POLITECNICO DI TORINO

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A CASE STUDY: PRESENT AND FUTURE ANLYSIS OF WATER NEEDS IN NORTHEN – AFRICA COUNTRIES AND THECNICAL FEASIBILITY OF ATMOSFERIC WATER HARVESTING TECHNOLOGY

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CHAPTER 1

1. The importance of water

The Earth is covered by 71 % by water and oceans hold about the 96,5 % of all Earth's water. Water is also in rivers, lakes, waterfalls, icecaps, glaciers; exists water in the air as water vapor and in the ground as soil moisture and in aquifers.

Water is fundamental for human, vegetable and animal life, but the majority of water on Earth is not fresh. The water consumed by people comes from freshwater resources, such as water falling from the sky (in form of rain, snow and hailstorm) and moving into streams, rivers, lakes, and groundwater. Fresh water is fundamental also for human activities, such as agriculture, municipalities and industries, and withdrawals are related to the geographic area. The constant rise of freshwater demand is linked to natural, geographical and social variables and represent one of the most critical problem of actual society. The global question is even more relevant also for future scenarios. Between the 2011 and 2050 , the world population is expected to increase by 33% , growing from 7.0 billion to 9.3 (UN DESA, 2011) and food demand will rise by 60% in the same period (Alexandratos and Bruinsma, 2012). Furthermore, it is projected that populations living in urban areas will almost double, from 3.6 billion in 2011 to 6.3 billion in 2050 (UN DESA, 2011). Furthermore different reports predict that in the future there will be most critical areas than others about water requirement; for example considering OECD's 2012 Global Environmental Outlook's Baseline Scenario (OECD, 2012a) in North and South Africa and South and Central Asia will be areas with severe water stress.

The insecurity and the shortage of freshwater resources in certain areas of the Earth influences the microeconomy of the area and determine an increase of the freshwater price. With the continuously rise of the population and the climate change, the scenario previously described is not bound only to defined areas of the Planet and the research of new fresh water resources and new methods to depurate water is a rising need at global level.

1.1 Fresh water consumption

ILO's statistics show that the global active workforce is increased from 2.3 billion people in 1991 to the 3.2 billion estimated in 2014, while the global population grew from 5.4 billion to 7.2 billion over the same period (UN DESA, 2001,2015). A consequence of this is an increase of industry and services sector, while employment in the agricultural sectors is decreased. Half of the global workforce is employed in eight water and natural resource-dependent industries: agriculture, forestry, fisheries, energy, resource intensive manufacturing, recycling, building and transport (ILO, 2013a).

The 78 % of jobs constituting global workforce are water dependent. In this percentage is not included others jobs in regulatory institutions within public administrations, infrastructure financing, real estate, wholesale and retail trade, and construction that are water dependent, too (UNITED NATIONS WORLD WATER DEVELOPMENT REPORT, 2016).

In areas where there is water shortage, such as Sub-Saharan Africa the agricultural sectors is at the base of its growth and economy appears a priority invest in water and aquaculture.

Water is also fundamental in the power sector, big amount of water are used for cooling auxiliary services; hydropower use huge amount of water all over the World. The demand of energy can be supply by renewable energy, such as PV (photovoltaic), geothermal and wind, that contextually use a low quantity of water and increase job possibilities.

The industrial sectors grows rapidly, driven by the increase of the population, and uses great quantity of water: food and drinks, mineral, chemical and pneumatical.

Growing population has as consequence a big use of water in municipalities and the total water required from them can represent up to 35% of the total water extracted for use in some countries (Jiménez Cisneros and Asano, 2008a). There are studies and plans which they provide the re-use of water for irrigation is the most common strategy for recycling waste water. It is important, for these reasons, invest high sums of money to strengthen the irrigation system and it could be a benefits under many aspects: for local jobs, and so microeconomy, but also macroeconomy.

This constant need of fresh water is a reason for the growth of desalination global market that is estimated to rise at a compounded annual growth rate of 8.1% between 2014 and 2020 (GWI, 2015), with the largest plants coming on line in the Middle East.

1.2 Fresh water production

1.2.1 Desalination

The constant requirement of freshwater and the impoverishment of water resources pushed science and technologies to search new ways to obtain freshwater. Considering that over the 96% of Earth's water is saline the methods most widespread to have potable water is the "desalination".
Actually, the desalination process is one of the most diffused for freshwater production, besides there are different type of desalination processes and with the help of the research and technology they are improved.
Generally, desalination refers to removal of salts and minerals from a substance that in most cases is water in order to produce water suitable for human use. A disadvantage of desalination processes is his cost for the need of high energy consumption.
The three principal methods of desalination are: thermal, electrical and pressure.
In *thermal desalination*, the water is boiled and then the steam is collected, leaving the salt behind; during the vaporization phase there is a significant requirement of energy and in order to reduce it last technologies utilize low-pressure vessels to reduce the boiling temperature of water. Examples of this methods are: vacuum distillation, as solar distillation, multi-stage flash distillation (MSF) and multiple-effect distillation (MED).
In the *electrical desalination*, electric current is used to separate the salt from the water, generally it is applied in the way to drive ions across a selectively permeable membrane, carrying the dissociated salt ions with it. The characteristic of this method is that the required energy depends on the quantity of salt in initial water. Examples of this methods are: electrodialysis reversal or membrane distillation.
The third principal desalination method is reverse osmosis, it is similar to the second one: with the pressure the water is drove through a selectively permeable membrane, leaving the salt behind. Also in this case the energy needed for the process depends on the initial salt quantity.
These methods have some relevant disadvantages: high energy consumption; high maintenance costs; considerable environmental impacts due to the use of fossil fuel.
To find a solution for these problems desalination's technologies is combined with renewable energy power plant, this can be a suitable solution also for countries with dry areas, without importing great quantity of petroleum. It is important to think that sometimes fresh water is required at localization far from energy grid – lines, requiring a local source of energy.

However, the principal disadvantage of desalination is the cost of water production system, even after joining a renewable power plant, for this reason is a technology limited for large scale systems.

1.2.2 Atmospheric water vapor processing

Desalination is not the only fresh water production process. With technological progresses was been possible to realize new techniques for fresh water supply and one of this is based on extraction of water from atmospheric air. Air, as water, is clean, renewable and exits everywhere, moreover atmosphere contains about 12,900 m^3 of fresh water, whereas liquid water resources of inhabited land is about 12,500 m^3 (A.M.K. El-Ghonemy,2012).

Air, composed for 78 % of nitrogen and 21 % of oxygen, contains varying amounts of water in vapor form, depending on its temperature and pressure. Water vapor molecules are present in every cubic meter of the atmosphere (in the troposphere layer) and water vapor density or absolute humidity at a specific location varies with geographical location, altitude, time of the day and season.

To understand how this process works is fundamental to remember that the amount of water in the atmosphere is calculated from its partial pressure (P) within the air mass. At a given temperature (and pressure), the partial pressure can not exceed a certain level without condensation occurring; this is the saturation pressure (P_s). The relative humidity (RH) is then defined as the ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at a given temperature ($RH=P/P_s$) and it depends on temperature and the pressure of the system of interest. The P_s rises in conjunction with the increase in air temperature (or pressure) and the water mass capacity of 1m^3 of air also rises. For air at a given temperature and RH, the psychometric diagram—representing the mass fraction of water in the air at different temperatures and RH—allows the air's water saturation point to be a ascertained. This is ‘‘dew temperature’’, the temperature at which water vapors condenses cooling down the steam at constant pressure.

Extraction of fresh water from atmospheric air is made by two steps. First, water vapor molecules are attracted to a limited volume within a container or to a surface connected to a water storage tank. A vapor pressure gradient is established so there is water vapor flux from the air to container interior or the surface. In this step there is a combined flux of mass, water vapor molecules themselves, and energy, latent heat contained in the gas phase of water molecules.

In the second step joins individual water vapor molecules, H_2O, by hydrogen bonds into water polymers or clusters $(H_2O)_c$, where c is number of molecules is inversely proportional to temperature. During the delicate change phase from water vapor to liquid water there is an energy barrier to overcome and the latent heat must be dissipated to prevent liquid water from re-evaporating before storage. In gas phase molecules are always in motion but the average speed of each molecule decreases as absolute temperature decreases, in this way there are more inter – molecular forces to act hydrogen bonding. For this reason, cooling a volume of moist air decreases kinetic or translational energy of water vapor molecules and probability increases that neighboring molecules will bond into clusters forming liquid water droplets.

Atmospheric water vapor processing (AWVP) are machines which extract water molecules from the atmosphere, ultimately causing a phase change from vapor to liquid. Generally, the most relevant machines can be divided in three main groups: one deals cooling a surface below the dew point of the ambient air, second on concentrate water vapor through use of solid or liquid desiccants and third on induce and control convection in a tower structure.

AWVP technologies can be a competitive solution to desalination plants because have the advantage to be simpler and less expensive to operate and maintain.

To the first group of atmospheric water vapor technologies belong machines with a cooled surface by heat pumps or radiative cooling.

AWVP technologies with a cooled surface by heat pumps, used to cool surfaces so water vapor can condense and be collected, are efficient when condenser air temperature is low and cooling coil air temperature is high (Harriman) and their maintenance is easy. These technologies have disadvantages for the application, in fact during cooling process it is possible that freeze the condensed vapor and frost can be an insulator to further cooling; in addition, for dew points less than 4.5 °C is required a special design. The refrigerant used is the chlorofluorocarbons (CFCs) which contribute to global high altitude ozone depletion and in order to minimize their use some researchers used thermo-electric (Peltier) heat pumps, but for these machines is necessary an high quantity of power.

AWVP technologies with a cooled surface by radiative cooling work without external energy sources and need of simple mechanical requirements, but they are dependent on radiation and energy requirements high for recovering potable water using desalination or distillation technology.

The second group of AWVP technologies is water vapor condensation by desiccants type, they act extracting water vapor from air by establishing a vapor pressure gradient causing flow of water molecules toward the desiccant surface. Their main advantages are:

- dry air to a low relative humidity;
- suitable for output air at low dew points;
- a well-develop technology for large scale.

While as disadvantages there are:

- a low value of heat of sorption, it can be 5 - 25 % of heat of vaporization and it must be considerate for the design;
- liquids used for absorption can concentrate contaminants from atmosphere;
- contaminants can pollute water produced, but they can also reduce the capacity of desiccants.

AWVP technologies with water vapor condensation by desiccants can be separated in other two subgroups: absorption in liquid desiccants and adsorption on solid desiccants. Absorbents and adsorbents are two typologies of desiccants: the first ones are desiccants that change chemically and physically when water vapor is added, the latter not. Generally, absorbents are liquids, while adsorbents are solids, but these are not the only differences between them and to understand desiccant technology it is important to known their principal characteristics.

Absorbent desiccant are systems more complex and have high capital cost for smaller units, besides they have a large central system and with long pipe so a response time. Must consider that liquids may be contaminated by organic solvents and it necessary an accurate maintenance to avoid corrosion's machines. To maximize the water molecules absorption a solution can be increasing surface area exposed to air and/or increasing contact time.

Adsorbent desiccant are simpler systems and relatively inexpensive, it is a technology suitable for smaller spaces and free - standing units and often solid packed tower is used for compressed air. In this case there is not a contamination of organic solvents, but it could be leakage of air between wet and dry airstreams and high activation energy, which increases operation costs.

Different classes of adsorbent materials can be used to produced water, some of the most diffused are:

- silica gels, not expensive, easy to customize for selective adsorption and it is a hard, granular, very porous product made from gel precipitated by acid treatment of sodium silicate solution;
- zeolites, naturally occurring, open crystalline lattice functions as sieve;
- synthetic polymers, new technology with desiccant properties with highest capacity of adsorbents.

The principal characteristics of an ideal adsorbent should be: insoluble, macroporous, mechanically and chemically stable, hydrophilic and resistant to microbial and enzymatic attack (A.M.K. El-Ghonemy, 2012).

The last group is formed by AWVP technologies with convection induced or controlled in a structure, where to have low air temperature below the dew point is to cause air parcels to expand, transforming a portion of their energy into work, cooling air to extract liquid water. Strengths of these technologies are lowest energy requirements of the three design strategies and engineering studies in removal of water from industrial compressed air systems is well – development, but them need large structures and AWVP designs which propose compression of air followed by expansion to cause cooling below dew point are energy intensive.

1.2.3 AWVP technologies

The discovery of AWVP technologies is water vapor condensation by desiccants type inspired different studies and research, particularly, in countries where there is the need to find new ways to produce fresh water and there are some systems that use also solar energy for the regeneration after absorption of water vapor from air. It is an investigation made in 2011 (Hamed AM, Aly AA, Zeidan EB, 2011), where was tested two methods : the first method was based on cooling moist air to a temperature lower than the air dew point using solar absorption cooling system; the second method was based on the absorption of moisture from atmospheric air during the night using calcium chloride solution as a liquid desiccant, with sub-sequent recovery of absorbed water during the day and this was the most suitable application of solar energy for water recovery from air. Solar – desiccant systems for water production are a solution in arid areas, but it is fundamental to consider them economical realization and the desiccant bed high cost can limit the diffusion on large scale. With the investigation was possible to see that in desert regions, mixing a sandy layer of the ground surface with desiccant is a promising method to minimize the cost absorption process. The sandy layer impregnated with desiccant is sub - jected to ambient atmosphere to absorb water vapor in the night, while during the sunshine period, the layer is covered with a greenhouse where desiccant is regenerated and water vapor is condensed on the transparent surface of the greenhouse or any other cold surface. In order to predict absorption cycle performance are required knowledges of the percentage approach to saturation and the desiccant to sand mass ratio affecting the rate of absorption and consequently the rate of water production.

At the end of investigation of 2011 (Hamed AM, Aly AA, Zeidan EB, 2011), a desiccant/collector solar regenerator has been designed, installed and tested at Taif area, Saudi Arabia and calcium chloride solution was used as desiccant. From the experimental measurements and data analysis, the conclusion was that the solar powered desiccant system which uses sandy bed can be successfully applied to recover water from air and an average amount of 1.0 liter of fresh water can be recovered per square meter, when the solution concentration at equilibrium with the night conditions is about 30%, but the season of operating can influence operating concentration of solution and it is better use solution with higher concentration for dry seasons and areas.

Others investigations were made on the extraction of water from air (EWA) patented technology, based on the extraction of air humidity into water stream, it is an alternative solution for water supply, where neither salty water, nor infrastructure is available. The EWA technology extracts the air humidity by a three stage process: absorption of humidity on a solid desiccant, desorption of the water to vapor at moderate heat (65 – 85 °C) and condensation with passive condenser connected to a heat pump.

The EWA technology for the need of moderate heating is environmentally friendly and has low cost heat energy, such as solar or waste heat, furthermore it could be operated at ambient temperature range between 5 - 45 °C and at relative humidity of 20 %. It is possible to use it in dry region South Mediterranean countries, tropical countries and and far from the seashores where long-pipe systems are not available.

1.3 Fresh water utilization

The fresh water production methods described in the previous paragraphs are few of the many possible solution. Choosing a technology for fresh water production means not only evaluate the best technique, but the best for area where it will be installed, respecting environment and population needs. It is also necessary considerate the economic factors of these technologies, their life time and impact on the local population.

The necessity of fresh water is a difficulty that affects many countries of Africa, Asia, America and Europe and each of them has different own geography, politic, culture, economy and laws. For all these reasons finding a solution to produce fresh water can be a problem and it is possible to make some changes to technologies used or combined two or more of them.

In *Figure 1* are signed with different colors the level of human pressure on water resources withdrawal by agriculture, municipalities and industries over total renewable water resources. It is easy to see that countries between Tropic of Cancer and Equator need more fresh water production, this zone has constantly warm weather and sun's rays are perpendicular, so with maximum intensity and furthermore there are arid or desert areas.

Generally, all African countries between Tropic of Cancer and Equator are united by the same climate and sometimes by the same economy based on agriculture and livestock breeding that could grow up with major fresh water quantity, also in rural towns far away from large population center.

The most of countries of the Arabian Peninsula have the same economy African countries, but some of them have a different economic development despite the circumscribed spaces. Qatar, United Arab Emirates and Kuwait are examples of countries that are developing rapidly, exploiting small spaces

and considerably increasing its population, where the necessity of fresh water grows with the population and the continuous tourism. Another aspect to consider, in this case, is the economic capital that could be suitable for cutting - edge technologies.
While, Asian countries have an economy not only based on primary sector, but the low cost of labor has allowed the emergence of a strong industrialization. From textile to metallurgical, from food to mechanical, from chemical to paper, all sectors with a great need not only for considerable amount of water but also for energy. It is also important considering that these countries are the most populated of the world and according to last investigations in Asia the 12,5 % do not have access to water, it is necessary fresh water production plants on large scale to satisfy the demand.

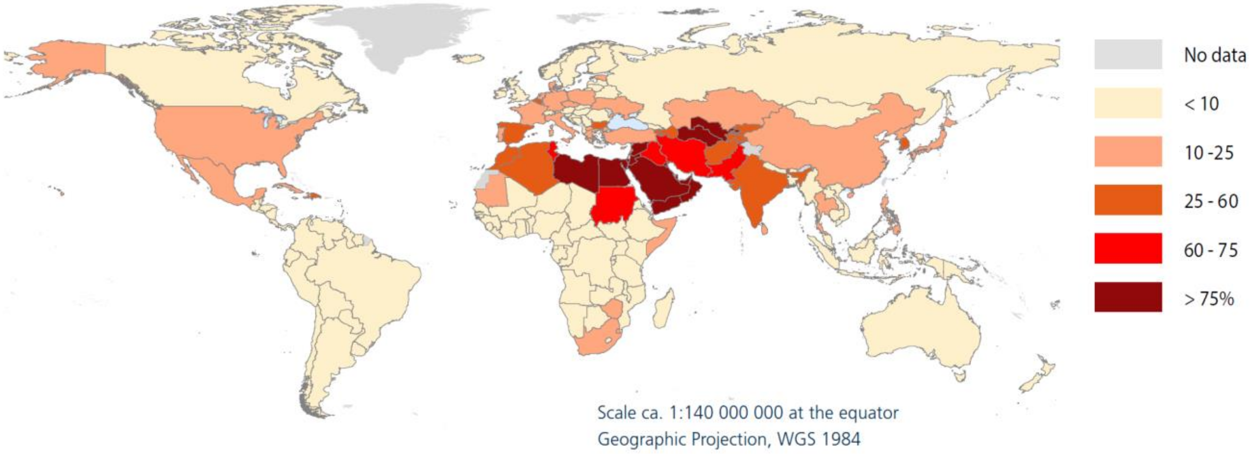

Figure 1 - Percentage of renewable water resources withdrawal.

Above the Tropic of Cancer, it is possible to see that all the countries of the Mediterranean basin have a high need for water compared to existing resources. In this case, it need to make more than a clarification:

- for African countries bathed by the Mediterranean Sea is the same of African countries between Tropic of Cancer and Equator, naturally with the necessary exception;
- for European countries there are to consider the environmental laws of UE to respect;
- each European countries have different economy, but generally all the three sectors are developed;
- climate change has affected a large part of Europe, drought and scarce rainfall rise fresh water necessity particularly during spring and summer seasons.

In the fig. 1 is possible to see that in America the countries with a major need for water than resources are USA and Mexico, but this need is less than other countries, such as countries of North Africa.

The same it is possible to say for China, Japan and South Korea. However, it is fundamental consider that in many countries the necessity of fresh water is due to the pollution of water resources.

1.4 Water footprints method

The Earth's freshwater resources changes are dependent by different environmental and social factors and there is the need to monitor them constantly collecting all data on water use, water withdrawals in the domestic, agricultural and industrial sector respectively (Gleick, 1993; Shiklomanov, 2000; FAO, 2003). In order to control in better way, the global water demand is taken into account the water demand for each country and subdividing water withdrawals for different sectors of economy, but this is not enough because sometimes the goods produced by a country can be consumed by other countries and this means that the real water demand of a country is higher than the national water withdrawals.

In 2002 was introduced the concept of water footprints, an indicator of consumption water that could provide useful information in addition to the traditional production-sector-based indicators of water use (Hoekstra and Hung, 2002). The water footprint of a nation is defined as the total volume of freshwater that is used to produce the goods and services consumed by the people of the nation. Since not all goods consumed in one particular country are produced in that country, the water footprint consists of two parts: use of domestic water resources and use of water outside the borders of the country.

The water footprint concept is closely linked to the virtual water concept. Virtual water concept was introduced by Allan in the early 1990s (Allan, 1993, 1994), when studying the option of importing virtual water (as opposed to real water) as a partial solution to problems of water scarcity in the Middle East, and it is defined as the volume of water required to produce a commodity or service.

A complete study over the water footprints of nations is done by Chapagain and Hoekstra (2006) and it is build a method inspired by two earlier methods: Hoekstra and Hung (2002, 2005) have quantified the virtual water flows related to the international trade of crop products and Chapagain and Hoekstra (2003) have done a similar study for livestock and livestock products. For this method is fundamental know that assess the footprints of a nation means quantify the flows of virtual water (m^3/ton) leaving and entering in a country and it is possible to define the internal water footprints (IWFP) and the external water footprints of a country (EWFP). The first one is the use of domestic water resources to produce goods and services consumed by inhabitants of the country. Traducing this definition in mathematically way it has the sum of the total water volume used from the domestic water resources in the national economy minus the volume of virtual water export to other countries insofar related to export of domestically produced products:

$$IWFP = AWU + IWW + DWW - VWE_{dom} \tag{1}$$

Where AWU is the agricultural water use term, taken equal to the evaporative water demand of the crops, IWW and DWW are the term of the water withdrawals in the industrial and domestic sectors respectively and VWE_{dom} is the virtual water export to other countries insofar related to export of domestically produced products. The AWU agricultural water use includes effective rainfall and the part of irrigation water used effectively for crop production, but not includes irrigation losses.
Instead the external water footprint of a country (EWFP) is defined as the annual volume of water resources used in other countries to produce goods and services consumed by the inhabitants of the country concerned. Mathematically it is equal to the so-called virtual water import into the country minus the volume of virtual water exported to other countries as a result of re-export of imported products:

$$EWFP = WVI - VWE_{re-export} \tag{2}$$

Both the internal and the external water footprint include the use of blue water, ground and surface water, and the use of green water, moisture stored in soil strata.
Analyzing in detail the footprints water for different nations all data is kept on AQUASTAT, database of FAO, in particular for industrial and domestic sectors, and the calculation total volume of water is made on the base of the use. For example, the total volume of water use in the agricultural sector has been calculated in this study based on the total volume of crop produced and its corresponding virtual water content or the virtual water content (m3/ton) of live animals has been calculated based on the virtual water content of their feed and the volumes of drinking and service water consumed during their lifetime.
Virtual water flows between nations have been calculated by multiplying commodity trade flows by their associated virtual water content:

$$VWF[n_e, n_i, c] = CT[n_e, n_i, c] \times VWC\ [n_e, c] \tag{3}$$

where VWF denotes the virtual water flow (m^3yr^{-1}) from exporting country n_e to importing country n_i as a result of trade in commodity c; CT the commodity trade (ton yr^{-1}) from the exporting to the importing country; and VWC the virtual water content (m^3 ton^{-1}) of the commodity, which is defined as the volume of water required to produce the commodity in the exporting country.

Virtual water flows in each sector are evaluated considering the quantity of water need by product. In 2006, for example the water used for rice crop production was the 21% of the total volume water used for global crop production and the second largest water consumer, 12%, was wheat, but it possible to estimate global average virtual water content of products. Below in the Table 1 there are some values of average virtual water content of products per unit of product:

Products	Virtual water content (litres)
1 glass of beer (250 ml)	75
1 glass of milk (200 ml)	200
1 potato (100 g)	25
1 apple (100 g)	70
1 cotton T-shirt (250 g)	2000
1 sheet of A4-paper (80 g/m^2)	20
1 egg (40 g)	135
1 hamburger (150 g)	2400
1 tomato (70 g)	13
1 orange (100 g)	50

Table 1 - Global average virtual water content of some selected products, per unit of product (A. Y. Hoekstra, A. K. Chapagain).

CHAPTER 2

2. Northern - African countries

In the following chapter the geography, the demography, the economy and the government of Northern - Africa countries will be analyzed to evaluate the past and actual water need for population and agriculture, in particular for main crops in each country.

The states of Northern Africa considered are:

- Algeria;
- Egypt;
- Libya;
- Morocco;
- Sudan;
- Tunisia.

Figure 2 - Countries of Northern - Africa.

2.1 Algeria

Algeria is located in the North – West of Africa between the Mediterranean Sea and the Sahara Desert, which is also known as the Maghreb. With around 2.4 million km^2, Algeria is the largest country of the continent and the Sahara Desert covers the 87% of the total surface.

In the North of the country there is a mountain area with the High Plateaus and the Saharan Atlas with an average altitude of 800 m. The Hoggar Mountains sit in South - East of the Country this area is largely rocky desert with an average elevation of more than 900 m above sea level.

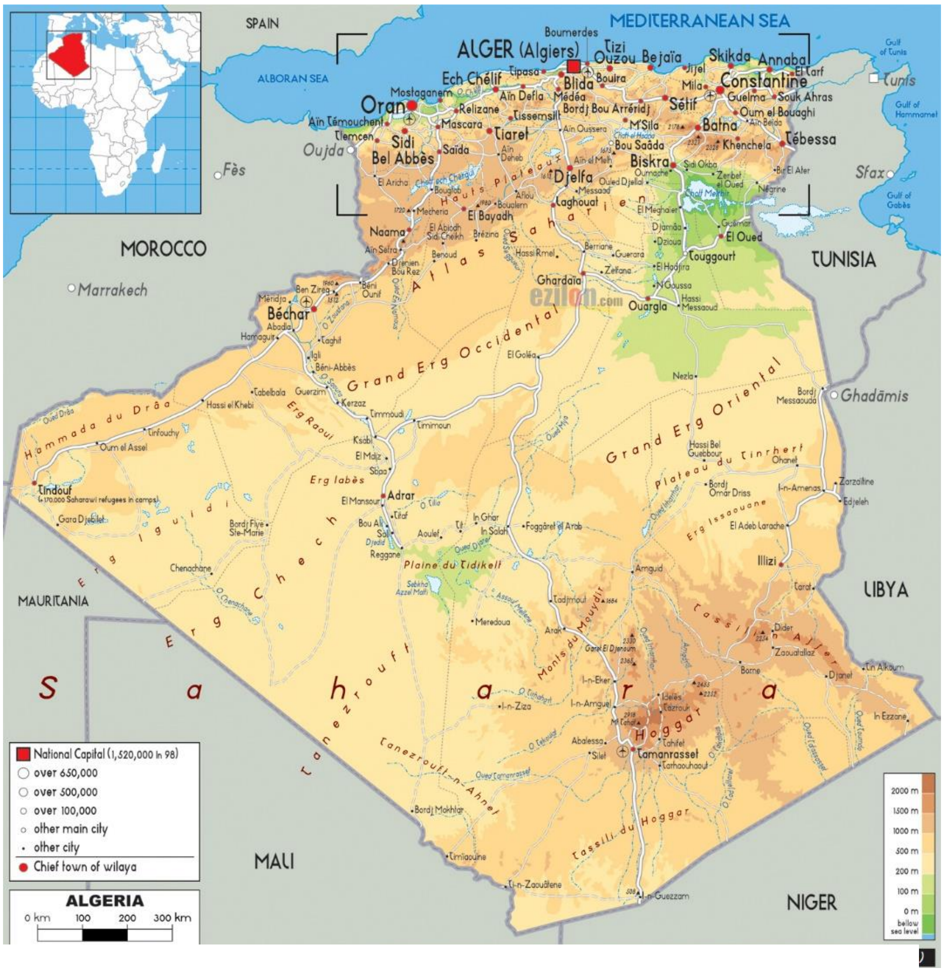

Figure 3 - Physical map of Algeria.

In Algeria there are three types of climate:

- the coast and Mountain range occupy the 4% of the total Country surface; one third of cultivated areas are compromised by excessive concentration of population and activity. Here the climate is typically Mediterranean, with mild, rainy winters and hot, sunny summers. The rains are scarcer in the western part where they fluctuate between 330 and 400 mm per year, while they become more abundant in the central and eastern parts, around 600 and 800 mm per year.
- the highlands are the 9% of the total Country surface with a semi-arid climate and precipitation amounts to 400 mm per year; around two thirds of cultivated area are in this region and the main problem is the big amount of salt in the soil. Moreover this region is subjected to desertification process because of drought, the weakening of the

lands subjected to the erosion of the wind, the weak water resources and the intensive practice of agro-pastoralism.

- Sahara Desert covers the 87% of the total Country surface with precipitation that amounts to 100 mm per year, limited cultivated areas and with extreme climate and high temperature excursions.

2.1.1 Demographics in Algeria

In 2017 Algerian population was 41,3 million of people and around 73 % of it was urban population compared to 2000 when the total population was 31,2 million of people and around 61 % of it was urban population.

The most populated cities are all in North, the capital Algiers and others cities such as Oran, Constantine, Annaba and Sétif that with them Mediterranean climate have fertile and rich in natural resources and this gave the opportunity to grew up the main economy activities of the Country in this area.

The population density of Algeria is 18 inhabit/km^2 (UNITED NATIONS,2017) and the median age is 27,8 years.

With the following area graph it is possible to see how the population of Algeria has changed from 1955 to 2017.

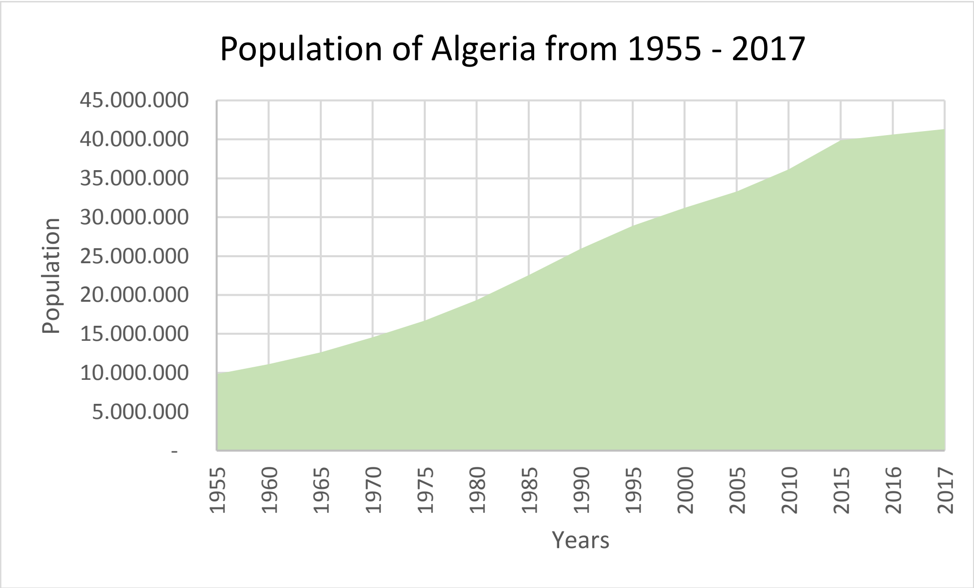

Figure 4 - Population of Algeria from 1955 to 2017.

The increasing population is due to a decrease in infant mortality, an increase in median age and a high birth rate. There is another factor to consider that is the migration rate, at moment this rate is not very high for Algeria, but to study Algerian demography is helpful to consider it.

Years	ALGERIA	Yearly % Change	Median Age	Fertility Rate
1955	9.829.719	2,05%	18,6	7,28
1960	11.124.888	2,48%	17,9	7,38
1965	12.626.952	2,53%	18,6	7,28
1970	14.550.034	2,84%	16,4	7,65
1975	16.709.099	2,77%	16,5	7,57
1980	19.337.715	2,92%	16,7	7,18
1985	22.565.905	3,09%	17,1	6,32
1990	25.912.367	2,77%	18	5,3
1995	28.904.298	2,18%	19,4	4,12
2000	31.183.660	1,52%	21,7	2,89
2005	33.288.437	1,31%	24,1	2,38
2010	36.117.637	1,63%	26	2,72
2015	39.871.528	1,98%	27,5	2,96
2016	40.606.052	1,84%	27,8	2,9
2017	41.318.142	1,75%	27,8	2,9

Table 2 - Main characteristics of Algerian population (1955-2017).

Table 2, as the graph in *Figure 4*, shows a continue increase of population in Algeria, but with a more accurate analysis it is possible see on the third column that yearly percentage increase decreases. For example, between 1965 -1970 the yearly percentage increase is 2,84 % compared to yearly percentage increase between 2015 to 2016 that is 1,84 % and the follow year is 1,75 %.

The yearly percentage increase is an index that decreases because the median age increases closer the 30 years, while fertility rate is decreasing from 1955 with a rate of 7,28 to 2,9 in 2017, but it is higher than other Countries (for example in Italy, during 2015, fertility rate was 1,35).

According to the United Nations database it is possible have an Algerian future population prospect:

Years	ALGERIA	Yearly % Change	Median Age	Fertility Rate
2020	43.333.255	1,66%	29,0	2,65
2025	46.307.643	1,33%	30,6	2,44
2030	48.821.963	1,06%	31,8	2,29
2035	51.070.401	0,90%	32,7	2,18
2040	53.248.997	0,84%	33,7	2,09
2045	55.411.769	0,80%	35,1	2,03
2050	57.436.703	0,72%	37,0	1,98
2055	59.106.493	0,57%	38,8	1,94
2060	60.316.226	0,40%	40,4	1,92

Table 3 - Population forecast of Algeria from database of DESA/POPULATION DEVITION, United Nations.

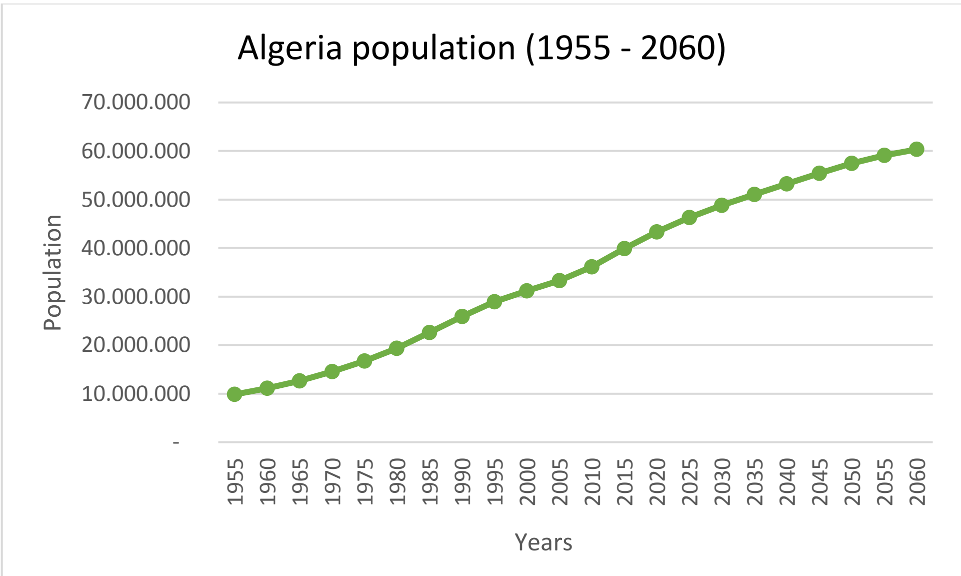

Figure 5 - Population of Algeria (1955 - 2060).

2.1.2 Availability and use of water in Algeria

In Algeria the amount of surface water produced internally is estimated at 9,76 million m^3/year (AQUASTAT, 2014) and the groundwater produced internally is equal to 1,487 million m^3/year (AQUASTAT, 2014). These water resources are fed by precipitations with a long-term average in Algeria equal to 89 mm/year (AQUASTAT, 2014), but they are irregular in time and space.

Water availability and resources in Algeria has different characteristics for each climate region.

In Northern Algeria, apart from the Lake of Fetzara, the others are generally temporary salt lakes resulting from heavy rains and flows in the depressions of the desert and they can form marshes. Further in this region, where the economic activity and population are concentrated, the disorderly economic and urban growth and the rapid increase of population have had significant effects. In Southern Algeria, the water resources most important are Lake Menghough at East while at West Sebkha el Melah that is an endorheic salt lake in Béchar Province.

Evaluating water availability in Algeria it is useful to consider the total renewable water resources, it corresponds to the maximum theoretical yearly amount of water available for a country at a given moment. It is defined as the sum of internal renewable water resources (IRWR) and external renewable water resources (ERWR). In Algeria the total renewable water resources is 11,67 million m^3/year (AQUASTAT). The total renewable water resources is an estimated data in AQUASTAT database, it has the same value from 1955 to 2015, in reality it is not constant because depends by the climate change and human use and it is difficult to calculate every minimum variation of this data. Knowing the total renewable water resources and the values of population every 5 years in Algeria it can be determinate the total renewable water resources per capita. All the results are showed in the *Table 4*.

Years	Population	Total renewable water resources per capita (m^3/inhabit/year)
1955	9.829.719	1.187,22
1960	11.124.888	1.049,00
1965	12.626.952	924,21
1970	14.550.034	802,06
1975	16.709.099	698,42
1980	19.337.715	603,48
1985	22.565.905	517,15
1990	25.912.367	450,36
1995	28.904.298	403,75
2000	31.183.660	374,23
2005	33.288.437	350,57
2010	36.117.637	323,11
2015	39.871.528	292,69

Table 4 - Total renewable water resources per capita and population in Algeria (1955 - 2015).

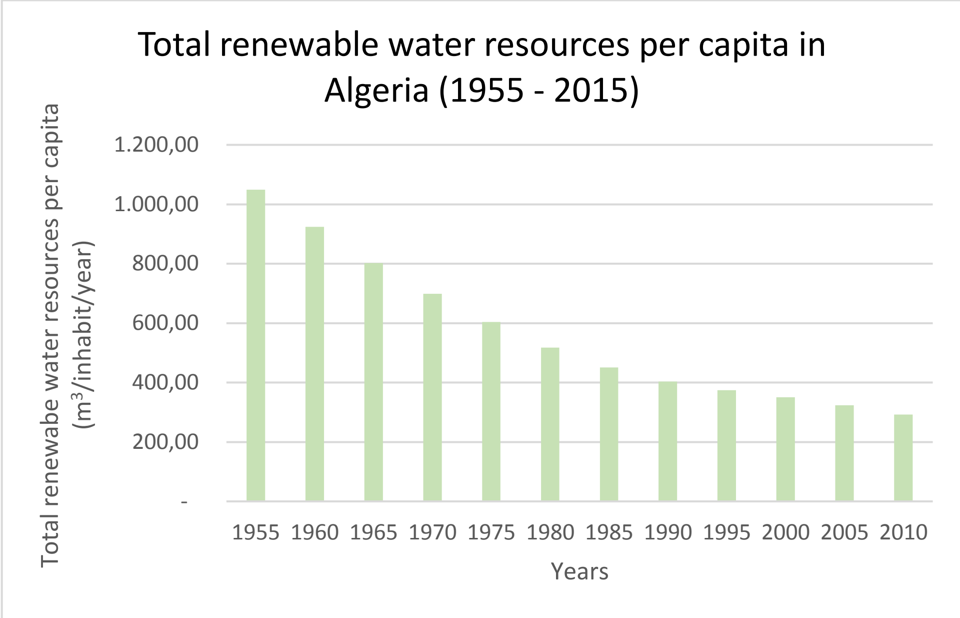

Figure 6 - Total renewable water resources per capita in Algeria (1955 - 2015).

In 60 years the population has grown of 30 million of people, in fact Algeria population is equivalent to 0.55% of the total World population and the 34 in the list of countries by population. The rapid growth of the Algeria population is not negligible if compared to the total renewable water resources. In 2015 total renewable water resources per capita is 292,9 m^3/year/capita this data is index of how Algeria is one of the most hydraulically stressed countries in the world, with per capita resources well below the threshold of absolute scarcity of water.

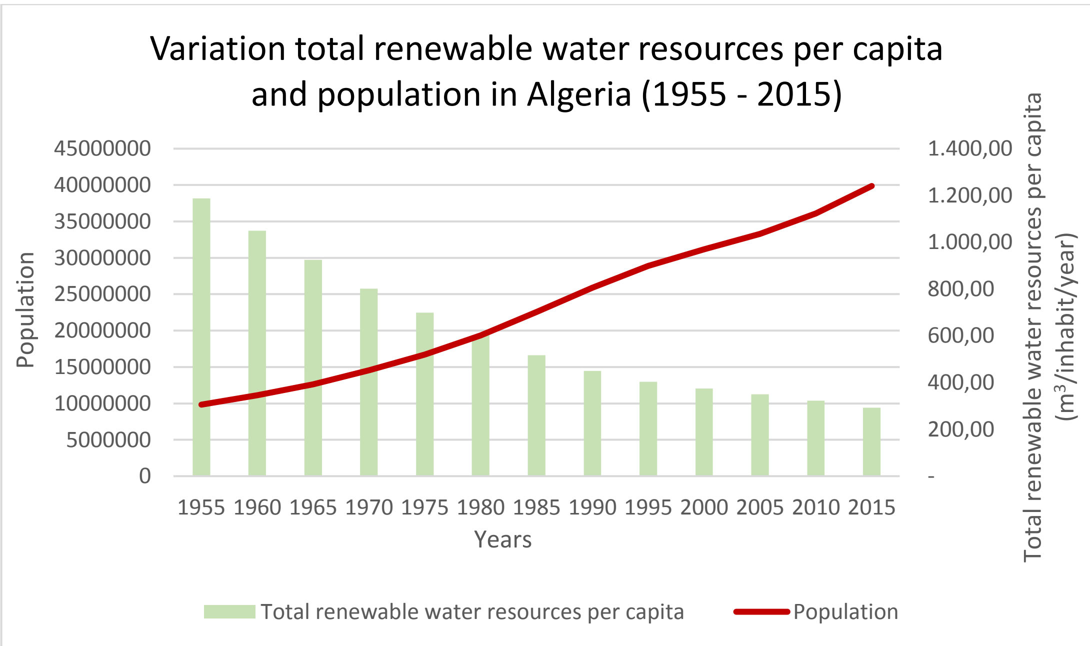

Figure 7 - Variation total renewable water resources per capita in Algeria and population in Algeria (1955 - 2015).

In AQUASTAT database there is also the percentage of total, urban and rural population with access to safe drinking – water from 1992 to 2015. Values show how the access to safe drinking-water for Algeria population decreases: in around 25 years in urban areas the access percentage is decreased of 13%. This can be an indicator of how urban growth, particularly in northern Algeria, is high and disordered and as consequences there are serious infrastructural deficiencies in sewers, aqueducts and electricity grids. For rural areas the access to safe-drinking is decreased in around 25 years less than 4% and it is a problem mostly for the Sothern Algeria where sit the Sahara Desert.

Years	Total population with access to safe drinking - water (%)	Urban population with access to safe drinking - water (%)	Rural population with access to safe drinking - water (%)
1992	91,7	97,4	85
1997	90,5	95	84,5
2002	88,8	92	83,7
2007	87	89,1	83
2012	84,9	86,1	82,2
2015	83,6	84,3	81,8

Table 5 - Percentage of total, urban and rural population with access to safe-drinking water in Algeria (1992 - 2015).

The sudden growth of urban areas and economic development have compromised quality of water, the pollution of water resources is taking on worrying proportions, particularly in the Northern Algeria where most of these resources are located. In terms of quality, 44% of the water examined by the studies is of good quality, 44% of satisfactory quality and 12% of poor quality.
Since the start of the new Millennium, with the increase of population, also the Algerian government gave big attention to the water problem with a large amount of the public budget dedicated to the water sector. Investment in the water sector, including agricultural water, doubled to 1.3 percent of GDP in 1999 2.6 per cent in 2006. This growth reflects the importance of efforts to mobilize more resources to meet the needs of both drinking and industrial water, protect the resource and meet the needs of agriculture. Thus, about two-thirds of the funding was earmarked for major mobilization infrastructures and for transmission and transfer works.
The use of water in Algeria is correlated to its economic development and its main economic activities, in order to analyze this aspect is useful to have an historical of Algeria GDP, Gross domestic product. With GDP it is possible understand also a necessary quantity of water for Algeria in the future. In *Table 6* every 5 years, like the previous, there are the historical GDP in current US$

in Algeria (WORLD BANK) and the GDP per capita calculated as the rapport of GDP values and population:

Years	GDP (current US$)	Population	GDP per capita (current US$/inhabit)
1960	2.723.648.551,75	11.124.888	244,82
1965	3.136.258.896,92	12.626.952	248,38
1970	4.863.487.492,66	14.550.034	334,26
1975	15.557.934.268,50	16.709.099	931,11
1980	42.345.277.342,02	19.337.715	2.189,78
1985	57.937.868.670,19	22.565.905	2.567,50
1990	62.045.099.642,78	25.912.367	2.394,42
1995	41.764.052.457,88	28.904.298	1.444,91
2000	54.790.245.600,58	31.183.660	1.757,02
2005	103.198.228.458,59	33.288.437	3.100,12
2010	161.207.268.655,39	36.117.637	4.463,39
2015	165.874.330.876,32	39.871.528	4.160,22

Table 6 - GDP (current US$) and GDP per capita in Algeria (1960-2015).

In the following area graph are showed the GDP in current US$ for each year from 1960 to 2017 (WORLD BANK) in Algeria in order to have a continue trend and pay more attention on its variation:

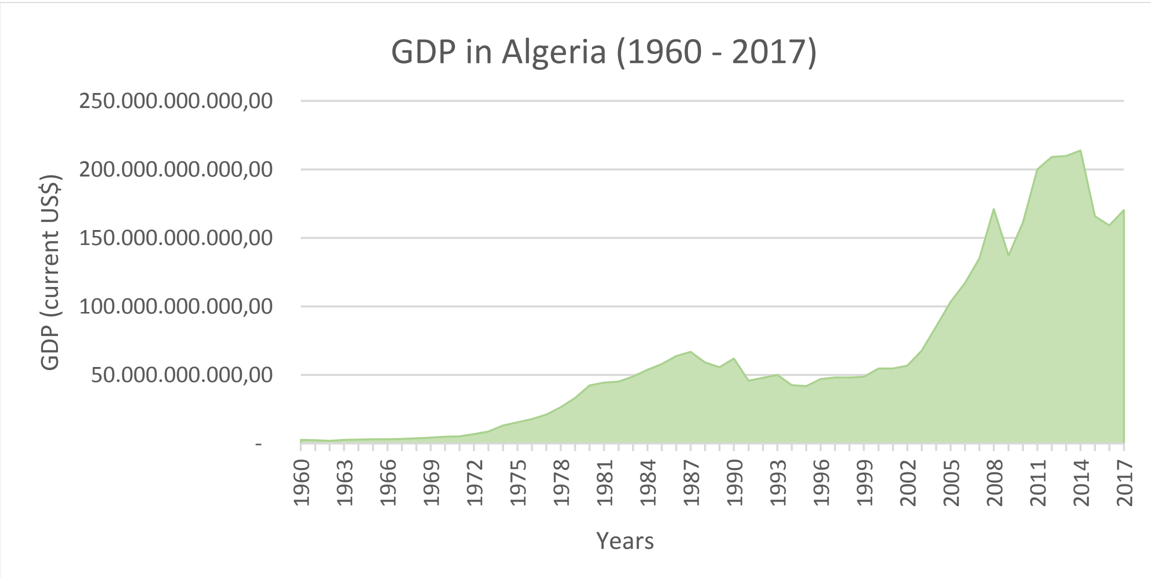

Figure 8 - GDP in Algeria (1960 - 2017).

