue fever (a viral disease).

Consequences of global warming on biodiversity

Global warming affects ecosystems, both terrestrial and marine. According to Ben Haj and Limam, (2010) [34], the forecasts concerning the consequences of global warming on biodiversity, as a whole, are very worrying. Based on a moderate climate change scenario, a recent estimation, taking into account 20% of the earth's surface, predicts the extinction of 15 to 37% of the species occupying this surface by 2050 [34].

The IUCN publication, (2008) [35], mentioned that out of 44,838 species, 16,928 are threatened with extinction leading to losses of 5% of species per decade. This biodiversity loss is essentially due to over-exploitation, demographic pressure, and climate change, which alone constitute the main threat to the biological diversity of the planet [36].

In addition to the effect of climate change, poor land management also constitutes a threat to biodiversity. Indeed, according to the World Wide Fund for Nature (WWF), more than 43 million hectares of forest were lost between 2004 and 2017 out of 377 million hectares monitored worldwide due to deforestation for the needs of urbanization and agriculture [37].

In terms of marine biodiversity, despite its taxonomic importance, it is sometimes ignored in the discussion of climate change, this is certainly because much of it is little known and less understood than its terrestrial counterpart [38]. That is why; many scientists have focused their studies on coral reefs worldwide that are simultaneously threatened by warming and acidifying waters [38]. In addition, some coral-associated fish have also disappeared over the course of recent bleaching events [38].

In the Mediterranean basin, several measurements carried out in the coastal waters during the last 30 years have shown warming of seawater of the order of 1°C ([40]; [41]. This should have significant consequences on coastal ecosystems, including sea level rise, which is already threatening ecosystems. Besides, the intensity of rainfall, causing flooding and massive terrigenous inputs in the coastal environment is also another factor whose effects on aquatic biodiversity are certain.

Consequences of climate change on the species distribution

Most plants and animals live in favorable climate conditions that allow them to grow well. Any change in that climate can profoundly affect them and the entire ecosystem in which they live. Some species respond to warmer climates by moving to cooler locations or to higher elevations to find suitable places to live.

The climate is continually changing, but the rate at which it has experienced change lately has been faster than some decades before. This change influences the distribution of plant and animal species, their rate of extinction, which is becoming more and more increased, their reproduction periods, which will be disrupted, and the duration of the growing seasons, which will be modified.

Indeed, global warming leads to environmental transformation which results in the disappearance and appearance of certain habitats and, more generally, in the displacement of the species range. As the climate warms, ranges migrate to higher latitudes and altitudes in search of more favorable conditions. Ecosystems, therefore, tend to move towards the north of the planet. Firstly, this modifies the type of cultivation in a given region, leading to the colonization of new territories by new species.

Facing this phenomenon, animal species with low mobility are at a disadvantage. In this case, the species concerned can sometimes survive to extinction by finding refuge in the few remaining habitats with a favorable microclimate. Otherwise, only human action can save these species.

According to Thomas *et al*., (2004) [42], 20 to 30% of species will be threatened with extinction if temperatures increase by more than 1.5 to 2.5°C, in every aspect of living things. For example in the freshwater ecosystem, which represents 0.01% of the water on earth but contains nearly 100,000 species, more than 20% of fish species have disappeared, are threatened, or are endangered [43].

How to combat global warming

To fight global warming, we must reduce our greenhouse gas emissions (GHG). Since the signing of the Kyoto Protocol in 1997, several countries have undertaken to reduce their GHG emissions with varying percentages compared to the reference year (1990) but each time, these countries revised the objectives set upwards.

1. Renewable energies

Fossil fuels emit a lot of CO2, and therefore their use contributes significantly to global warming. On the contrary, renewable energies have, at least, the merit of not being a carbon-emitting energy source. It is therefore essential to change our energy consumption habits in order to have a better environmental impact. So, the first way to fight against climate change is to turn to renewable energies, which cover six energy sources: bioenergy, solar energy, geothermal energy, hydropower energy, ocean energy, and wind energy. In addition, we must reduce our energy consumption, avoid food waste, and optimize the use of resources. For that reason, we must adapt our way of life to the notion of resilience and sustainable development. We must transform our societies to move towards an industrial model and globalization that considers ecology.