Algeria GDP began to have significant growth since the 70s, not exceeding 100 billion US$ until 2005 when the GDP registered 103 billion US$. It is after 2005 until 2014 that the highest GDP growth was recorded, with a single decrease in 2009. The economy of Algeria is based on hydrocarbon wealth, in fact about 30% of GDP depends on the extraction of fossil coal: Algeria has the 10th-largest reserves of natural gas in the world and is the sixth-largest gas exporter.

In AQUASTAT database it is possible observe in Algeria which is the economic sector that requires more water. First, it is useful introduces the total water withdrawal: the annual quantity of water withdrawn for agricultural, industrial and municipal purposes. The total water withdrawal, in AQUASTAT database, was calculated very 5 years from 1970 to 1990 and in 2001 and 2012 in Algeria. In order to estimate its value in a year not listed, it is possible plot the total water withdrawal values and to calculate with a graphic interpolation the requested value. In *Table 9*, there are the total water withdrawal values from 1970 to 2012 and in *Figure 8* have plotted them.

Having total water withdrawal, GDP and population values in Algeria it is possible to compare these data and observe their trends. Total water withdrawal data are less than GDP and population, for this reasons with graphical interpolation will be calculated total water withdrawal data for 1995, 2000, 2005, 2010.

Years	Total water withdrawal (10^9 m^3/year)
1970	2
1975	2,5
1980	3
1985	3,5
1990	4,5
2001	5,723
2012	8,425

Table 7 - Total water withdrawal in Algeria (1970 - 2012).

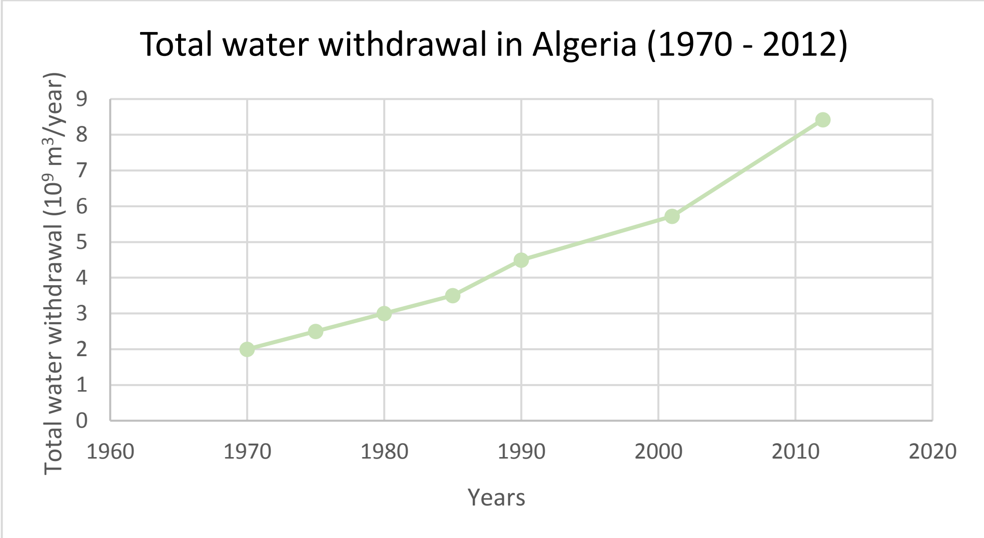

Figure 9 - Total water withdrawal in Algeria (1970 - 2012).

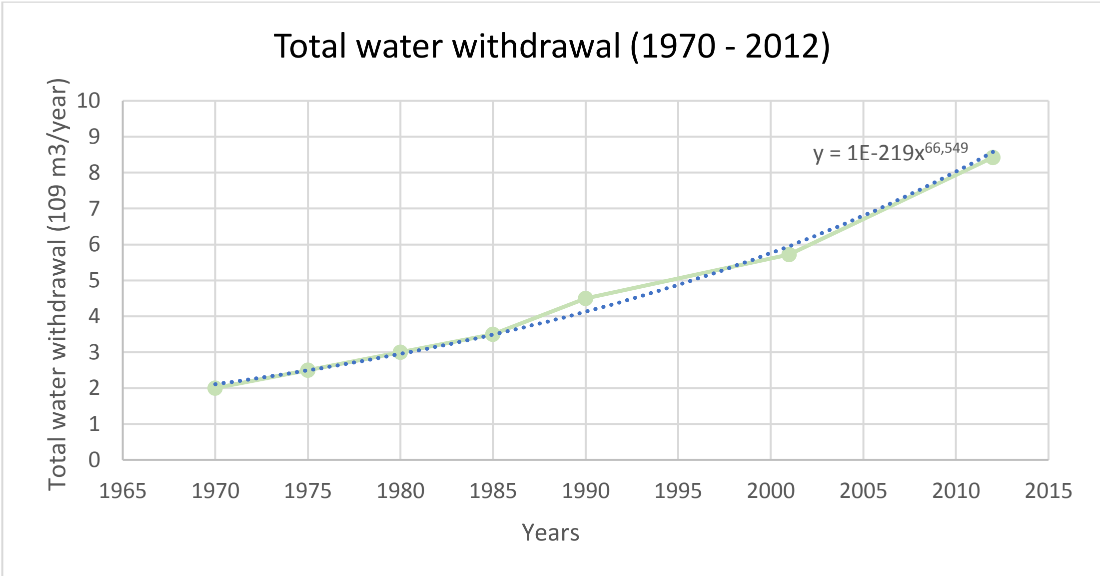

Figure 10 - Total water withdrawal trend in Algeria (1970 - 2012).

With Excel is possible to obtain a total water withdrawal trend from 1970 to 2012 in order to have the missing values (*Figure 10*). Values obtained are show in bold in *Table 8* to have an historical of total water withdrawal, GDP and population values in Algeria it is possible to compare these data and to observe if there could be a relation between them.

Years	Total water withdrawal(10^9 m^3/year)	GDP (current US$)	Population
1970	2	4.863.487.492,66	14.550.034
1975	2,5	15.557.934.268,50	16.709.099
1980	3	42.345.277.342,02	19.337.715
1985	3,5	57.937.868.670,19	22.565.905
1990	4,5	62.045.099.642,78	25.912.367
1995	**4,9**	41.764.052.457,88	28.904.298
2001	5,723	54.744.714.396,17	31.657.652
2005	**6,8**	103.198.228.458,59	33.288.437
2012	8,425	209.058.991.952,13	37.295.072

Table 8 - Historical total water withdrawal, GDP and Population in Algeria (1970 - 2012).

A first comparison is between the variation of total water withdrawal and GDP in Algeria: the total water withdrawal increase reflects an increase of GDP from 1970 – 2012.

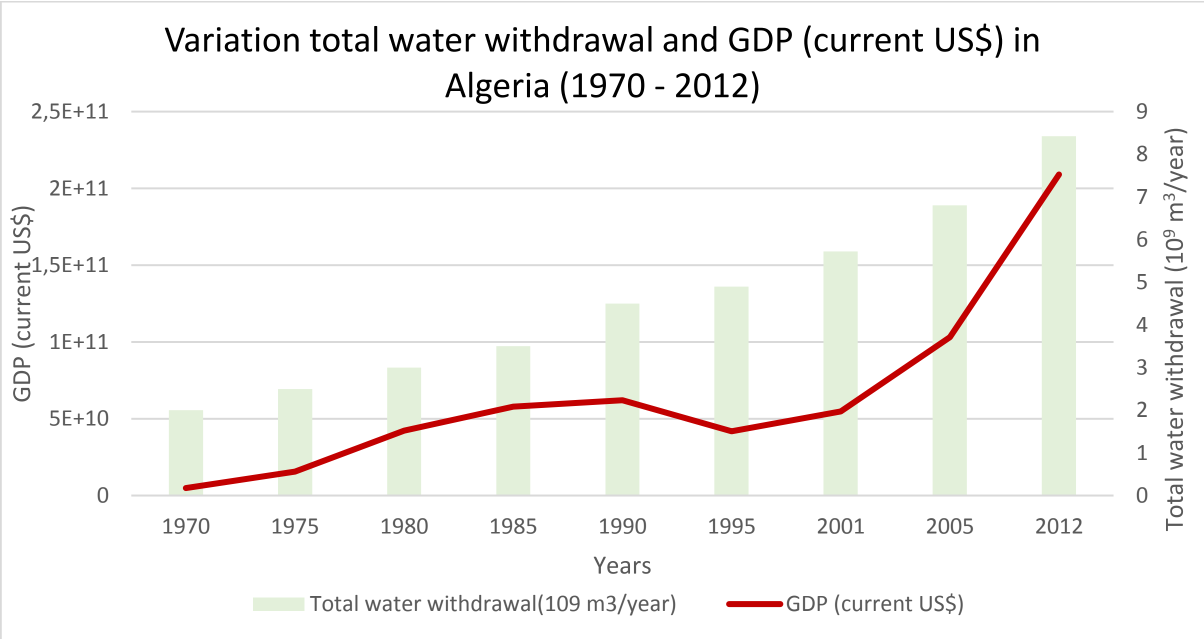

Figure 11 - Variation total water withdrawal and GDP in Algeria (1970 - 2012).

A second comparison can be made between the total water withdrawal and the variation of population in Algeria, a part of this term depends also by municipalities how is showed in *Figure 12*.

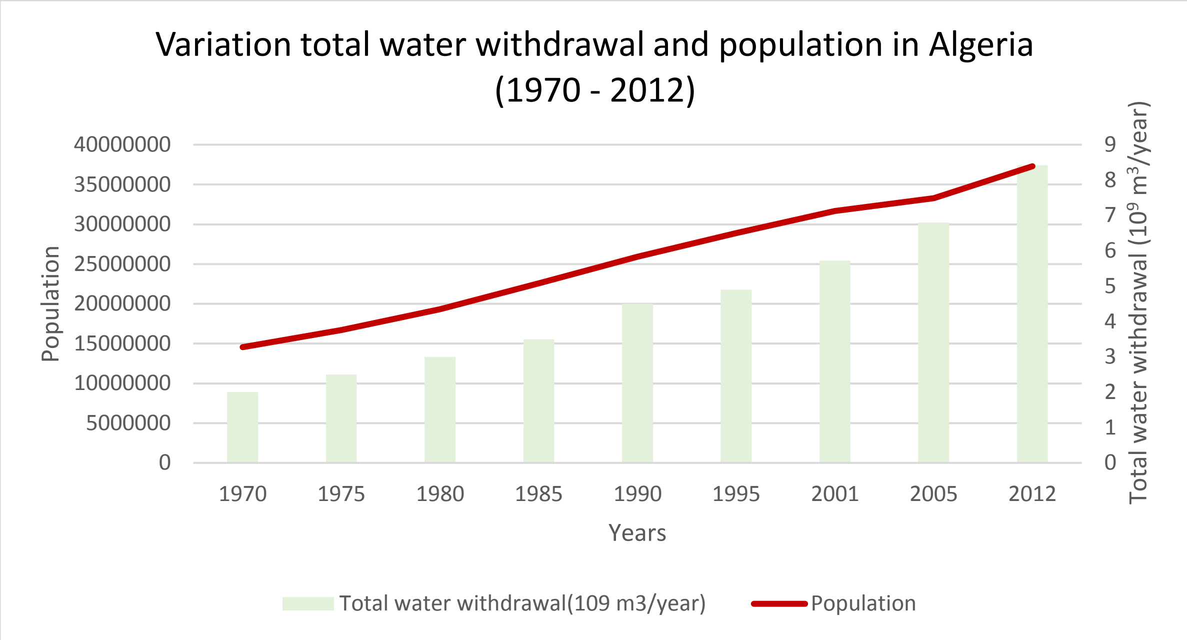

Figure 12 - Variation total water withdrawal and population in Algeria (1970 - 2012).

In AQUASTAT database, there are agricultural, industrial and municipal water withdrawal percentages on the total water withdrawal from 1980 to 2012 with a gap of around 10 years. Data show how agricultural percentage had a significant decrease from 1980 to 1990 to stabilize, after, around 60 %. The industrial percentage increase in 90s from 4 % to 15,11 % to decrease at the start of the new Millennium in favor of a growth of municipal water withdrawal percentage that is in 2012 more than a third of the total. Percentage trend are showed in the column chart in *Figure 13*.

Years	1980	1990	2001	2012
Agricultural water withdrawal as % of total water withdrawal (%)	74	60	61,19	59,23
Industrial water withdrawal as % of total water withdrawal (%)	4	15,11	8,737	4,926
Municipal water withdrawal as % of total withdrawal (%)	22	24,89	30,07	35,85

Table 9 - Agricultural, industrial and municipal water withdrawal percentages in Algeria (1980 - 2012).

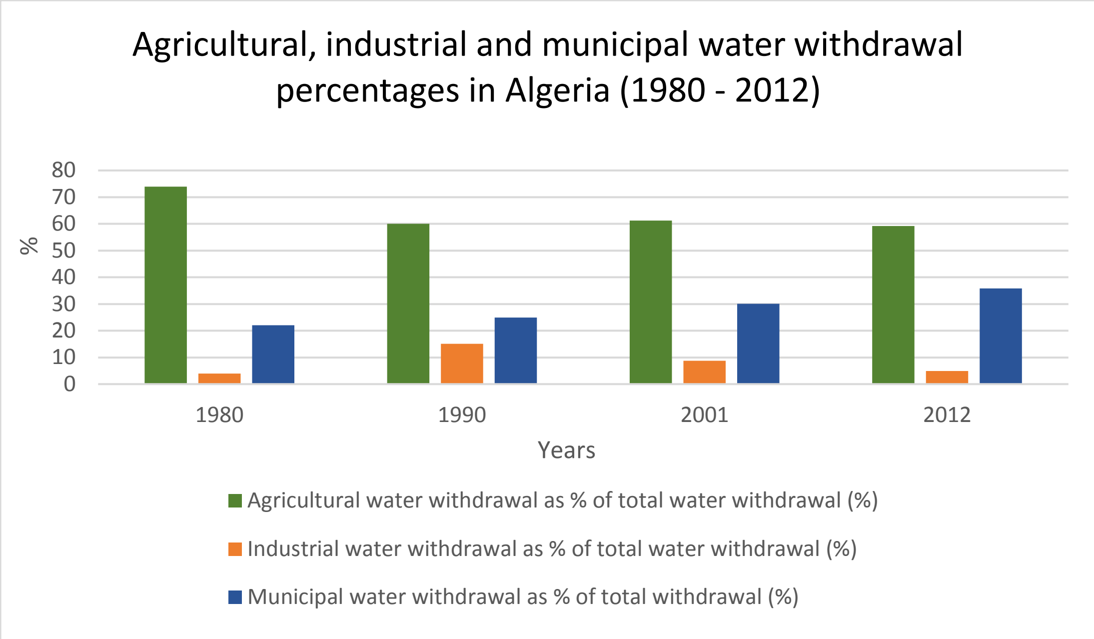

Figure 13 - Agricultural, industrial and municipal water withdrawal percentages in Algeria (1980 - 2012).

More than half of the water withdrawal is used for agriculture in the country, to get more details on the use of water in this sector in Algeria it may be useful to consider other FAOSTAT data.
Other data that can be find in FAOSTAT database are:

- country area;
- agricultural area (includes arable land, permanent crops and permanent pastures);
- forest (area covered with forest);
- arable land (land under temporary crops, temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow);
- permanent crops (land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest);
- cultivated area (the sum of the arable land area and the area under permanent crops);
- area harvested (ex, area harvested for grain is defined as the total number of hectares of a specific crop in a specific production season that are actually harvested for grain).

Country Area (ha)	238.174.000
Agricultural Area (ha)	41.431.000
Forest (ha)	1.948.400
Arable land (ha)	7.469.000
Permanent Crops (ha)	969.800
Cultivated area (ha)	8.439.000
Area harvested (ha)	4.033.310

Table 10 - Main Algerian data land (official data, FAOSTAT, AQUASTAT 2014).

Having an area harvested historical data can be a good way to calculate the needed water quantity in agricultural sector in Algeria. With the FAOSTAT database, it is possible create an historical of area harvested considering all crops in this country and a historical of production quantity. The years considered will be the same considered in the past tables in order to obtain a data comparison in same conditions.

Years	Total area harvested (ha)
1965	3.552.354
1970	4.009.520
1975	4.085.770
1980	4.129.680
1985	4.250.135
1990	3.315.249
1995	3.702.732
2000	2.082.193
2001	3.485.594
2005	3.833.927
2010	4.615.994
2012	4.892.809
2015	4.242.307

Table 11 - Historical area harvested (1965 - 2015).

Making a more accurate study, it considers total area harvested in hectares and the production in tons of main crops in Algeria. The main crops considered are: lemons and limes, olives, oranges, tobacco unmanufactured, tomatoes, potatoes, fresh vegetables and derivates, vegetables leguminous and derivates, oats, barley and dates. All the values of main crops are in *Table 12* from 1990 to 2015.

Crops		1990	1995	2000	2001	2005	2010	2012	2014	2015
BARLEY	Area harvested (ha)	1.095.120	824.170	215.630	515.690	684.648	1.018.792	1.030.477	791.843	802.336
	Production (tonnes)	833.400	584.980	163.287	574.654	1.032.819	1.503.900	1.591.715	939.401	1.030.556
DATES	Area harvested (ha)	78.640	87.020	101.820	104.390	147.906	161.091	163.985	165.378	166.893
	Production (tonnes)	205.907	285.155	365.616	437.332	516.293	644.741	789.357	934.377	990.377
LEMONS AND LIMES	Area harvested (ha)	1.020	1.880	2.690	2.720	3.162	4.344	4.486	3.858	3.790
	Production (tonnes)	11.921	15.666	29.281	31.644	47.305	52.136	76.082	85.642	72.562
OATS	Area harvested (ha)	82.080	73.740	14.660	49.700	61.227	81.670	85.245	64.801	68.096
	Production (tonnes)	41.300	53.100	8.170	43.661	77.500	101.500	109.703	56.580	68.203
OLIVES	Area harvested (ha)	170.170	160.780	168.080	177.220	239.352	294.200	328.884	383.443	406.571
	Production (tonnes)	177.907	130.964	217.112	200.339	316.489	311.252	393.840	482.860	653.725
ORANGES	Area harvested (ha)	24.290	25.420	27.180	27.560	29.697	46.884	47.733	42.952	43.328
	Production (tonnes)	183.830	226.716	299.583	327.083	435.236	582.496	802.517	955.206	1.005.079
POTATOES	Area harvested (ha)	102.430	87.740	72.690	65.790	99.717	121.996	138.666	156.176	153.313
	Production (tonnes)	808.541	1.200.000	1.207.690	967.232	2.156.550	3.300.312	4.219.476	4.673.516	4.539.577
TOBACCO UNMANUFACTURATED	Area harvested (ha)	2.900	2.650	6.450	6.300	4.897	4.219	4.149	4.427	4.508
	Production (tonnes)	3.578	2.790	7.153	7.776	6.500	7.604	7.630	8.707	8.800
TOMATOES	Area harvested (ha)	32.000	46.690	16.710	16.760	21.089	21.358	21.542	22.646	24.065
	Production (tonnes)	402.020	858.637	341.447	373.534	513.780	718.235	796.963	1.065.609	1.163.766
VEGETABLES,FRESH NES	Area harvested (ha)	25.700	30.550	25.520	26.190	40.000	34.243	37.735	44.010	49.664
	Production (tonnes)	161.909	265.735	246.899	282.837	400.000	460.692	559.763	980.652	931.536
VEGETABLES,LEGUMINOUS NES	Area harvested (ha)	19.770	20.780	19.570	19.970	23.280	27.782	29.567	30.833	30.055
	Production (tonnes)	78.298	110.515	77.719	124.959	207.500	248.347	257.700	295.972	249.537
WHEAT	Area harvested (ha)	1.187.820	1.680.720	827.000	1.836.410	1.603.744	1.755.728	1.945.776	1.651.311	1.814.722
	Production (tonnes)	750.080	1.499.920	760.361	2.039.213	2.414.728	2.605.178	3.432.231	2.436.197	2.656.731

Table 12 - Area harvested and production of main crops in Algeria (1990 - 2015).

Now, the aim of the study is to calculate the water quantity in a year for each main crop in Algeria in 1990, 2001, 2012.

Having total water withdrawal, expressed in m^3/year, and the percentage of agricultural water withdrawal it is possible to obtain the agricultural water withdrawal in m^3/year in Algeria for 1990, 2001, 2012. The results of agricultural water withdrawal are showed in the last column in *Table 13*.

Years	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal as % of total water withdrawal (%)	Agricultural water withdrawal (10^9 m^3/year)
1990	4,5	60	2,70
2001	5,723	61,19	3,50
2012	8,425	59,23	4,99

Table 13 - Agricultural water withdrawal (m^3/year) in Algeria (1990, 2001, 2012).

Another value it can be calculated is the agricultural water withdrawal per hectare in these years in Algeria as showed in *Table 14*.

Years	Area harvested (ha)	Total water withdrawal(109 m3/year)	Agricultural water withdrawal (109 m3/year)	Agricultural water withdrawal per hectare (lt/ha)
1990	3.315.249	4,5	2,70	814.418,46
2001	3.485.594	5,723	3,50	1.004.679,17
2012	4.892.809	8,425	4,99	1.019.890,11

Table 14 - Agricultural water withdrawal per hectare in Algeria (1990, 2001, 2012).

With *Table 12* and data *Table 14*, it can obtain the water liters used in 1990, 2001, 2012 for the main crop in Algeria. All the results are reported in *Table 15* with tons produced.

Crops	1990			2001			2012		
	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)
BARLEY	1.095.120	833.400	891.885,95	515.690	574.654	518.103,00	1.030.477	1.591.715	1.050.973,30
DATES	78.640	205.907	64.045,87	104.390	437.332	104.878,46	163.985	789.357	167.246,68
LEMONS AND LIMES	1.020	11.921	830,71	2.720	31.644	2.732,73	4.486	76.082	4.575,23
OATS	82.080	41.300	66.847,47	49.700	43.661	49.932,55	85.245	109.703	86.940,53
OLIVES	170.170	177.907	138.589,59	177.220	200.339	178.049,24	328.884	393.840	335.425,54
ORANGES	24.290	183.830	19.782,22	27.560	327.083	27.688,96	47.733	802.517	48.682,41
POTATOES	102.430	808.541	83.420,88	65.790	967.232	66.097,84	138.666	4.219.476	141.424,08
TOBACCO UNMANUFACTURATED	2.900	3.578	2.361,81	6.300	7.776	6.329,48	4.149	7.630	4.231,52
TOMATOES	32.000	402.020	26.061,39	16.760	373.534	16.838,42	21.542	796.963	21.970,47
VEGETABLES,FRESH NES	25.700	161.909	20.930,55	26.190	282.837	26.312,55	37.735	559.763	38.485,55
VEGETABLES, LEGUMINOUS NES	19.770	78.298	16.101,05	19.970	124.959	20.063,44	29.567	257.700	30.155,09
WHEAT	1.187.820	750.080	967.382,54	1.836.410	2.039.213	1.845.002,87	1.945.776	3.432.231	1.984.477,70

Table 15 - Water withdrawal in liters for each main crop in Algeria (1990, 2001, 2012).

2.2 Egypt

Egypt lies in the northeastern corner of the African continent and has a total area of about 1 million km². The Egyptian terrain consists of a vast desert plateau interrupted by the Nile Valley and Delta, which occupy about 4 % of the total country area. The land surface rises on both sides of the Valley reaching about 1 000 m above sea level in the east and about 800 m above sea level in the west. The highest point of the country, at Mount Catherine in Sinai, is 2 629 m above sea level and the lowest point, at the Qattara Depression in the northwest, is 133 m below mean sea level.

Figure 14 - Physical map of Egypt.

Most of the country is a desert and only 35000 square kilometers of the total land is arable and populated. The country can be separated into 4 ecological zones: Western Desert, Nile Delta and Valley, Eastern Desert and Sinnai Peninsula.

Egypt has an unusually hot, sunny and dry climate. Average high temperatures are high in the north but very to extremely high in the rest of the country during summer. The cooler Mediterranean winds consistently blow over the northern sea coast, which helps to get more moderated temperatures, especially at the height of the summertime.

2.2.1 Demographics in Egypt

In 2017 Egyptian population was 97 million of people and 38 % of it was urban population compared to 2000 when the total population was 69,9 million of people and around 41 % of it was urban population.

The most populated cities are in Nile Valley and Delta or on the Mediterranean. In order six of the most populated cities are: Cairo, Alexandria, Giza, Shubra El Kheima, Port Said and Suez.

The population density of Egypt is 98 inhabit/km^2 (UNITED NATIONS,2017) and the median age is 24.8.

With the following area graph it is possible to see how the population of Egypt is changed from 1955 to 2017.

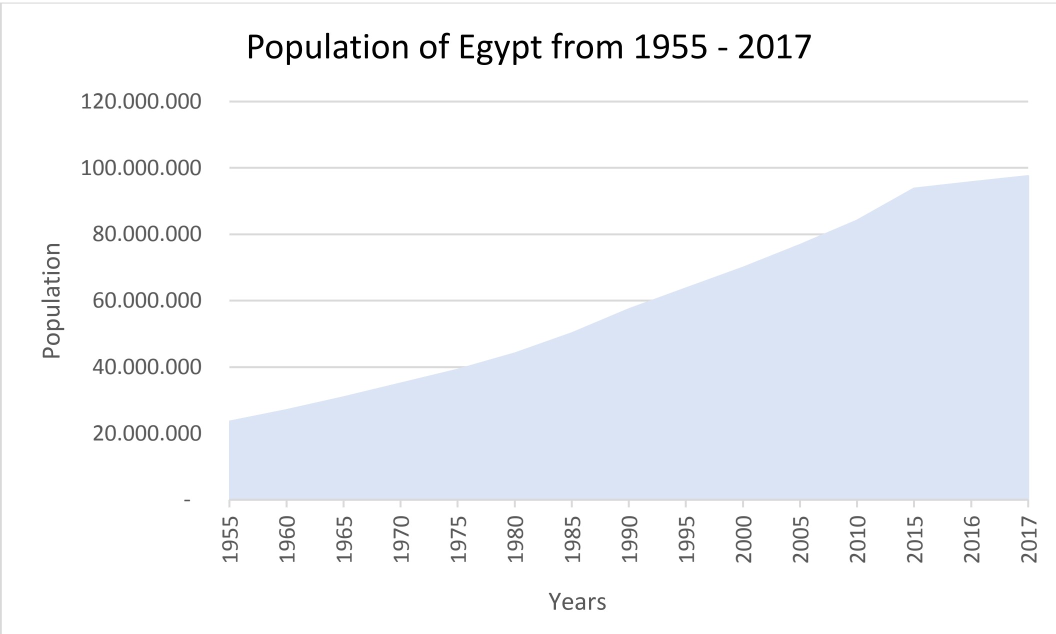

Figure 15 - Population of Egypt from 1955 – 2017.

Egypt population is equivalent to 1,3 % of the total world population and ranks number 14 in the list of countries by population. Respect to the year 1955 the population has increased more than four times, also in this case the decrease of infant mortality, an increase in median age and a high birth rate have influenced this fact. In Egypt, however, the median age is less than in Algeria otherwise the fertility rate is higher: during the 2015 the fertility rate in Algeria was 2,96, in Egypt in the same year the rate was 3,38.

Years	EGYPT	Yearly % Change	Median Age	Fertility Rate
1955	23.523.384	2,54%	20,7	6,75
1960	26.996.533	2,75%	19,9	6,75
1965	30.875.964	2,68%	19,0	6,65
1970	35.046.273	2,53%	19,0	6,45
1975	39.187.702	2,23%	19,2	6,00
1980	44.099.142	2,36%	19,4	5,70
1985	50.204.985	2,59%	19,5	5,49
1990	57.412.215	2,68%	19,6	5,15
1995	63.714.386	2,08%	20,1	4,12
2000	69.905.988	1,86%	21,2	3,40
2005	76.778.149	1,88%	22,6	3,15
2010	84.107.606	1,82%	23,9	2,98
2015	93.778.172	2,18%	24,7	3,38
2016	95.688.681	1,95%	24,8	3,33
2017	97.553.151	1,87%	24,8	3,33

Table 16 - Main characteristics of Egyptian population (1955-2017).

In area graph, *Figure 15*, shows a rapid increase of population in Egypt, but with a more accurate analysis it is possible see in *Table 16* on the third column that yearly percentage increase decreases but it is not less than 1,8 %.

The median age in Egypt has grown from 19 of 1965 to 24,7 of 2015, but is a index that suggests a very young population in Egypt.

According to the United Nations database it is possible have an Egyptian future population prospect:

Years	EGYPT	Yearly % Change	Median Age	Fertility Rate
2020	102.941.484	1,86%	25,3	3,15
2025	111.470.930	1,59%	25,9	2,96
2030	119.745.677	1,43%	26,6	2,80
2035	128.264.287	1,37%	27,4	2,67
2040	137.065.513	1,33%	28,5	2,56
2045	145.575.547	1,20%	29,9	2,45
2050	153.433.492	1,05%	31,2	2,36
2055	160.546.412	0,91%	32,4	2,28
2060	167.005.245	0,79%	33,4	2,20

Table 17 - Population forecast of Egypt from database of DESA/POPULATION DEVITION, United Nations.

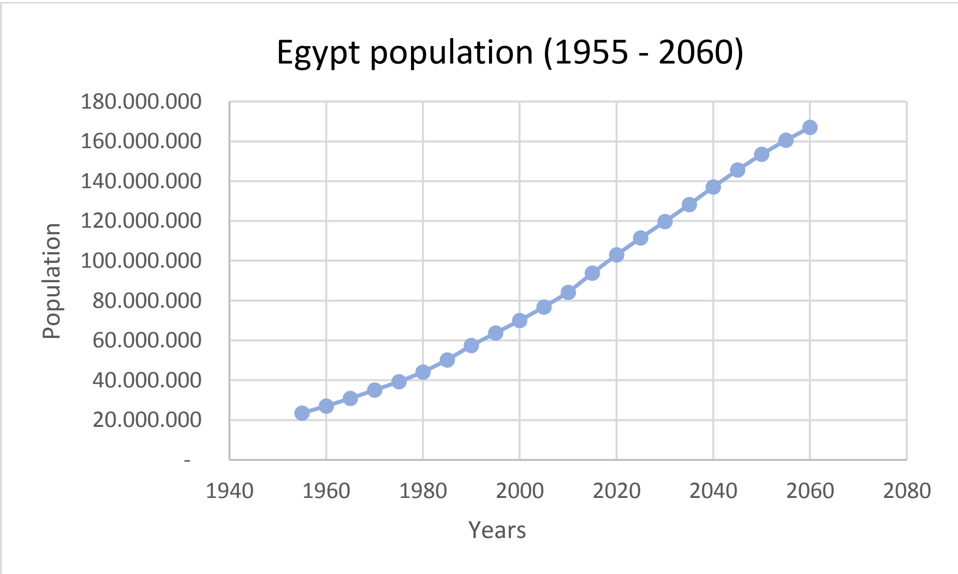

Figure 16 - Egypt population (1955 - 2060).

2.2.2 Availability and use of water in Egypt

In Egypt the amount of surface water produced internally is estimated at 500 million m^3/year (AQUASTAT, 2014) and the groundwater produced internally is equal to 1300 million m^3/year (AQUASTAT, 2014).

The amount of water is due to the presence for most of the Egyptian territory of the Nile river with a total length of about 6 650 km and under the Nile Waters Agreement of 1959 between Egypt and

Sudan, 55 500 million m³/year flows annually from the Nile into Egypt. The Egyptian territory comprises the following river basins:

- the Northern Interior Basin, covering 520 881 km² or 52 % of the total area of the country in the east and southeast of the country. A sub-basin of the Northern Interior Basin is the Qattara Depression.
- The Nile Basin, covering 326 751 km² (33 %) in the central part of the country in the form of a broad north-south strip.
- The Mediterranean Coast Basin, covering 65 568 km² (6 %).
- The Northeast Coast Basin, a narrow strip of 88 250 km² along the coast of the Red Sea (8 %).

Precipitations has a long-term average in Egypt equal to 51 mm/year (AQUASTAT, 2014), a value not very high but natural for that kind of climate zone.
The total renewable water resources in Egypt is 58 300 million m³/year, as in the case of Algeria this value is the same from 1955 to 2015, it is not constant because depends by the climate change and human use and it is difficult to calculate every minimum variation of this data. Knowing the total renewable water resources and the values of population every 5 years in Algeria it can be determinate the total renewable water resources per capita. All the results are showed in the *Table 18*.

Years	Population	Total renewable water resources per capita (m³/inhabit/year)
1955	23.523.384	2.478
1960	26.996.533	2.160
1965	30.875.964	1.888
1970	35.046.273	1.664
1975	39.187.702	1.488
1980	44.099.142	1.322
1985	50.204.985	1.161
1990	57.412.215	1.015
1995	63.714.386	915
2000	69.905.988	834
2005	76.778.149	759
2010	84.107.606	693
2015	93.778.172	622

Table 18 - Total renewable water resources per capita and population in Egypt (1955 - 2015).

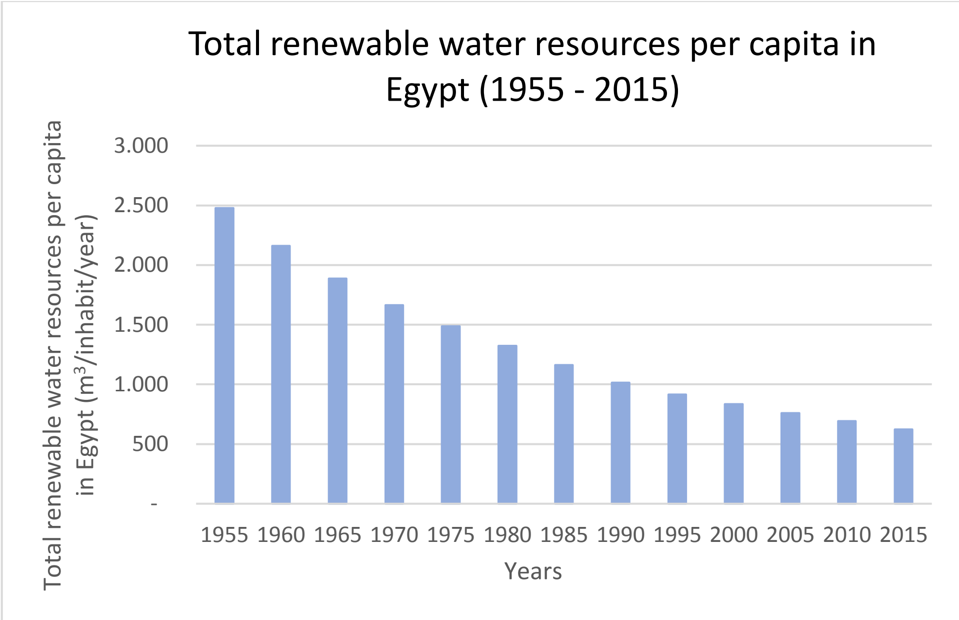

Figure 17 - Total renewable water resources per capita in Egypt (1955 - 2015).

The total renewable water resources per capita decreases from 1955 to 2015 due to the strong growth of the population until a value around 622 m³/year/capita in 2015, but considering population growth is expected to drop below the 500 m³ threshold of absolute water scarcity by 2030.

In *Figure 18* is showed how the population increase can affect the total renewable water resources.

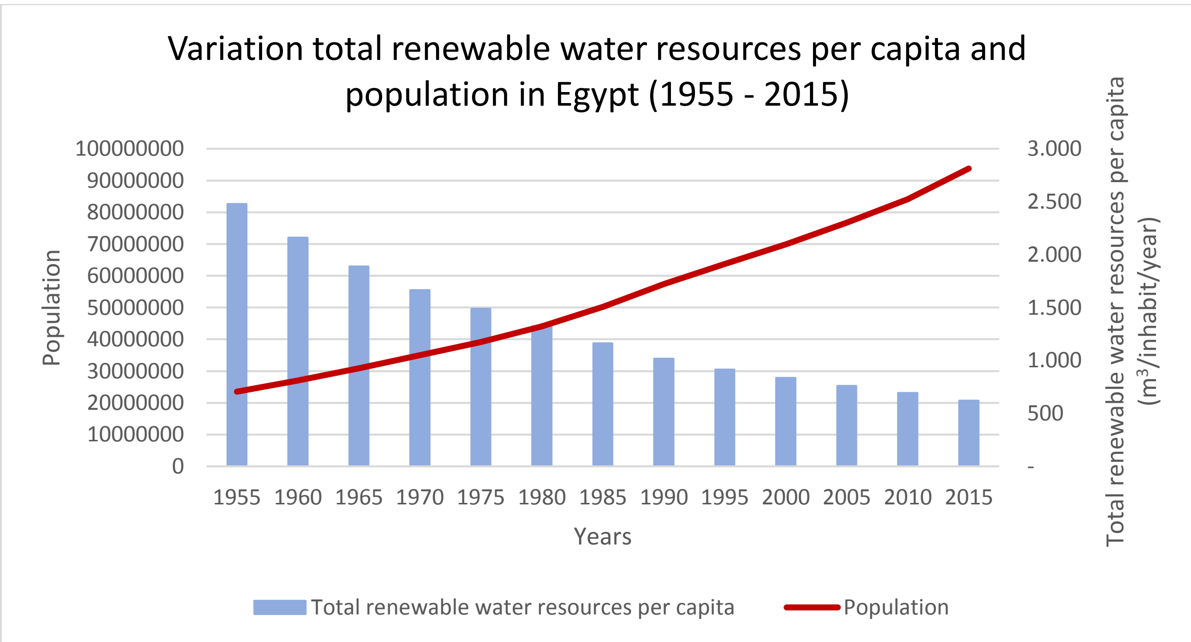

Figure 18 - Variation total renewable water resources per capita and population in Egypt (1955 - 2015).

In AQUASTAT database there is also the percentage of total, urban and rural population with access to safe drinking – water from 1992 to 2015. Values show a good access to safe drinking-water for the population in Egypt: in 2015, all the urban population in Egypt has access to safe drinking – water.

For rural population there is also a good result, the 99 % of population, in 2015, has access to safe drinking – water. These data are very different from Algerian data in the same section.

Years	Total population with access to safe drinking - water (%)	Urban population with access to safe drinking - water (%)	Rural population with access to safe drinking - water (%)
1992	93,9	97	91,6
1997	95,1	97,7	93,2
2002	96,4	97	94,8
2007	97,6	99,2	96,4
2012	98,8	99,99	98
2015	99,4	100	99

Table 19 - Percentage of total, urban and rural population with access to safe-drinking water in Egypt (1992 - 2015).

Also for Egypt, as for Algeria, it can be useful to have an historical of GDP, Gross domestic product, to analyze the water use in this country.

In *Table 20* every 5 years, like the previous, there are the historical GDP in current US$ in Egypt (WORLD BANK) and the GDP per capita calculated as the rapport of GDP values and population:

Years	GDP (current US $)	Population	GDP per capita (current US$/inhabit)
1965	5.111.621.014	30.875.964	165,55
1970	7.682.491.836	35.046.273	219,21
1975	11.437.965.585	39.187.702	291,88
1980	22.912.500.556	44.099.142	519,57
1985	34.689.560.465	50.204.985	690,96
1990	43.130.416.913	57.412.215	751,24
1995	60.159.245.060	63.714.386	944,20
2000	99.838.543.960	69.905.988	1.428,18
2005	89.685.725.230	76.778.149	1.168,12
2010	218.888.324.505	84.107.606	2.602,48
2015	332.698.041.031	93.778.172	3.547,71

Table 20 - GDP (current US$) and GDP per capita in Egypt (1965-2015).

In the following area graph are showed the GDP in current US$ for each year from 1965 to 2017 (WORLD BANK) in Egypt in order to have a continue trend and pay more attention on its variation:

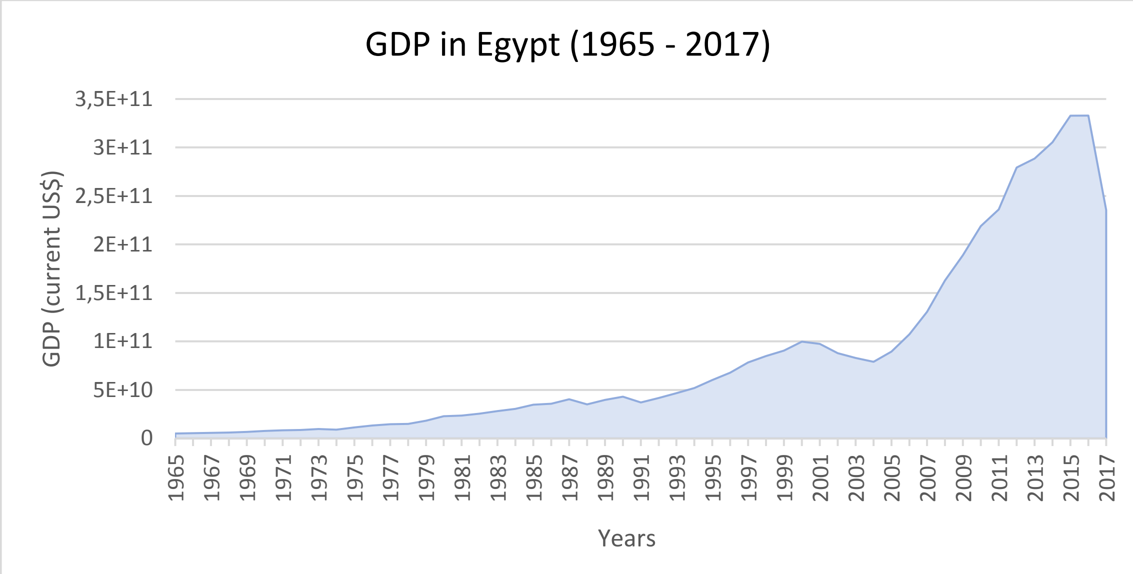

Figure 19 - GDP in Egypt (1960 - 2017).

From the second half of the 60s up to the beginning of the new millennium, the GDP in Egypt had a slow and moderate growth, in 2005 there was a rapid increase that suffered a setback only in the past year. The economy of Egypt depends mainly on agriculture, media, petroleum imports, natural gas, and tourism.

In AQUASTAT database there are the historical of total water withdrawal in Egypt from 1975 to 2010 with missing values for some years.

Years	Total water withdrawal (10^9 m^3/year)
1975	48,2
1995	58,87
2000	68,3
2010	78

Table 21 - Total water withdrawal in Egypt (1975 - 2010).

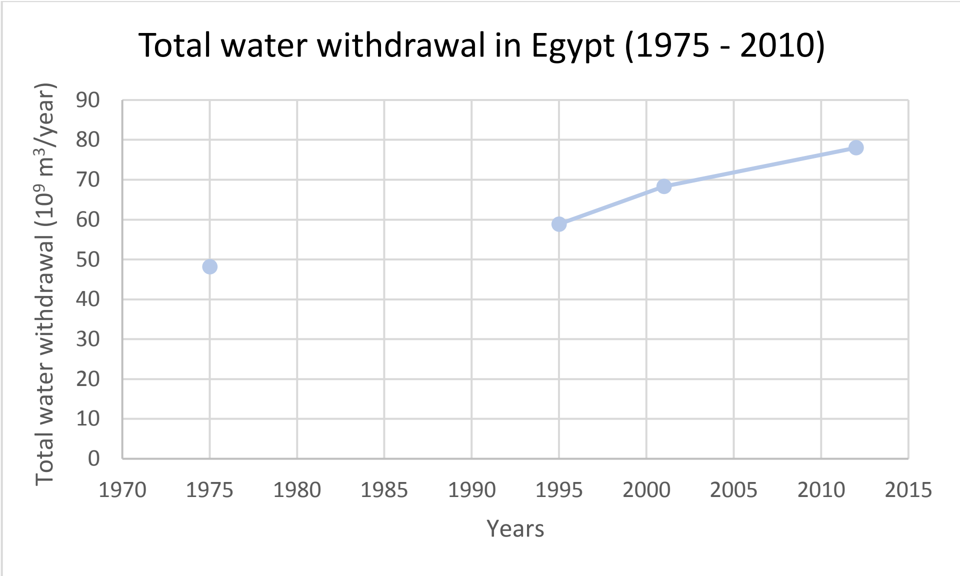

Figure 20 - Total water withdrawal in Egypt (1975 - 2012).

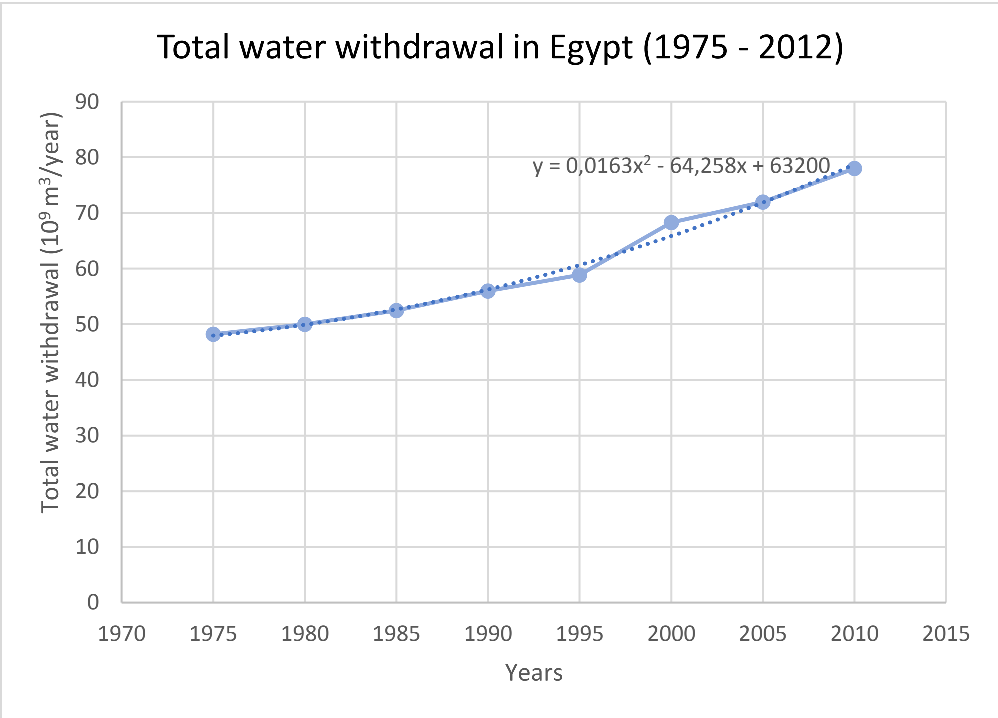

Figure 21 - Total water withdrawal trend in Egypt (1975 - 2010).