2. Use of new technologies in agriculture (short-cycle varieties, treated wastewater, water desalination)

Noblet *et al*., (2018) [44] proposed solutions for adapting to global warming in the agricultural sector based on technologies to combat drought, desertification, and temperature rise. In this context, several actions can be considered, including the use of short-cycle varieties that are able to finish their development cycle before the beginning of drought and high temperatures. The identification of varieties capable of withstanding high temperatures has also been experimented with in some research institutions [15]. A similar experience was implemented in Morocco to identify

a suitable quinoa cultivar, which has shown that early sowing of short-cycle cultivars constitutes a good strategy to enhance growth and yields in the context of climate change [45].

(FAO, ICRISAT, CIAT, 2018) [46] mentioned the Crop-based Climate-Smart Agriculture practices and technologies such as the short-duration crop varieties that were used among the Benin farming population to avert the climate-related risks.

Climate change has an impact on the quality, quantity, and availability of water resources and agriculture production around the world. Investing in innovative technologies to improve agricultural productivity, conserve and protect natural resources, recycle wastewater, and desalinate brackish water should start as soon as possible, especially in arid countries where water is scarce; additionally, looking for opportunities to harvest rainwater and improve water storage, including groundwater recharge to address climate change.

The mandatory establishment of the water tank (Majel) construction for each newly built house in rural areas to collect rainwater that could be used either for human or animal abbreviation or for family garden irrigation.

The role of the world's vulnerable states is also important in the construction of hill lakes, the fight against water erosion, institutional support, and the training of political decision-makers and technicians on the scientific issues of climate change. In this context, the Tunisian state, through the Ministry of Agriculture, Hydraulic Resources and Fisheries, has launched an ambitious program to carry out hydraulic facilities in all the semi-arid regions of the country and adaptation measures reducing the impacts of climate variability. For example, from the beginning of the 1990s until 2014, Tunisia has built 893 hill lakes, 253 hill dams, 33 dams (and 6 others under construction), 146,000 surface wells, and 17,000 deep water boreholes [47], [48]. In addition, supply networks for access to water drinking have also been set up by interconnecting dams in the North (more rainy regions) with those in the center (less rainy regions) to compensate for shortages of drinking water and irrigation.

The pressure on water resources in arid countries is increasing day by day. These countries, which are very vulnerable to the effects of climate change, have already opted for the mobilization of unconventional water resources: the desalination of saline water and the treatment of wastewater.

The use of treated water for irrigation has become a necessity. Today, with global warming observed on a global scale, the major challenge for preserving the quantity and quality of water in rural areas is the treatment of wastewater, which constitutes an ideal resource to replace the use of fresh water in agriculture.

3. Adaptation of agricultural systems to the scarcity of water resources

The West Asia and North Africa region (WANA) is by far the driest and most water-scarce region in the world. The situation is expected to worsen due to rapid population growth, irrigation expansion, and climate change [49]. Because of chronic water deficiencies, a wide variety of large to small hydraulic techniques have been built over many centuries to provide drinking water for the population and for agriculture. These techniques want from the micro-catchment water called Meskat and Jessour (a traditional technique used for water harvesting and irrigating olive trees in Tunisia) to dams passing by the runoff water collection and storage in reservoirs of variable capacities, which provides drinking water for people and animals, as well as water for irrigation purposes.

The Tunisian National Water Saving Program launched in response to climate change emphasized localized irrigation (drip) which has been applied to about 46% of the total irrigated area, irrigation by sprinkler covering 30% of irrigated areas, and 24% for improved gravity irrigation [50].

Besides the use of technical know-how inherited from our ancestors in terms of harvesting and storing runoff, the digging of Majels (tanks dug into the ground to collect rainwater) for harvesting rainwater from the roofs of houses must be maintained in each rural house to cope permanently with the risks of droughts and water shortage.

However, as explained above, the main adaptation initiatives concern the development and mobilization of unconventional water, such as the desalination of seawater and the recovery of treated wastewater.