With Excel is possible to obtain a total water withdrawal trend from 1975 to 2010 in order to have the missing values (*Figure 21*). Values obtained are show in bold in *Table 22* to have an historical of total water withdrawal, GDP and population values in Egypt to compare these data and to observe if there could be a relation between them.

Years	Total water withdrawal(10^9 m^3/year)	GDP (current US$)	Population
1975	48,2	11.437.965.585	39.187.702
1980	**50**	22.912.500.555	44.099.142
1985	**52,5**	34.689.560.464	50.204.985
1990	**56**	43.130.416.913	57.412.215
1995	58,87	60.159.245.060	63.714.386
2000	68,3	97.632.008.709	69.905.988
2005	**72**	89.685.725.230	76.778.149
2010	78	279.372.758.361	84.107.606

Table 22 - Historical total water withdrawal, GDP and Population in Egypt (1975 - 2010).

A first comparison is between the variation of total water withdrawal and GDP in Egypt: the total water withdrawal increase reflects an increase of GDP from 1975 – 2010. The same happens with the second comparison between the variation of total water withdrawal and population in Egypt.

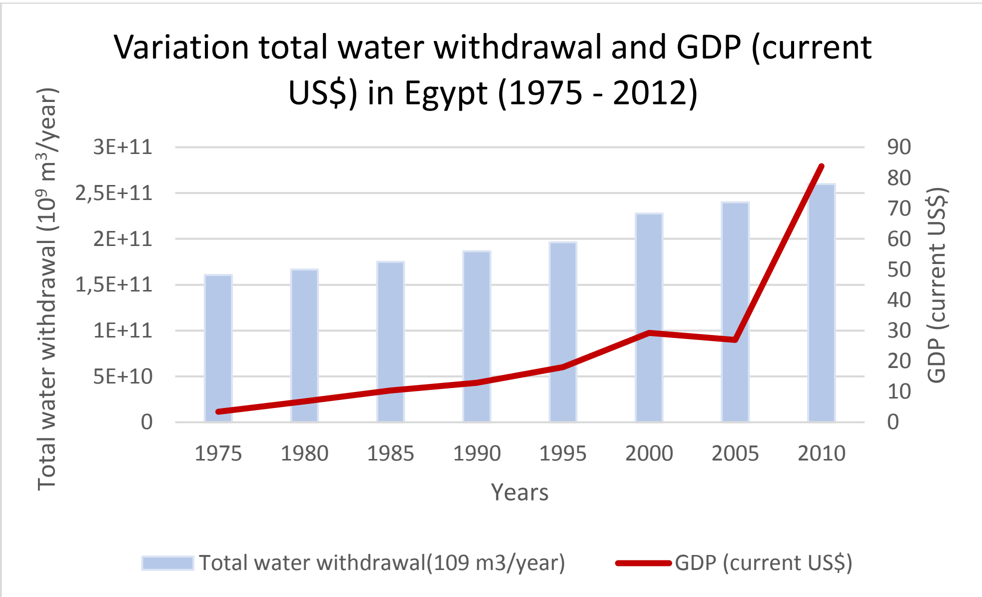

Figure 22 - Variation total water withdrawal and GDP in Egypt (1975 -2010).

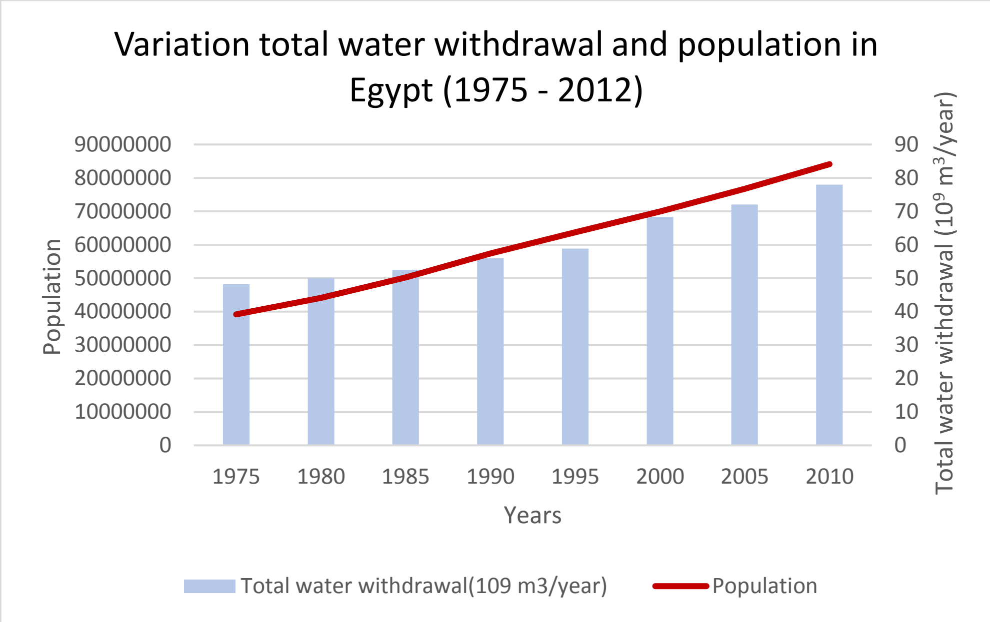

Figure 23 - Variation total water withdrawal and population in Egypt (1975 - 2010).

In AQUASTAT database, there agricultural, industrial and municipal water withdrawal on the total water withdrawal percentages from 1995 to 2010 every 5 years. Data show how agricultural percentage had a significant weight on the total and its value is around 86 %. The industrial percentage has never been very high and it has always been below 10 % but in 2010 the value has reached less than 3 %. Egypt is not one of North – African country with an high urban population, but percentage municipal water withdrawal reaches its most makeable value in 2011 with 11 %. Percentage trend are showed in the column chart in *Figure 24*.

Years	1995	2000	2010
Agricultural water withdrawal as % of total water withdrawal (%)	86,14	86,38	85,9
Industrial water withdrawal as % of total water withdrawal (%)	7,523	5,857	2,564
Municipal water withdrawal as % of total withdrawal (%)	6,334	7,76	11,54

Table 23 - Agricultural, industrial and municipal water withdrawal percentages in Egypt (1995 - 2010).

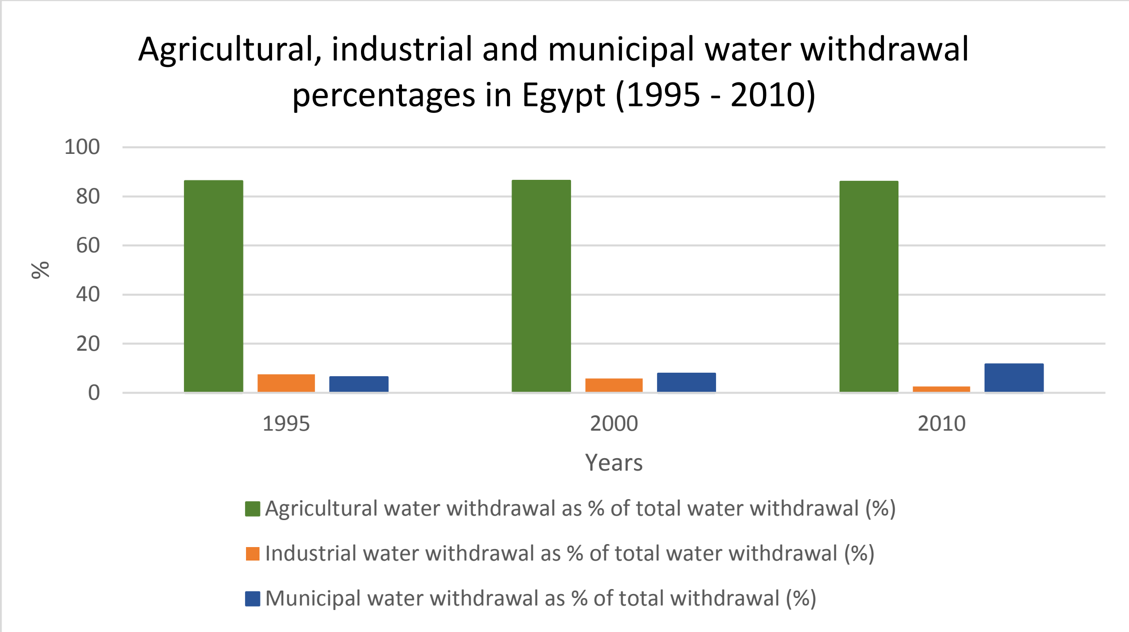

Figure 24 - Agricultural, industrial and municipal water withdrawal percentages in Egypt (1995 - 2010).

In FAOSTAT and AQUASTAT database it is possible also to find data on the land in Egypt:

Country Area (ha)	100.145.000
Agricultural Area (ha)	3.745.000
Forest (ha)	72.400
Arable land (ha)	2.670.000
Permanent Crops (ha)	1.075.000
Cultivated area (ha)	3.745.000
Area harvested (ha)	5.609.559

Table 24 - Main Egyptian data land (official data, FAOSTAT, AQUASTAT 2014).

In Egypt, agriculture is one of the important sector in the economy of the country. As seen in *Table 23* much of the total water is used for agriculture and that and this allows a good use of the arable land increasing the annual harvested. In *Table 25*, it is possible see how the area harvested is more of agricultural area. Remembering that an area harvested for example for grain crop is defined as the total number of hectares of a specific crop in a specific production season that are actually harvested for grain, major availability of water gives the opportunity to make the most of the land and increase crops over the seasons.

Years	Area harvested (ha)
1975	3.518.949
1980	3.535.929
1985	3.490.625
1990	3.935.332
1995	4.466.325
2000	4.662.672
2005	5.057.801
2010	5.190.955
2015	5.605.627

Table 25 - Historical area harvested in Egypt (1975 - 2015).

Making a more accurate study, it considers total area harvested in hectares and the production in tons of main crops in Egypt. The main crops considered are: wheat, rice, maize, olives, oranges, tomatoes, potatoes, fresh vegetables and derivates, dates, sugar, cotton and sorghum. All the values of main crops are in *Table 27* from 1995 to 2016.

Crops		1995	2000	2005	2010	2015	2016
BANANAS	Area harvested (ha)	14.473	22.053	21.550	22.665	27.520	27.632
	Production (tonnes)	498.679	760.505	922.600	1.028.946	1.314.177	1.341.478
DATES	Area harvested (ha)	25.652	28.982	36.150	41.945	48.576	48.153
	Production (tonnes)	677.934	1.006.710	1.159.690	1.352.954	1.684.917	1.694.813
LEMONS AND LIMES	Area harvested (ha)	14.427	15.287	15.000	15.534	15.092	14.981
	Production (tonnes)	307.547	274.484	338.000	318.111	352.522	341.451
MAIZE	Area harvested (ha)	735.874	843.029	868.210	968.519	1.060.996	1.082.766
	Production (tonnes)	4.535.175	6.474.450	7.085.190	7.041.099	7.803.183	8.001.411
OLIVES	Area harvested (ha)	22.076	45.513	49.000	50.161	69.707	67.293
	Production (tonnes)	207.982	281.745	310.000	390.932	698.927	694.309
ORANGES	Area harvested (ha)	85.924	87.704	84.520	101.263	131.335	136.015
	Production (tonnes)	1.555.024	1.610.520	1.940.420	2.401.015	3.351.307	3.438.030
POTATOES	Area harvested (ha)	123.038	75.018	126.280	140.550	183.776	184.592
	Production (tonnes)	2.599.100	1.769.910	3.167.430	3.643.217	4.955.445	5.029.022
RICE,PUDDY	Area harvested (ha)	588.538	659.217	613.300	459.525	510.853	672.582
	Production (tonnes)	4.788.097	6.000.490	6.125.300	4.329.503	4.817.964	6.300.000
SEED COTTON	Area harvested (ha)	298.406	217.781	275.000	155.039	101.164	55.000
	Production (tonnes)	639.740	553.883	560.000	377.527	320.000	175.000
SORGHUM	Area harvested (ha)	147.697	162.597	152.000	140.157	150.197	154.094
	Production (tonnes)	661.242	941.188	853.000	701.629	720.291	696.611
SUGAR BEET	Area harvested (ha)	21.034	56.984	70.305	134.538	233.168	254.991
	Production (tonnes)	919.926	2.890.360	3.429.535	7.840.304	11.982.946	13.323.369
SUGAR CANE	Area harvested (ha)	128.773	133.990	134.980	134.538	137.864	137.011
	Production (tonnes)	14.104.772	15.705.800	16.317.320	15.708.879	15.903.336	15.760.418
TOMATOES	Area harvested (ha)	149.342	195.444	195.000	216.385	196.853	199.712
	Production (tonnes)	5.034.197	6.785.640	7.600.000	8.544.993	7.737.827	7.943.285
VEGETABLES, FRESH NES	Area harvested (ha)	22.000	35.100	86.700	131.454	132.915	138.141
	Production (tonnes)	450.000	550.000	650.000	574.952	658.260	660.887
WHEAT	Area harvested (ha)	1.055.384	1.034.985	1.253.820	1.287.627	1.457.506	1.368.767
	Production (tonnes)	5.722.441	6.564.053	8.140.960	7.177.399	9.607.736	9.000.000

Table 26 - Area harvested and production of main crops in Egypt (1990 - 2015).

Now, the aim of the study is to calculate the water quantity in a year for each main crop in Egypt in 1995, 2000, 2010.

Having total water withdrawal, expressed in m^3/year, and the percentage of agricultural water withdrawal it is possible to obtain the agricultural water withdrawal in m^3/year in Egypt for 1995, 2000, 2010. The results of agricultural water withdrawal are showed in the last column in *Table 27*.

Years	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal as % of total water withdrawal (%)	Agricultural water withdrawal (10^9 m^3/year)
1995	58,9	86,14	50,71
2000	68,3	86,38	59,00
2010	78	85,9	67,00

Table 27 - Agricultural water withdrawal (m^3/year) in Egypt (1990, 2000, 2010).

Another value it can be calculated is the agricultural water withdrawal per hectare in these years in Egypt as showed in *Table 28*.

Years	Area harvested (ha)	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal (10^9 m^3/year)	Agricultural water withdrawal per hectares (lt/ha)
1995	4.466.325	58,9	50,71	11.353.991,93
2000	4.662.672	68,3	59,00	12.653.161,11
2010	5.190.955	78	67,00	12.907.451,52

Table 28 - Agricultural water withdrawal per hectare in Egypt (1995, 2000, 2010).

With *Table 26* and data *Table 28*, it can obtain the water liters used in 1995, 2000, 2010 for the main crop in Egypt. All the results are reported in *Table 29* with tons produced.

There is a big attention in Egypt for agricultural water withdrawal. The National Water Resources Plan 2017 estimates that the total cultivated areas would increase to 4 053 000 ha by the year 2017, and 4 830 000 ha by 2030. It also is anticipated that the cropped area would increase to about 8 064 000 ha at an intensification rate of 198 percent in 2017, and to about 9 660 000 ha at an intensification rate of 199 percent in 2030.

	1995			2000			2010		
	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)
Crops									
BANANAS	14.473	498.679	164.326,33	22.053	760.505	279.040,16	22.665	1.028.946	292.547,38
DATES	25.652	677.934	291.252,60	36.150	1.159.690	457.411,77	41.945	1.352.954	541.403,05
LEMONS AND LIMES	14.427	307.547	163.804,04	15.287	274.484	193.428,87	15.534	318.111	200.504,35
MAIZE	735.874	4.535.175	8.355.107,46	843.029	6.474.450	10.666.981,75	968.519	7.041.099	12.501.112,04
OLIVES	22.076	207.982	250.650,73	45.513	281.745	575.883,32	50.161	390.932	647.450,67
ORANGES	85.924	1.555.024	975.580,40	87.704	1.610.520	1.109.732,84	101.263	2.401.015	1.307.047,26
POTATOES	123.038	2.599.100	1.396.972,46	75.018	1.769.910	949.214,84	140.550	3.643.217	1.814.142,31
RICE,PUDDY	588.538	4.788.097	6.682.255,70	659.217	6.000.490	8.341.178,90	459.525	4.329.503	5.931.296,65
SEED COTTON	298.406	639.740	3.388.099,32	217.781	553.883	2.755.618,08	155.039	377.527	2.001.158,37
SORGHUM	147.697	661.242	1.676.950,55	162.597	941.188	2.057.366,04	140.157	701.629	1.809.069,68
SUGAR BEET	21.034	919.926	238.819,87	56.984	2.890.360	721.027,73	134.538	7.840.304	1.736.542,71
SUGAR CANE	128.773	14.104.772	1.462.087,60	133.990	15.705.800	1.695.397,06	134.538	15.708.879	1.736.542,71
TOMATOES	149.342	5.034.197	1.695.627,86	195.444	6.785.640	2.472.984,42	216.385	8.544.993	2.792.978,89
VEGETABLES, FRESH NES	22.000	450.000	249.787,82	86.700	650.000	1.097.029,07	131.454	574.952	1.696.736,13
WHEAT	1.055.384	5.722.441	11.982.821,42	1.034.985	6.564.053	13.095.831,95	1.287.627	7.177.399	16.619.983,08

Table 29 - Water withdrawal in liters for each main crop in Egypt (1995, 2000, 2010).

2.3 Libya

Libya is in the North of Africa and it is bordered in the north by the Mediterranean Sea, in the east by Egypt, in the southeast by Sudan, in the south by Chad and Niger, and in the west by Algeria and Tunisia. Libya has a total area of about 1.76 million km² and the 95 % of it is desert. All the country can be divided in four physiographic regions:

- the coastal plains that run along the Libyan coast and vary in width;
- the northern mountains that run close to the coastal plains and include the Jabal Nafusah in the west and the Jabal al Akhdar in the east;
- the internal depressions that cover the centre of Libya and include several oases;
- the southern and western mountains.

Figure 25 - Physical map of Libya.

The climatic conditions are influenced by the Mediterranean Sea to the north and the Sahara desert to the south, resulting in an abrupt transition from one kind of weather to another. Along the Mediterranean coast there are dry summers and relatively wet winters, despite in the Jabal Natusah and Jabal al Akhdar highlands experience a steppe climate with higher rainfall and humidity and low winter temperatures, including snow on the hills and in the interior there are a pre-desert and desert climate with torrid temperatures and large daily thermal variations.

2.3.1 Demographics in Libya

In 2017 Libyan population was 6,4 million of people and 80 % of it was urban population. The most populated cities are all in the Northern, along the Mediterranean coast and they are: the capital Tripoli, Benghazi, Misurata, Bayda and Al Khums.

In Libya, total population is very different from that of Egypt and Algeria, in fact Libya population is equivalent to 0,08 % of the total world population and ranks number 108 in the list of countries by population. This is not the only value about population different from the previous North African countries: the population density in Libya is 4 inhabit/km^2 (UNITED NATIONS,2017) and the median age is 27,6.

Even if the total population of Libya is the less in all North Africa, the percentage of urban population is the highest with 80 % in 2017 (UNITED NATIONS).

With the following area graph it is possible to see how the population of Libya is changed from 1955 to 2017.

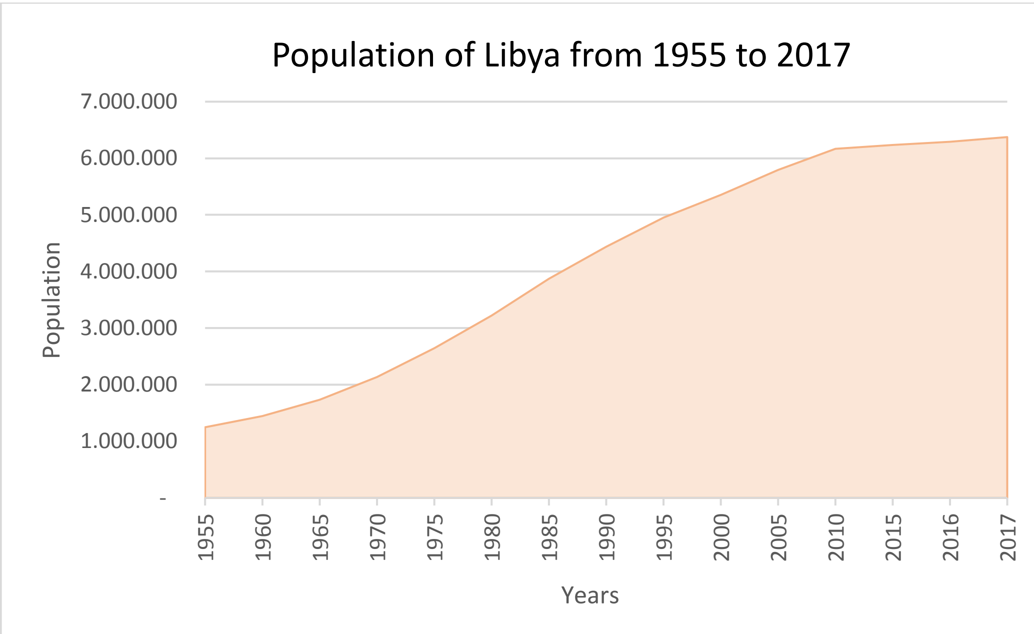

Figure 26 - Population of Libya from 1955 to 2017.

An increase in population can be seen in the graph, in *Figure 26*. Paying more attention to the *Table 30*, where are listed the main characteristics of the Libyan population from 1955 to 2017 it can note the annual population growth rate for the period 2010-2015 was estimated at 0.21 % in sharp decline since the 1980s and 1990s. The growth of the population in Libya seems to have flattened in the last decade with an average age that has stabilized around 27 years.

Years	LIBYA	Yearly % Change	Median Age	Fertility Rate
1955	1.245.358	2,04%	21,0	7,14
1960	1.448.417	3,02%	19,8	7,20
1965	1.733.306	3,59%	19,3	7,30
1970	2.133.526	4,16%	18,5	7,99
1975	2.645.139	4,30%	17,0	8,10
1980	3.219.466	3,93%	16,1	7,67
1985	3.873.781	3,70%	16,1	6,68
1990	4.436.661	2,71%	17,4	5,71
1995	4.948.798	2,18%	18,5	4,22
2000	5.355.751	1,58%	20,2	3,20
2005	5.792.688	1,57%	22,1	2,64
2010	6.169.140	1,26%	24,0	2,43
2015	6.234.955	0,21%	25,8	2,40
2016	6.293.253	0,94%	27,2	2,36
2017	6.374.616	1,29%	27,6	2,36

Table 30 - Main characteristics of Libyan population (1955 - 2017).

In the United Nations database it is possible have an Algerian future population prospect:

Years	LIBYA	Yearly % Change	Median Age	Fertility Rate
2020	6.662.173	1,32%	29,0	2,21
2025	7.031.832	1,08%	30,8	2,06
2030	7.342.346	0,86%	32,5	1,94
2035	7.603.743	0,70%	34,2	1,86
2040	7.825.251	0,57%	35,8	1,81
2045	8.003.680	0,45%	37,4	1,78
2050	8.123.669	0,30%	38,9	1,76
2055	8.175.198	0,13%	40,4	1,75
2060	8.163.080	-0,03%	41,6	1,75

Table 31 - Population forecast of Libya from database of DESA/POPULATION DEVITION, United Nations.

According to United Nations forecasts, the Libyan population will increase even if moderately, remaining the least populous country in North Africa. The considerable increase will be of the average age that in 2060 should align itself with the European averages with a value equal to 41 years.
In Figure 27, there is the plot of variation of Libyan population from 1955 to 2060.

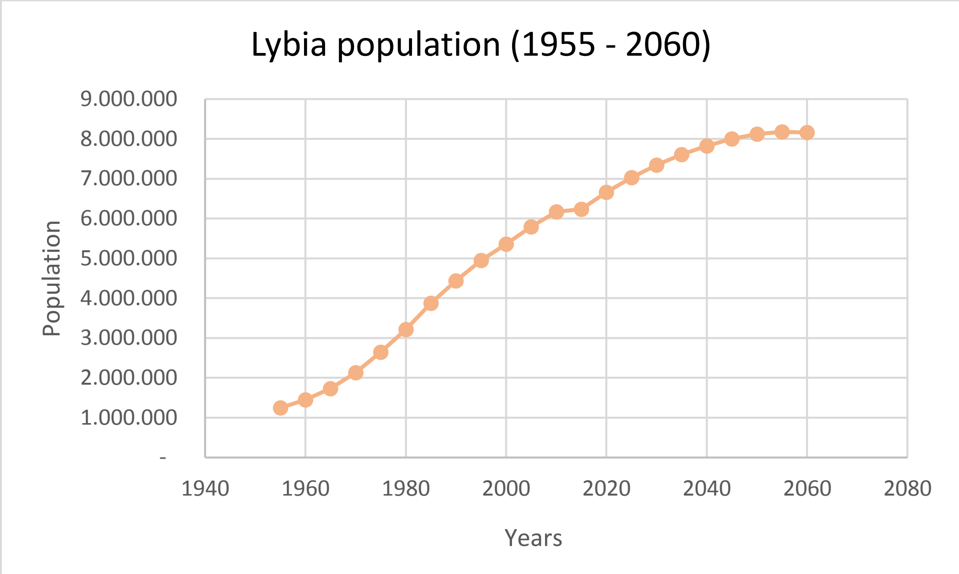

Figure 27 - Population of Libya (1955 - 2060).

2.3.2 Availability and use of water in Libya

In Libya the amount of surface water produced internally is estimated at 200 million m^3/year (AQUASTAT, 2014) and the groundwater produced internally is equal to 600 million m^3/year (AQUASTAT, 2014) but 100 million m^3/year is considered to overlap between surface water and groundwater, which gives a value of total renewable water resources of 700 million m^3/year.

Libya is very poor in permanent water resources and no surface water or groundwater is entering the country. Adding that precipitations has a long-term average in Libya equal to 56 mm/year (AQUASTAT, 2014), there is a big water emergency in the country.

A solution was found, in the early 1960s desalination started and installed capacity reached 226.3 million m^3/year in 2006 for a total of more than 400 desalination plants, including 17 large ones (GEC, 2006). In 2012, the total desalinated water produced in Libya is estimated at 70 million m^3/year aimed at municipal and industrial water demands and using both thermal and membrane technologies. Thermal desalination plants are located directly at electricity generation facilities.

The water crises in Libya is demonstrated also by the results of the total renewable water resources per capita, all values are listed in *Table 32* from the year 1955 to 2015.

The total renewable water resources per capita is valuated also in this case considering the total renewable water resources, an estimated data in AQUASTAT database, constant from 1955 to 2015 in Libya and its historical of demographics.

Years	Population	Total renewable water resources per capita (m³/inhabit/year)
1955	1.245.358	562,1
1960	1.448.417	483,3
1965	1.733.306	403,9
1970	2.133.526	328,1
1975	2.645.139	264,6
1980	3.219.466	217,4
1985	3.873.781	180,7
1990	4.436.661	157,8
1995	4.948.798	141,4
2000	5.355.751	130,7
2005	5.792.688	120,8
2010	6.169.140	113,5
2015	6.234.955	112,3

Table 32 - Total renewable water resources per capita and population in Egypt (1955 - 2015).

The most remarkable results is that the total renewable water resources per capita is 112,3 m³/year per capita in 2015, Libya being thus well under the absolute water scarcity threshold of 500 m³/year per capita. Total renewable water resources per capita is under the m³/year per capita since 1960 becoming critic around 1990.

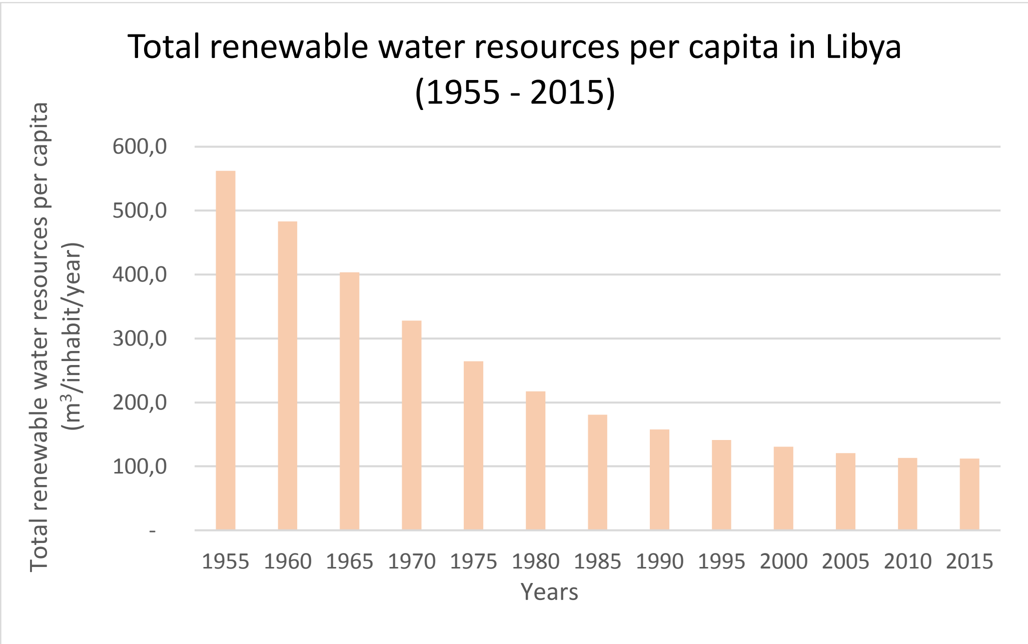

Figure 28 - Total renewable water resources per capita in Libya (1955 - 2015).

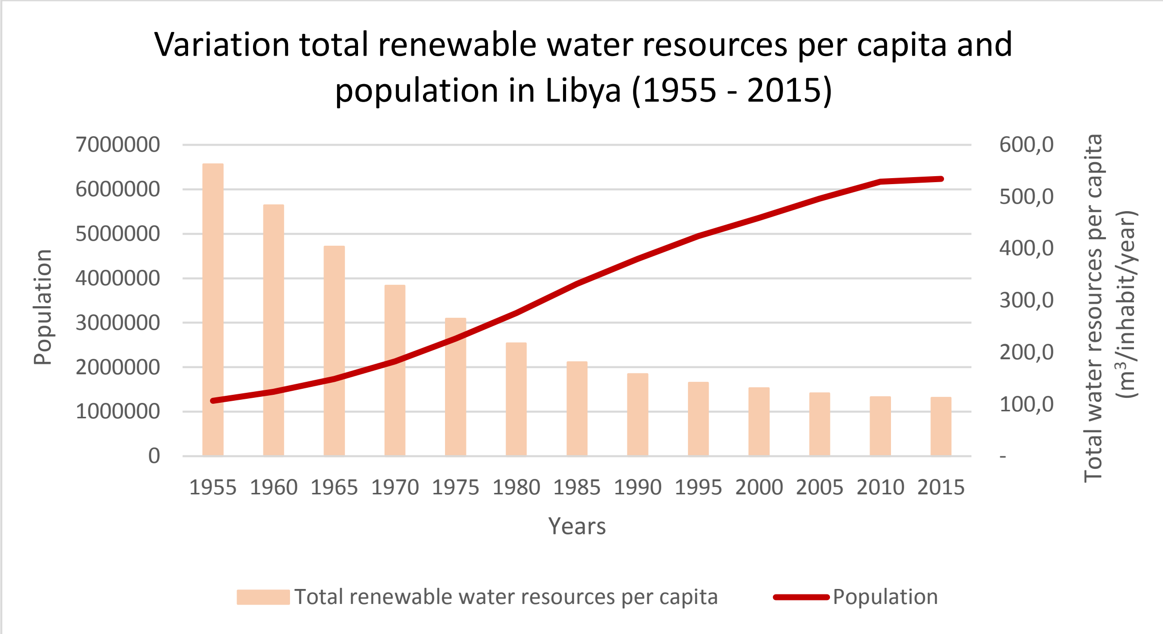

Figure 29 - Variation total renewable water resources per capita and population in Libya (1955 - 2015).

In AQUASTAT database there is also the percentage of total, urban and rural population with access to safe drinking – water, but only from 1992 to 2001.

Years	Total population with access to safe drinking - water (%)	Urban population with access to safe drinking - water (%)	Rural population with access to safe drinking - water (%)
1992	71,2	72,1	68,4
1997	71,2	72,1	68,3
2001	71,2	72,1	68,3

Table 33 - Percentage of total, urban and rural population with access to safe drinking - water (1992 - 2001).

The data available are not updated, but the stable values suggest that in recent years they have not undergone many changes. The percentage of total population with access to safe drinking – water is around 71 % a good result on average with the same data in Algeria and in Egypt.
Also in this case, it is possible to have an historical of Libyan GDP in current US$, with an interval of 5 years (WORLD BANK) and the GDP per capita calculated as the rapport of GDP values and population, as showed in *Table 34*.

Years	GDP (current US $)	Population	GDP per capita (current US$/inhabit)
1990	28.901.836.158	4.436.661	6.514,32
1995	25.544.128.199	4.948.798	5.161,68
2000	38.270.206.950	5.355.751	7.145,63
2005	47.334.148.578	5.792.688	8.171,36
2010	74.773.444.901	6.169.140	12.120,56
2015	29.274.816.454	6.234.955	4.695,27

Table 34 - GDP (current US$) and GDP per capita in Libya (1990-2015).

In the following area graph are showed the GDP in current US$ for each year from 1990 to 2017 (WORLD BANK) in Libya in order to have a continue trend and pay more attention on its variation:

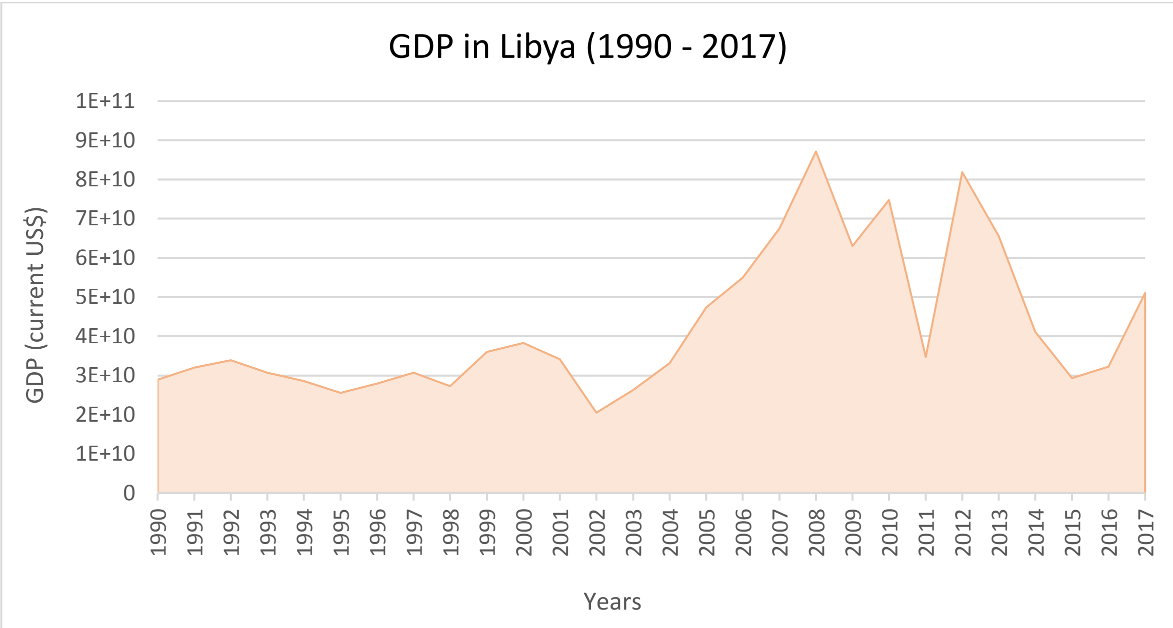

Figure 30 - GDP in Libya (1990 - 2017).

Although the data available since 1990 show how the Libyan GDP has a variable trend. The Libyan economy depends primarily upon revenues from the oil sector, which account for over half of GDP and 97% of exports. As it is possible observe in *Table 34*, for the small population the GDP per capita is the highest in all Africa.

In AQUASTAT database there are the historical of total water withdrawal in Libya from 1975 to 2010 with missing values for some years.

Years	Total water withdrawal(10^9 m^3/year)
1975	1,2
1980	1,47
1985	3,115
1990	4,76
1994	4,6
2000	4,326
2005	4,869
2012	5,83

Table 35 - Total water withdrawal in Libya (1975 - 2012).

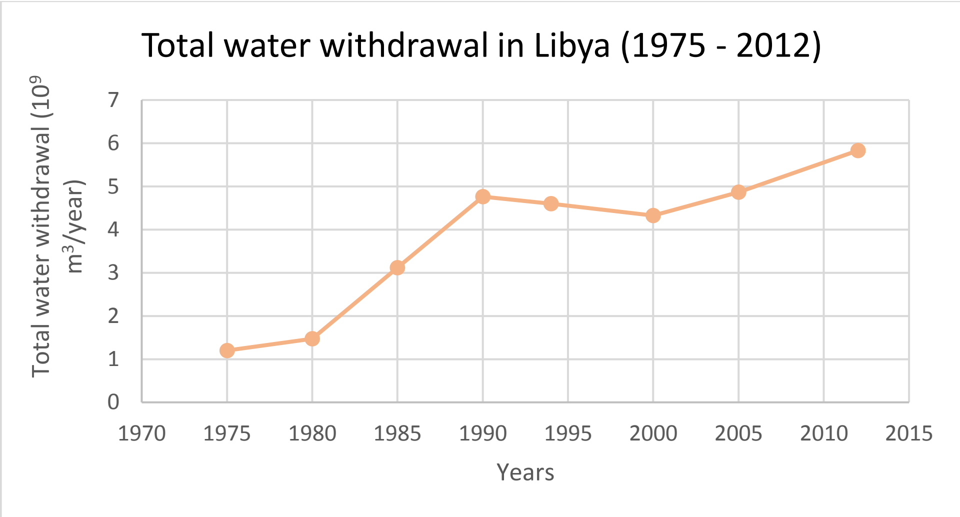

Figure 31 - Total water withdrawal in Libya (1975 - 2012).

In AQUASTAT database for Libya there are total water withdrawal data only from 1975 – 2012, despite in the WORLD BANK there are Libyan GDP data only from 1990 to 2015.
Comparing total water withdrawal, GDP and population values in Libya and to observe if there could be a relation between them the time period analyzed will be 1990 - 2015.

Years	Total water withdrawal(10^9 m^3/year)	GDP (current US$)	Population
1990	4,76	28.901.836.158	4.436.661
1994	4,6	28.607.921.929	4.917.595
2000	4,326	38.270.206.950	5.355.751
2005	4,869	47.334.148.578	5.792.688
2012	5,83	81.873.662.519	6.324.602

Table 36 - Historical total water withdrawal, GDP and Population in Libya (1990 - 2012).

A first comparison is between the variation of total water withdrawal and GDP in Libya: the total water withdrawal oscillates around an average value that only in 2012 increase until 5830 million m^3/year, otherwise the GDP increases slowly from 1990 to 2012. With the second comparison between the variation of total water withdrawal and population in Libya it can be seen that the population increases rapidly and the total water withdrawal is more or less stable.

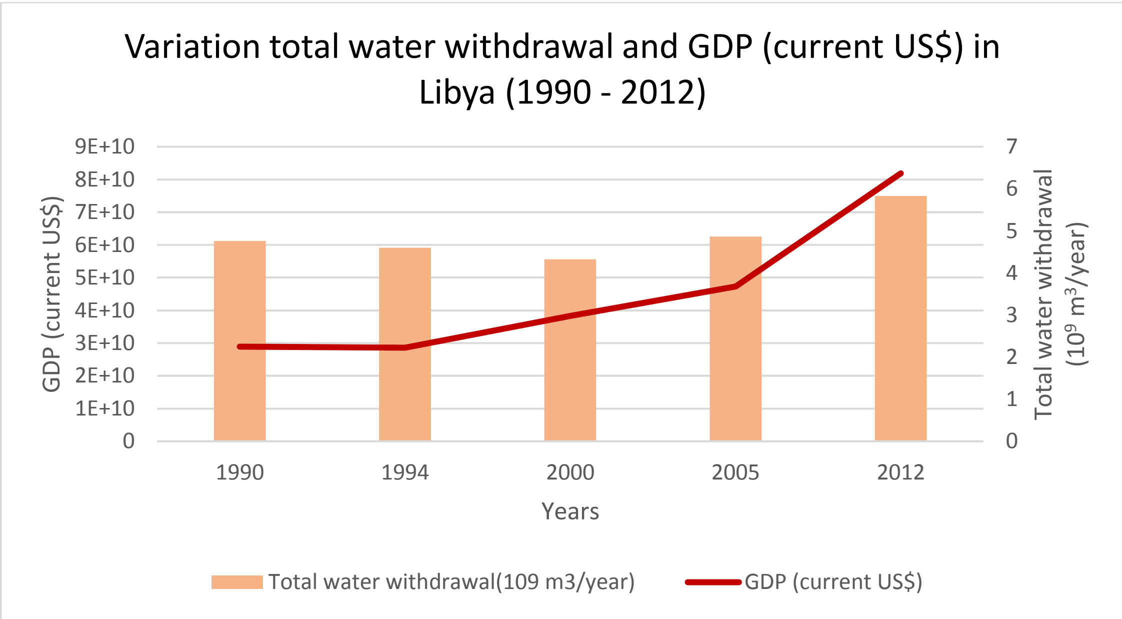

Figure 32 – Variation total water withdrawal and GDP in Libya (1990 – 2012).

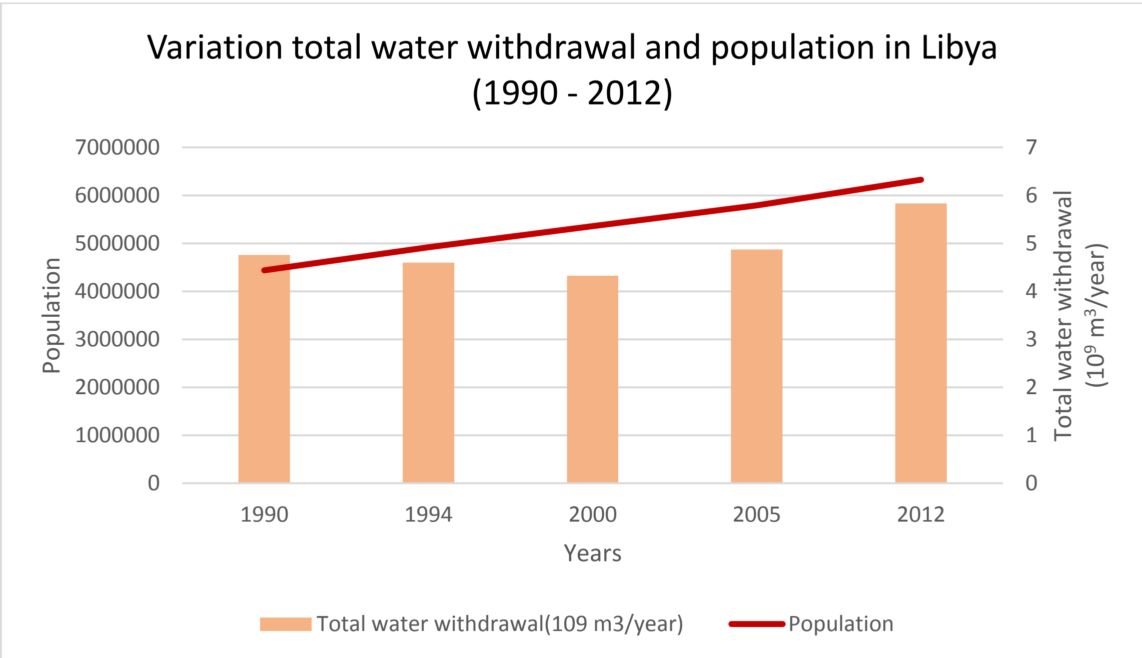

Figure 33 - Variation total water withdrawal and population in Libya (1990 - 2012).

In AQUASTAT database, there also the agricultural, industrial and municipal water withdrawal percentages on the total water withdrawal in Libya from 1990 to 2012. Data show how agricultural percentages had a significant weight on the total and its value is around 90 % in 1990 to decrease until 2012 to a value around 83 % . The industrial percentage has never been very high and it has always been below 5 %. The low population has also effects on the municipal water withdrawal: data from 1990 to 2012 is ever less than one sixth of total water withdrawal in Libya as possible to see in last row of *Table 37*. In *Figure 34*, the percentages are showed and compared in order to see the major and the minor.

Years	1990	1994	2000	2012
Agricultural water withdrawal as % of total water withdrawal (%)	89,92	86,96	82,85	83,19
Industrial water withdrawal as % of total water withdrawal (%)	1,471	2,174	3,051	4,803
Municipal water withdrawal as % of total withdrawal (%)	8,613	10,87	14,1	12,01

Table 37 - Agricultural, industrial and municipal water withdrawal percentages in Libya (1990 - 2012).

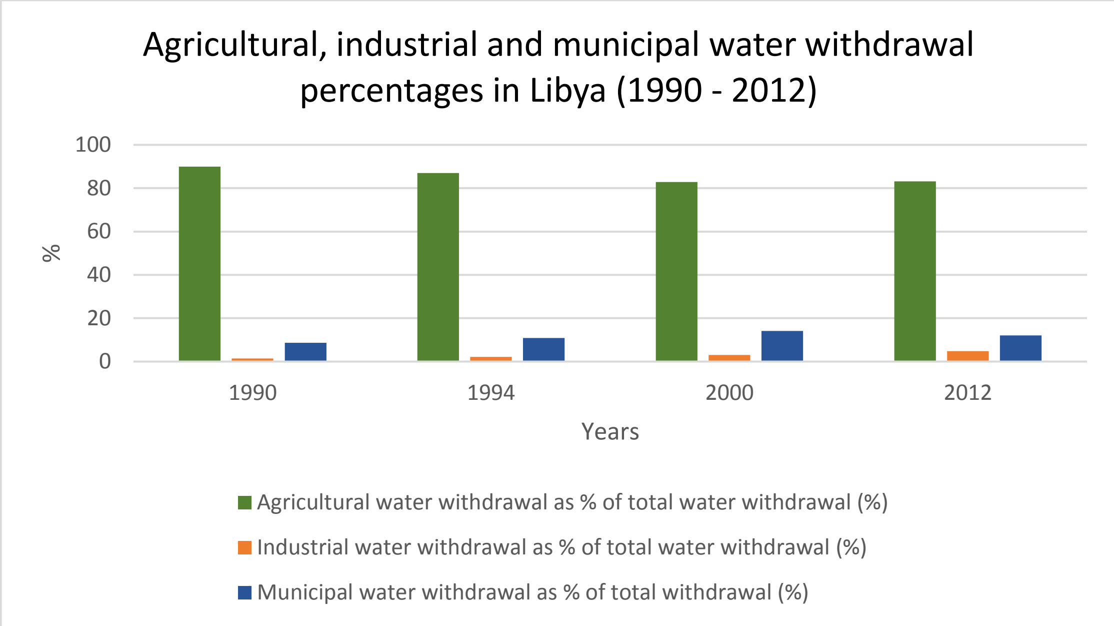

Figure 34 - Agricultural, industrial and municipal water withdrawal percentages in Lybia (1990 - 2012).

In FAOSTAT and AQUASTAT database it is possible also to find data on the land in Lybia:

Country Area (ha)	175.954.000
Agricultural Area (ha)	15.350.000
Forest (ha)	217.000
Arable land (ha)	1.720.000
Permanent Crops (ha)	330.000
Cultivated area (ha)	2.050.000
Area harvested (ha)	963.654

Table 38 - Main Libyan data land (official data, FAOSTAT, AQUASTAT 2014).

In Libya, agriculture is one of the important sector in the economy of the country. As seen in *Table 37* much of the total water is used for agriculture, but a low water availability does not allow to exploit the agricultural area at best and for this there is a low value of harvested area.

In Libya, cultivated products do not meet domestic demand and in re-2011, the country usually imported 80 % of its food consumption requirement, and up to 90 % of its cereals requirements.

The main agricultural products imported are wheat flour, maize oil and milk, corresponding to about 40 % of all agricultural products imported (WFP and FAO, 2011).

Years	Area harvested (ha)
1990	675.047
1994	527.573
1995	503.282
2000	676.323
2005	773.296
2010	805.868
2012	927.752
2015	984.475

Table 39 - Historical area harvested in Libya (1990 - 2015).

Making a more accurate study, it considers total area harvested in hectares and the production in tons of main crops in Libya. The main crops considered are: olives, oranges, tomatoes, potatoes, dates, barley and almonds. All the values of main crops are in *Table 40* from 1990 to 2015.

Crops		1990	1994	1995	2000	2005	2010	2012	2015
ALMONDS, WITH SHELL	Area harvested (ha)	61.960	54.844	53.000	51.928	50.500	53.000	55.000	57.115
	Production (tonnes)	33.070	27.660	27.000	26.100	25.500	29.500	32.000	33.109
BARLEY	Area harvested (ha)	296.742	85.000	50.000	180.000	204.080	186.500	192.980	181.727
	Production (tonnes)	141.476	40.000	23.000	85.000	100.000	102.000	97.368	92.550
DATES	Area harvested (ha)	15.718	20.000	22.000	24.000	27.052	30.766	30.898	31.992
	Production (tonnes)	74.000	105.000	125.000	120.000	147.071	166.721	166.241	171.720
LEMONS AND LIMES	Area harvested (ha)	290	930	1.050	1.350	1.773	1.749	1.886	2.014
	Production (tonnes)	3.400	9.500	11.000	14.000	18.245	17.905	19.388	20.683
OLIVES	Area harvested (ha)	62.247	85.000	90.000	130.000	196.423	228.760	259.625	327.278
	Production (tonnes)	67.998	140.000	168.000	165.000	181.170	175.547	185.577	188.126
ONIONS	Area harvested (ha)	5.400	8.500	9.670	13.000	9.403	9.580	9.164	9.090
	Production (tonnes)	82.200	135.000	164.600	178.000	182.122	190.548	183.222	184.354
ORANGES	Area harvested (ha)	8.000	5.000	4.400	4.200	4.358	4.600	5.000	4.924
	Production (tonnes)	91.000	53.800	45.000	42.500	43.721	46.400	50.000	49.454
POTATOES	Area harvested (ha)	18.000	15.000	12.000	9.500	15.860	15.273	19.000	16.970
	Production (tonnes)	145.000	175.000	198.320	190.000	250.000	296.068	360.000	336.485
TOBACCO UNMANUFACTURATED	Area harvested (ha)	480	550	600	682	700	700	625	627
	Production (tonnes)	1.250	1.250	1.300	1.500	1.498	1.477	1.311	1.304
TOMATOES	Area harvested (ha)	11.000	10.500	8.130	16.500	10.227	10.242	10.303	10.379
	Production (tonnes)	150.000	161.000	162.500	225.000	188.828	212.150	211.223	214.613
WATERMELONS	Area harvested (ha)	12.500	11.000	13.170	13.500	15.075	17.066	16.604	18.206
	Production (tonnes)	200.000	210.000	214.390	214.000	223.967	232.048	217.843	219.439
WHEAT	Area harvested (ha)	104.538	155.000	160.000	154.608	165.000	172.210	251.334	249.642
	Production (tonnes)	128.760	120.000	117.000	125.000	125.000	132.888	200.000	198.440

Table 40 - Area harvested and production of main crops in Libya (1990 - 2015).

Now, the aim of the study is to calculate the water quantity in a year for each main crop in Algeria in 1990, 1994, 2000 and 2012.

Having total water withdrawal, expressed in m^3/year, and the percentage of agricultural water withdrawal it is possible to obtain the agricultural water withdrawal in m^3/year in Libya for 1990, 1994, 2000 and 2012. The results of agricultural water withdrawal are showed in the last column in *Table 41*.

Years	Area harvested (ha)	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal (10^9 m^3/year)
1990	675.047	4,76	4,28
1994	527.573	4,6	4,00
2000	676.323	4,326	3,58
2012	927.752	5,83	4,85

Table 41 - Agricultural water withdrawal (m^3/year) in Libya (1990, 1994, 2000, 2012).

Another value it can be calculated is the agricultural water withdrawal per hectare in these years in Algeria as showed in *Table 42*.

Years	Area harvested (ha)	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal (10^9 m^3/year)	Agricultural water withdrawal per hectares (lt/ha/year)
1990	675.047	4,76	4,28	6.340.583,69
1994	527.573	4,6	4,00	7.582.192,42
2000	676.323	4,326	3,58	5.299.377,66
2012	927.752	5,83	4,85	5.227.665,37

Table 42 - Agricultural water withdrawal per hectare in Libya (1990, 1994, 2000, 2012).

With *Table 40* and data *Table 42*, it can obtain the water liters used in 1990, 2001, 2012 for the main crop in Algeria. All the results are reported in *Table 43* with tons produced.

	1990			1994			2000			2012		
	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)	Area harveste d (ha)	Production (tonnes)	Water withdrawal (10^6 lt)	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)
Crops												
ALMONDS, WITH SHELL	61.960	33.070	392.863	54.844	27.660	415.838	51.928	26.100	275.186	55.000	32.000	287.522
BARLEY	296.742	141.476	1.881.517	85.000	40.000	644.486	180.000	85.000	953.888	192.980	97.368	1.008.835
DATES	15.718	74.000	99.661	20.000	105.000	151.644	24.000	120.000	127.185	30.898	166.241	161.524
LEMONS AND LIMES	290	3.400	1.839	930	9.500	7.051	1.350	14.000	7.154	1.886	19.388	9.859
OLIVES	62.247	67.998	394.682	85.000	140.000	644.486	130.000	165.000	688.919	259.625	185.577	1.357.233
ONIONS	5.400	82.200	34.239	8.500	135.000	64.449	13.000	178.000	68.892	9.164	183.222	47.906
ORANGES	8.000	91.000	50.725	5.000	53.800	37.911	4.200	42.500	22.257	5.000	50.000	26.138
POTATOES	18.000	145.000	114.131	15.000	175.000	113.733	9.500	190.000	50.344	19.000	360.000	99.326
TOBACCO UNMANUFACTURATED	480	1.250	3.043	550	1.250	4.170	682	1.500	3.614	625	1.311	3.267
TOMATOES	11.000	150.000	69.746	10.500	161.000	79.613	16.500	225.000	87.440	10.303	211.223	53.861
WATERMELONS	12.500	200.000	79.257	11.000	210.000	83.404	13.500	214.000	71.542	16.604	217.843	86.800
WHEAT	104.538	128.760	662.832	155.000	120.000	1.175.240	154.608	125.000	819.326	251.334	200.000	1.313.890

Table 43 - Water withdrawal in liters for each main crop in Libya (1990, 1994, 2000, 2012).

2.4 Morocco

Morocco, located at the extreme North-west of the African continent, has a total area of 446 550 km^2. Along the Western coast it is bathed by the Atlantic Ocean, while in the North it is bathed by the Mediterranean Sea; its relief is characterized by mountain ranges:

- the Rif to the north;
- the Atlas (including the Middle Atlas, the High Atlas and the Anti-Atlas) which culminates at 4 165 m (Toubkal). Plains extend along the whole coast of the country; they are narrow along the Mediterranean and wide along the Atlantic;
- to the south-east of the Atlas and to the south of the country, there are plateaus and desert plains to semi-desert.

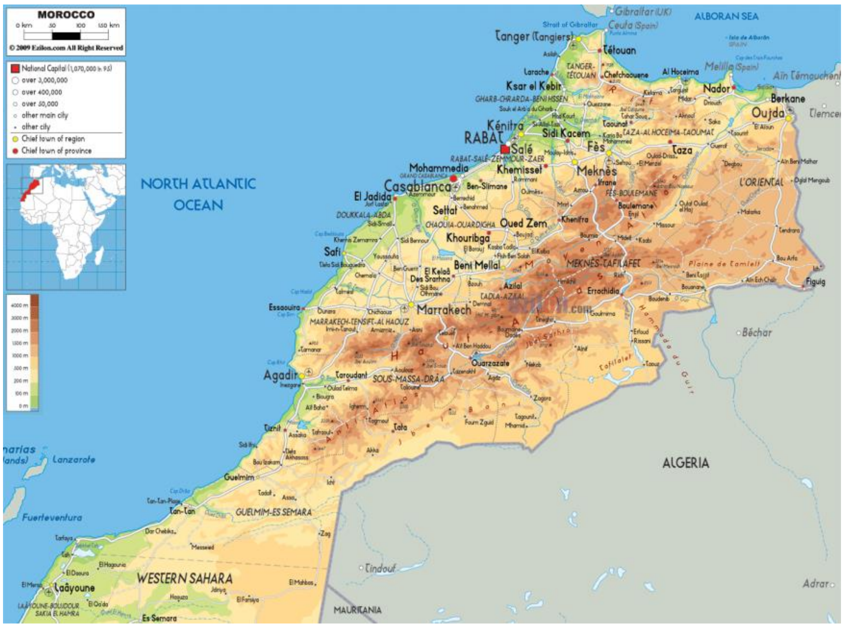

Figure 35 - Physical map of Morocco.

Given its particular geography, Morocco has more climate zones:

- Mediterranean, along the 500 km strip in North and part of Atlantic coast, with hot and dry summers and mild and wet winters. Annual Precipitation in this area vary from 600–800 mm in the west to 350–500 mm in the east.
- Sub – Mediterranean with two main influencing climates: Oceanic and Continental.

The first has cooler summer while winters are chilly to mild and wet. Annual precipitation varies from 400 to 700 mm. Notable cities that fall into this zone are Rabat, Casablanca, Kénitra, Salé and Essaouira. The second is determined by the bigger gap between highs and lows, that results in hotter summers and colder winters. Annual precipitation varies between 500 and 900 mm.

- Continental, this type of climate dominates the mountainous regions of the north and central parts of the country, where summers are hot to very hot and winters on the other hand are cold, and lows usually go beyond the freezing point. Precipitation varies between 400 and 800 mm.
- Alpine: this climate zone is found in some parts of the Middle Atlas Mountain range and the eastern part of the High Atlas Mountain range. Summers are very warm to moderately hot, and winters are longer, cold and snowy. Precipitation varies between 400 and 1200 mm.
- Semi – Arid: this type of climate is found in the south of the country and some parts of the east of the country, where rainfall is lower and annual precipitations are between 200 and 350 mm.

2.4.1 Demographics in Morocco

In 2017 Moroccan population was 35,7 million of people and around 59,6 % of it was urban population compared to 2000 when the total population was 28,8 million of people and around 53,1 % of it was urban population. Morocco population is equivalent to 0,47 % of the total world population and ranks number 40 in the list of countries by population.

The most populated cities are all towards Atlantic Ocean: Casablanca, Fez, Tangier, Marrakesh and Salé.

The population density of Morocco is 81 inhabit/km^2 (UNITED NATIONS,2017) and the median age is 28,3 years.

With the following area graph (*Figure 36*) it is possible to see how the population of Morocco has changed from 1955 to 2017: the population has grown rapidly tripling from 1955 to 2015.

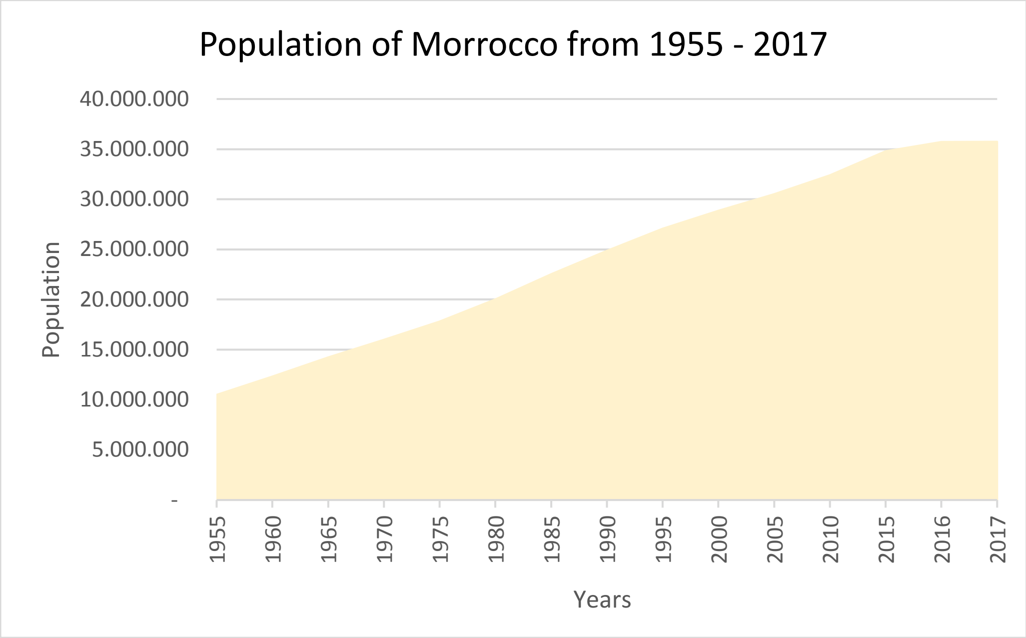

Figure 36 - Population of Morocco from 1955 to 2017.

Years	MOROCCO	Yearly % Change	Median Age	Fertility Rate
1955	10.502.666	3,12%	19,2	6,9
1960	12.328.532	3,21%	18,1	7,1
1965	14.229.044	2,87%	16,3	6,85
1970	16.000.008	2,35%	16,2	6,4
1975	17.803.698	2,14%	16,8	5,9
1980	20.019.847	2,35%	17,8	5,4
1985	22.537.376	2,37%	18,7	4,45
1990	24.879.136	1,98%	19,8	3,7
1995	27.075.232	1,69%	21,1	2,97
2000	28.849.621	1,27%	22,7	2,68
2005	30.521.070	1,13%	24,4	2,55
2010	32.409.639	1,20%	26,3	2,6
2015	34.803.322	1,42%	27,9	2,4
2016	35.726.786	1,36%	28,3	2,56
2017	35.739.580	1,31%	28,3	2,56

Table 44 - Main characteristics of Moroccan population (1955-2017).

All columns list values in line with those of the other Northern - African countries.

In the United Nations database it is possible have an Moroccan future population prospect:

Years	MOROCCO	Yearly % Change	Median Age	Fertility Rate
2020	37.070.718	1,26%	29,6	2,42
2025	39.100.641	1,07%	31,4	2,28
2030	40.873.592	0,89%	33,0	2,17
2035	42.407.174	0,74%	34,6	2,08
2040	43.713.705	0,61%	36,0	2,00
2045	44.798.428	0,49%	37,4	1,94
2050	45.659.886	0,38%	38,9	1,89
2055	46.301.091	0,28%	40,6	1,86
2060	46.709.789	0,18%	42,2	1,84

Table 45 - Population forecast of Morocco from database of DESA/POPULATION DEVITION, United Nations.

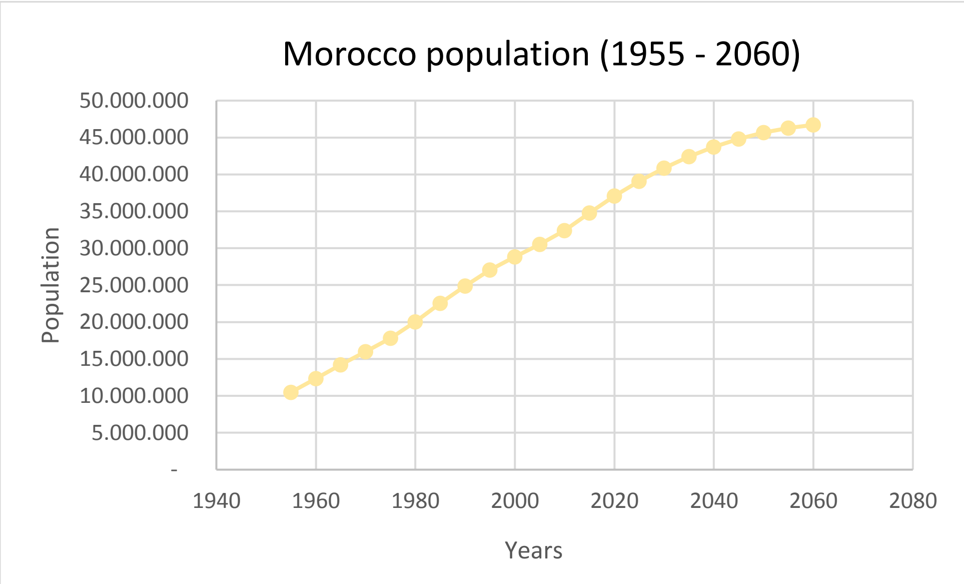

Figure 37 - Morocco population (1955 - 2060).

2.4.2 Availability and use of water in Morocco

In Morocco the amount of surface water produced internally is estimated at 22 000 million m^3/year (AQUASTAT, 2014) and the groundwater produced internally is equal to 10 000 million m^3/year (AQUASTAT, 2014) but 3 000 million m^3/year is considered to overlap between surface water and groundwater, which gives a value of total renewable water resources of 29 000 million m^3/year.

The water crises in Libya is demonstrated also by the results of the total renewable water resources per capita, all values are listed in *Table 46* from the year 1955 to 2015.

The total renewable water resources per capita is valuated also in this case considering the total renewable water resources, an estimated data in AQUASTAT database, constant from 1955 to 2015 in Morocco and its historical of demographics.

Years	Population	Total renewable water resources per capita (m^3/inhabit/year)
1955	10.502.666	2.761,204
1960	12.328.532	2.352,267
1965	14.229.044	2.038,085
1970	16.000.008	1.812,499
1975	17.803.698	1.628,875
1980	20.019.847	1.448,563
1985	22.537.376	1.286,751
1990	24.879.136	1.165,635
1995	27.075.232	1.071,090
2000	28.849.621	1.005,213
2005	30.521.070	950,163
2010	32.409.639	894,796
2015	34.803.322	833,254

Table 46 - Total renewable water resources per capita and population in Morocco (1955 - 2015).

As for the previous countries analyzed the total renewable water resources per capita decreases, but in Morocco its values is not under the absolute water scarcity threshold.

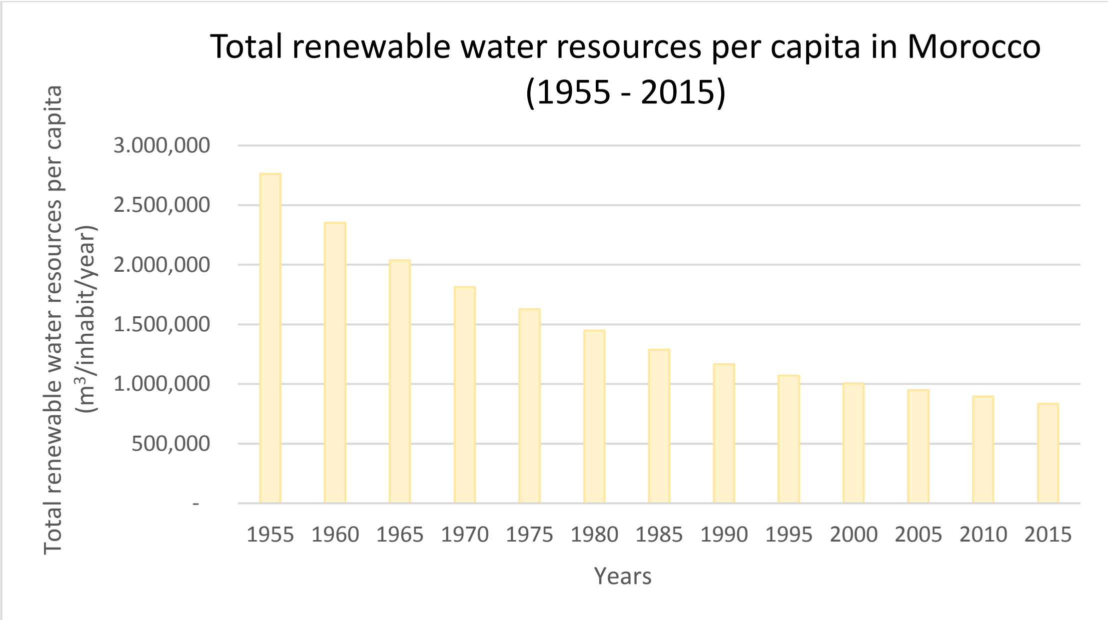

Figure 38 - Total renewable water resources per capita in Morocco.

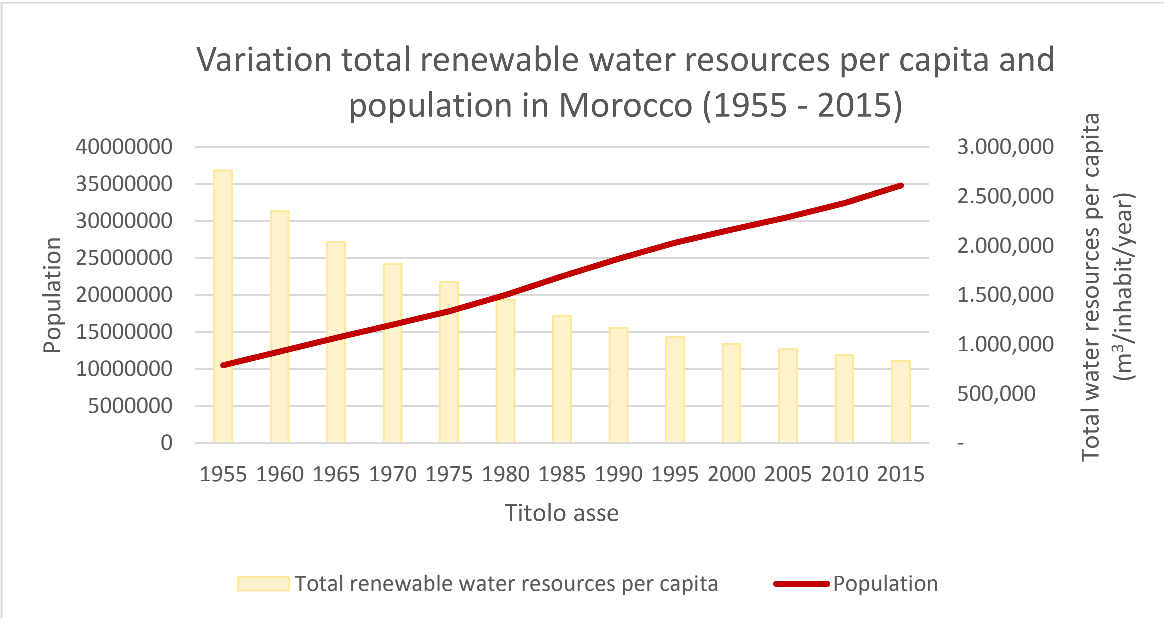

Figure 39 - Variation total renewable water resources per capita and population in Morocco (1955 - 2015).

In AQUASTAT database there is also the percentage of total, urban and rural population in Morocco with access to safe drinking – water, but only from 1992 to 2015.

Years	Total population with access to safe drinking - water (%)	Urban population with access to safe drinking - water (%)	Rural population with access to safe drinking - water (%)
1992	74	94	54,1
1997	76,9	95,2	56,7
2002	79,3	96,3	59,4
2007	81,9	97,4	62,1
2012	84,6	98,5	64,8
2015	85,4	98,7	65,3

Table 47 - Percentage of total, urban and rural population with access to safe-drinking water in Morocco (1992 - 2015).

From 1992 to 2015 the percentage of total, urban and rural population with access to safe-drinking water in Morocco is increased. The urban population has a major percentage for the access to safe drinking – water and even if the percentage of rural population is not a critic value as for the Morocco.

Another important element to understand the water use in a country is the GDP, in order to see how much grow the economy of a country and in which sector can be more used the water.

Years	GDP (current US $)	Population	GDP per capita (current US$/inhabit)
1960	2.037.150.716,33	12.328.532	165,24
1965	2.948.325.264,30	14.229.044	207,20
1970	3.956.328.426,04	16.000.008	247,27
1975	8.984.824.182,60	17.803.698	504,66
1980	21.728.770.055,38	20.019.847	1.085,36
1985	14.991.283.215,74	22.537.376	665,17
1990	30.180.108.561,93	24.879.136	1.213,07
1995	39.030.285.468,38	27.075.232	1.441,55
2000	38.857.251.336,34	28.849.621	1.346,89
2005	62.343.022.650,87	30.521.070	2.042,62
2010	93.216.746.661,60	32.409.639	2.876,20
2015	100.593.283.696,73	34.803.322	2.890,34

Table 48 - GDP (current US$) and GDP per capita in Morocco (1960 - 2015).

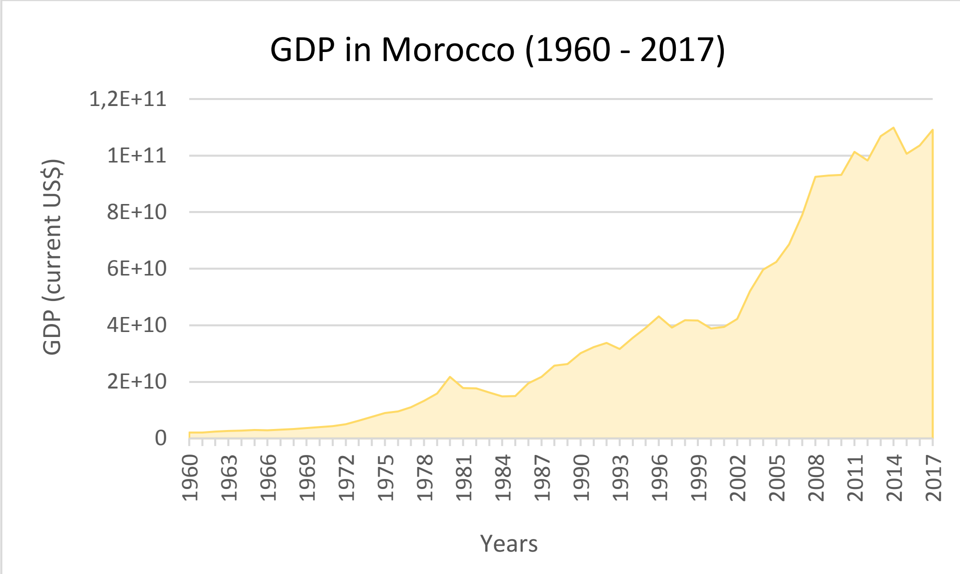

Figure 40 - GDP in Morocco (1960- 2017).

Morocco GDP began to have significant growth since the start of new millennium until 100 billion around 2015. The major resources of the Moroccan economy are agriculture, phosphates, and tourism. Sales of fish and seafood are important as well. Industry and mining contribute about one-third of the annual GDP. Knowing that agriculture is a relevant sector in Moroccan economy, it is possible to image that this sector required more water. From AQUASTAT database there are total water withdrawal values from 1975 to 2010 in Morocco and they are listed in *Table 49* and plotted in *Figure 40*.

Years	Total water withdrawal(10^9 m^3/year)
1975	9
1980	10,05
1985	11
1992	11,04
1995	11,26
2002	14,82
2010	10,43

Table 49 - Total water withdrawal in Morocco (1975 - 2010).

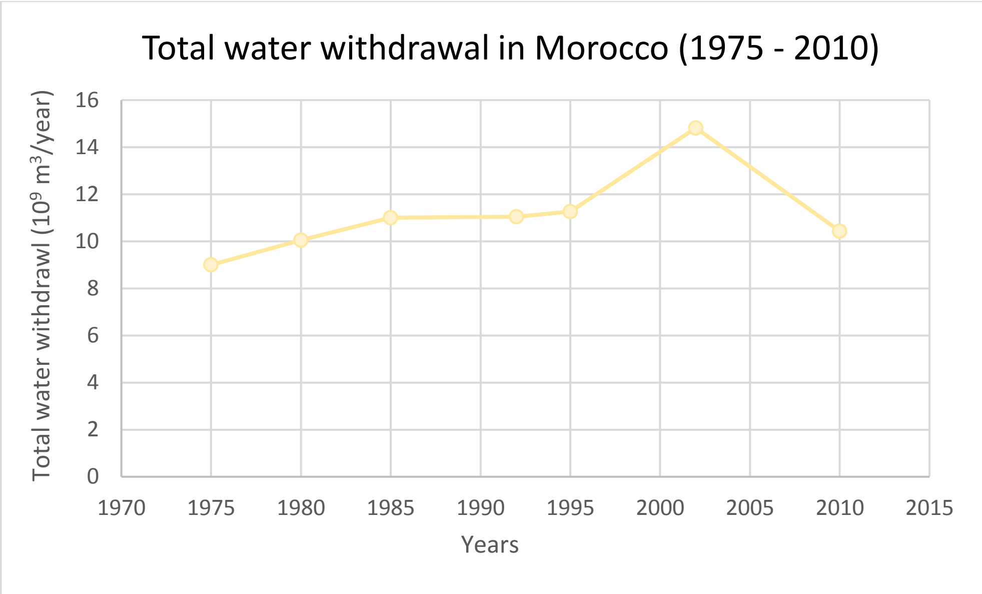

Figure 41 - Total water withdrawal in Morocco (1975 - 2015).

In *Table 49* there is not the total water withdrawal in 2005, it is possible to obtain its value from the *Figure 40* with a graphic interpolation assuming that from 2002 to 2010 the total water withdrawal decreases.

Having total water withdrawal, GDP and population values in Morocco it is possible to compare these data and observe their trends. All data listed in *Table 50*, are plotted in *Figure 42* showing the variation of total water withdrawal and GDP and in *Figure 43* are plotted the variation of total water withdrawal and population. The total water withdrawal rapidly increased from 1975 to 2002, but after this year it decreased this is maybe for political and economic issues.

Years	Total water withdrawal(10^9 m^3/year)	GDP (current US$)	Population
1975	9	8.984.824.183	17.803.698
1980	10,05	21.728.770.055	20.019.847
1985	11	14.991.283.216	22.537.376
1992	11,04	33.711.069.431	25.864.350
1995	11,26	39.030.285.468	27.075.232
2002	14,82	42.236.836.821	29582401,37
2005	**13,1**	62.343.022.651	30.521.070
2010	10,43	93.216.746.662	32.409.639

Table 50 - Historical total water withdrawal, GDP and Population in Morocco (1975 - 2010).

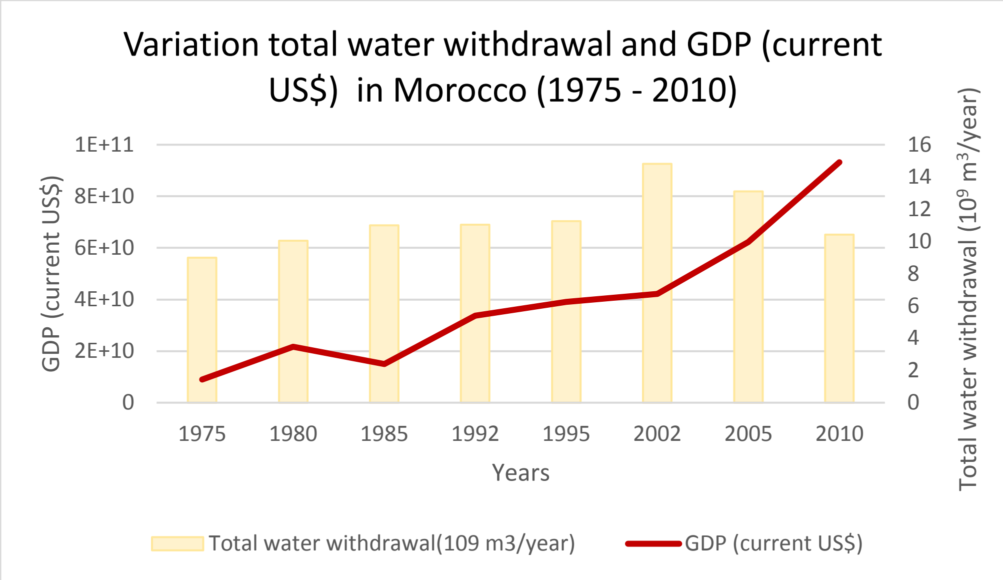

Figure 42 - Variation total water withdrawal and GDP in Morocco (1975 - 2010).

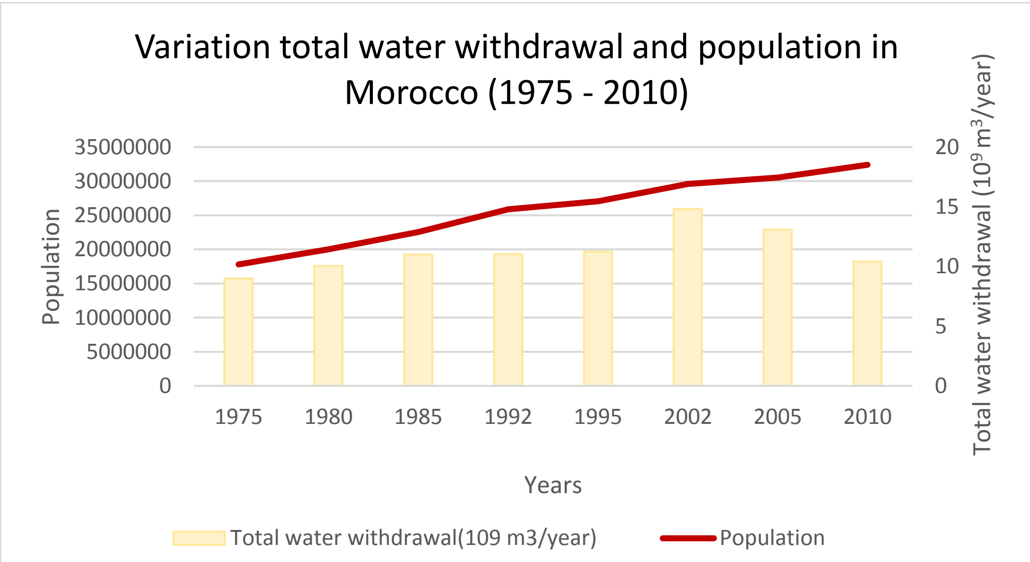

Figure 43 - Variation total water withdrawal and population in Morocco (1975 - 2010).

In AQUASTAT database, there also percentages of agricultural, industrial and municipal water withdrawal on the total water withdrawal in Morocco from 1992 to 2010. Data show the importance of water in Moroccan agriculture, the most recent data is in 2010 with 87,79 %. The industrial percentage has never been very high, and it has always been below 5 %. The population growth has a considerable effect on municipal water withdrawal: its percentage changed from around 5 % in 1992 to 10,19 % in 2010.

Years	1992	2002	2010
Agricultural water withdrawal as % of total water withdrawal (%)	92,21	74,56	87,79
Industrial water withdrawal as % of total water withdrawal (%)	2,917	5,169	2,033
Municipal water withdrawal as % of total withdrawal (%)	4,918	20,24	10,19

Table 51 - Agricultural, industrial and municipal water withdrawal percentages in Morocco (1992, 2002, 2010).

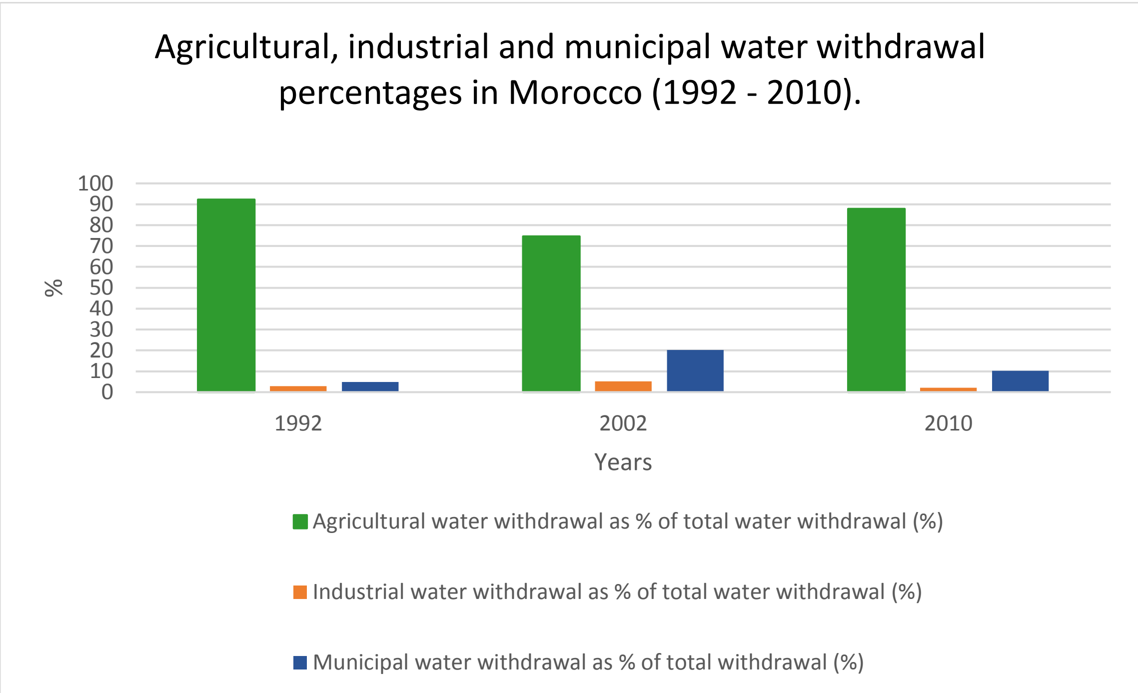

Figure 44 - Agricultural, industrial and municipal water withdrawal percentages in Morocco (1992, 2002, 2010).

In FAOSTAT and AQUASTAT database it is possible also to find data on the land in Morocco:

Country Area (ha)	44.655.000
Agricultural Area (ha)	30.591.500
Forest (ha)	5.640.000
Arable land (ha)	8.130.000
Permanent Crops (ha)	1.462.000
Cultivated area (ha)	9.592.000
Area harvested (ha)	7.122.253

Table 52 - Main Moroccan data land (official data, FAOSTAT, AQUASTAT 2014).

In Morocco, agriculture is one of the important sector in the economy of the country. In *Table 54*, there is the historical of area harvested in ha from 1975 to 2015.

Years	Total area harvested (ha)
1975	5.414.750
1980	5.548.566
1985	6.279.600
1990	7.395.628
1992	6.807.342
1995	5.528.206
2000	7.168.752
2002	6.697.801
2005	7.366.624
2010	7.288.772
2015	7.901.090

Table 53 - Historical area harvested in Morocco (1975 - 2015).

Making a more accurate study, it considers total area harvested in hectares and the production in tons of main crops in Morocco. The main crops considered are: wheat, barley, olives, almonds, maize, oranges, tangerines, chick pens, tomatoes, potatoes, dates, sugar and beans. All the values of main crops are in *Table 55* from 1992 to 2015.

Crops		1990	1992	1995	2000	2002	2005	2010	2015
ALMONDS, WITH SHELL	Area harvested (ha)	107.000	117.000	128.000	138.000	134.141	141.550	142.018	160.018
	Production (tonnes)	57.700	55.000	45.700	65.044	82.400	70.629	87.104	97.723
BARLEY	Area harvested (ha)	2.414.900	2.232.900	1.578.500	2.250.900	2.002.400	2.179.800	1.919.500	2.000.164
	Production (tonnes)	2.137.640	1.080.690	607.690	466.810	1.668.980	1.102.130	2.566.450	3.396.992
BEANS	Area harvested (ha)	224.400	216.800	118.000	137.000	154.100	145.600	196.900	191.300
	Production (tonnes)	134.080	67.520	35.910	32.600	88.780	72.960	149.380	90.279
CHICK PEAS	Area harvested (ha)	77.000	78.900	62.600	66.100	71.600	76.300	78.100	59.472
	Production (tonnes)	58.890	26.300	11.590	15.060	51.340	32.270	56.620	65.559
DATES	Area harvested (ha)	22.000	23.500	44.200	30.400	33.000	34.700	68.176	57.859
	Production (tonnes)	120.000	82.000	97.600	74.000	33.200	47.500	101.351	100.376
MAIZE	Area harvested (ha)	375.600	453.600	387.400	237.500	265.400	246.200	230.100	125.967
	Production (tonnes)	435.620	215.600	50.490	95.000	198.880	50.120	279.150	95.032
OLIVES	Area harvested (ha)	365.000	395.000	415.200	540.000	477.300	600.000	830.481	1.006.491
	Production (tonnes)	396.000	380.000	436.360	400.000	455.200	750.000	1.506.473	1.144.238
ORANGES	Area harvested (ha)	52.400	53.600	52.000	51.200	50.100	48.800	44.900	54.390
	Production (tonnes)	786.000	810.000	702.000	870.000	723.100	835.000	849.197	869.020
POTATOES	Area harvested (ha)	51.298	60.656	53.600	60.510	57.520	62.100	56.600	64.515
	Production (tonnes)	881.561	918.397	891.390	1.090.350	1.334.380	1.478.540	1.604.620	1.924.430
SUGAR BEET	Area harvested (ha)	64.300	52.100	58.100	54.100	59.500	69.500	43.200	60.909
	Production (tonnes)	2.983.590	2.754.070	2.717.400	2.883.400	2.986.850	3.301.540	2.435.910	3.875.638
TANGERINES, MANDARINS, CLEMENTINES	Area harvested (ha)	18.000	17.500	21.700	24.000	24.800	28.000	47.537	59.362
	Production (tonnes)	225.000	273.000	276.000	531.000	405.700	463.400	472.834	993.182
TOMATOES	Area harvested (ha)	26.014	25.226	13.763	26.000	19.070	22.100	20.534	17.539
	Production (tonnes)	871.836	893.775	623.580	1.008.900	991.020	1.205.510	1.433.937	1.412.380
WHEAT	Area harvested (ha)	2.719.200	2.228.300	1.967.900	2.901.600	2.625.400	2.965.800	2.852.400	3.273.869
	Production (tonnes)	3.613.890	1.562.160	1.090.710	1.380.700	3.358.680	3.043.080	4.876.140	8.074.659

Table 54 - Area harvested and production of main crops in Morocco (1990 - 2015).

Now, the aim of the study is to calculate the water quantity needed in a year for each main crop in Morocco in 1992, 2002, 2010.

Having total water withdrawal, expressed in m^3/year, and the percentage of agricultural water withdrawal it is possible to obtain the agricultural water withdrawal in m^3/year in Morocco for 1990, 2001, 2012. The results of agricultural water withdrawal are showed in the last column in *Table 55*.

Years	Total water withdrawal (10^9 m^3/year)	Agricultural water withdrawal as % of total water withdrawal (%)	Agricultural water withdrawal (10^9 m^3/year)
1992	11,04	92,21	10,18
2002	14,82	74,56	11,05
2010	10,43	87,79	9,16

Table 55 - Agricultural water withdrawal (m^3/year) in Morocco (1992, 2002, 2010).

Another value it can be calculated is the agricultural water withdrawal per hectare in these years in Morocco as showed in *Table 56*.

Years	Area harvested (ha)	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal (10^9 m^3/year)	Agricultural water withdrawal per hectares (lt/ha)
1992	6.807.342	11,04	4,28	628.732,92
2002	6.697.801	14,82	4	597.210,94
2010	7.288.772	10,43	3,58	491.166,41

Table 56 - Agricultural water withdrawal per hectare in Morocco (1992, 2002, 2010).

With *Table 55* and data *Table 56*, it can obtain the water liters used in 1992, 2002, 2010 for the main crop in Morocco. All the results are reported in *Table 57* with tons produced.

	1992			2002			2010		
	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)
Crops									
ALMONDS, WITH SHELL	117.000	55.000	73.561,75	134.141	82.400	80.110,47	142.018	87.104	69.754,47
BARLEY	2.232.900	1.080.690	1.403.897,74	2.002.400	1.668.980	1.195.855,19	1.919.500	2.566.450	942.793,92
BEANS	216.800	67.520	136.309,30	154.100	88.780	92.030,21	196.900	149.380	96.710,67
CHICK PEAS	78.900	26.300	49.607,03	71.600	51.340	42.760,30	78.100	56.620	38.360,10
DATES	23.500	82.000	14.775,22	33.000	33.200	19.707,96	68.176	101.351	33.485,76
MAIZE	453.600	215.600	285.193,25	265.400	198.880	158.499,78	230.100	279.150	113.017,39
OLIVES	395.000	380.000	248.349,50	477.300	455.200	285.048,78	830.481	1.506.473	407.904,37
ORANGES	53.600	810.000	33.700,08	50.100	723.100	29.920,27	44.900	849.197	22.053,37
POTATOES	60.656	918.397	38.136,42	57.520	1.334.380	34.351,57	56.600	1.604.620	27.800,02
SUGAR BEET	52.100	2.754.070	32.756,99	59.500	2.986.850	35.534,05	43.200	2.435.910	21.218,39
TANGERINES, MANDARINS, CLEMENTINES	17.500	273.000	11.002,83	24.800	405.700	14.810,83	47.537	472.834	23.348,58
TOMATOES	25.226	893.775	15.860,42	19.070	991.020	11.388,81	20.534	1.433.937	10.085,61
WHEAT	2.228.300	1.562.160	1.401.005,57	2.625.400	3.358.680	1.567.917,60	2.852.400	4.876.140	1.401.003,07

Table 57 - Water withdrawal in liters for each main crop in Morocco (1992, 2002, 2010).

2.5 Sudan

Sudan is located in Northern Africa to Africa south of the Sahara. It has an area of about 1,88 million km² (the exact area still needs to be confirmed) and is the third largest country in Africa, after Algeria and the Democratic Republic of the Congo. Before the independence of South Sudan in 2011, it was the largest country in Africa.

Figure 45 - Physical map of Sudan.

In Sudan there are three climate areas:

- the desert area with the Nubian Desert and the Bayuda Desert in the central and the northern of the country;
- semi – desert area in southern of the country people rely on the scant rainfall for basic agriculture and many are nomadic, travelling with their herds of sheep and camels;
- low rainfall savannah, with red ironstone soils.

2.5.1 Demographics in Sudan

In 2017 Sudan population was 40,5 million of people and 35 % of it was urban population compared to 2000 when the total population was 27,25 million of people and around 33 % of it was urban population.