4. Establishment and implementation of climate change adaptation strategies

Adapting to climate change has become an obligation and a necessary component of planning at all levels in all countries of the world. For example, in Tunisia, a national strategy was put in place in October 2012 as part of the implementation of the United Nations Framework Convention on Climate Change, with the support of the German cooperation (GIZ). Several activities in terms of adaptation to climate change have been carried out, according to a sectoral approach (agriculture, biodiversity, ecosystems, energy, forestry, human health, transport, tourism, urban, and environment).

Tunisia has committed to reducing its carbon emissions intensity by 13% by 2030 compared to 2010 levels. Mitigation efforts will be particularly focused on the energy sector leading to a reduction in primary energy demand of 34% in 2030. But other sectors are taken into consideration (National Strategy for the Development and Sustainable Management of Waste, National Transport Strategy, National Strategy for the Sustainable Management of Forests and Rangelands, National Biodiversity Strategy, Tunisian Tourism Strategy Vision, …)

5. Coastal erosion control

Coastal changes induced by erosion are natural processes that take place on a range of time scales. Orogenic cycles and tectonic activities can significantly change the coastal aspect and sea level. Wind, waves, and water currents are natural forces that easily move sand from the coastal zone, resulting in rapid changes in the position of the coastline.

From the beginning of the 1990s, the IPCC formulated three options for adaptation in coastal areas, which are still valid today

- Protection, by building hard structures such as dykes or flexible solutions such as dunes and vegetation.
- Accommodation (raising or setback of residences). This option includes, among other things, the elevation of buildings on pillars,
- Withdrawal population also called "strategic withdrawal" or "relocation of goods and activities in the face of coastal risks", consisting of moving and

relocating to the hinterland goods and activities subject to weather-marine hazards and associated risks.

5.1. Protection by hard structures

Hard coastal protection structures are common throughout the world. They are designed to resist wave energy and protect the coastline. They include different structures such as breakwaters, seawalls, groyns designed to resist wave energy and increase sediment storage on the shore.

Seeing what some, vulnerable countries have done to fight coastal erosion. According to Rangel-Buitrago *et al*, (2018) [51], at least 1484 hard structures have been built along the Colombian Caribbean coast but most of them have failed in their purpose by intensifying the erosion processes and altering the landscape. Similarly, [52] have mentioned that 152 structures were mapped comprising 112 groynes, 20 revetments, and 20 jetties at Ghana ports and new fishing harbors which constituted about 20% of the total coastline.

In North Africa, the Tunisian government has already been trying for several decades to counter the negative impacts of this natural phenomenon by so-called hard protection measures: dykes, protective walls, and riprap or cliff stabilization. These works began in the early 1980s, with the installation of rock-fill structures for jumpers, groynes, and breakwaters. A total of 30 km of coastline has been protected by submerged (barriers) and/or emerged (groynes) structures. These activities have made it possible to consolidate the coastline where they are located.

The submerged barriers that are installed underwater, 150 to 300m from the beach, are intended to dissipate the energy of the swell and to prevent or slow down the departure of sediments offshore. The emerged barriers (the groynes) which are the best known allow the cutting of the littoral drift and thus block the sand and maintain the coastline's integrity.

5.2. Soft coastal protection

It is the stabilization of the coastline using environmentally friendly techniques to protect properties and shorelines from erosion. It is clear that this technique is more suitable to solve most of the coastal problems, saving ecosystems, and reducing the protection cost [53].

In terms of so-called soft protection, the Tunisian Coastal Protection and Planning Agency (CPPA) began, at the end of the 1990s, to seek new flexible methods for coastal protection. These activities included techniques for stabilizing the top of the beach using fences and stabilization actions using geo-tubes of sand.

Fences distributed among several sites protected a total of 6530 m of coastline. It included also the stabilization of dunes by vegetation and the establishment of windbreaks formed of local materials such as pinewood and palms.