The most populated cities with more of 1 million of people are: the capital Khartoum where there is a confluence of the White Nile, flowing north from Lake Victoria, and the Blue Nile; Omdurman, lying on the western banks of the River Nile and Khartoum North.

The population density of Sudan is 23 inhabit/km^2 (UNITED NATIONS,2017) and the median age is 19.

With the following area graph it is possible to see how the population of Sudan is changed from 1955 to 2017.

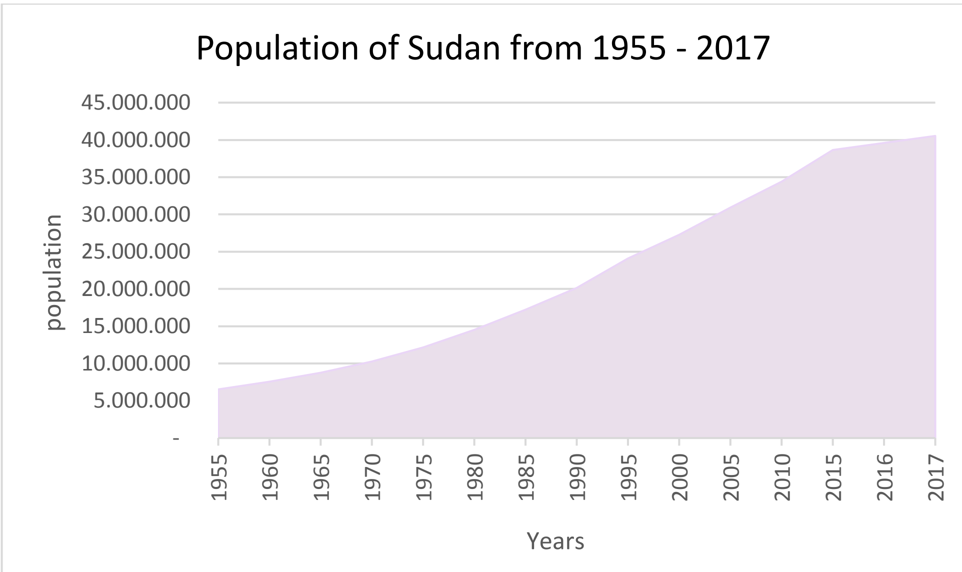

Figure 46 - Population of Sudan from 1955 - 2017.

An increase in population can be seen in the graph, in *Figure 46*. Paying more attention to the *Table 58*, where are listed the main characteristics of the Sudan population from 1955 to 2017. Sudan ranks number 35 in the list of countries by population, its population is equivalent to 0,54 % of the total world population. Sudan population has growth rapidly from 1955 to 2015, but it could grow more considering dimensions of the country. The median age is the lowest of all Northern Africa.

Years	SUDAN	Yearly % Change	Median Age	Fertility Rate
1955	6.549.298	2,66%	17,8	6,65
1960	7.544.491	2,83%	17,5	6,65
1965	8.770.097	3,01%	17,1	6,75
1970	10.281.700	3,18%	16,8	6,86
1975	12.144.135	3,33%	16,5	6,90
1980	14.507.468	3,56%	16,4	6,92
1985	17.210.187	3,42%	16,6	6,63
1990	20.147.590	3,15%	17,0	6,30
1995	24.102.986	3,58%	17,7	6,00
2000	27.250.535	2,46%	17,9	5,65
2005	30.911.914	2,52%	18,1	5,30
2010	34.385.963	2,13%	18,3	5,00
2015	38.647.803	2,34%	18,9	4,75
2016	39.578.828	2,41%	19,0	4,69
2017	40.533.330	2,41%	19,0	4,69

Table 58 - Main characteristics of Sudan population (1955-2017).

In the United Nations database it is possible have an Sudan future population prospect:

Years	SUDAN	Yearly % Change	Median Age	Fertility Rate
2020	43.541.203	2,38%	19,7	4,43
2025	48.999.711	2,36%	20,6	4,15
2030	54.842.478	2,25%	21,6	3,89
2035	60.996.110	2,13%	22,5	3,65
2040	67.357.464	1,98%	23,3	3,45
2045	73.834.917	1,84%	24,2	3,27
2050	80.385.607	1,70%	25,1	3,11
2055	86.991.221	1,58%	26,2	2,97
2060	93.616.439	1,47%	27,2	2,85

Table 59 - Population forecast of Sudan from database of DESA/POPULATION DEVITION, United Nations.

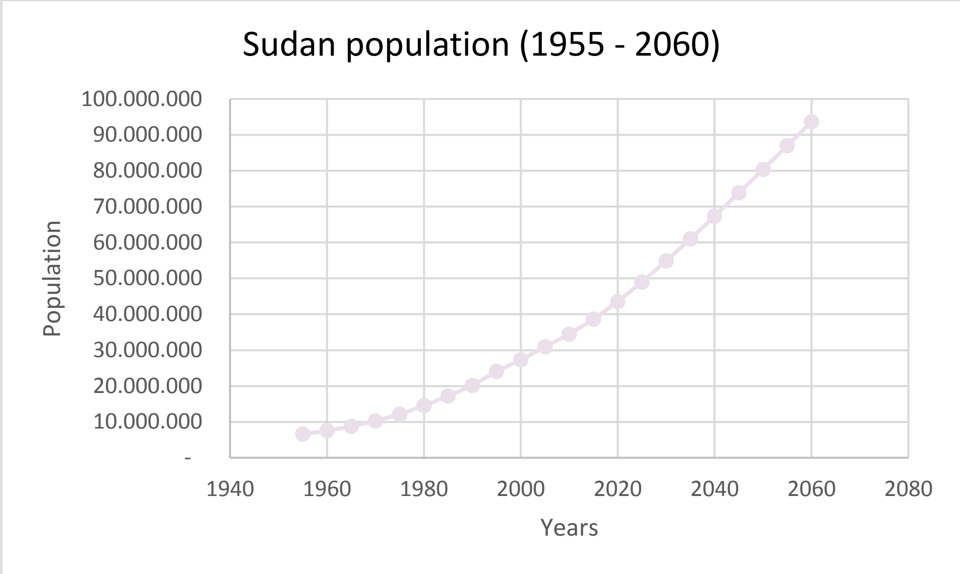

Figure 47 - Sudan population (1955 - 2060).

2.5.2 Availability and use of water in Sudan

In Sudan the amount of surface water produced internally is estimated at 2 000 million m^3/year (AQUASTAT, 2014) and the groundwater produced internally is equal to 3 000 million m^3/year (AQUASTAT, 2014) but 1 000 million m^3/year is considered to overlap between surface water and groundwater, which gives a value of total renewable water resources of 4 000 million m^3/year. Internal renewable water resources in Sudan are rather limited. The principal surface water resource in Sudan is the Nile river: 43 % of the Nile basin lies within Sudan, while 72 % of Sudan lies in the Nile basin. Even more, the erratic nature of the rainfall and its concentration in a short season places Sudan in a vulnerable situation, especially in rainfed areas. In a year precipitations in Sudan have a value equal to 250 mm.

Also in this case it is possible considering the value of the total renewable water resources constant and knowing the historical of population from 1955 to 2015 to obtain the total renewable water resources per capita. For Sudan, AQUASTAT database has total renewable water resources per capita values starting from 2010. Considering the reasoning utilized for the previous countries in *Table 60* there will be the historical of total renewable water resources per capita from 1955 to 2015.

Years	Population	Total renewable water resources per capita (m^3/inhabit/year)
1955	6.549.298	610,752
1960	7.544.491	530,188
1965	8.770.097	456,095
1970	10.281.700	389,041
1975	12.144.135	329,377
1980	14.507.468	275,720
1985	17.210.187	232,420
1990	20.147.590	198,535
1995	24.102.986	165,955
2000	27.250.535	146,786
2005	30.911.914	129,400
2010	34.385.963	116,327
2015	38.647.803	103,499

Table 60 - Total renewable water resources per capita and population in Sudan (1955 - 2015).

The most remarkable results is that the total renewable water resources per capita is 103,49 m^3/year per capita in 2015, Sudan being thus well under the absolute water scarcity threshold of 500 m^3/year per capita. Total renewable water resources per capita is under the m^3/year per capita since 1965.

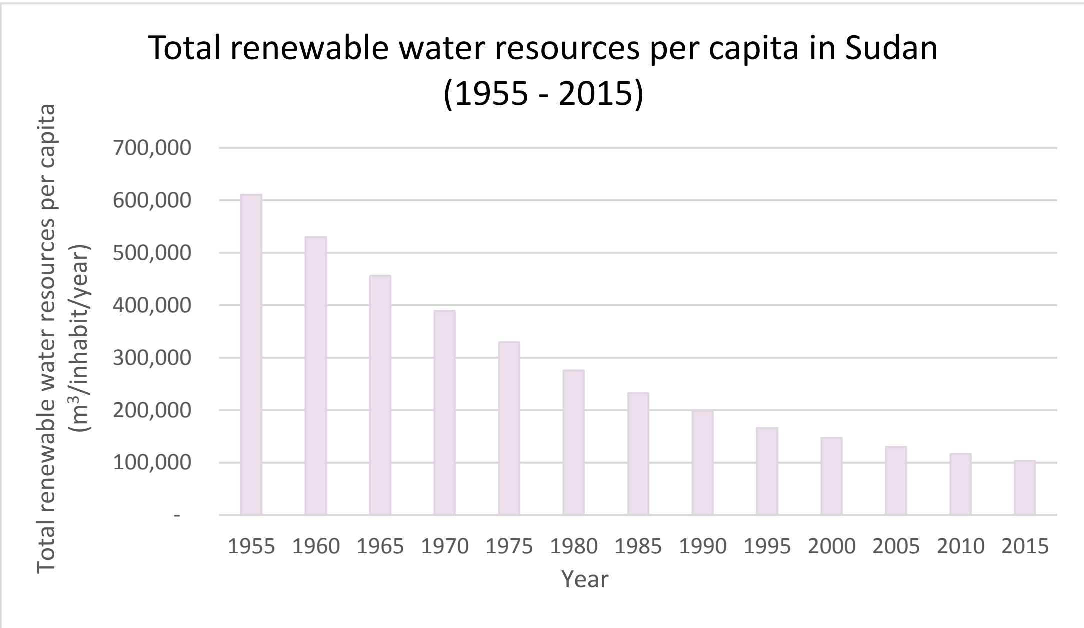

Figure 48 - Total renewable water resources per capita in Sudan (1955 – 2015).

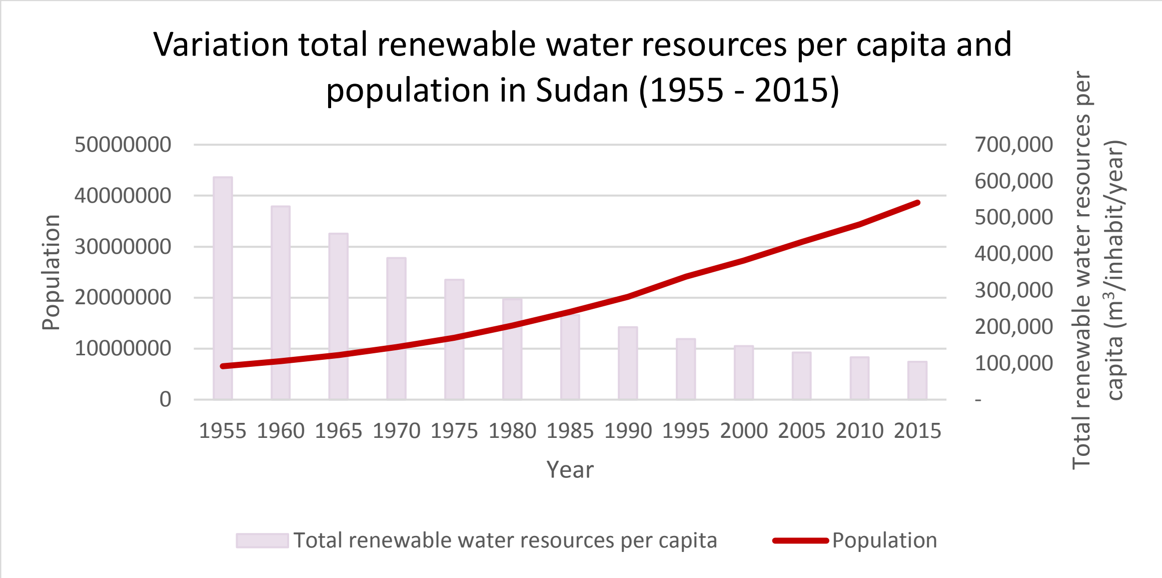

Figure 49 - Variation total renewable water resources per capita in Algeria and population in Sudan (1955 - 2015).

In AQUASTAT database there is also the percentage of total, urban and rural population in Sudan with access to safe drinking – water, but only from 2007 to 2012.

Years	Total population with access to safe drinking - water (%)	Urban population with access to safe drinking - water (%)	Rural population with access to safe drinking - water (%)
2007	55,5	66	50,2
2012	55,5	66	50,2

Table 61 - Percentage of total, urban and rural population with access to safe-drinking water in Sudan (2007 - 2012).

For Sudan, data in AQUASTAT database are poor they are referred to recent years. Percentages of *Table 61* show how in Sudan there is also a problem with access to safe drinking – water: almost half of the total population doesn’t have access to safe drinking – water. Rural population has the same problem, only urban population has a percentage bigger.

In *Table 62*, there are GDP, population and GDP per capita from 1960 to 2015 in order to observe evolution of Sudan’s economy.

Years	GDP (current US $)	Population	GDP per capita (current US$/inhabit)
1960	1.307.333.333	7.544.491	173,28
1965	1.679.333.333	8.770.097	191,48
1970	2.437.666.667	10.281.700	237,09
1975	5.598.000.000	12.144.135	460,96
1980	7.459.833.333	14.507.468	514,21
1985	12.403.733.333	17.210.187	720,72
1990	12.408.647.541	20.147.590	615,89
1995	13.829.744.879	24.102.986	573,78
2000	12.257.418.326	27.250.535	449,80
2005	26.524.538.566	30.911.914	858,07
2010	65.634.109.237	34.385.963	1.908,75
2015	97.156.119.150	38.647.803	2.513,88

Table 62 - GDP (current US$) and GDP per capita in Sudan (1960 - 2015).

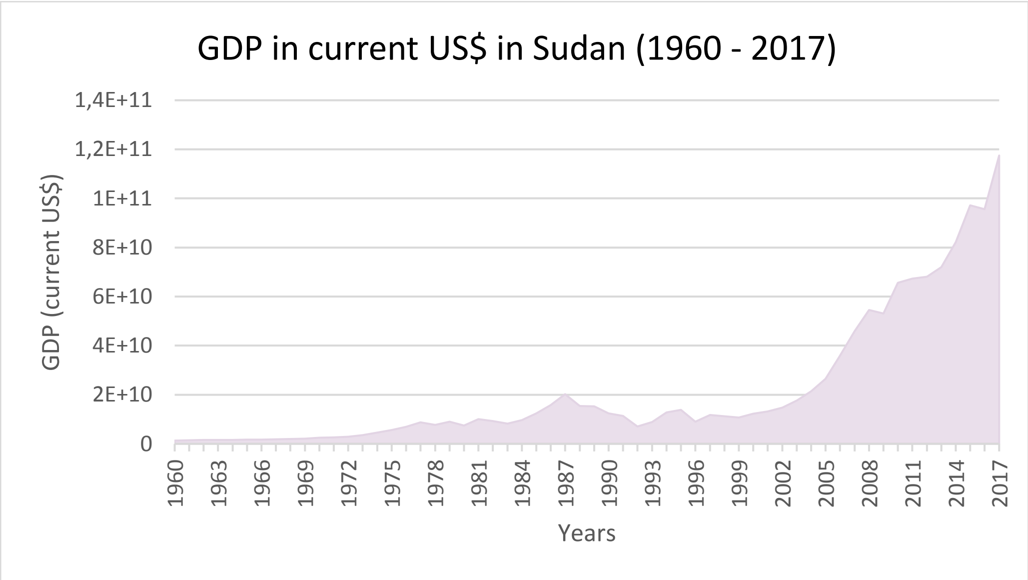

Figure 50 - GDP in Sudan (1960- 2017).

Sudan is an extremely poor country amongst others as a result of social conflict and civil war. In 2012 Sudan's economy has been affected by falling oil revenues due to the secession of South Sudan in July 2011 and the resultant loss of about 75 % of the country's oil resources.

In Sudan' s economy, the most dominant sector is agricultural, even if the industrial sector from the start of new millennium had a relevant growth.

Naturally agricultural sector needs water and from AQUASTAT database it is possible to have the total water withdrawal as showed in *Table 63*.

Year	Total water withdrawal (10^9 m³/year)
2010	26,96

Table 63 - Total water withdrawal in Sudan (2010).

As it was said before, for Sudan many data miss and this happens also for the total water withdrawal: the only value available is that of 2010. Given the lack of a data history for the total water withdrawal in Sudan a hypothesis is that its value from 2010 to today is constant. In general, in Sudan the difficulty to have data behind 2010 is due to political instability and tension situation. As done for other countries, in the following *Table 64* there are the total water withdrawal, GDP and population in Sudan in 2010.

Year	Total water withdrawal (10^9 m³/year)	GDP (current US$)	Population
2010	26,96	65.634.109.237	34.385.963

Table 64 - Total water withdrawal, GDP and Population in Sudan 2010.

Also, for Sudan it can be helpful to have percentages of agricultural, industrial and municipal water withdrawal on the total water withdrawal. In AQUASTAT database the only year reported is 2011 as showed in *Table 66*.

Year	2011
Agricultural water withdrawal as % of total water withdrawal (%)	96,21
Industrial water withdrawal as % of total water withdrawal (%)	0,2785
Municipal water withdrawal as % of total withdrawal (%)	3,528

Table 65 - Agricultural, industrial and municipal water withdrawal percentages in Sudan (2011).

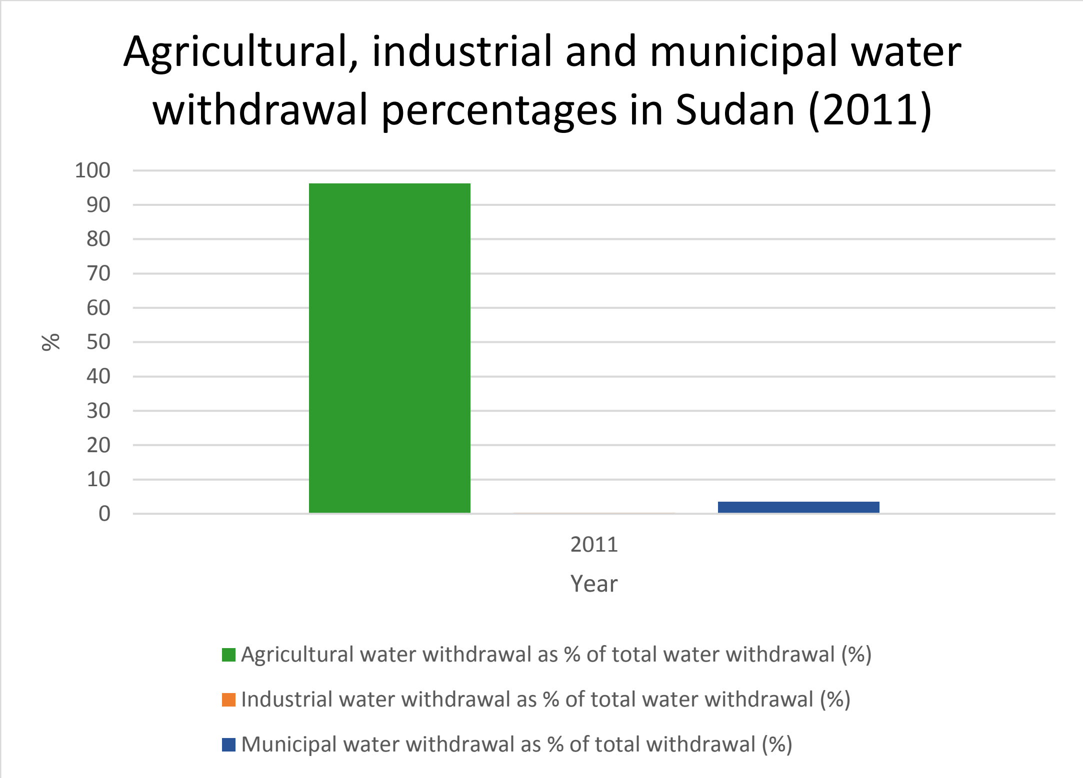

Figure 51 - Agricultural, industrial and municipal water withdrawal percentages in Sudan (2011).

In FAOSTAT and AQUASTAT database it is possible also to find data on the land in Sudan:

Country Area (ha)	187.936.000
Agricultural Area (ha)	No data available
Forest (ha)	No data available
Arable land (ha)	19.823.000
Permanent Crops (ha)	1.680.000
Cultivated area (ha)	19.991.000
Area harvested (ha)	18.225.644

Table 66 - Main Sudan data land (official data, FAOSTAT, AQUASTAT 2014).

As showed in *Table 66* and *Figure 51*, Sudan water withdrawal is the highest for agriculture. In AQUASTAT database are listed all area harvested and production data for each crop cultivated in Sudan.

First, it is possible to obtain a historical on the total area harvested in Sudan starting from 2012 (*Table 67*) from AQUASTAT database.

Years	Total area harvested (ha)
2012	9.675.387
2013	15.997.538
2014	18.225.644
2015	12.056.136
2016	18.927.770

Table 67 - Historical area harvested in Sudan (2012 - 2016).

Making a more accurate study, it considers total area harvested in hectares and the production in tons of main crops in Sudan. The main crops considered are: sorghum, millet, groundnuts, sesame seed, wheat, pulses, onions, sugar cane, fruit and vegetables All the values of main crops are in *Table 70* from 1992 to 2016.

Crops		2012	2013	2014	2015	2016
FRUIT, FRESH NES	Area harvested (ha)	45.000	47.000	50.000	52.986	55.340
	Production (tonnes)	250.000	275.000	300.000	325.000	350.000
GROUNDNUTS, WITH SHELL	Area harvested (ha)	1.619.520	2.161.740	2.183.160	1.464.960	2.315.040
	Production (tonnes)	1.032.000	1.767.000	1.871.000	1.042.000	1.826.000
MILLET	Area harvested (ha)	1.302.840	2.782.080	3.151.200	1.704.360	3.007.200
	Production (tonnes)	378.000	1.090.000	1.245.000	486.000	1.449.000
ONIONS, DRY	Area harvested (ha)	59.640	59.700	77.377	85.974	87.696
	Production (tonnes)	1.036.000	1.037.000	1.425.060	1.583.400	1.583.900
PULSE, NES	Area harvested (ha)	93.000	97.000	102.000	104.030	105.396
	Production (tonnes)	84.000	85.000	90.000	92.266	93.338
SESAME SEED	Area harvested (ha)	820.260	2.157.540	2.532.000	1.450.260	2.134.860
	Production (tonnes)	187.000	562.000	721.000	329.000	525.000
SORGHUM	Area harvested (ha)	4.103.400	7.079.583	8.377.600	5.197.080	9.157.680
	Production (tonnes)	2.249.000	4.524.000	6.281.000	2.744.000	6.466.000
SUGAR CANE	Area harvested (ha)	61.653	69.804	69.876	69.876	69.564
	Production (tonnes)	6.172.671	6.797.900	5.807.500	5.548.597	5.525.059
VEGETABLES, FRESH NES	Area harvested (ha)	35.000	40.000	45.000	48.977	53.994
	Production (tonnes)	265.000	275.000	300.000	313.696	324.705
WHEAT	Area harvested (ha)	187.320	135.660	222.916	226.380	216.720
	Production (tonnes)	324.000	265.000	473.000	778.600	516.000

Table 68 - Area harvested and production of main crops in Sudan (2012 - 2016).

Calculating the water quantity needed in a year for each main crop in Sudan starting from 2012 it is fundamental to have the total water withdrawal , expressed in m^3/year, and the percentage of agricultural water withdrawal in that year.

In Sudan case, it is available only the total water withdrawal actualized at 2010 and the percentage of agricultural water withdrawal actualized at 2011. For simplicity, it will be supposed that these two values not change in a range of year from 2012 to 2016 and finally to have the agricultural water withdrawal in m^3/year.

The results of agricultural water withdrawal are showed in the last column in *Table 69*.

Years	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal as % of total water withdrawal (%)	Agricultural water withdrawal (10^9 m^3/year)
2012 - 2016	26,96	96,21	25,94

Table 69 - Agricultural water withdrawal (m^3/year) in Sudan (2012 - 2016).

Another value it can be calculated is the agricultural water withdrawal per hectare from 2012 to 2016 in Sudan as showed in *Table 70*.

Years	Area harvested (ha)	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal (10^9 m^3/year)	Agricultural water withdrawal per hectares (lt/ha/year)
2012	9.675.387	26,96	25,94	2.681.029,71
2013	15.997.538	26,96	25,94	1.621.499,51
2014	18.225.644	26,96	25,94	1.423.269,32
2015	12.056.136	26,96	25,94	2.151.601,47
2016	18.927.770	26,96	25,94	1.370.473,12

Table 70 - Agricultural water withdrawal per hectare in Sudan (2012 - 2016).

With *Table 68* and data *Table 70*, it can obtain the water liters used from 2012 to 2016 for each main crop in Sudan. All the results are reported in *Table 71* with tons produced.

	2012			2013			2014		
	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)
Crops									
FRUIT, FRESH NES	45.000	250.000	120.646,34	47.000	275.000	76.210,48	50.000	300.000	71.163
GROUNDNUTS, WITH SHELL	1.619.520	1.032.000	4.341.981,24	2.161.740	1.767.000	3.505.260,35	2.183.160	1.871.000	3.107.225
MILLET	1.302.840	378.000	3.492.952,75	2.782.080	1.090.000	4.511.141,36	3.151.200	1.245.000	4.485.006
ONIONS, DRY	59.640	1.036.000	159.896,61	59.700	1.037.000	96.803,52	77.377	1.425.060	110.128
PULSE, NES	93.000	84.000	249.335,76	97.000	85.000	157.285,45	102.000	90.000	145.173
SESAME SEED	820.260	187.000	2.199.141,43	2.157.540	562.000	3.498.450,05	2.532.000	721.000	3.603.718
SORGHUM	4.103.400	2.249.000	11.001.337,31	7.079.583	4.524.000	11.479.540,37	8.377.600	6.281.000	11.923.581
SUGAR CANE	61.653	6.172.671	165.293,52	69.804	6.797.900	113.187,15	69.876	5.807.500	99.452
VEGETABLES, FRESH NES	35.000	265.000	93.836,04	40.000	275.000	64.859,98	45.000	300.000	64.047
WHEAT	187.320	324.000	502.210,49	135.660	265.000	219.972,62	222.916	473.000	317.270

	2015			2016		
	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)
Crops						
FRUIT, FRESH NES	52.986	325.000	114.004,76	55.340	350.000	75.841,98
GROUNDNUTS, WITH SHELL	1.464.960	1.042.000	3.152.010,09	2.315.040	1.826.000	3.172.700,09
MILLET	1.704.360	486.000	3.667.103,48	3.007.200	1.449.000	4.121.286,77
ONIONS, DRY	85.974	1.583.400	184.981,78	87.696	1.583.900	120.185,01
PULSE, NES	104.030	92.266	223.831,10	105.396	93.338	144.442,38
SESAME SEED	1.450.260	329.000	3.120.381,55	2.134.860	525.000	2.925.768,24
SORGHUM	5.197.080	2.744.000	11.182.044,97	9.157.680	6.466.000	12.550.354,28
SUGAR CANE	69.876	5.548.597	150.345,30	69.564	5.525.059	95.335,59
VEGETABLES, FRESH NES	48.977	313.696	105.378,99	53.994	324.705	73.997,33
WHEAT	226.380	778.600	487.079,54	216.720	516.000	297.008,93

Table 71 - Water withdrawal in liters for each main crop in Sudan (2012 - 2016).

2.6 Tunisia

Tunisia is a Northern – Africa country and it is between Algeria and Libya, while the coast is on Mediterranean Sea. Tunisia is the smaller country of all North – Africa, but its environmental diversity is due its vertical extension. In the Eastern part of the country there are part of the Atlas Mountains, the Dorsal, while near the sea there is the plan Sahel. Between the Sahel and the Dorsal there are the steppes and the internal part of the country is a desert area.

Figure 52 - Physical map of Tunisia.

The Tunisian climate can be divided in three areas:

- Mediterranean climate along the coast;
- Cold semi-arid climate in mountains area;
- Semi – arid climate in the intern part of the country.

2.6.1 Demographics in Tunisia

In 2017 Moroccan population was 11,6 million of people and around 66,9 % of it was urban population compared to 2000 when the total population was 9,69 million of people and around 62,5 % of it was urban population. Morocco population is equivalent to 0,15 % of the total world population and ranks number 78 in the list of countries by population.
The most three populated cities are all towards Mediterranean Sea : Tunis, Sfax and Sousse.
The population density of Morocco is 194 inhabit/km2 (UNITED NATIONS,2017) and the median age is 31,4 years.
With the following area graph (*Figure 53*) it is possible to see how the population of Tunisia has changed from 1955 to 2017: the population has grown rapidly quadrupling from 1955 to 2015.

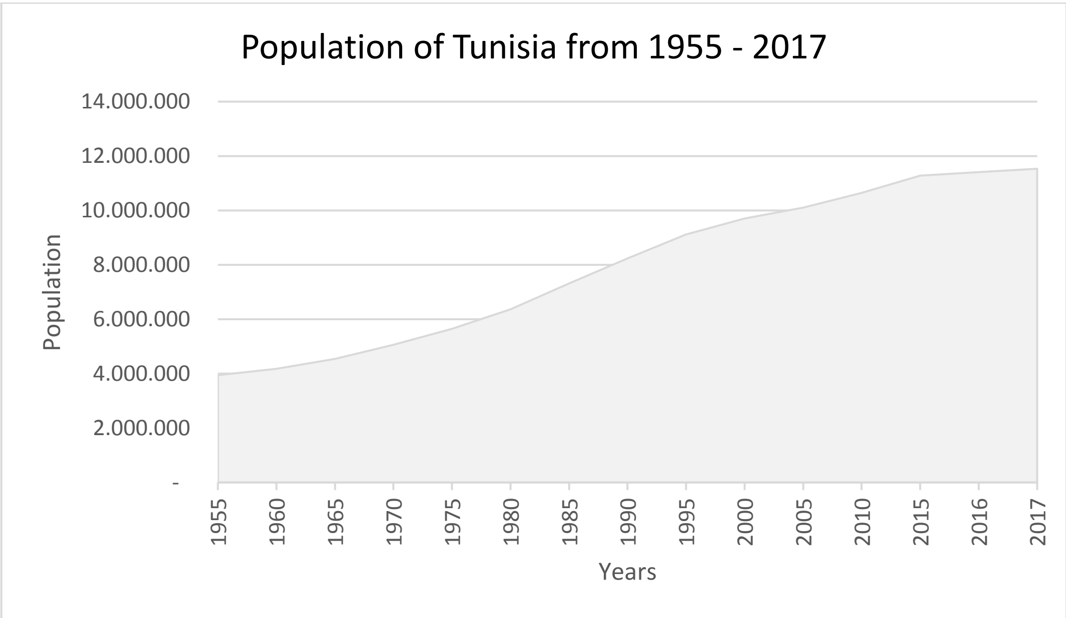

Figure 53 - Population of Tunisia from 1955 - 2017.

Tunisia is the second less populated country in Northern – Africa after Libya, but it is related to the fact that Tunisia is the smaller country of this area of the Continent.
The yearly percentage change of Tunisia has values lower than the average of other Northern – Africa countries and in population forecast of UNITED NATIONS there will be yearly percentage change under 1 %.
For the median age there are also data very different by other median ages in Northern – Africa countries, with the highest median age recorded in 2015.

Years	TUNISIA	Yearly % Change	Median Age	Fertility Rate
1955	3.943.528	1,79%	19,4	6,65
1960	4.176.266	1.15%	18,5	6,85
1965	4.545.339	1.69%	17,5	6,99
1970	5.060.397	2,15%	17,0	6,92
1975	5.652.476	2,21%	17,8	6,38
1980	6.368.167	2,38%	18,6	5,65
1985	7.321.876	2,79%	19,9	4,82
1990	8.232.797	2,34%	21,3	4,00
1995	9.113.975	2,03%	23,1	2,98
2000	9.699.197	1,24%	25,1	2,34
2005	10.102.482	0,82%	27,2	2,04
2010	10.639.931	1,04%	29,2	2,02
2015	11.273.661	1,16%	31,1	2,25
2016	11.403.248	1,15%	31,1	2,23
2017	11.532.127	1,13%	31,1	2,23

Table 72 - Main characteristics of Tunisian population (1955-2017).

In the United Nations database, it is possible have an Tunisian future population prospect:

Years	TUNISIA	Yearly % Change	Median Age	Fertility Rate
2020	11.903.136	1,09%	32,7	2,15
2025	12.431.567	0,87%	34,5	2,06
2030	12.841.615	0,65%	36,2	2,00
2035	13.161.033	0,49%	37,6	1,94
2040	13.434.541	0,41%	38,5	1,91
2045	13.681.104	0,36%	39,2	1,88
2050	13.883.996	0,29%	39,9	1,86
2055	14.015.357	0,19%	41,3	1,85
2060	14.063.520	0,70%	42,6	1,84

Table 73 - Population forecast of Tunisia from database of DESA/POPULATION DEVITION, United Nations

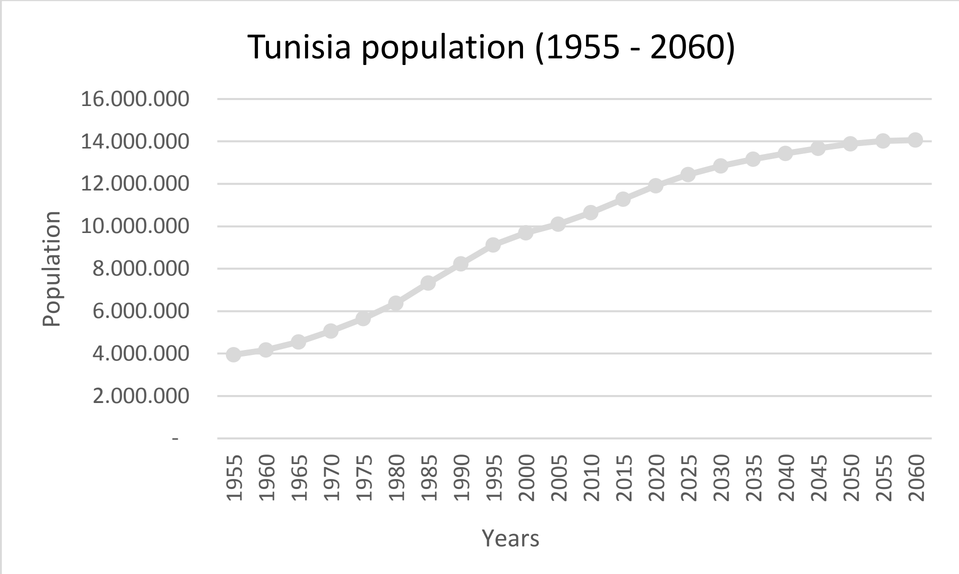

Figure 54 - Tunisian population (1955 - 2060).

2.6.2 Availability and use of water in Tunisia

In Tunisia the amount of surface water produced internally is estimated at 3 100 million m^3/year (AQUASTAT, 2014) and the groundwater produced internally is equal to 1 495 million m^3/year (AQUASTAT, 2014) but 400 million m^3/year is considered to overlap between surface water and groundwater, which gives a value of total renewable water resources of 4 195 million m^3/year.
The amount of internal renewable water resources in Tunisia is very low. The principal surface water resource in Tunisia is the Medjerda river. It is born in Algeria and it is long 365 km, ¾ of the river are in Tunisia.
Also in this case it is possible considering the value of the total renewable water resources constant and knowing the historical of population from 1955 to 2015 to obtain the total renewable water resources per capita.
Considering the reasoning utilized for the previous countries in *Table 74* there will be the historical of total renewable water resources per capita from 1955 to 2015.

Years	Population	Total renewable water resources per capita (m³/inhabit/year)
1955	3.943.528	1.063,77
1960	4.176.266	1.004,49
1965	4.545.339	922,92
1970	5.060.397	828,99
1975	5.652.476	742,15
1980	6.368.167	658,75
1985	7.321.876	572,94
1990	8.232.797	509,55
1995	9.113.975	460,28
2000	9.699.197	432,51
2005	10.102.482	415,24
2010	10.639.931	394,27
2015	11.273.661	372,11

Table 74 - Total renewable water resources per capita and population in Tunisia (1955 - 2015).

The most remarkable results is that the total renewable water resources per capita is 372,11 m³/year per capita in 2015, Tunisa being thus well under the absolute water scarcity threshold of 500 m³/year per capita. Total renewable water resources per capita is under the m³/year per capita since 1995.

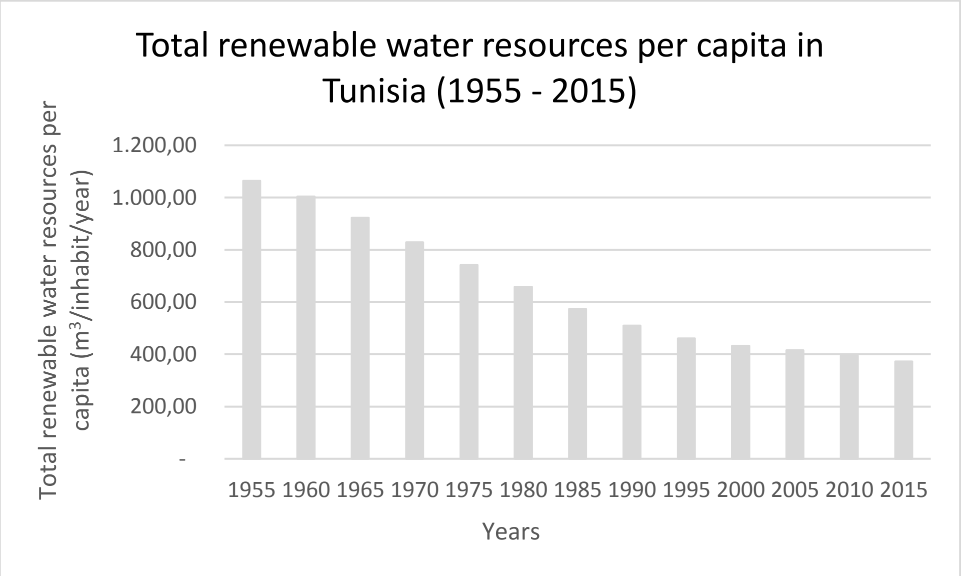

Figure 55 - Total renewable water resources per capita in Tunisia (1955 – 2015).

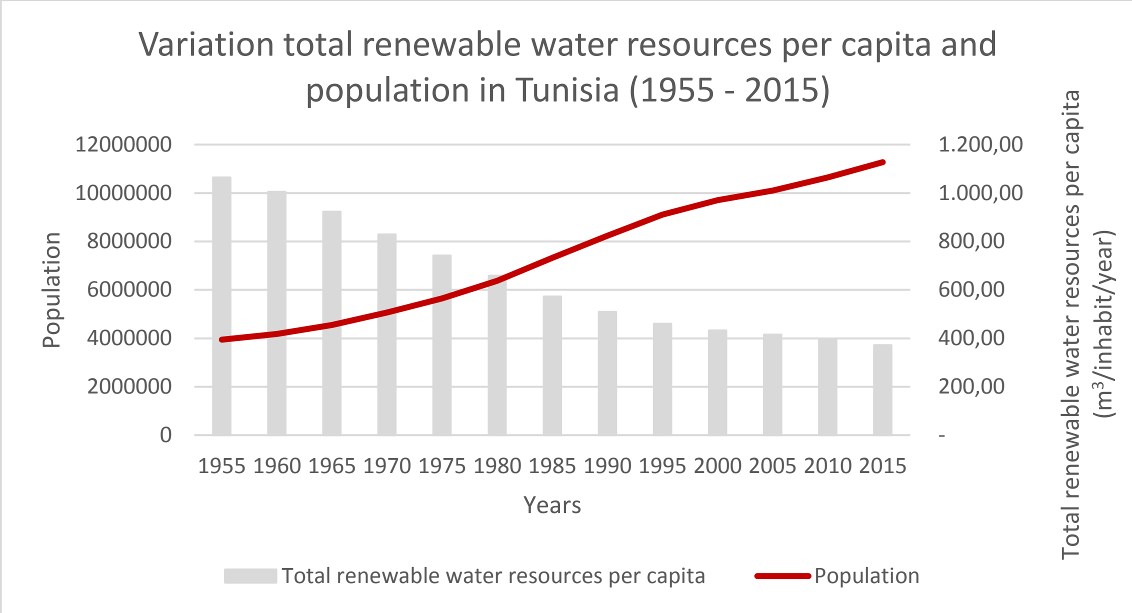

Figure 56 - Variation total renewable water resources per capita in Algeria and population in Tunisia (1955 - 2015).

In AQUASTAT database there is also the percentage of total, urban and rural population in Tunisia with access to safe drinking – water, but only from 1992 to 2015.

Years	Total population with access to safe drinking - water (%)	Urban population with access to safe drinking - water (%)	Rural population with access to safe drinking - water (%)
1992	84,2	96,1	66,8
1997	87,9	97	72,8
2002	94,1	99	84,8
2007	94,1	99	84,8
2012	96,9	100	90,8
2015	97,7	100	93,2

Table 75 - Percentage of total, urban and rural population with access to safe-drinking water in Tunisia (1992 - 2015).

From 1992 to 2015 the percentage of total, urban and rural population with access to safe-drinking water in Tunisia is increased. All the urban population has access to safe drinking – water from 2012, while the rural population has a percentage of access to safe drinking – water more than 90 %.

Also for Tunisia, it is possible to have an historical of Tunisian GDP in current US$, with an interval of 5 years (WORLD BANK) and the GDP per capita calculated as the rapport of GDP values and population, as showed in *Table 76*.

Years	GDP (current US $)	Population	GDP per capita (current US$/inhabit)
1965	991.047.619	4.545.339	218,04
1970	1.439.238.095	5.060.397	284,41
1975	4.328.610.490	5.652.476	765,79
1980	8.744.134.354	6.368.167	1.373,10
1985	8.410.185.740	7.321.876	1.148,64
1990	12.290.568.182	8.232.797	1.492,88
1995	18.030.876.599	9.113.975	1.978,38
2000	21.473.188.882	9.699.197	2.213,91
2005	32.273.007.554	10.102.482	3.194,56
2010	44.050.929.160	10.639.931	4.140,15
2015	43.156.708.809	11.273.661	3.828,10

Table 76 - GDP (current US$) and GDP per capita in Tunisia (1965 - 2015).

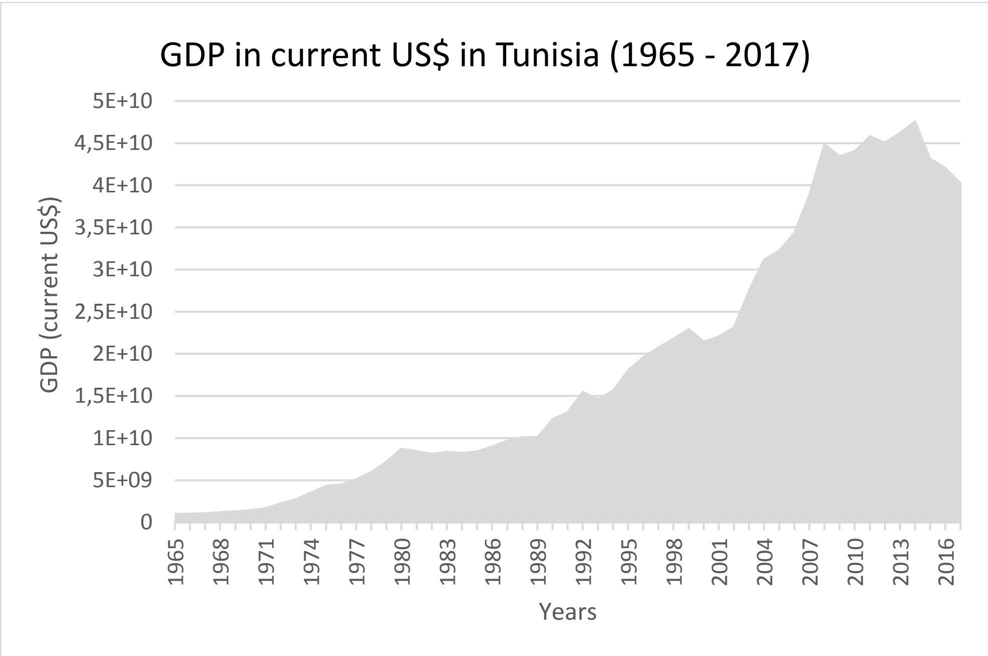

Figure 57 - GDP in Tunisia (1965- 2017).

Tunisia is 81° for GDP and as all Northern – Africa countries has grown since 80s. The 15 % of GDP in Tunisia is due the agriculture. 28,5 % industry and 55,5 % transports. In order to understand the amount of water used in each sector in Tunisia and in particular by agriculture, it is possible to consider from AQUASTAT database the total water withdrawal values from 1975 to 2011 in Tunisia and they are listed in *Table 77* and plotted in *Figure 58*.

Years	Total water withdrawal(10^9 m^3/year)
1975	1,07
1980	1,9
1985	2,3
1990	3,075
1995	2,857
2001	2,85
2011	3,305

Table 77 - Total water withdrawal in Tunisia (1975 - 2011).

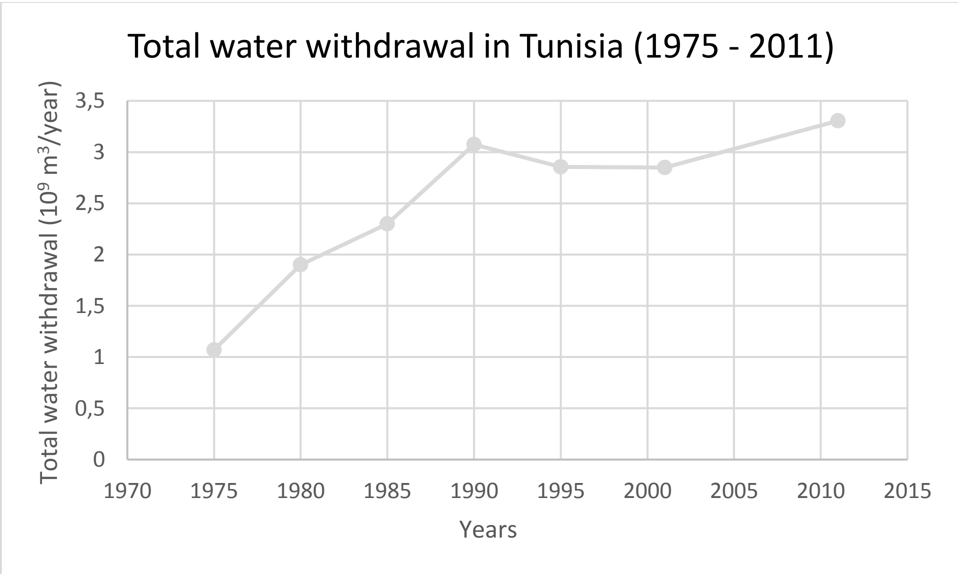

Figure 58 - Total water withdrawal in Tunisia (1975 - 2011).

In *Table 77* there is not the total water withdrawal in 2005, it is possible to obtain its value from the *Figure 58* with a graphic interpolation assuming that from 2001 to 2011 the total water withdrawal increases.

Having total water withdrawal, GDP and population values in Morocco it is possible to compare these data and observe their trends. All data are listed in *Table 78*, in *Figure 58* are plotted the variation of total water withdrawal and GDP and in *Figure 60* are plotted the variation of total water withdrawal and population. The total water withdrawal rapidly increased from 1975 to 2002, but after this year it decreased this is maybe for political and economic issues.

Years	Total water withdrawal(10^9 m^3/year)	GDP (current US$)	Population
1975	1,07	5.598.000.000	5.652.476
1980	1,9	7.459.833.333	6.368.167
1985	2,3	12.403.733.333	7.321.876
1990	3,075	12.408.647.541	8.232.797
1995	2,857	13.829.744.879	9.113.975
2001	2,85	13.182.979.784	9.819.467
2005	**3**	26.524.538.566	10.102.482
2011	3,305	67.327.289.320	10.750.586

Table 78 - Historical total water withdrawal, GDP and Population in Tunisia (1975 - 2011).

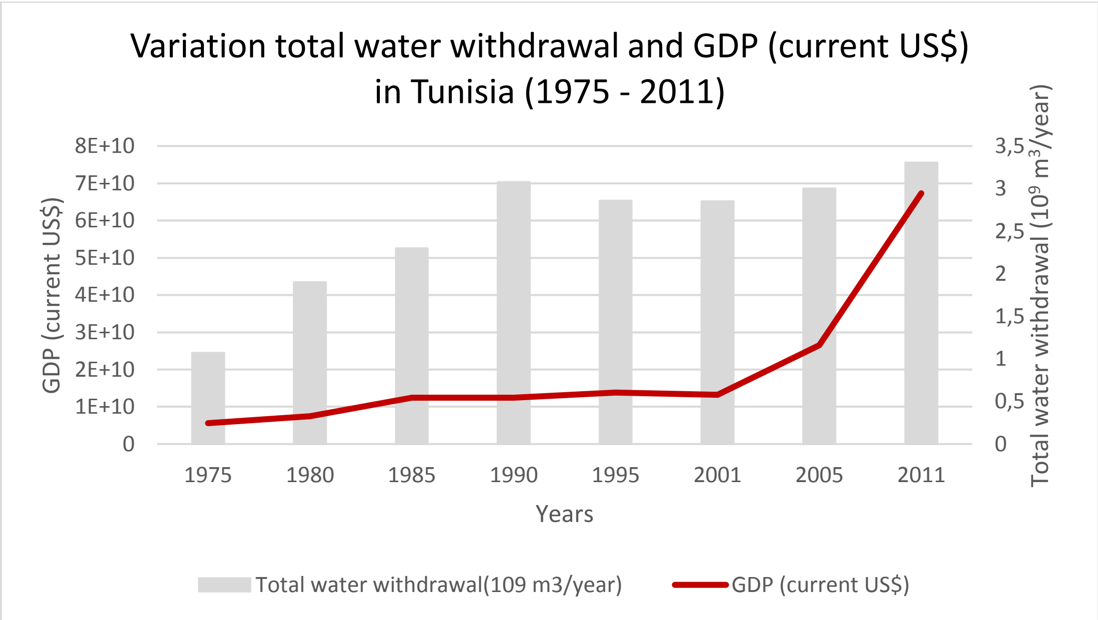

Figure 59 - Variation total water withdrawal and GDP in Tunisia (1975 – 2011).

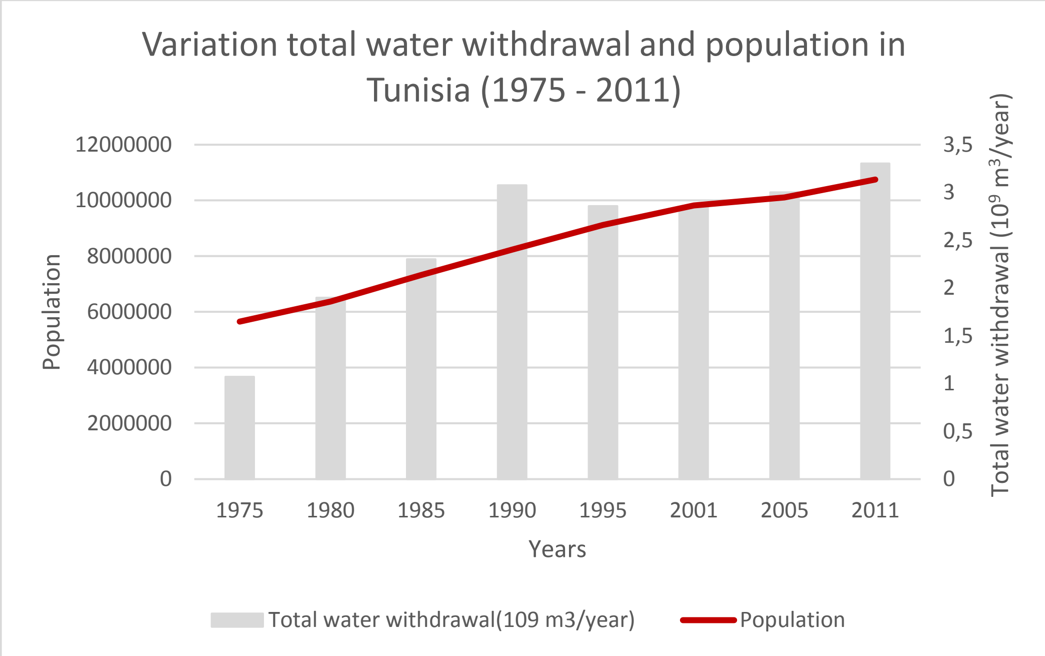

Figure 60 - Variation total water withdrawal and population in Tunisia (1975 - 2011)

In AQUASTAT database, there also percentages of agricultural, industrial and municipal water withdrawal on the total water withdrawal in Tunisia from 1990 to 2011.

Years	1990	1995	2001	2011
Agricultural water withdrawal as % of total water withdrawal (%)	88,72	85,61	75,96	80
Industrial water withdrawal as % of total water withdrawal (%)	2,797	3,43	3,86	4,992
Municipal water withdrawal as % of total withdrawal (%)	8,488	3,86	12,81	15,01

Table 79 - Agricultural, industrial and municipal water withdrawal percentages in Tunisia (1990 - 2011).

Data show how the highest amount of water is used for agriculture, the most recent data is in 2011 with 80 % even if it is a value that decreased since 1990. The industrial percentage has never been very high, and it has always been below 5 %. The population growth has a considerable effect on municipal water withdrawal: its percentage changed from around 8,5 % in 1990 to 15 % in 2011.

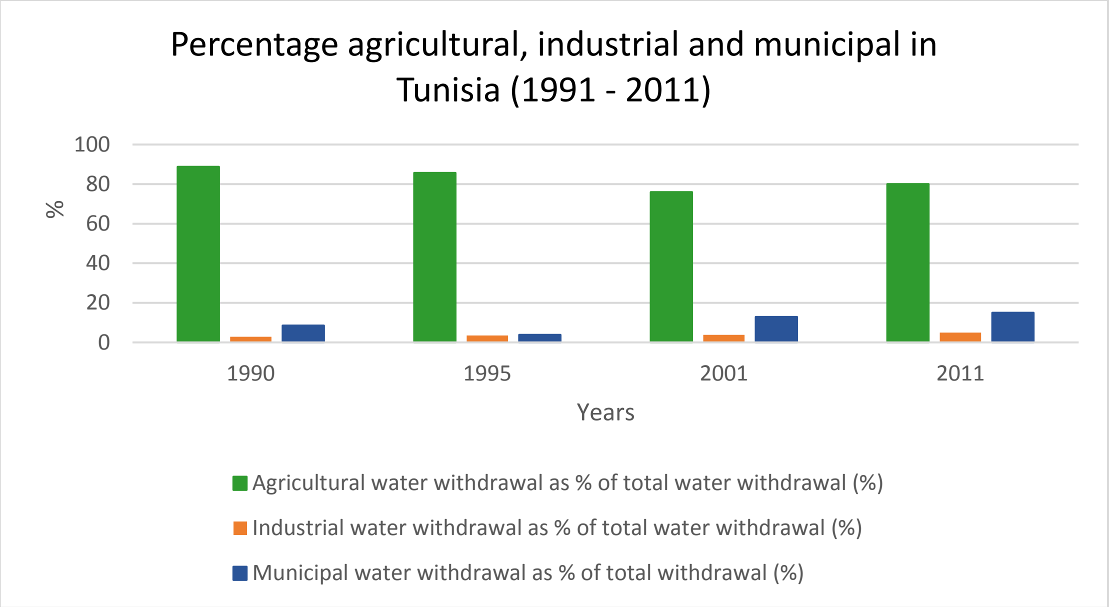

Figure 61 - Agricultural, industrial and municipal water withdrawal percentages in Tunisia (1990 - 2011).

In FAOSTAT and AQUASTAT database it is possible also to find data on the land in Tunisia:

Country Area (ha)	16.361.000
Agricultural Area (ha)	10.073.000
Forest (ha)	1.030.800
Arable land (ha)	2.900.000
Permanent Crops (ha)	2.332.000
Cultivated area (ha)	5.232.000
Area harvested (ha)	3.627.916

Table 80 - Main Tunisian data land (official data, FAOSTAT, AQUASTAT 2014).

In *Table 81*, there is the historical of area harvested in ha from 1975 to 2015.

Years	Total area harvested (ha)
1975	3.206.448
1980	3.196.646
1985	3.851.944
1990	3.461.943
1995	2.688.669
2000	3.227.581
2001	2.883.698
2010	3.856.749
2011	3.888.919
2015	3.568.049

Table 81 - Historical area harvested in Tunisia (1975 - 2015).

Making a more accurate study, it considers total area harvested in hectares and the production in tons of main crops in Tunisia. The main crops considered are: wheat, barley, olives, almonds, cereals, pistachios, pulses and tomatoes. All the values of main crops are in *Table 82* from 1990 to 2015.

Crops		1990	1995	2000	2001	2005	2010	2011	2015
ALMONDS, WITH SHELL	Area harvested (ha)	146.000	168.200	201.720	202.340	190.000	164.899	189.590	182.970
	Production (tonnes)	52.200	35.000	60.000	32.000	43.000	52.000	61.000	70.500
APPLES	Area harvested (ha)	9.700	15.500	25.660	25.770	25.780	26.335	26.339	19.170
	Production (tonnes)	41.800	65.000	108.000	108.000	100.000	126.000	128.000	90.000
BARLEY	Area harvested (ha)	509.300	121.500	372.000	199.000	470.000	184.700	560.760	513.210
	Production (tonnes)	477.500	80.300	241.500	233.000	465.200	236.900	680.900	364.330
CEREALS, NES	Area harvested (ha)	18059	30000	39.195	43.000	39.137	20.748	19.610	17.900
	Production (tonnes)	17.347	25.000	32.550	35.000	36.028	31.517	30.955	29.000
DATES	Area harvested (ha)	21.000	29.460	31.610	39.980	39.970	48.222	51.000	49.150
	Production (tonnes)	81.200	69.000	105.000	105.000	113.000	174.000	190.000	223.000
GRAPES	Area harvested (ha)	28.950	26.940	26.866	31.000	23.973	23.521	25.126	22.060
	Production (tonnes)	77.350	105.000	140.500	121.000	122.000	129.000	147.600	150.300
OLIVES	Area harvested (ha)	1.392.000	1.460.000	1.387.240	1.377.700	1.672.900	1.763.450	1.763.450	1.624.980
	Production (tonnes)	825.000	300.000	550.000	150.000	1.050.000	873.000	562.000	1.700.000
PISTACHIOS	Area harvested (ha)	27.703	35.000	21.670	21.600	36.000	35.262	33.220	26.660
	Production (tonnes)	600	900	1.600	1.100	2.500	2.300	2.100	3.000
POTATOES	Area harvested (ha)	15900	17000	20700	21300	25080	23800	24200	23240
	Production (tonnes)	217.000	233.000	290.000	330.000	310.000	370.000	360.000	400.000
PULSES, NES	Area harvested (ha)	16.600	18.759	22.000	22.727	24.084	27.289	28.402	29.767
	Production (tonnes)	10.700	15.200	17.500	18.617	20.031	23.151	24.184	25.639
TOMATOES	Area harvested (ha)	21.000	23.700	24.900	21.800	26.600	33.000	32.200	27.732
	Production (tonnes)	530.000	580.000	950.000	750.000	960.000	1.296.000	1.284.000	1.350.000
WHEAT	Area harvested (ha)	882.000	415.350	718.000	559.000	961.500	434.400	772.200	652.530
	Production (tonnes)	1.122.000	530.800	842.000	1.118.000	1.626.700	822.000	1.605.500	912.570

Table 82 - Area harvested and production of main crops in Tunisia (1990 - 2015).

Now, the aim of the study is to calculate the water quantity in a year for each main crop in Tunisia in 1990, 2001, 2011.

Having total water withdrawal, expressed in m^3/year, and the percentage of agricultural water withdrawal it is possible to obtain the agricultural water withdrawal in m^3/year in Egypt for 1990, 2001, 2011. The results of agricultural water withdrawal are showed in the last column in *Table 83*.

Years	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal as % of total water withdrawal (%)	Agricultural water withdrawal (10^9 m^3/year)
1990	3,075	88,72	2,73
1995	2,857	85,61	2,45
2001	2,85	75,96	2,16
2011	3,305	80	2,64

Table 83 - Agricultural water withdrawal (m3/year) in Tunisia (1990, 1995, 2001, 2011).

Another value it can be calculated is the agricultural water withdrawal per hectare in these years in Tunisia as showed in *Table 84.*

Years	Area harvested (ha)	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal (10^9 m^3/year)	Agricultural water withdrawal per hectares (lt/ha/year)
1990	3.461.943	3,075	106454,75	788.037,24
1995	2.688.669	2,857	76815,27	909.698,33
2001	2.883.698	2,85	82185,39	750.723,55
2011	3.888.919	3,305	128528,77	679.880,45

Table 84 - Agricultural water withdrawal per hectare in Tunisia (1990, 1995, 2001, 2011).

With *Table 82* and data *Table 84*, it can obtain the water liters used in 1990, 1995, 2001, 2011 for the main crop in Tunisia. All the results are reported in *Table 85* with tons produced.

	1990			1995			2001			2011		
	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)	Area harvested (ha)	Production (tonnes)	Water withdrawal (10^6 lt)
Crops												
ALMONDS, WITH SHELL	146.000	52.200	115.053	168.200	35.000	153.011	202.340	32.000	151.901	189.590	61.000	128.899
APPLES	9.700	41.800	7.643	15.500	65.000	14.100	25.770	108.000	19.346	26.339	128.000	17.907
BARLEY	509.300	477.500	401.347	121.500	80.300	110.528	199.000	233.000	149.394	560.760	680.900	381.250
CEREALS, NES	18.059	17.347	14.231	30000	25.000	27.291	43.000	35.000	32.281	19.610	30.955	13.332
DATES	21.000	81.200	16.548	29.460	69.000	26.800	39.980	105.000	30.014	51.000	190.000	34.674
GRAPES	28.950	77.350	22.813	26.940	105.000	24.507	31.000	121.000	23.272	25.126	147.600	17.083
OLIVES	1.392.000	825.000	1.096.947	1.460.000	300.000	1.328.160	1.377.700	150.000	1.034.272	1.763.450	562.000	1.198.935
PISTACHIOS	27.703	600	21.831	35.000	900	31.839	21.600	1.100	16.216	33.220	2.100	22.586
POTATOES	15.900	217.000	12.529	17.000	233.000	15.465	21.300	330.000	15.990	24.200	360.000	16.453
PULSES, NES	16.600	10.700	13.081	18.759	15.200	17.065	22.727	18.617	17.062	28.402	24.184	19.310
TOMATOES	21.000	530.000	16.548	23.700	580.000	21.560	21.800	750.000	16.366	32.200	1.284.000	21.892
WHEAT	882.000	1.122.000	695.048	415.350	530.800	377.843	559.000	1.118.000	419.654	772.200	1.605.500	525.004

Table 85- Water withdrawal in liters for each main crop in Tunisia (1990, 1995, 2001, 2011).

2.7 Northern – Africa countries comparison

Considering all data and results obtained for each country is possible to make a comparison to see the difference between them.

Algeria is the most extended country among Norther – Africa countries, followed in order by Sudan, Libya, Egypt, Morocco and Tunisia.

Northern Africa population is equivalent to 3,12 % of the total world population and round 50 % is urban. Figure 62 shows which country is more populated than others with population data of 2015:

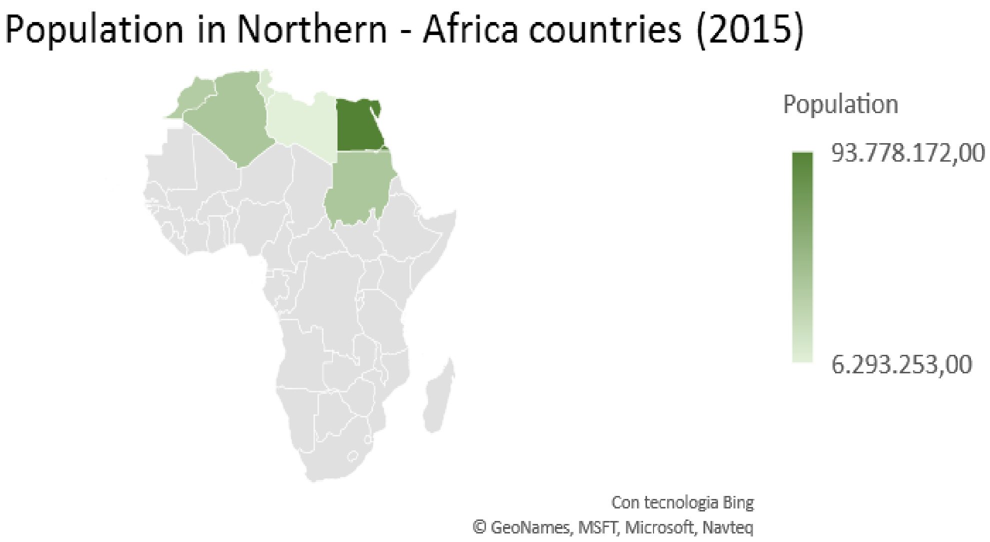

Figure 62 - Population in Northern - Africa countries (2015).

Egypt is the most populated country in Northern – Africa, instead the less populated is Libya. Despite Egypt and Libya are two neighboring countries they have political, economic, geographical and social differences, these are the motivation of the opposite values of population.

Another useful comparison can be made on the total renewable water resources in each country, its value is considered constant for each country in AQUASTAT database.

Figure 63 shows how this data changes in each country.

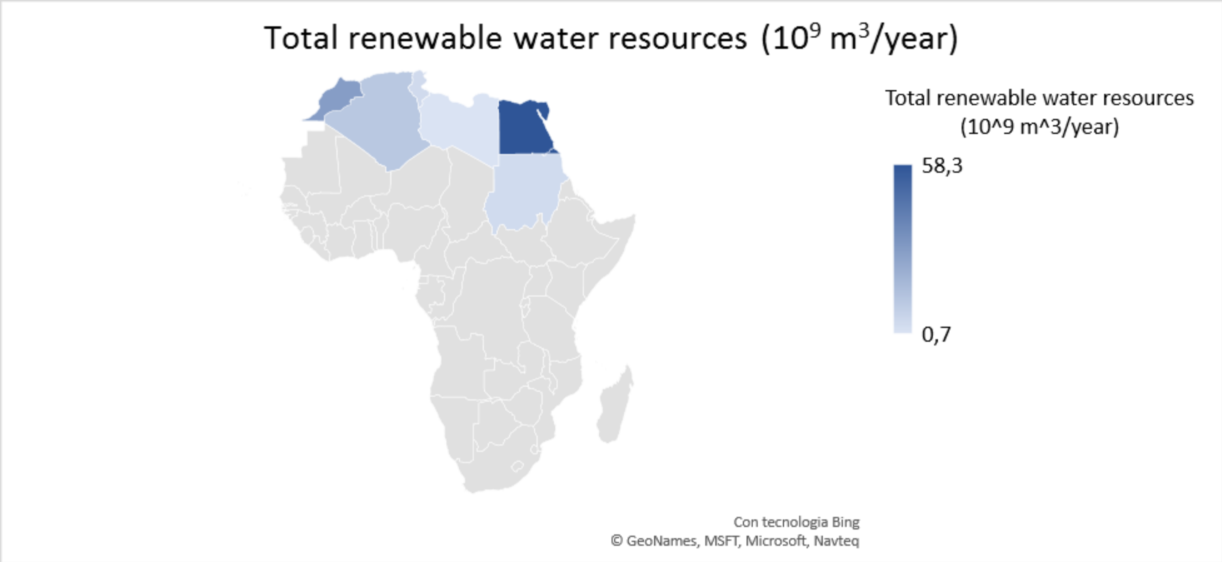

Figure 63 - Total renewable water resources.

Egypt has the major value of total renewable water resources: 58,3 billion m^3/year. The second country is Morocco with a value of 29 billion m^3/year followed in order by Algeria with 11,67 billion m^3/year, Tunisia with 4,165 billion m^3/year, Sudan with 4 billion m^3/year and Libya with 700 million m^3/year. The high amount of renewable water resources is explained by the presence of Nile river, the cradle of many civilizations since ancient times.

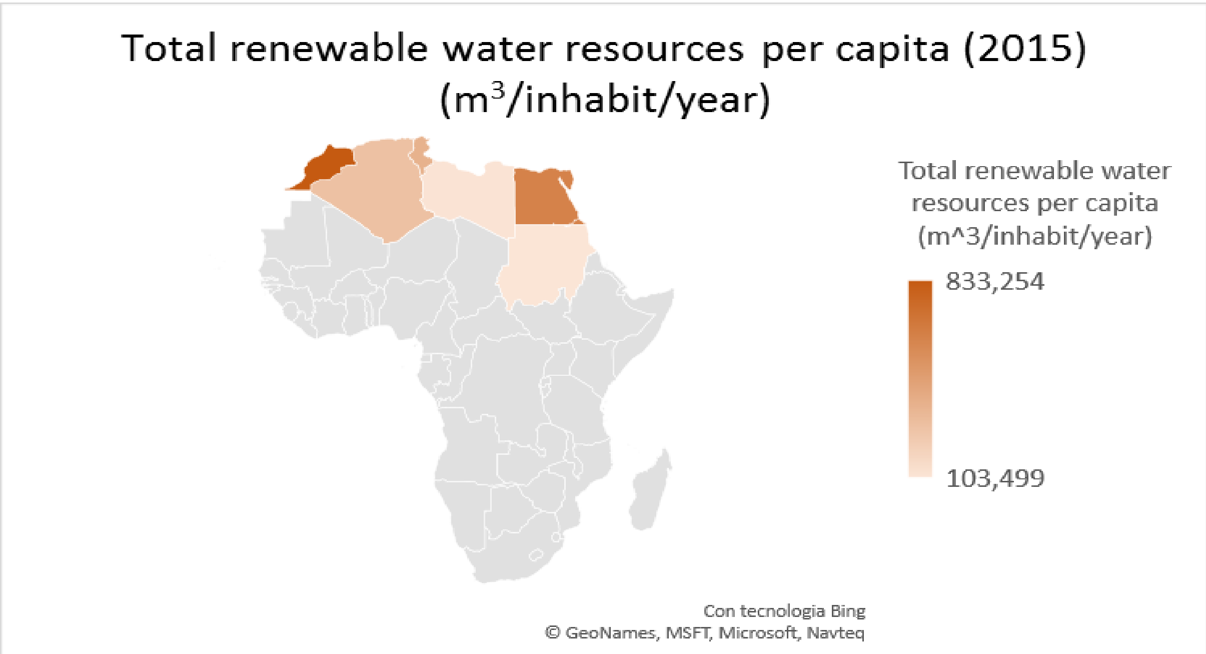

Figure 64 - Total renewable water resources per capita (2015).

Having showed the total population, in 2015, and the total renewable water resources is possible to combine data in total renewable water resources per capita in 2015.

In *Figure 64* is showed this value for all Northern – Africa countries in 2015. The attention is on Algeria, Libya, Sudan and Tunisia being under the absolute water scarcity threshold of 500 m^3/year per capita. Algeria has a total renewable water resources per capita equal to 292,69, Libya equal to 112,3 m^3/year, Sudan 103,49 m^3/year and Tunisia 372, 11 m^3/year. These data are very important because demonstrate how is important find for Northern – Africa countries a new technology to produce fresh water.

CHAPTER 3

3. Determination future water needs in Northern - Africa countries

In the CHAPTER 2 was analyzed the past and actual use of water in Northern – Africa countries for main crops of each country in order to see the see importance of water in agriculture and the impact on economies of these countries.

Now, for purpose of the study it is necessary determinate the water demand forecast for main crops in each Northern – Africa country.
First step is chosen an interval time and the choice is from 2017 to 2030 because the FAOSTAT databases for these country have data on their crops until to 2016. In Second step, it is considered as forecasting method the CAGR: compound annual growth rate. After with all available data it is possible determinate the water demand forecast for main crops in each Northern – Africa country.

3.1 CAGR method

CAGR is a term that usually used in business, but in recent studies its application is adopted to do different forecast as in a study of University of Texas at El Paso on the Electricity consumption in Seattle[53].
To apply this method it is fundamental to have some data in order of time, minimum three, identifying an ending value and a beginning value it is possible determine the CAGR with an easy formula. In order to explain the method below there is an explanation with some Excel images.
For example, it has to calculate the area harvested in 2017 and in 2018 in Algeria. Data available in FAOSTAT database are area harvested in 2012, 2013, 2014, 2015, 2016. The total area harvested in 2016 is the ending value and the total area harvested in 2012 is the beginning value, respectively D4 and E4 Excel cell in *Figure 63.* The number of years is four (F4) and the CAGR is the determinate with formula in Excel cell G4.

	A	B	C	D	E	F	G
1	ALGERIA						
2	Years	Total Area Harvested		Ending value	Beginnig Value	Number of years	CAGR
3	2012	4.576.591					
4	2013	4.892.809		3.772.220	4.576.591	4	=(D4/E4)^(1/F4)-1
5	2014	4.033.310					
6	2015	4.242.307					
7	2016	3.772.220					

Figure 65 - Example of CAGR calculation for total area harvested in Algeria with Excel.

After the determination of CAGR it is possible to obtain the forecast of total area harvested in Algeria in 2017 as showed in *Figure 64*.

	A	B	C	D	E	F	G
1	ALGERIA						
2	Years	Total Area Harvested		Ending value	Beginnig Value	Number of years	CAGR
3	2012	4.576.591					
4	2013	4.892.809		3.772.220	4.576.591	4	-4,717%
5	2014	4.033.310					
6	2015	4.242.307					
7	2016	3.772.220					
8	2017	=B7+B7*G4					

Figure 66- Example of forecast total area harvested calculation in Algeria with Excel.

In this way, it can be calculated all the total area harvested for the following years.

	A	B	C	D	E	F	G
1	ALGERIA						
2	Years	Total Area Harvested		Ending value	Beginnig Value	Number of years	CAGR
3	2012	4.576.591					
4	2013	4.892.809		3.772.220	4.576.591	4	-4,717%
5	2014	4.033.310		3.594.270	4.892.809	4	-7,421%
6	2015	4.242.307					
7	2016	3.772.220					
8	2017	3.594.270,36					
9	2018	3.327.544,41					

Figure 67 - Example of forecast total area harvested calculation in Algeria with Excel - CAGR method.

3.2 Total water demand forecast for main crops in Algeria

To analyze the water demand forecast for main crops in Algeria from 2017 to 2030, it were calculated the forecast of the following elements:

- Total area harvested (ha);
- Area harvested for main crops in Algeria (ha);
- Production for main crops in Algeria (tonnes);
- Total water withdrawal (m^3/year);
- Percentage agricultural water withdrawal respect to total water withdrawal;
- Agricultural water withdrawal per hectares (lt/ha)
- Water demand forecast for each main crop in Algeria (lt).

How showed in paragraph 3.1, in order to calculate all these elements was applied the CAGR method. The forecast for the total area harvested gave the results listed in *Table 86*:

Years	Total area harvested (ha)
2017	3.594.270,36
2018	3.448.362,42
2019	3.371.839,36
2020	3.318.416,61
2021	3.286.702,62
2022	3.265.756,46
2023	3.252.722,51
2024	3.244.282,52
2025	3.238.936,14
2026	3.235.498,68
2027	3.233.306,44
2028	3.231.900,55
2029	3.231.001,64
2030	3.230.425,69

Table 86 - Forecast total area harvested in Algeria (2017 - 2030).

In the same way were calculated area harvested and production forecast of main crops in Algeria. The main crops of Algeria are the same analyzed in *Table 12* and in *Table 15*: barley, dates, lemons and limes, oats, olives, oranges, potatoes, unmanufactured tobacco, tomatoes, fresh vegetables and leguminous.

To calculate the water demand forecast for each main crop it was adopted the same calculation described in paragraph 2.1.2, where all the value are showed in *Table 12*, *Table 13*, *Table 14* and *Table 15*.

Given total area harvested and area harvested for each main crop forecast, it is necessary to have the total water withdrawal forecast. For Algeria, in *Table 8* there is the historical of total water withdrawal in m^3/year, but to apply the CAGR are necessary an order sequence of data that miss for total water withdrawal.

In AQUASTAT database, some data, as total water withdrawal, are supposed constant for a time interval of four years, for example a data of 2001 is constant from 1998 to 2002. Making this hypothesis and with data of *Table 8* it is possible to obtain total water withdrawal forecast.

Years	Total water withdrawal (10^9 m^3/year)
1993-1997	4,9
1998-2002	5,7
2003-2007	6,8
2008-2012	8,425
2013-2017	10,09
2018-2022	11,51
2023-2027	12,78
2028-2032	13,82

Table 87 - Total water withdrawal data (1993 - 2032).

The same hypothesis was made to calculate the percentage of agriculture water withdrawal respect the total water withdrawal and for the years where percentage value miss it was made an average. With total water withdrawal and agricultural water withdrawal percentage forecast values it is easy determinate agricultural water withdrawal in m^3/year forecast.

Years	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal as % of total water withdrawal (%)	Agricultural water withdrawal (10^9 m^3/year)
2013-2017	10,09	59,65	6,02
2018-2022	11,51	59,10	6,80
2023-2027	12,78	59,06	7,55
2028-2032	13,82	58,87	8,14

Table 88 - Total water withdrawal, Agricultural water withdrawal percentage and agricultural water withdrawal water forecast in Algeria (2013 - 2032).

Having total area harvested forecast and agricultural water withdrawal it is possible calculate the agricultural water withdrawal per hectares.

Years	Total area harvested (ha)	Agricultural water withdrawal per hectares (lt/ha)
2017	5.782.429,45	1.041.111,29
2018	5.872.910,95	1.158.688,74
2019	5.948.697,56	1.143.927,01
2020	6.033.615,95	1.127.827,13
2021	6.115.610,06	1.112.705,96
2022	6.200.814,43	1.097.416,45
2023	6.286.143,21	1.200.435,37
2024	6.373.184,82	1.184.040,46
2025	6.461.158,61	1.167.918,81
2026	6.550.485,17	1.151.992,33
2027	6.640.976,53	1.136.295,04
2028	6.732.753,54	1.208.469,03
2029	6.825.780,86	1.191.999,02
2030	6.920.102,69	1.175.751,93

Table 89 - Agricultural water withdrawal per hectares forecast in Algeria (2017 - 2030).

With the agricultural water withdrawal per hectares forecast and the area harvested for each main crop in Algeria it is possible to define the water withdrawal forecast for each main crops in liters.

To simplify the water withdrawal forecast for each main crop are showed in *Figure 68* and *Figure 69*.

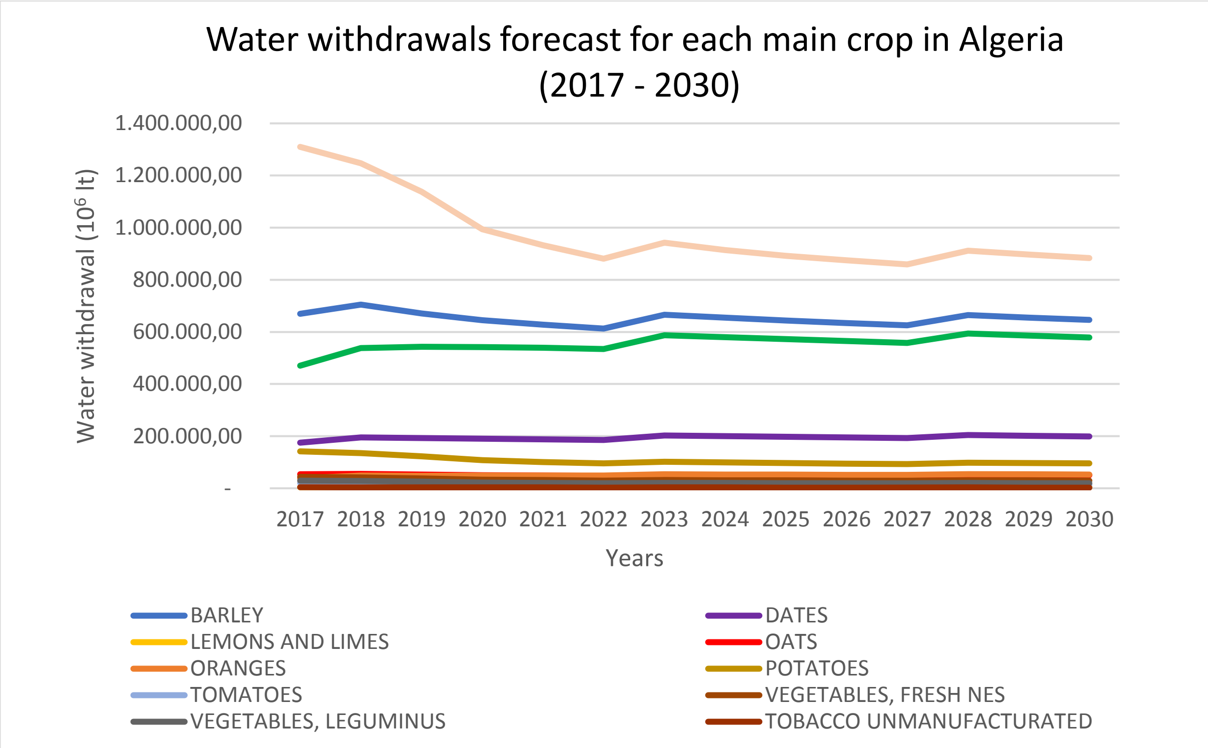

Figure 68 – Water withdrawals forecast for each main crop in Algeria (2017 - 2030).

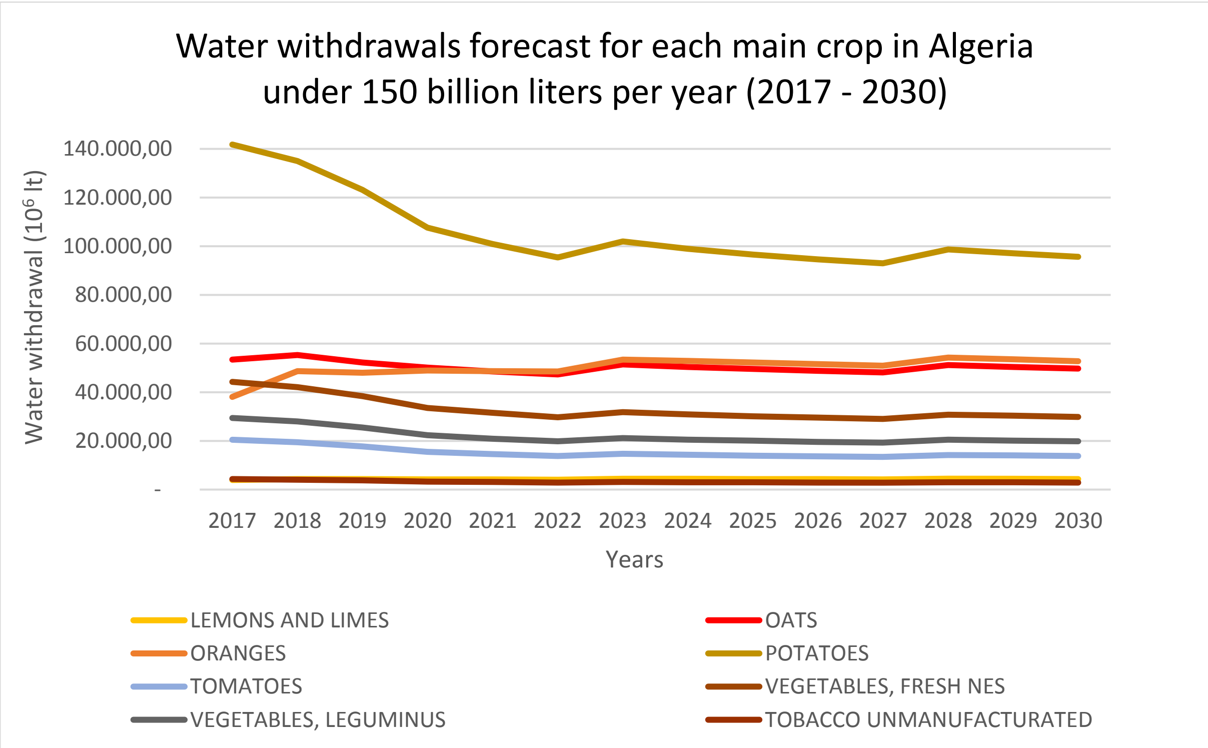

Figure 69 – Water withdrawals forecast for each main crop in Algeria under 150 billion liters per year (2017 - 2030).

With all these data it is possible obtain the total water withdrawal forecast for main crops in Algeria from 2017 to 2030.

Years	Total water withdrawal (10^6 lt)
2017	2.960.022,09
2018	3.021.080,06
2019	2.856.978,56
2020	2.656.787,30
2021	2.559.313,27
2022	2.475.406,71
2023	2.679.436,76
2024	2.623.505,23
2025	2.576.401,59
2026	2.533.878,49
2027	2.494.806,76
2028	2.650.143,60
2029	2.612.070,85
2030	2.575.229,14

Table 90 - Total water withdrawal forecast for main crops in Algeria (2017 - 2030).

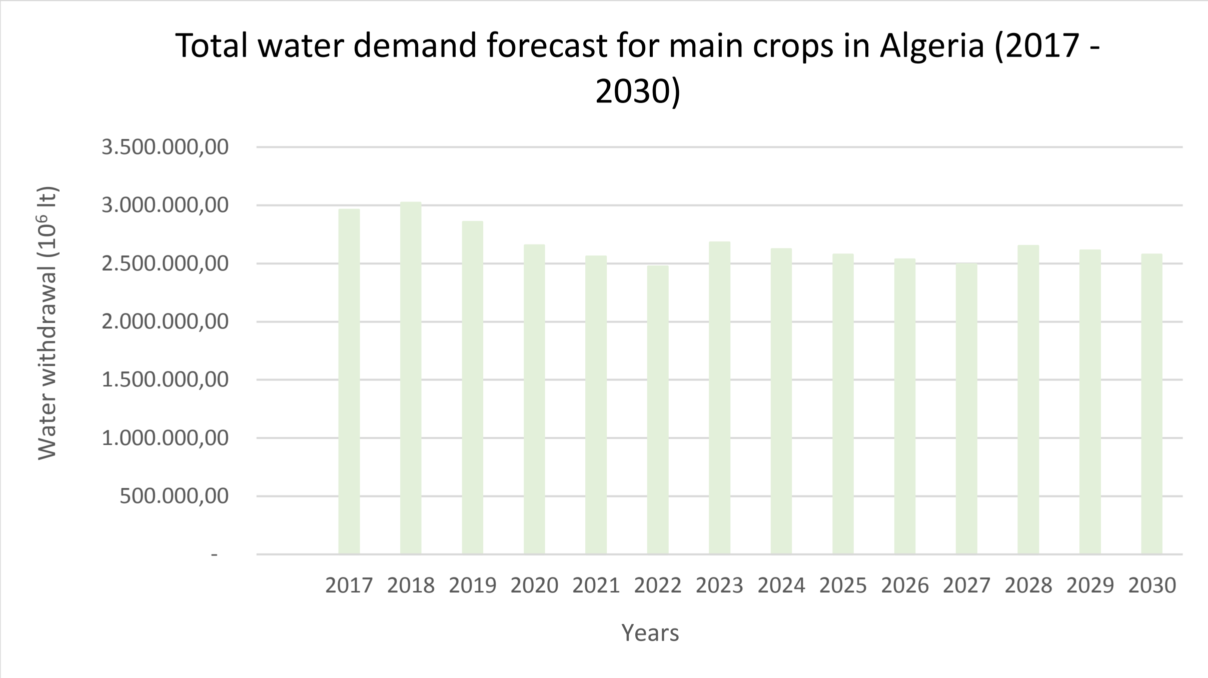

Figure 70 - Total water demand forecast for main crops in Algeria (2017 - 2030).

3.3 Total water demand forecast for main crops in Egypt

The calculations made for Algeria, in order to have the forecast of water withdrawal of main crops from 2017 to 2030, are repeated for all Northern – Africa countries. Below will be reported in tables and figures the results for Egypt.

Also for Egypt, the main crops are the same previously analyzed in *Table 26* and in *Table 29*: bananas, dates, lemons and limes, maize, olives, oranges, potatoes, rice, seed, sorghum, sugar beet, sugar cane, tomatoes, fresh vegetables and wheat.

The forecast for the total area harvested in Egypt is listed in *Table 91*:

Years	Total area harvested (ha)
2017	5.782.429,448
2018	5.872.910,95
2019	5.948.697,561
2020	6.033.615,945
2021	6.115.610,059

2022	6.200.814,433
2023	6.286.143,209
2024	6.373.184,819
2025	6.461.158,607
2026	6.550.485,17
2027	6.640.976,526
2028	6.732.753,536
2029	6.825.780,858
2030	6.920.102,689

Table 91 - Forecast total area harvested in Egypt (2017 - 2030).

In the same way were calculated area harvested and production forecast of main crops in Egypt. Making the same hypothesis of Algeria case and with data of *Table 22* it is possible to obtain the forecast of: total water withdrawal forecast, the percentage of agriculture water withdrawal respect the total water withdrawal and agricultural water withdrawal in m^3/year.

Years	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal as % of total water withdrawal (%)	Agricultural water withdrawal (10^9 m^3/year)
2013-2017	85,67	85,82	73,52
2018-2022	90,78	85,76	77,85
2023-2027	95,49	85,71	81,85
2028-2032	99,01	85,68	84,83

Table 92 - Total water withdrawal, Agricultural water withdrawal percentage and agricultural water withdrawal water forecast in Egypt (2013 - 2032).

Having total area harvested forecast and agricultural water withdrawal it is possible calculate the agricultural water withdrawal per hectares.

Years	Total area harvested (ha)	Agricultural water withdrawal per hectares (lt/ha)
2017	5.782.429,448	12.714.727,15
2018	5.872.910,95	13.256.415,83

2019	5.948.697,561	13.087.528,63
2020	6.033.615,945	12.903.331,99
2021	6.115.610,059	12.730.332,53
2022	6.200.814,433	12.555.407,12
2023	6.286.143,209	13.020.445,76
2024	6.373.184,819	12.842.619,35
2025	6.461.158,607	12.667.756,93
2026	6.550.485,17	12.495.011,37
2027	6.640.976,526	12.324.751,69
2028	6.732.753,536	12.599.355,17
2029	6.825.780,858	12.427.640,86
2030	6.920.102,689	12.258.250,62

Table 93 - Agricultural water withdrawal per hectares forecast in Egypt (2017 - 2030).

With the agricultural water withdrawal per hectares forecast and the area harvested for each main crop in Egypt it is possible to define the water withdrawal forecast for each main crops in liters.

To simplify the water withdrawal forecast for each main crop are showed in *Figure 71* and *Figure 72*.

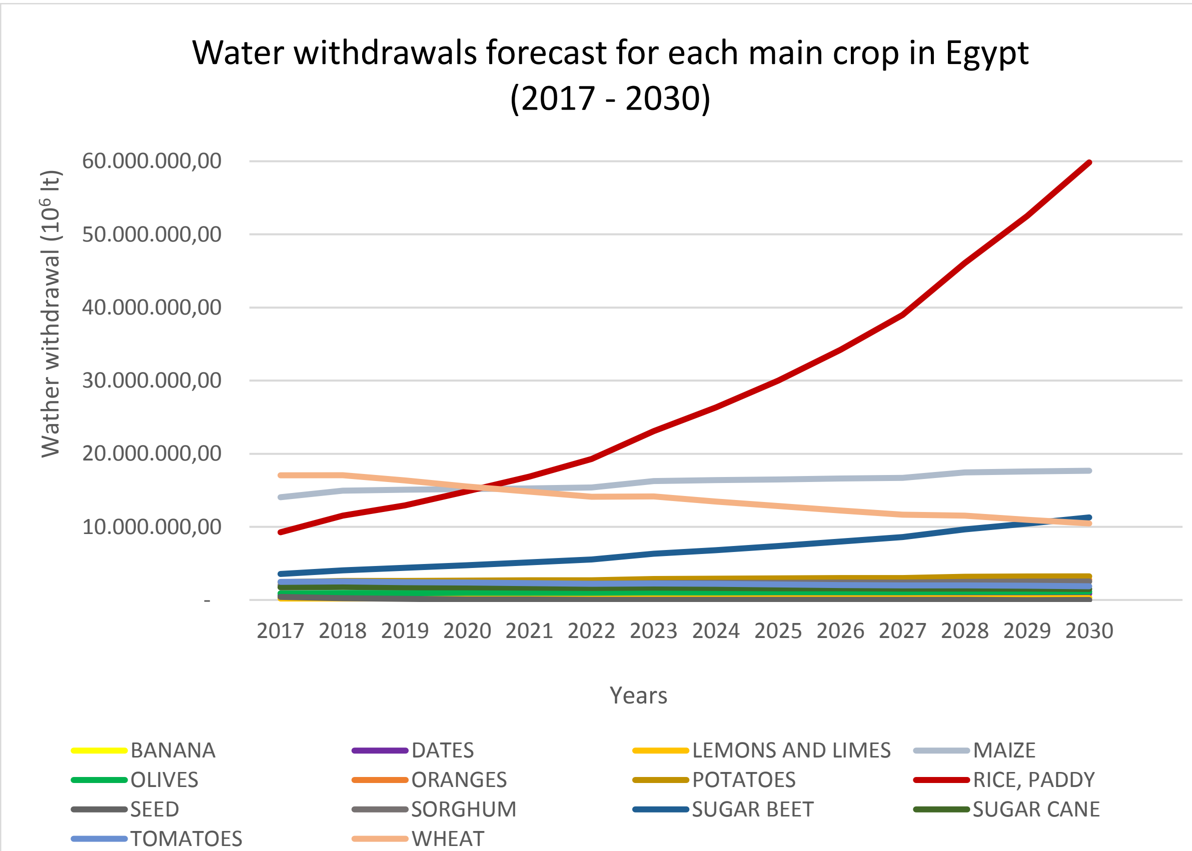

Figure 71 – Water withdrawals forecast for each main crop in Egypt (2017 - 2030).