The Tunisian Agency for the Protection and Development of the Coastline and the KFW Development Bank have carried out work to protect coastal erosion. The program started in 2013. So far, 27 kilometers of Tunisia's coastline have been rehabilitated at different sites of the littoral. Protection measures are based on "hard" protection measures as well as nature-based solutions, such as beach nourishment and refilling or the protection, growth, and stabilization of sand dunes. This last measure was done mainly by fencing sensitive areas, planting protective vegetation, and installing fences for sand-trapping.

5.3. Withdrawal of threatened populations.

It is rare for populations to agree to be dislodged from their environment where they have lived for several decades or even for several generations. Relocating a building on the seaboard involves constructing a new foundation, and reconnecting public utilities, sewage systems, and landscaping. This phenomenon seems like an expensive process but can be a viable and most profitable option, in the long term, for coastal owners. Coastal areas are of capital importance for these populations not only for biodiversity preservation but also for the development of a blue economy, synonymous with wealth production, job creation, and source of income.

A recent report, assessing changes in the North African coastal landscape, showed that beach erosion reached an average rate of 15 centimeters (cm) per year, more than double the world average (7 cm). Tunisia experienced the highest rate of erosion, with an annual retreat of nearly 70 cm on average [54]. Faced with the rise in sea level and the increase of extreme meteorological phenomena frequency, these erosions will increase and will lead to the disappearance of coastal populations and their means of subsistence, if no adaptation measures are set in place. In this context, one of the measures undertaken must be the withdrawal of coastal populations to prevent risks due to coastal erosion. However, this option is difficult to realize not only in Africa but also all over the world. However, some measures have already been observed in some countries, in particular operations to relocate populations threatened by coastal erosion were observed in Senegal in 1987 [44]. More recently, in 2015-2016, residents of several localities in Saint Louis (Senegal) affected by erosion phenomena and marine flooding were rehoused in social housing.

In France, the city of Lacanau located on the seaside of the Aquitaine region, has taken measures aimed at limiting reception capacities on the seafront. New constructions were authorized there but were subject to being temporary, precarious, and reversible. Similarly, the relocation of approximately 1,200 apartments has been envisaged, which would limit the exposure of goods and people to the risks due to coastal erosion.

In the USA, climate-related impacts are forcing the relocation of tribal and indigenous communities, particularly in coastal regions. Many indigenous communities in Alaska and other parts of the US coast are now facing resettlement due to climate change and other stressors [55].

Likewise, coastal Louisiana tribal communities are experiencing climate change-induced sea level rise, forcing them to relocate. Thus, in 2016, the American government granted the inhabitants of Jean Charles Island (southeast Louisiana) a subsidy of 92.6 million dollars, including 48 million dollars to relocate to higher ground.

At present, the institutional frameworks and financial capacity of several countries do not facilitate the relocation of entire communities. Many national, regional, or local government agencies lacked the technical, organizational, and financial capacity to implement resettlement processes for communities displaced by climate change [56].

International organizations including the World Bank, the GIZ, and others are trying to finance the relocation of populations threatened by coastal erosion. They support the National Integrated Coastal Zone Management Strategies of several African countries, which integrate the dimension of

climate change and adaptation measures into their action plan. However, these actions remain insufficient to protect all the world's populations threatened by coastal erosion.

Conclusion

The Current greenhouse gas concentrations in the atmosphere are very high. They will continue to increase more causing disastrous climate changes. Most polluting countries do not take seriously the limitation of their emission of these gases. Therefore, the whole world will be exposed to serious problems, knowing the expected negative effects of these changes on natural ecosystems, on the ocean's average level, as well as on humanity's health and the environment are catastrophic.

The severity of these impacts will depend, in part, on the seriousness of global efforts to mitigate climate change by shifting the world's overreliance on fossil fuels for energy toward renewable energy.

Fortunately, climate change is happening gradually and if prompt action is taken in a timely manner, it is possible to design better control and prevention strategies.

Each country should rely on itself to design adequate measures to cope with climate change according to its material possibilities.

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Competing interests

The authors have no conflicts of interest to declare. There is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

Aurhor's contributions

All authors have contributed equally to this manuscript. They have read and approved this manuscript before the submission

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