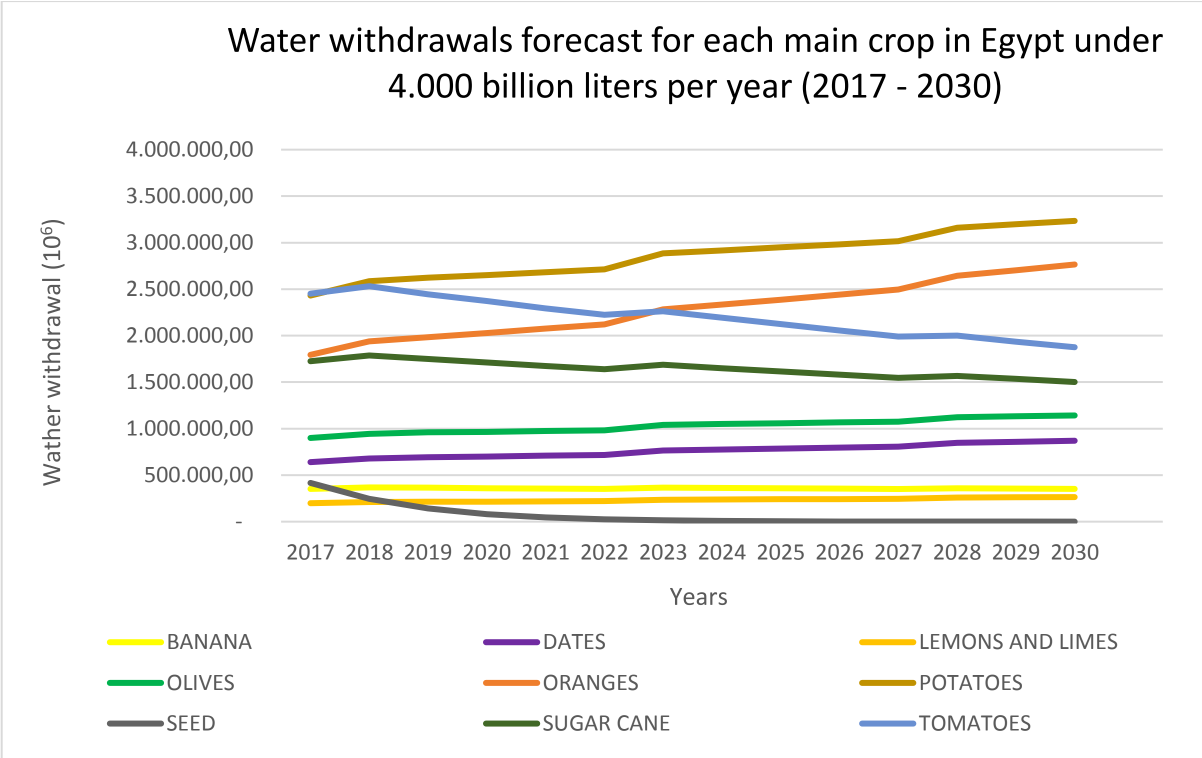

Figure 72 – Water withdrawals forecast for each main crop in Egypt under 4.000 billion liters per year (2017 - 2030).

With all these data it is possible obtain the total water withdrawal forecast for main crops in Egypt from 2017 to 2030.

Years	Total water withdrawal (10^6 lt)
2017	56.833.756,6
2018	61.024.177,3
2019	62.055.738,8
2020	63.547.547,5
2021	65.308.032,2
2022	67.498.669,0
2023	73.661.787,9
2024	76.861.996,3
2025	80.582.153,3
2026	84.907.381,3
2027	89.898.554,4
2028	99.129.891,6
2029	105.968.869,8
2030	113.805.237,4

Table 94 - Total water withdrawal forecast for main crops in Egypt (2017 - 2030).

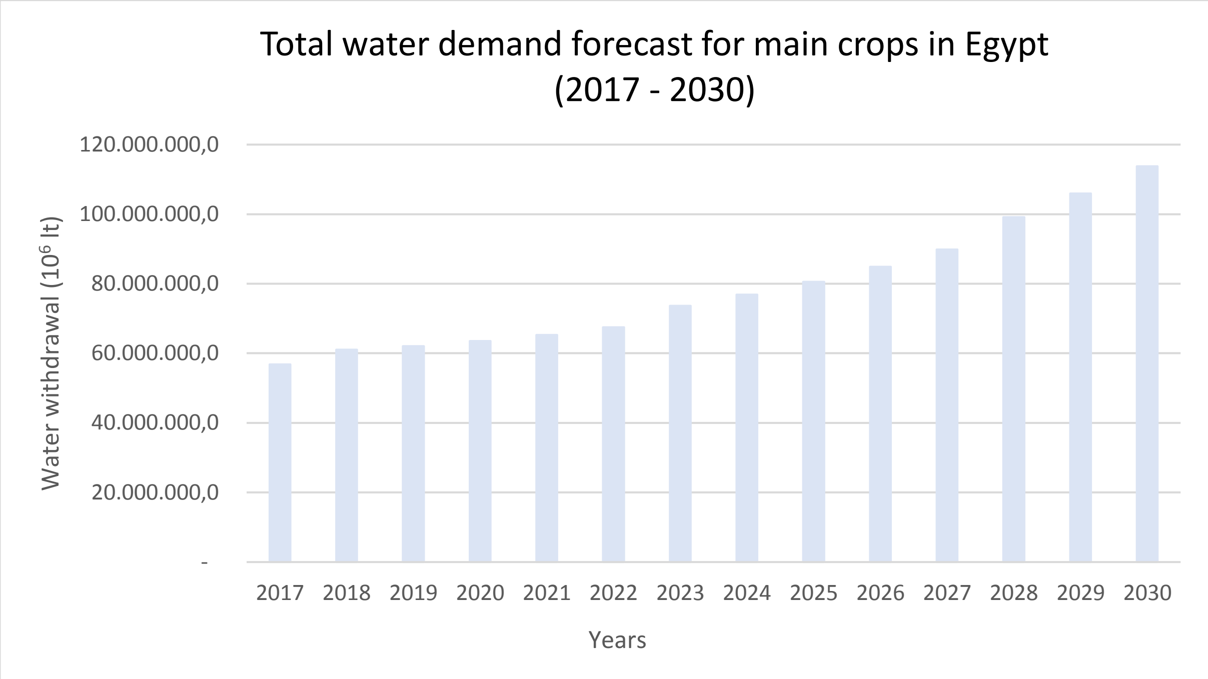

Figure 73 - Total water demand forecast for main crops in Egypt (2017 - 2030).

3.4 Total water demand forecast for main crops in Libya

In Libya the main crops, the same previously analyzed in *Table 40* and in *Table 43*, are: almonds, barley, dates, lemons and limes, olives, onions, oranges, potatoes, tobacco, tomatoes, watermelons and wheat.

The forecast for the total area harvested in Libya is listed in *Table 995*:

Years	Total area harvested (ha)
2017	858.695,350
2018	855.285,119
2019	852.724,420
2020	851.238,186
2021	850.229,448
2022	849.606,846
2023	849.199,500
2024	848.942,208
2025	848.776,130

2026	848.670,320
2027	848.602,362
2028	858.695,350
2029	855.285,119
2030	852.724,420

Table 95 - Forecast total area harvested in Libya (2017 - 2030).

In the same way were calculated area harvested and production forecast of main crops in Libya. Making the same hypothesis of Algeria case and with data of *Table 35* it is possible to obtain the forecast of: total water withdrawal forecast, the percentage of agriculture water withdrawal respect the total water withdrawal and agricultural water withdrawal in m^3/year.

Years	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal as % of total water withdrawal (%)	Agricultural water withdrawal (10^9 m^3/year)
2013-2017	6,31	81,97	5,17
2018-2022	7,15	80,77	5,78
2023-2027	8,13	80,48	6,55
2028-2032	9,09	79,79	7,25

Table 96 - Total water withdrawal, Agricultural water withdrawal percentage and agricultural water withdrawal water forecast in Libya (2013 - 2032).

Having total area harvested forecast and agricultural water withdrawal it is possible calculate the agricultural water withdrawal per hectares.

Years	Total area harvested (ha)	Agricultural water withdrawal per hectares (lt/ha)
2017	858.695,350	5.786.083,09
2018	855.285,119	6.623.501,34
2019	852.724,420	6.676.052,47
2020	851.238,186	6.729.772,90
2021	850.229,448	6.756.606,15
2022	849.606,846	6.776.895,99

2023	849.199,500	7.690.647,02
2024	848.942,208	7.699.771,44
2025	848.776,130	7.705.413,92
2026	848.670,320	7.709.110,07
2027	848.602,362	7.711.446,50
2028	858.695,350	8.544.788,66
2029	855.285,119	8.545.854,00
2030	852.724,420	8.546.538,37

Table 97 - Agricultural water withdrawal per hectares forecast in Libya (2017 - 2030).

With the agricultural water withdrawal per hectares forecast and the area harvested for each main crop in Libya it is possible to define the water withdrawal forecast for each main crops in liters.

To simplify the water withdrawal forecast for each main crop are showed in *Figure 74* and *Figure 75*.

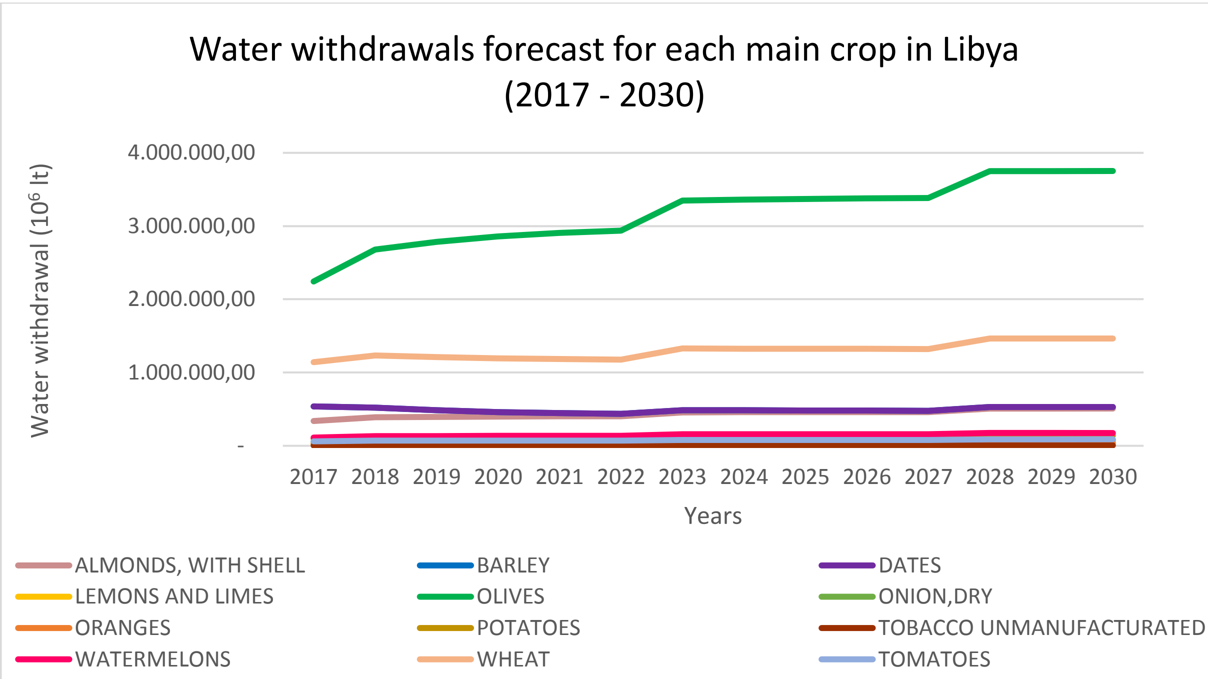

Figure 74 – Water withdrawals forecast for each main crop in Libya (2017 - 2030).

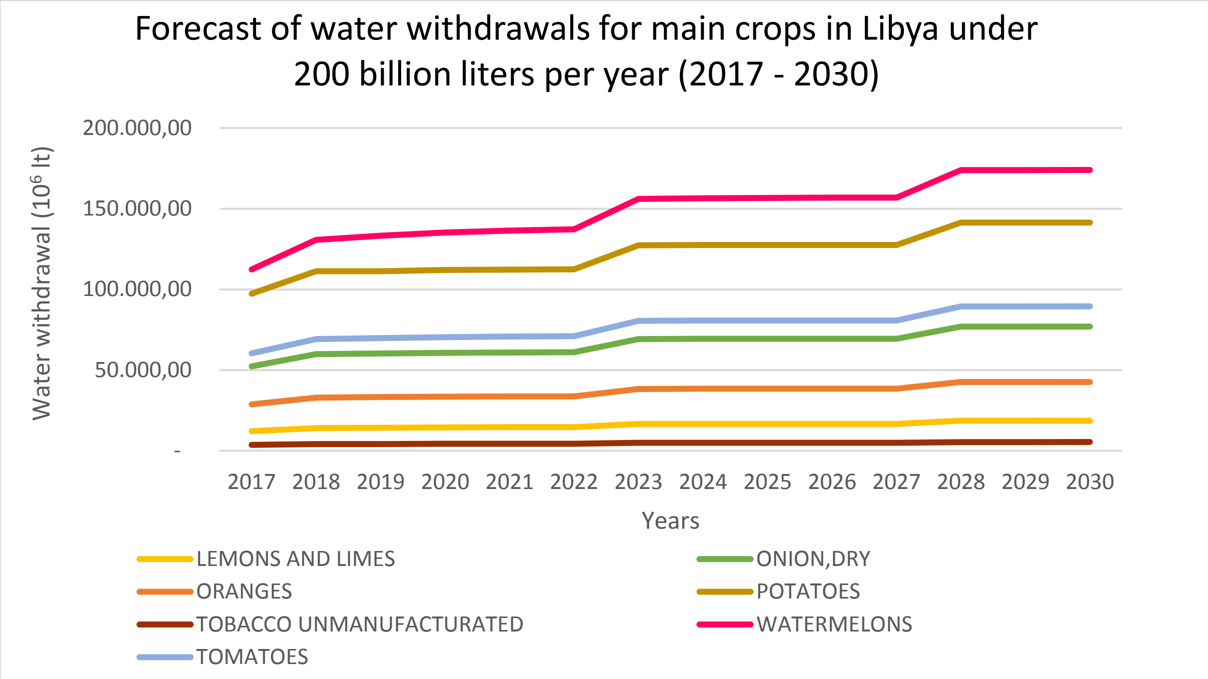

Figure 75 - Forecast of water withdrawals for main crops in Egypt under 200 billion liters per year (2017 - 2030).

With all these data it is possible obtain the total water withdrawal forecast for main crops in Libya from 2017 to 2030.

Years	Total water withdrawal (10^6 lt)
2017	5.876.588,31
2018	6.761.603,39
2019	6.834.125,08
2020	6.887.953,77
2021	6.923.587,39
2022	6.947.744,80
2023	7.916.644,13
2024	7.928.292,75
2025	7.935.787,16
2026	7.940.628,88
2027	7.943.735,70
2028	8.878.741,15
2029	8.880.171,09
2030	8.881.088,08

Table 98 - Total water withdrawal forecast for main crops in Libya (2017 - 2030).

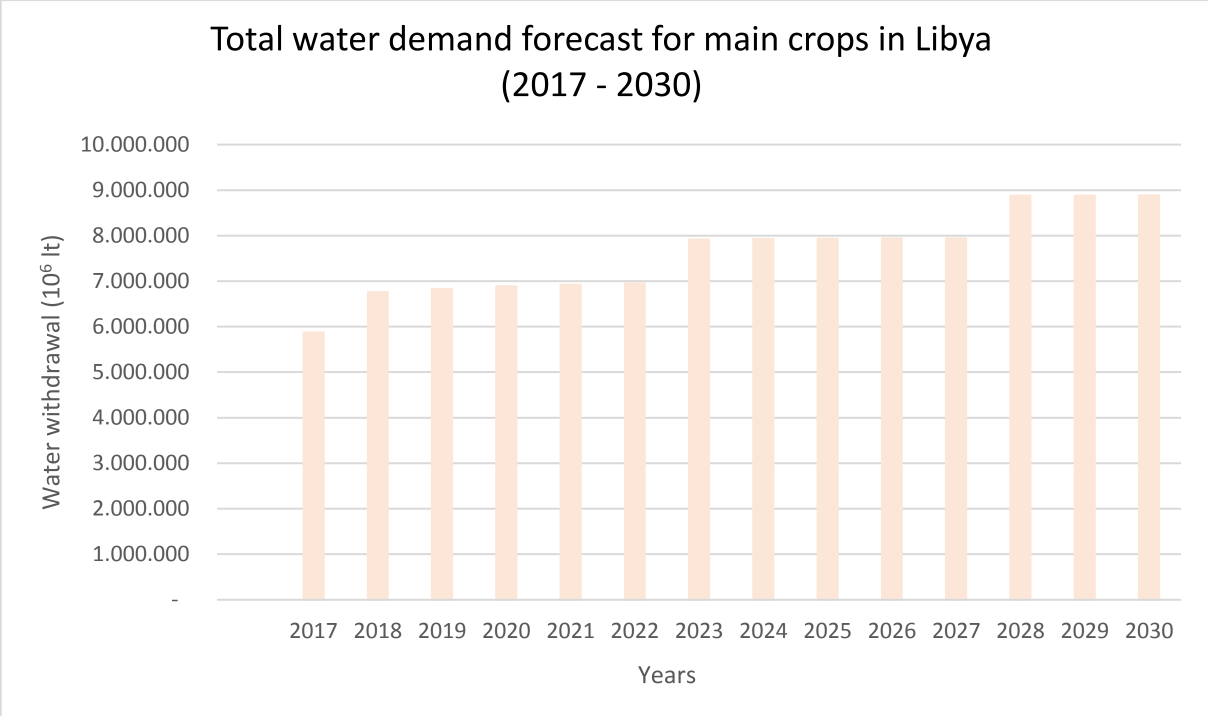

Figure 76 - Total water demand forecast for main crops in Libya (2017 - 2030).

3.5 Total water demand forecast for main crops in Morocco

In Morocco the main crops, the same previously analyzed in *Table 54* and in *Table 57*, are: almonds, barley, green beans, chick peas, dates, maize, olives, oranges, potatoes, sugar beet, tangerines, clementines, tomatoes and wheat.

The forecast for the total area harvested in Libya is listed in *Table 99*:

Years	Total area harvested (ha)
2017	5.764.592,118
2018	5.327.690,374
2019	5.154.087,862
2020	5.011.844,943
2021	4.935.853,813
2022	4.882.754,694
2023	4.851.005,044
2024	4.830.021,741

2025	4.816.927,730
2026	4.808.445,871
2027	4.803.066,980
2028	4.799.608,029
2029	4.797.401,108
2030	4.797.401,108

Table 99 - Forecast total area harvested in Morocco (2017 - 2030).

In the same way were calculated area harvested and production forecast of main crops in Morocco.

Making the same hypothesis of Algeria case and with data of *Table 50* it is possible to obtain the forecast of: total water withdrawal forecast. In Morocco case is not possible to apply the CAGR method to the percentage of agriculture water withdrawal respect the total water withdrawal because the result are unrealistic. For this reason the value of the percentage of agriculture water withdrawal respect the total water withdrawal it will assumed constant and equal to the last value registered in AQUASTAT database. With all these data it is possible calculate also the agricultural water withdrawal in m^3/year.

Years	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal as % of total water withdrawal (%)	Agricultural water withdrawal (10^9 m^3/year)
2013-2017	10,17	89,31	5,17
2018-2022	8,97	89,31	5,78
2023-2027	7,90	89,31	7,06
2028-2032	7,20	89,31	6,43

Table 100 - Total water withdrawal, Agricultural water withdrawal percentage and agricultural water withdrawal water forecast in Morocco (2013 - 2032).

Having total area harvested forecast and agricultural water withdrawal it is possible calculate the agricultural water withdrawal per hectares.

Years	Total area harvested (ha)	Agricultural water withdrawal per hectares (lt/ha)
2017	5.764.592,118	1.575.173,70
2018	5.327.690,374	1.503.180,72

2019	5.154.087,862	1.553.811,59
2020	5.011.844,943	1.597.910,86
2021	4.935.853,813	1.622.511,88
2022	4.882.754,694	1.640.156,42
2023	4.851.005,044	1.454.938,75
2024	4.830.021,741	1.461.259,51
2025	4.816.927,730	1.465.231,70
2026	4.808.445,871	1.467.816,30
2027	4.803.066,980	1.469.460,09
2028	4.799.608,029	1.340.606,58
2029	4.797.401,108	1.341.223,29
2030	4.797.401,108	1.341.223,29

Table 101 - Agricultural water withdrawal per hectares forecast in Morocco (2017 - 2030).

With the agricultural water withdrawal per hectares forecast and the area harvested for each main crop in Morocco it is possible to define the water withdrawal forecast for each main crops in liters.

To simplify the water withdrawal forecast for each main crop are showed in *Figure 77*.

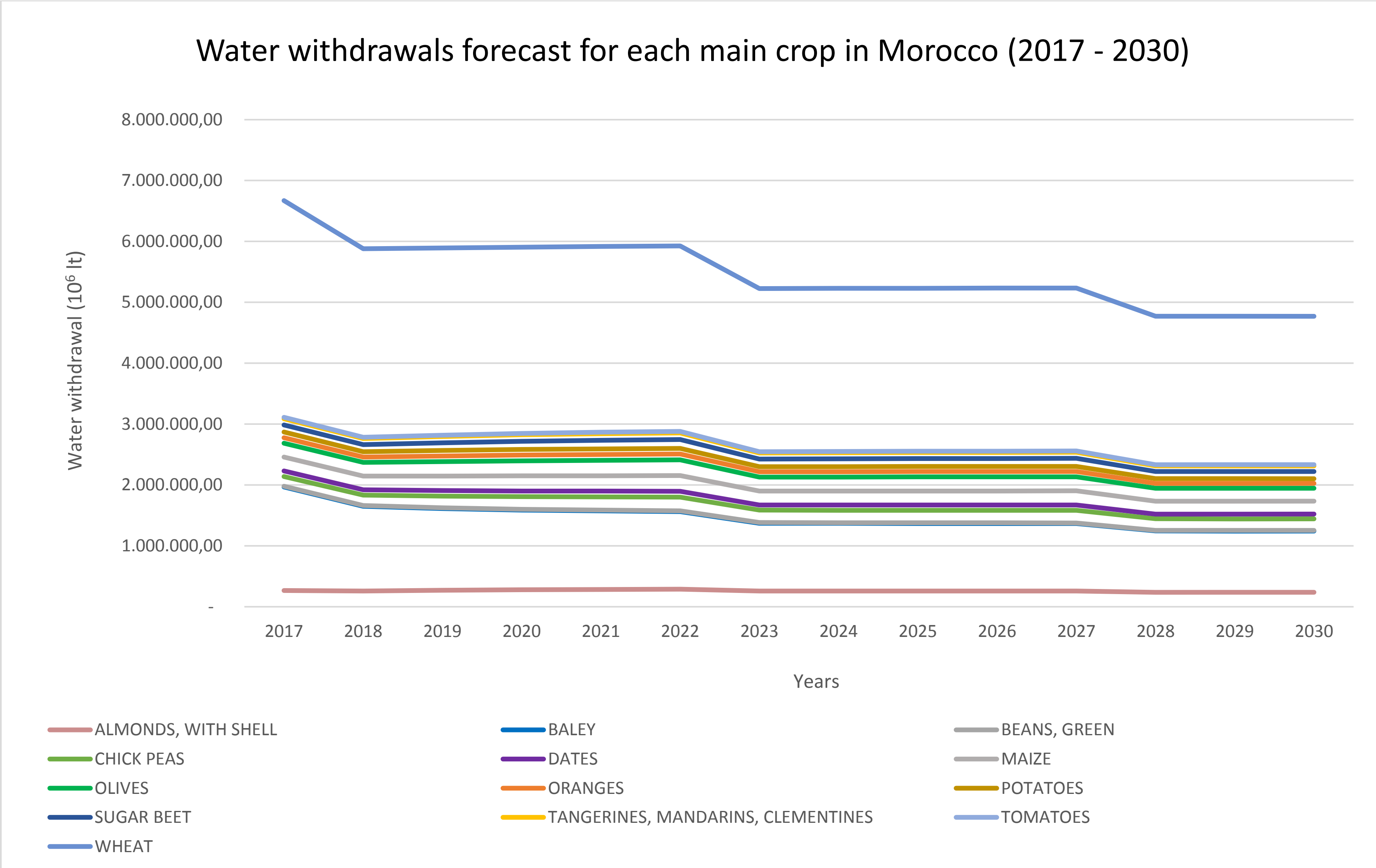

Figure 77 - Water withdrawals forecast for each main crop in Morocco (2017 - 2030).

With all these data it is possible obtain the total water withdrawal forecast for main crops in Morocco from 2017 to 2030.

Years	Total water withdrawal (10^6 lt)
2017	9.010.921,344
2018	8.051.867,996
2019	8.118.222,277
2020	8.174.860,182
2021	8.210.372,766
2022	8.235.714,611
2023	7.272.365,584
2024	7.281.837,112
2025	7287.888,757
2026	7.291826,92
2027	7.294.347,705
2028	6.651.411,917
2029	6.652.360,259
2030	6.651.006,158

Table 102 - Total water withdrawal forecast for main crops in Morocco (2017 - 2030).

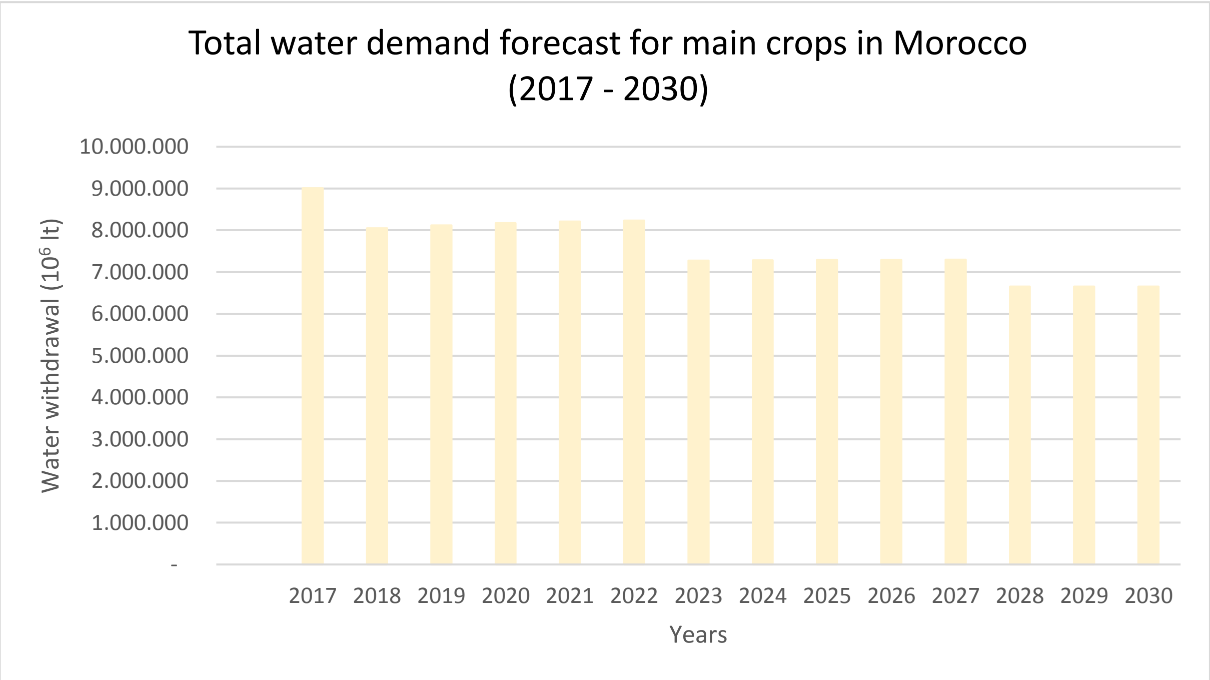

Figure 78 - Total water demand forecast for main crops in Morocco(2017 - 2030).

3.6 Total water demand forecast for main crops in Sudan

In Sudan the main crops, the same previously analyzed in *Table 68* and in *Table 71*, are: fresh fruit, groundnut, millet, onions, pulses, sesame seed, sorghum, sugar cane, fresh vegetables and wheat.

The forecast for the total area harvested in Sudan is listed in *Table 103*:

Years	Total area harvested (ha)
2017	22.385.006,57
2018	24.346.315,47
2019	26.174.044,46
2020	31.771.411,54
2021	36.163.526,57
2022	40.770.793,34
2023	46.379.722,04
2024	53.510.926,19
2025	60.959.859,51
2026	69.460.395,70
2027	79.356.823,54
2028	90.760.798,76
2029	103.576.747,60
2030	118.254.274,42

Table 103 - Forecast total area harvested in Sudan (2017 - 2030).

In the same way were calculated area harvested and production forecast of main crops in Sudan. In Sudan case is not possible to apply the CAGR method and to estimate a forecast for: the total water withdrawal, agricultural water percentage and agricultural water withdrawal in m^3/year. The problem is the lack of data in AQUASTAT database for Sudan before 2011. In order to continue the study on Sudan and its water needs, it is possible to an hypothesis: consider constant the last values of total water withdrawal, agricultural water withdrawal percentage and agricultural water withdrawal in m^3/year. These values was showed in *Table 64* yet.

Years	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal as % of total water withdrawal (%)	Agricultural water withdrawal (10^9 m^3/year)
2013 - 2032	26,96	96,21	25,94

Table 104 - Total water withdrawal, Agricultural water withdrawal percentage and agricultural water withdrawal water forecast in Sudan (2013 - 2032).

Having total area harvested forecast and agricultural water withdrawal it is possible calculate the agricultural water withdrawal per hectares.

Years	Total area harvested (ha)	Agricultural water withdrawal per hectares (lt/ha)
2017	22.385.006,57	1.158.811,36
2018	24.346.315,47	1.065.458,96
2019	26.174.044,46	991.058,15
2020	31.771.411,54	816.457,27
2021	36.163.526,57	717.297,30
2022	40.770.793,34	636.239,77
2023	46.379.722,04	559.296,15
2024	53.510.926,19	484.760,81
2025	60.959.859,51	425.525,92
2026	69.460.395,70	373.450,22
2027	79.356.823,54	326.878,00
2028	90.760.798,76	285.806,21
2029	103.576.747,60	250.442,31
2030	118.254.274,42	219.357,82

Table 105 - Agricultural water withdrawal per hectares forecast in Sudan (2017 - 2030).

With the agricultural water withdrawal per hectares forecast and the area harvested for each main crop in Sudan it is possible to define the water withdrawal forecast for each main crops in liters.

To simplify the water withdrawal forecast for each main crop are showed in *Figure 79*.

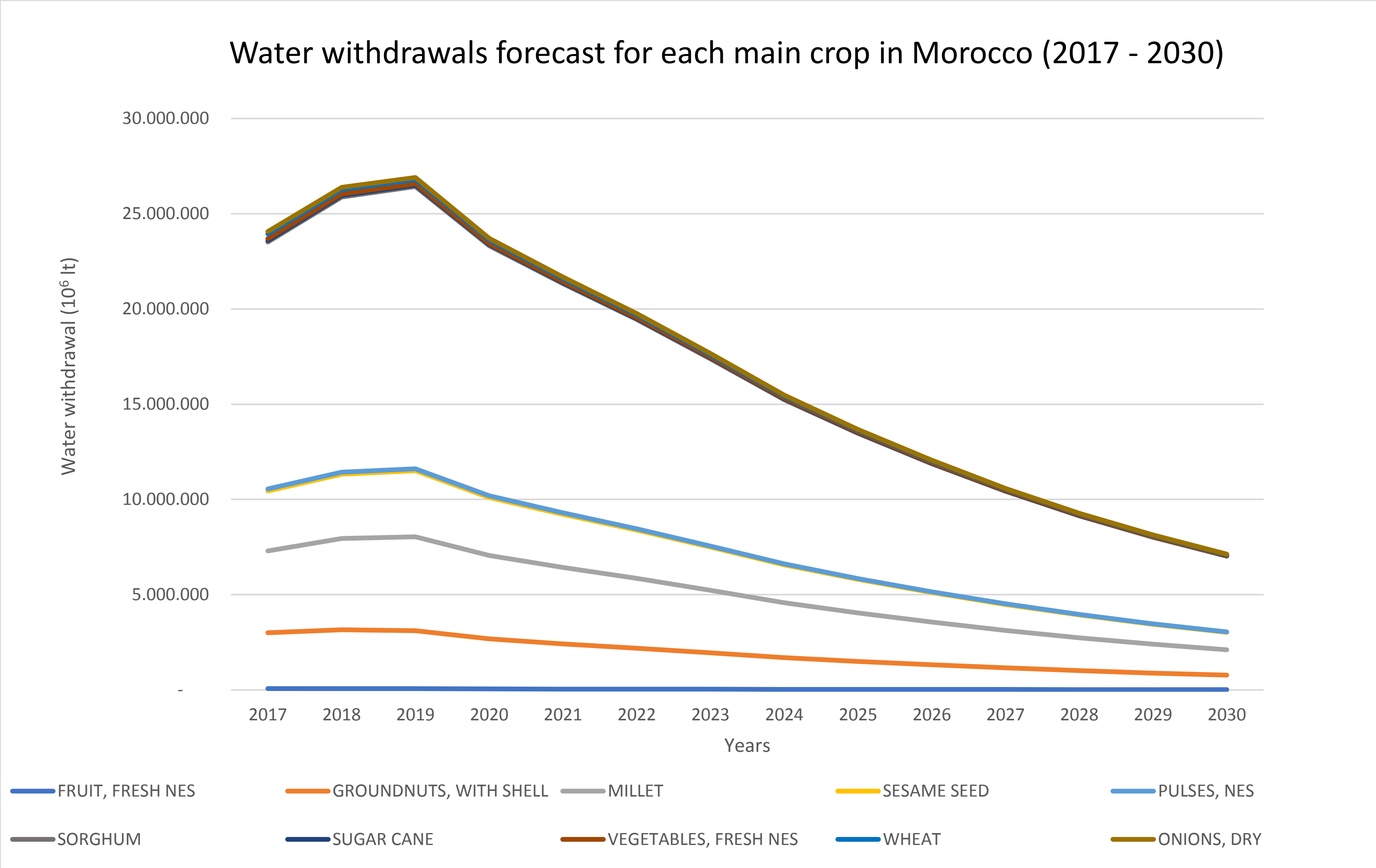

Figure 79 - Water withdrawals forecast for each main crop in Sudan (2017 - 2030).

With all these data it is possible obtain the total water withdrawal forecast for main crops in Sudan from 2017 to 2030.

Years	Total water withdrawal (10^6 lt)
2017	24.060.148,44
2018	26.383.631,62
2019	26.904.494,35
2020	23.710.354,54
2021	21.680.269,72
2022	19.754.730,43
2023	17.658.881,84
2024	15.473.616,56
2025	13.677.144,93
2026	12.057.015,72
2027	10.583.486,68
2028	9.270.608,75
2029	8.133.017,53
2030	7.128.897,69

Table 106 - Total water withdrawal forecast for main crops in Sudan (2017 - 2030).

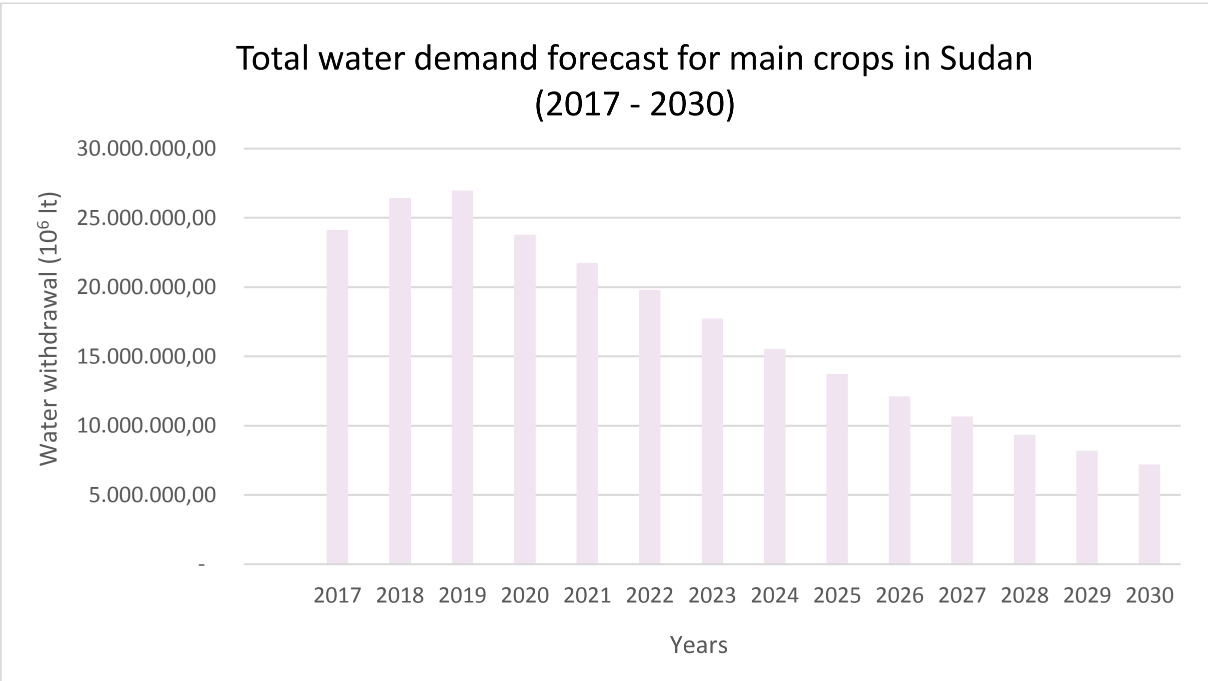

Figure 80 - Total water demand forecast for main crops in Sudan (2017 - 2030).

3.7 Total water demand forecast for main crops in Tunisia

In Tunisia the main crops, the same previously analyzed in *Table 83* and in *Table 86*, are: almonds, apples, barley, cereals, dates, grapes, olives, pistachios, potatoes, pulses, tomatoes and wheat.

The forecast for the total area harvested in Sudan is listed in *Table 107*:

Years	Total area harvested (ha)
2017	3.099.039,294
2018	2.991.755,865
2019	2.930.376,254
2020	2.889.664,764
2021	2.864.691,042
2022	2.848.501,096
2023	2.838.302,130
2024	2.831.742,973
2025	2.827.568,869
2026	2.824.891,902
2027	2.823.181,726
2028	2.822.086,004
2029	2.821.384,965
2030	2.821.384,965

Table 107 - Forecast total area harvested in Tunisia (2017 - 2030).

In the same way were calculated area harvested and production forecast of main crops in Tunisia.

Making the same hypothesis of Algeria case and with data of *Table 79* it is possible to obtain the forecast of: total water withdrawal forecast, the percentage of agriculture water withdrawal respect the total water withdrawal and agricultural water withdrawal in m^3/year.

Years	Total water withdrawal(10^9 m^3/year)	Agricultural water withdrawal as % of total water withdrawal (%)	Agricultural water withdrawal (10^9 m^3/year)
2013-2017	3,46	78,21	2,71
2018-2022	3,63	78,29	2,84
2023-2027	3,75	77,73	2,91
2028-2032	3,85	77,57	2,99

Table 108 - Total water withdrawal, Agricultural water withdrawal percentage and agricultural water withdrawal water forecast in Sudan (2013 - 2032).

Having total area harvested forecast and agricultural water withdrawal it is possible calculate the agricultural water withdrawal per hectares.

Years	Total area harvested (ha)	Agricultural water withdrawal per hectares (lt/ha)
2017	3.099.039,294	950.428,50
2018	2.991.755,865	970.336,16
2019	2.930.376,254	984.006,89
2020	2.889.664,764	992.585,24
2021	2.864.691,042	998.226,77
2022	2.848.501,096	1.026.914,31
2023	2.838.302,130	1.029.292,95
2024	2.831.742,973	1.030.812,41
2025	2.827.568,869	1.031.789,24
2026	2.824.891,902	1.032.414,26
2027	2.823.181,726	1.058.441,24
2028	2.822.086,004	1.058.704,23
2029	2.821.384,965	1.058.704,23
2030	2.821.384,965	950.428,50

Table 109 - Agricultural water withdrawal per hectares forecast in Tunisia (2017 - 2030).

With the agricultural water withdrawal per hectares forecast and the area harvested for each main crop in Tunisia it is possible to define the water withdrawal forecast for each main crops in liters.

To simplify the water withdrawal forecast for each main crop are showed in *Figure 81* and *Figure 82*.

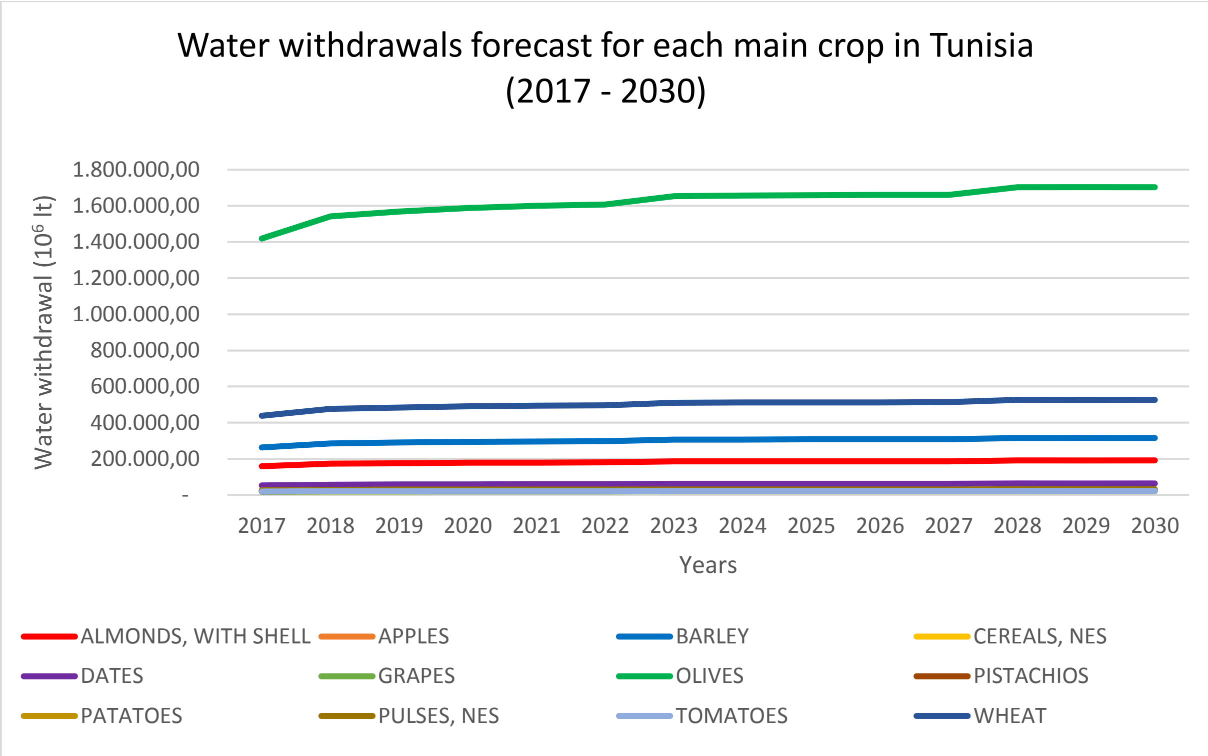

Figure 81 - Water withdrawals forecast for each main crop in Tunisia (2017 - 2030).

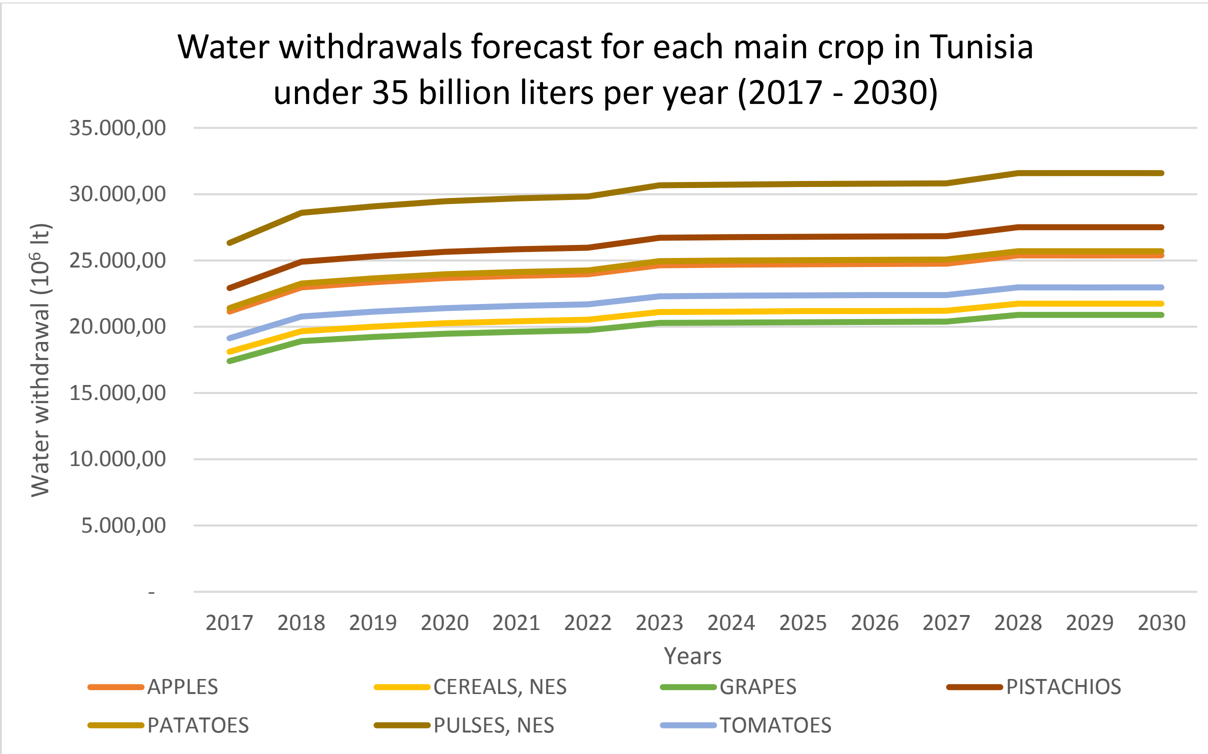

Figure 82 - Water withdrawal forecast for each main crop in Tunisia under 35 billion liters per year (2017 - 2030).

With all these data it is possible obtain the total water withdrawal forecast for main crops in Tunisia from 2017 to 2030.

Years	Total water withdrawal (10^6 lt)
2017	2.478.695,38
2018	2.692.447,94
2019	2.738.693,25
2020	2.773.812,68
2021	2.794.535,20
2022	2.808.672,69
2023	2.888.047,67
2024	2.893.951,47
2025	2.897.690,30
2026	2.900.105,98
2027	2.901.646,65
2028	2.974.656,57
2029	2.975.305,27
2030	2.975.247,64

Table 110 - Total water withdrawal forecast for main crops in Tunisia (2017 - 2030).

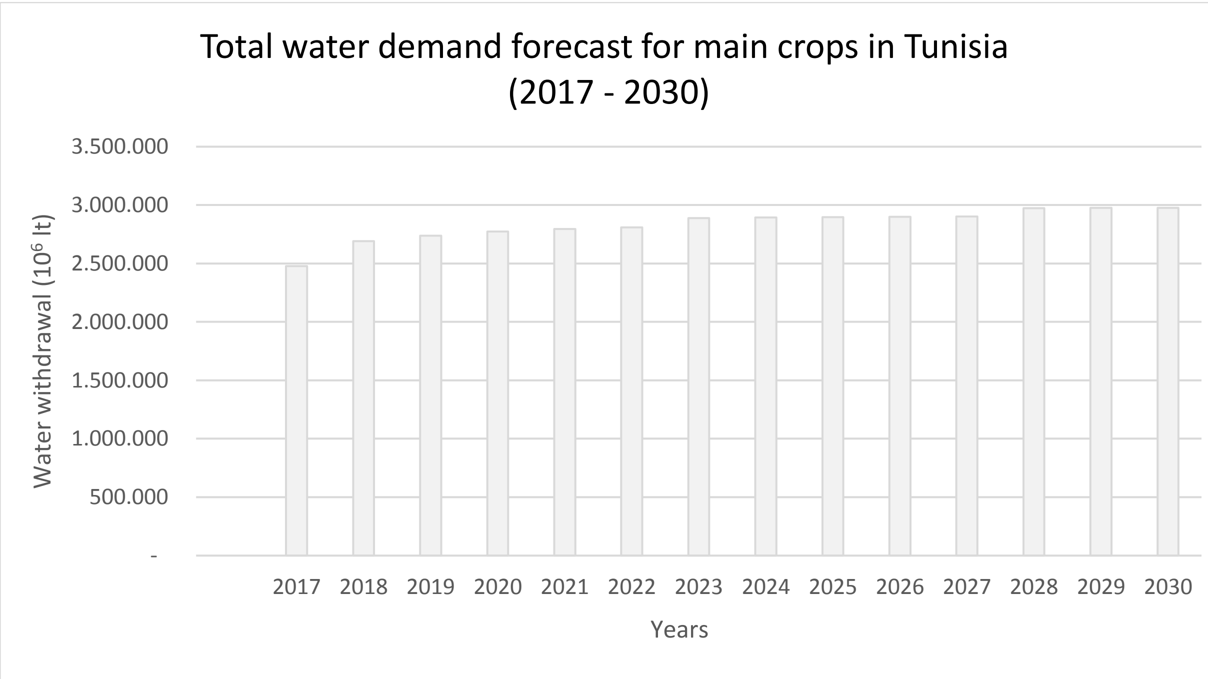

Figure 83 - Total water demand forecast for main crops in Tunisia (2017 - 2030).

3.8 Comparison of total water demand forecasts for main crops in each Northern – Africa countries

Having analyzed the total water demand forecast for main crops in Northern – Africa countries, it is possible to do a comparison between results.

The forecast from 2017 to 2030 is obtained by CAGR method with a calculation based on data from 2012 to 2016. With this method, data of time interval 2012 – 2016 influence the forecast trend.

In *Figure 84*, there are the forecast trends of the six countries:

- Egypt is the Northern – Africa country with the major availability of water, but in the future it will be necessary an even increasing quantity of water to satisfy the agriculture needs until about 113. 000 billion of liters in 2030;

- for Sudan data available are very few and this is a problem to realize a realistic forecast, but with the hypothesis made in the previous paragraphs it is possible obtain a forecast that shows how the water demand for agriculture will decrease;

- Morocco shows a decreasing trend, losing an agricultural water withdrawal of 2,5 billion liters from 2017 to 2030;

- Libya will increase the agricultural water withdrawal of 3 billion liters from 2017 to 2030;

- Algeria and Tunisia have a similar values, but the first decreases slightly while the second increases;

- the trend and values of agricultural water demand forecast for main crops in Egypt are very different from the other five countries, this suggests that the application of a new technology to produce fresh – water can change the trends of forecast for agricultural water needs for these countries, so the production and the economy.

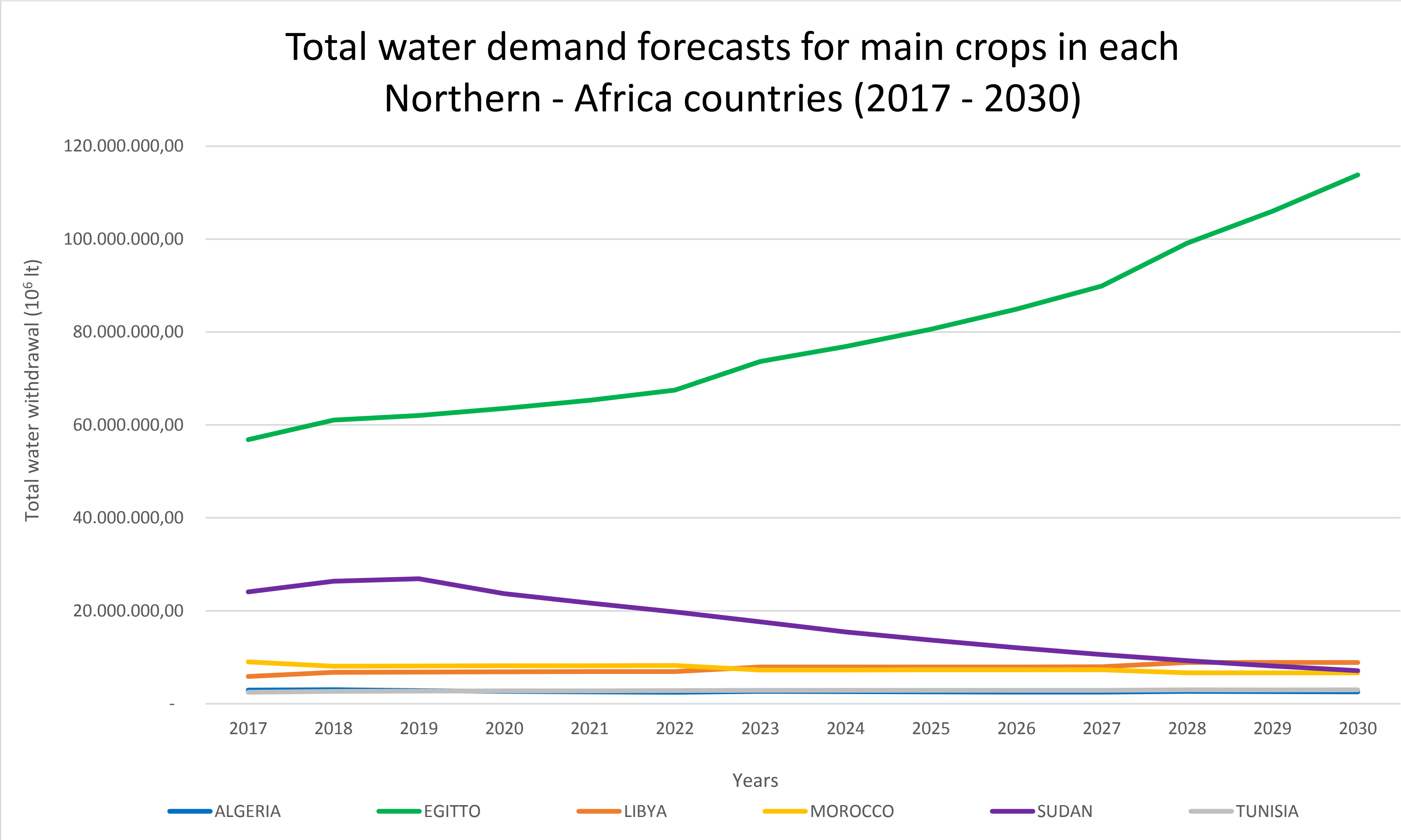

Figure 84 - Total water demand forecasts for main crops in each Northern - Africa countries (2017 - 2030).

CHAPTER 4

4. Feasibility study of atmospheric water harvesting technology

In order to make a feasibility study of atmospheric water harvesting technology in the six Northern – Africa countries, previously analyzed, was used Trnsys. Trnsys is a simulation program used to analyze the behavior of transient systems.

In this case, Trsnsys was used: in a first phase, to collect all weather data for the World area studied, and in a second phase to simulate the behavior of solar system hypothetically installed in defined cities of Northern – Africa.

For the first phase, weather data in Trnsys library are available for locations listed in *Table 111*.

Location	Lat [°N]	Lon [°E]	Elev [m]
ALGERIA (DZ)			
Béchar	31.62	-2.23	772
Darel Beida	36.72	3.25	25
Tamanrasset	22.78	5.52	1377
EGYPT (EG)			
Aswan	23.97	32.78	192
Asyut	27.05	31.02	69
Bahtim	30.15	31.25	17
El Arish	31.12	33.75	17
El Kharga	25.45	30.53	78
Giza	30.05	31.22	21
Mersa Matruh	31.33	27.22	38
Sidi-Barrani	31.63	25.40	27
LIBYA (LY)			
Kufra	24.22	23.30	435
Sebha	27.02	14.43	432
Tripoli Int Air	32.67	13.15	81
MOROCCO (MA)			
Casablanca	33.57	-7.67	55
SUDAN (SD)			
Dongola	19.17	30.48	255
Hudeiba	17.57	33.93	350
Khartoum	15.60	32.55	380
Nyala	12.05	24.88	674
Port Sudan	19.58	37.22	3
Shambat	15.67	32.53	376
TUNISIA (TN)			
Tunis	36.83	10.23	3

Table 111 – Locations where are registered weather data for Trnsys library in Northern – Africa countries (Trnsys 17).

All data are collected with a *simulation time step no stop* equal to 1 hr, starting from the 21st June (4128 hr) and ending the 23rd September (6384 hr).
The weather data collected from Trnsys labrary and useful for the following simulation are:

- dry bulb temperature (°C);
- total horizontal radiation (kJ/hr·m^2);
- total tilted surface radiation for surface (kJ/hr·m^2);
- sky diffuse radiation on the horizontal (kJ/hr·m2);
- angle of incidence for surface (degrees);
- slope of surface (degrees);
- ground reflectance (fraction).

In order to understand better weather condition of the selected cities, it can be helpful to add to previous these parameters:

- humidity ratio (-);
- monthly average temperature (°C);
- precipitable water (mm).

4.1 Simulation on Trnsys

Having all data necessary, it is possible start the simulation considering three flat plate solar thermal collectors in series with the characteristics of *Table 112*.

Parameters	Value	Unit
Aperture area (Aa)	2,57	m²
Gross length	1.260	mm
Gross height	2.160	mm
Gross area (AG)	2,72	mm
Collector efficiency	0,788	-
Efficiency slope (a1a)	5,14	W/m²K
Efficiency curvature (a2a)	0,017	W/m²K²
Stagnation temperature (tstg)	151,9	°C
Effective thermal capacity (ceff)	9,78	kJ/m²K
Max operation temperature	1	Mpa
Solar irradiance	1000	W/m²
Fluid	Water	-
Flow rate	0,02	kg/s

Table 112 - Flat plate solar thermal collector parameters.

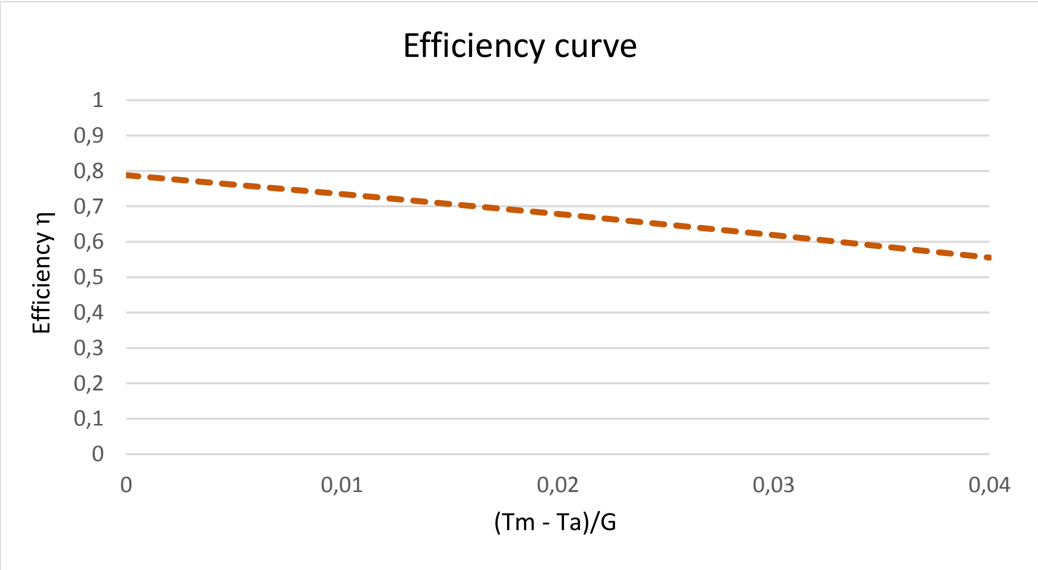

Figure 85 - Efficiency curve of solar thermal collector selected.

In *Figure 85*, there is the efficiency curve of the flat plate solar thermal collector selected obtained with the European method. Once that the parameters of collectors in *Table 112* are modified in Trnsys, the elements of simulation need to connect each other (*Figure 86*).

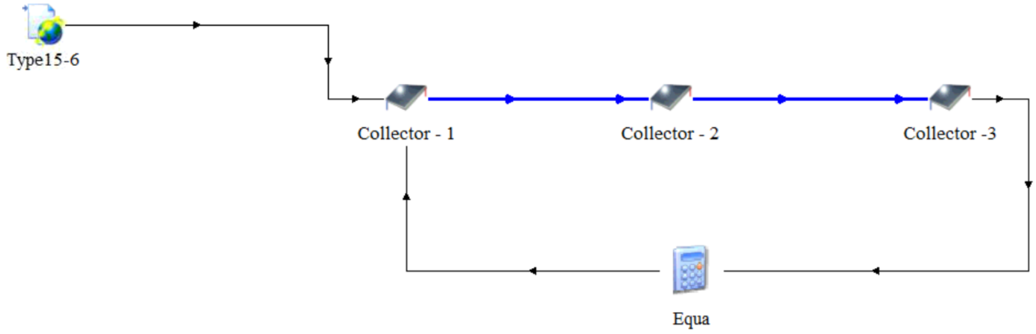

Figure 86 - Simulation system on Trnsys.

Connecting all the elements, is possible to define data to enter as input and output in each element. Connections between *Type 15 – 6*, the weather data, with *Collector – 1* are the following:

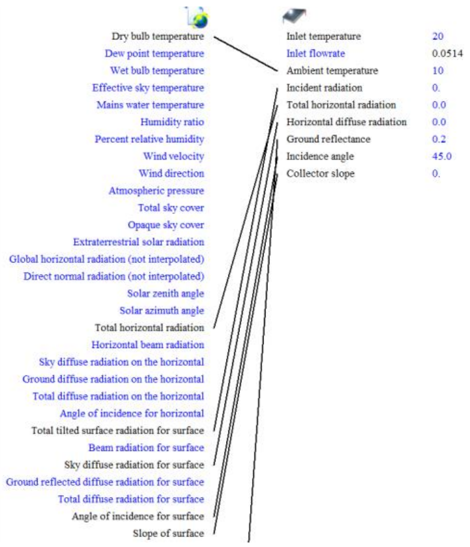

Figure 87 – Connections between Type 15 (weather data) and Collector - 1 with the link tool.

- Dry bulb temperature → Ambient temperature
- Total horizontal radiation → Total horizontal radiation
- Sky diffuse radiation on the horizontal → Horizontal diffuse radiation
- Total tilted surface radiation for surface → Incident radiation
- Angle of incidence for surface → Incidence angle
- Slope of surface → Collector slope

- Ground reflectance → Ground reflectance

Connections between collectors are:

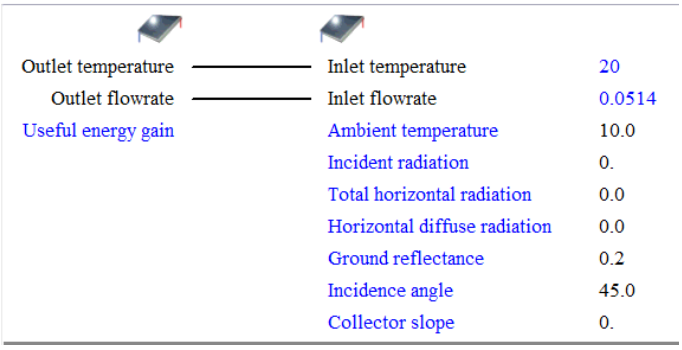

Figure 88 - Connections between collectors with the link tool.

- Outlet temperature → Inlet temperature
- Outlet flowrate → Inlet flowrate

How it is possible to see in *Figure 87* there is an input parameter without connection: *inlet temperature*. To obtain the *inlet temperature* is necessary to add an equation that connect the last collector to the first. To do that can be considered a thermal loss function of absorption coefficient and it is possible to make a power balance to the collector to have the *inlet temperature*.
Assuming that power dissipated is given by product of flow rate equal 0,72 lt h^{-1} (q) and the specific consumption equal to 0,70 kWh lt^{-1}(L). Making the balance on the collector:

$$\mathbf{m_c \cdot c_P \cdot (T_{out} - T_{in}) = L \cdot q} \quad (4)$$

4.2 Results of Trnsys for Algeria

As listed in *Table 111*, the locations for which are available weather data in Algeria are *Béchar*, in northwestern region with an hot desert climate, *Darel Beida*, a suburb of the capital Algiers, and *Tamanrasset,* an oasis capital in southern Algeria in the Ahaggar Mountains.
As said before during the first there is a collection of weather data to understand the meteorological conditions during which the system works from the 21st June to 23rd September.
In *Figure 90*, there are the *humidity ratio* trend in all three locations in Algeria during the time period established. Remembering that the humidity is the amount of water vapor in the air, the *humidity ratio* is the rapport of mass of water vapor in the humid air to the mass of dry air:

$$x = m_w/m_a(kg_{water}/kg_{dry\ air}) \tag{5}$$

In *Table 113*, there the *monthly average temperature*:

Temperature [°C]				
Locations	June (21^{st}-30^{th})	July	August	September (1^{st} - 23^{rd})
Béchar	28,83	33,09	32,6	27,47
Darel Beida	21	24,73	25,17	22,87
Tamanrsset	28,6	28,8	28,2	26,1

Table 113 - Monthly average temperature in Algerian locations.

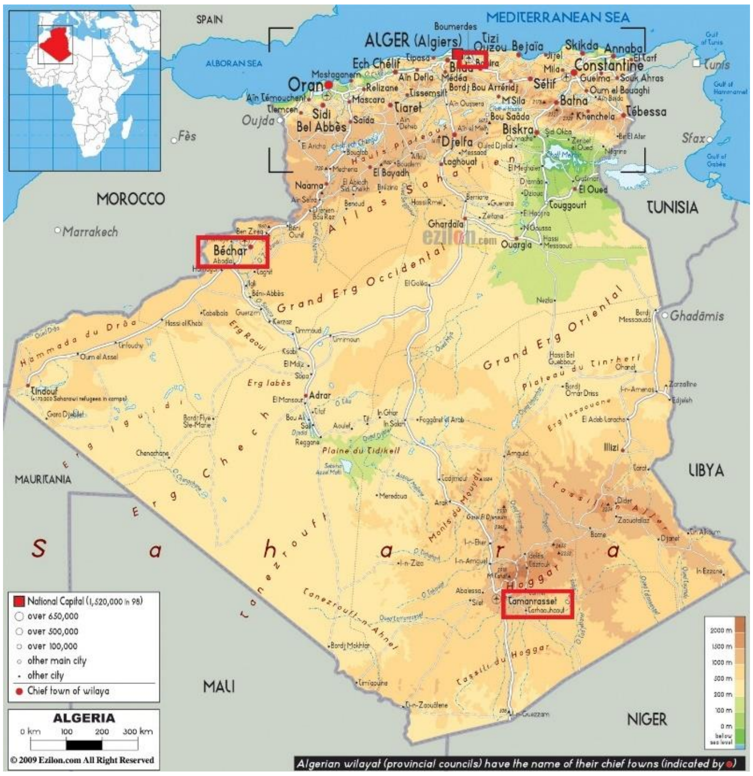

Figure 89 - Physical map of Algeria with locations with meteorological stations of Trnsys.

Starting the simulation system, in *Figure 86*, for each locations in Algeria for which are available weather data, it is possible to obtain four *outlet temperature* values: out the three collectors and the outlet temperature considering the dissipated power. Plotting all data from 21^{st} June to 23^{rd} September every 1 hour (*Figure 91*, *Figure 92*, *Figure 93*).

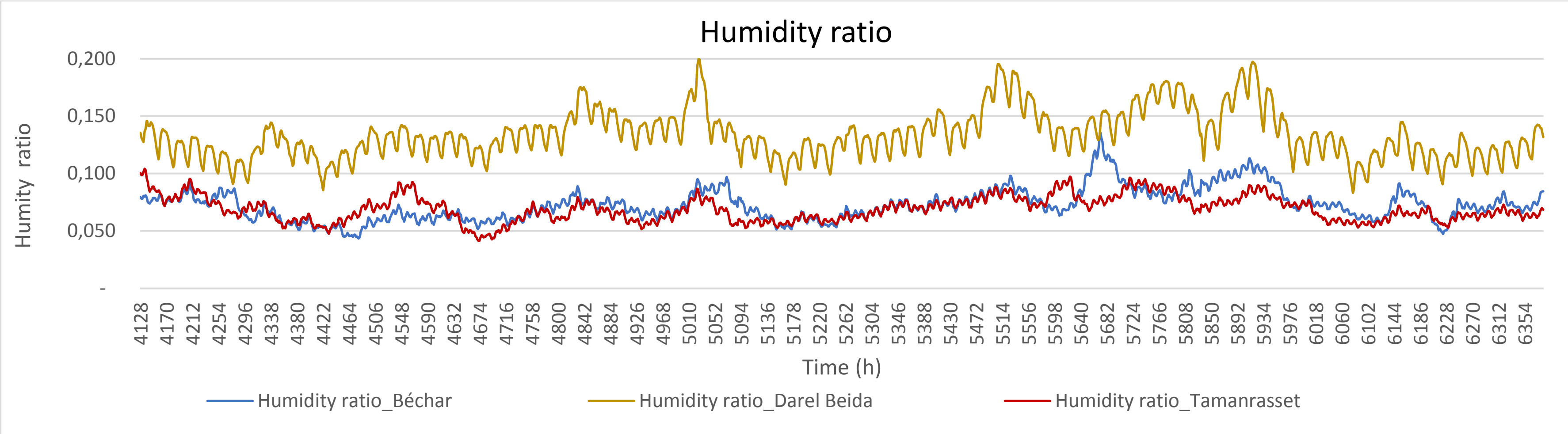

Figure 90 - Humidity ratio in Algerian locations.

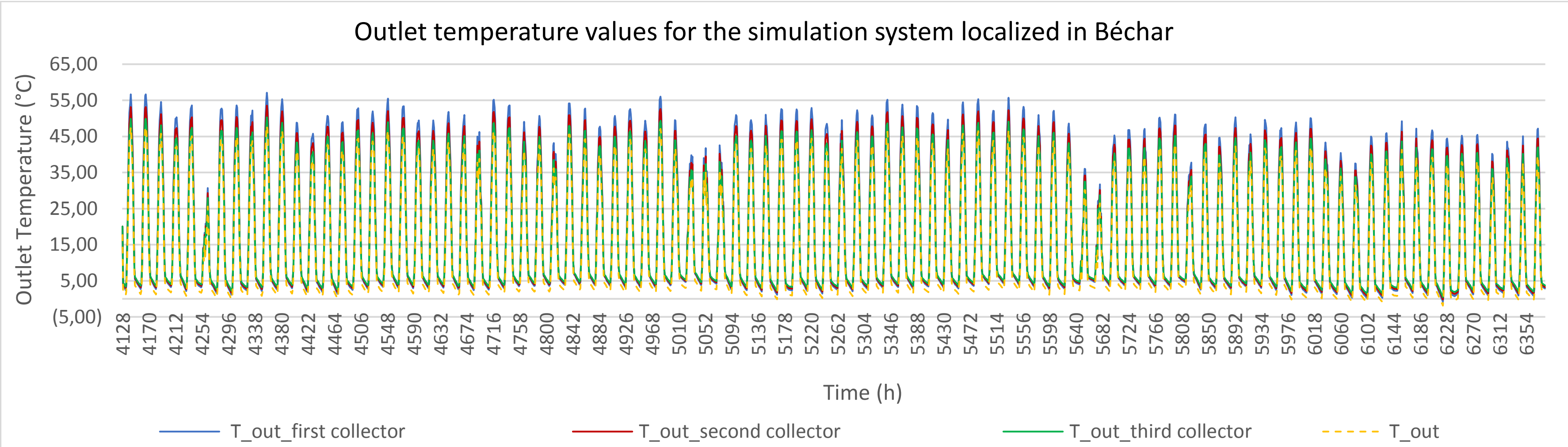

Figure 91 - Outlet temperature values for the simulation system localized in Béchar

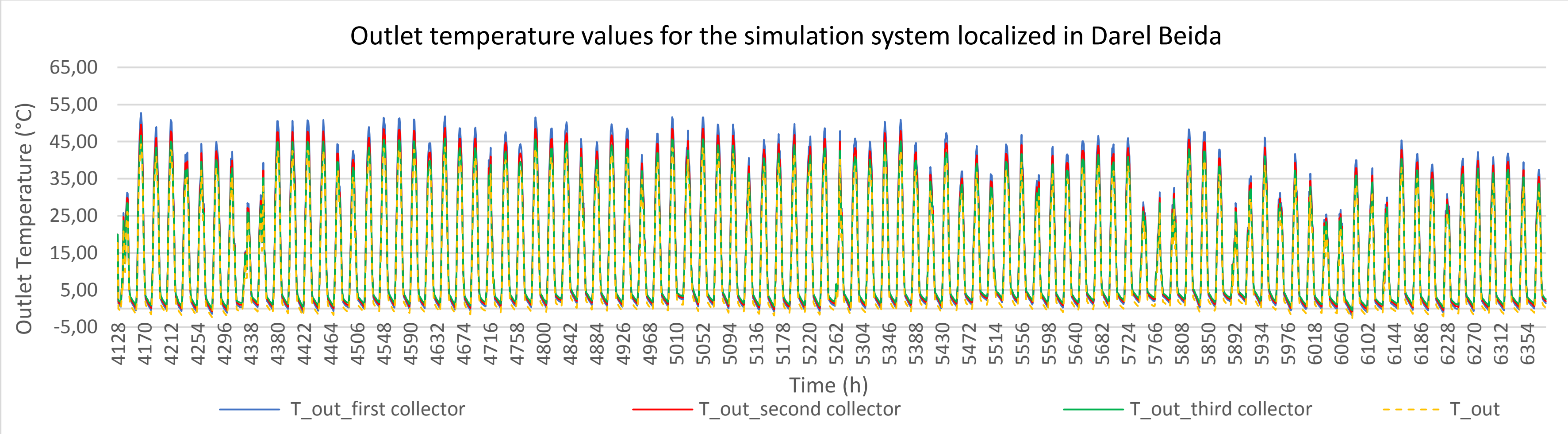

Figure 92 - Outlet temperature values for the simulation system localized in Darel Beida.

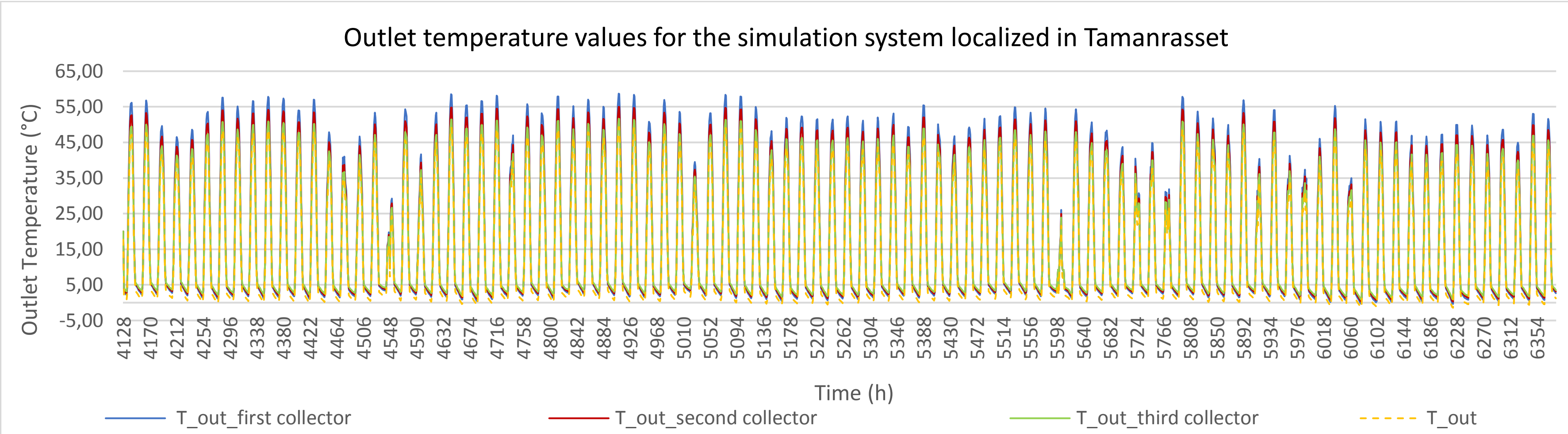

Figure 93 - Outlet temperature values for the simulation system localized in Tamanrasset.

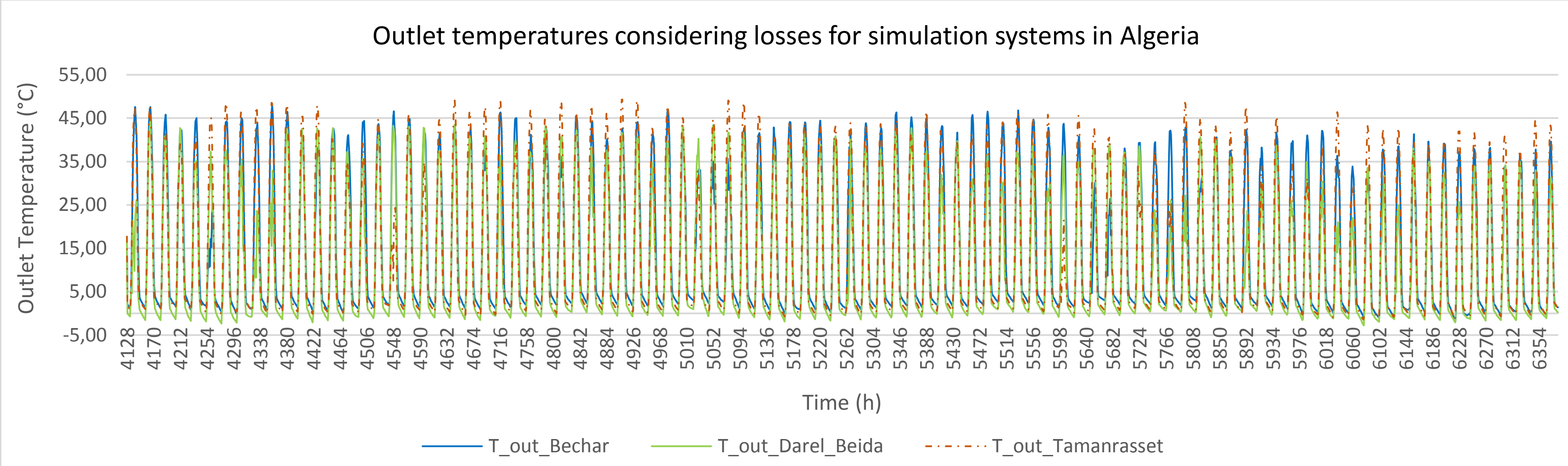

Figure 94 - Outlet temperatures considering losses for simulation systems in Algeria

From *Figure 90*, *Figure 91* and *Figure 92* it is possible to see:

- *outlet temperatures* from the first collector is for the three locations higher than the other *outlet temperatures*;
- highest *outlet temperature* individualized from the first collector in Béchar is 57,10 °C at hour number 4357, this hour is 13 p.m. of 30th June;
- highest *outlet temperature* individualized from the first collector in Darel Beida is 52,74 °C at hour number 4165, this hour is 13 p.m. of 22th June;
- highest *outlet temperature* individualized from the first collector in Tamanrasset is 58,7 °C at hour number 4908, this hour is 12 a.m. of 23rd July;
- lowest *outlet temperature* individualized from the first collector in Béchar is -0,87 °C at hour number 6222, this hour is 6 a.m. of 16th September;
- lowest *outlet temperature* individualized from the first collector in Darel Beida is -1,88 °C at hour number 6078, this hour is 6 a.m. of 10th September;
- lowest *outlet temperature* individualized from the first collector in Tamanrasset is -0,36 ° C at hour number 6222, this hour is 6 a.m. of 16th September;
- all temperatures have the same trends;
- *outlet temperature*s obtained considering losses during the simulation are the lowest than the other *outlet temperatures* for all three locations;
- highest *outlet temperature* individualized considering losses during the simulation in Béchar is 47,96 °C at hour number 4357, this hour is 13 p.m. of 30th June;
- highest *outlet temperature* individualized considering losses during the simulation in Darel Beida is 44,29 °C at hour number 4165, this hour is 13 p.m. of 22th June;
- highest *outlet temperature* individualized considering losses during the simulation in Tamanrasset is 49,31 °C at hour number 4908, this hour is 12 a.m. of 23rd July;
- lowest *outlet temperature* individualized considering losses during the simulation in Béchar is -1,88 °C at hour number 6222, this hour is 6 a.m. of 16th September;

- lowest *outlet temperature* individualized considering losses during the simulation in Darel Beida is -2,78 °C at hour number 6078, this hour is 6 a.m. of 10^{th} September;

- lowest *outlet temperature* individualized considering losses during the simulation in Tamanrasset is -1,44 ° C at hour number 6222, this hour is 6 a.m. of 16^{th} September;

In *Figure 93* are plotted the outlet temperatures for each localizations in Algeria considering losses during the simulations on Trnsys:

- in general, the highest *outlet temperatures* are that of Tamanrasset, 22.78 °N 5.52 °E, at an altitude of 1377 m;

- there are few hours in which Tamanrasset *outlet temperatures* are the lowest, for example at 21 p.m. of 8^{th} July or at 18 p.m. of 21^{th} of August;

- the lowest *outlet temperatures* are that of Darel Beida, 36.72 °N 3.25 °E, at an altitude of 25 m;

- *outlet temperatures* of Béchar have a constant trend and less big variations.

4.3 Results of Trnsys for Egypt

Egyptian locations listed in *Table 111* for which are available weather data are:

- *Aswan*, a city in the south of Egypt near the Nile river;
- *Asyut*, a city in the center of Egypt near the Nile river;
- *Bahtim,* a city in the northern of Egypt on the Mediterranean coast;
- *El Arish*, a city in the northeastern of Egypt on the Mediterranean coast;
- *El Kharga*, the most inner city among those listed for Egypt;
- *Giza*, a city near the capital El Cairo;
- *Mersa Matruh*, a city on the Mediterranean coast;
- *Sidi – Barrani*, a city in the north-western of Egypt.

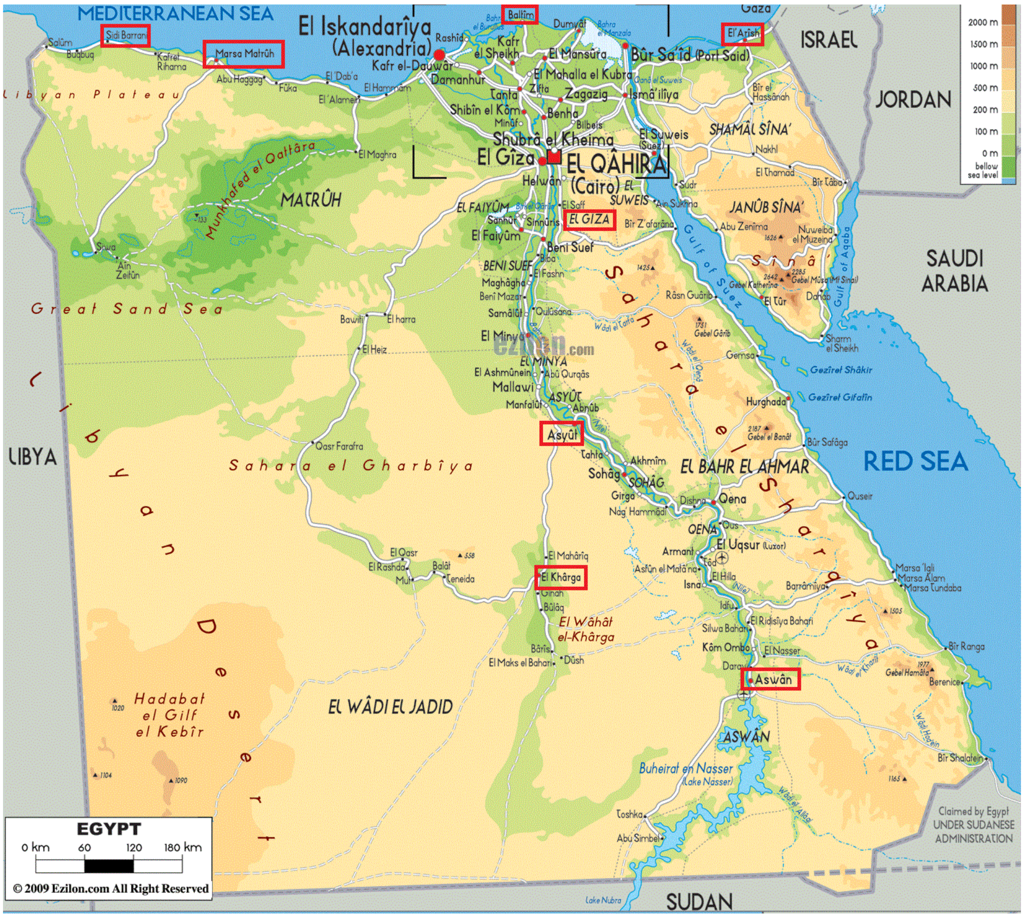

Figure 95 - Physical map of Egypt with locations with meteorological stations of Trnsys.

In *Figure 96*, there are the *humidity ratio* trend in all eight locations in Egypt during the time period established.

In *Table 114*, there the *monthly average temperature* for each Egyptian locations:

Temperature [°C]				
Locations	June (21^{st}-30^{th})	July	August	September (1^{st} - 23^{rd})
Aswan	33	33,6	33,2	30,8
Asyut	29,3	29,7	29	26,5
Bahtim	26,9	27,7	27,4	25,6
El Arish	24,1	26	26,2	26,5
El Kharga	32,1	32,8	32,1	28,6
Giza	26,9	27,7	27,4	25,6
Marsa Matruh	23,1	25	25,5	23,9
Sidi-Barrani	25,3	27,2	27,2	25,7

Table 114 - Monthly average temperature in Egyptian locations.

Starting the simulation system, in *Figure 86*, for each location in Egypt for which are available weather data, it is possible to obtain four *outlet temperature* values: out the three collectors and the outlet temperature considering the dissipated power. Plotting all data from 21^{st} June to 23^{rd} September every 1 hour (*Figure 96*, *Figure 97*, *Figure 98, Figure 99, Figure 100, Figure 101, Figure 102, Figure 103, Figure 104*).

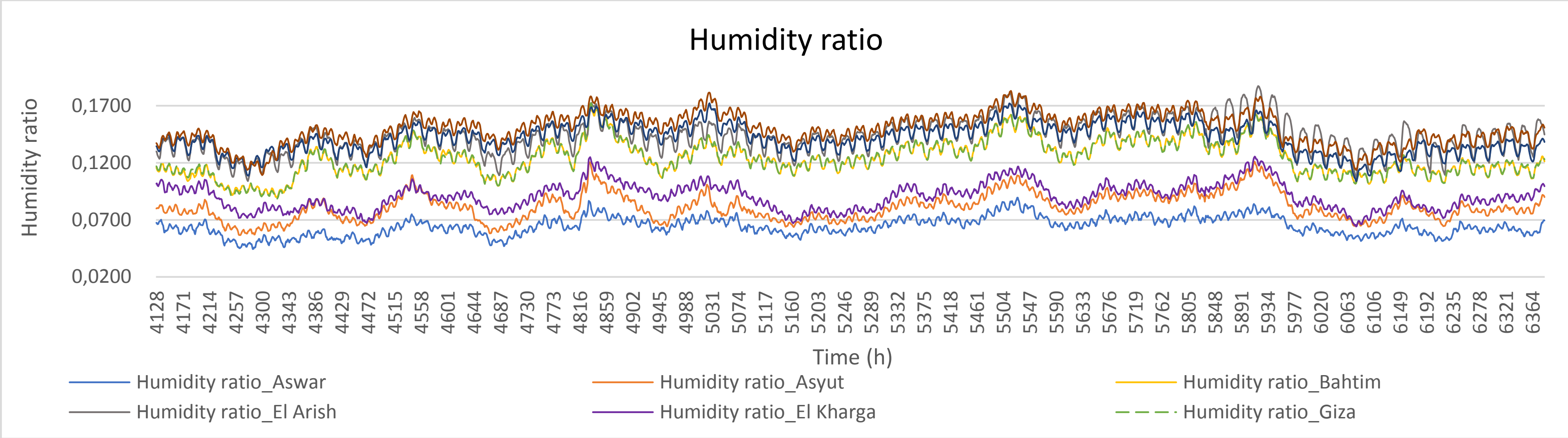

Figure 96 - Humidity ratio in Egyptian locations.

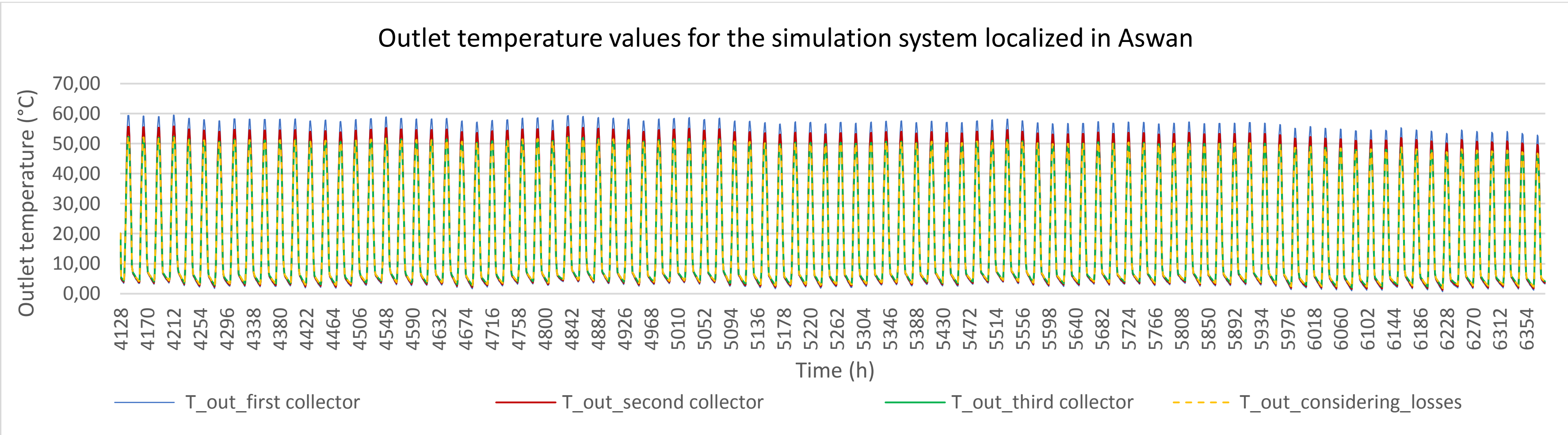

Figure 97 - Outlet temperature values for the simulation system localized in Aswan.

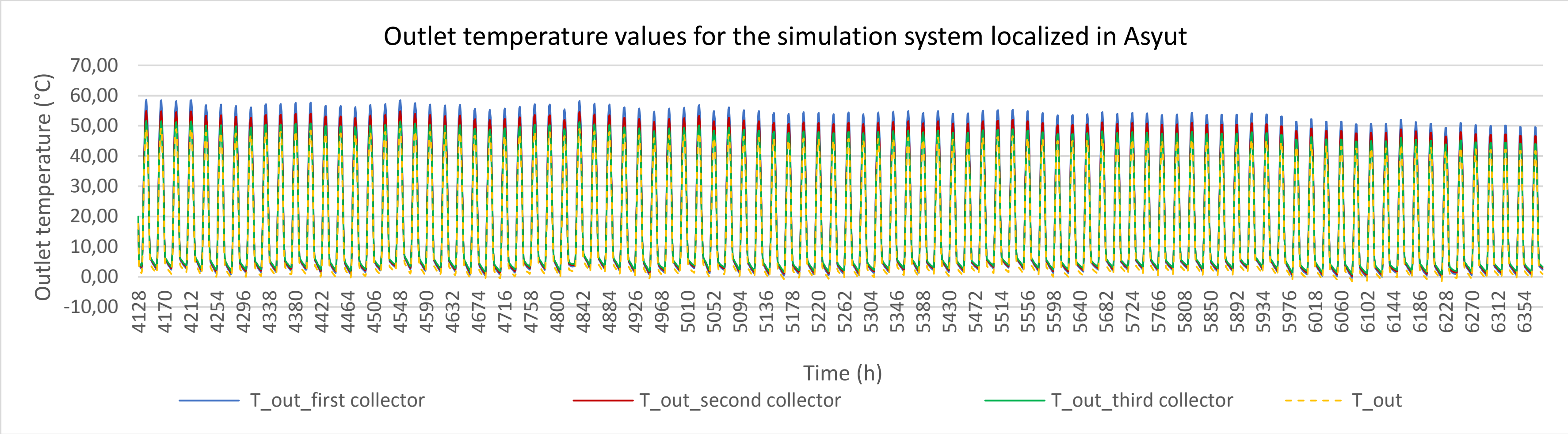

Figure 98 - Outlet temperature values for the simulation system localized in Asyut.

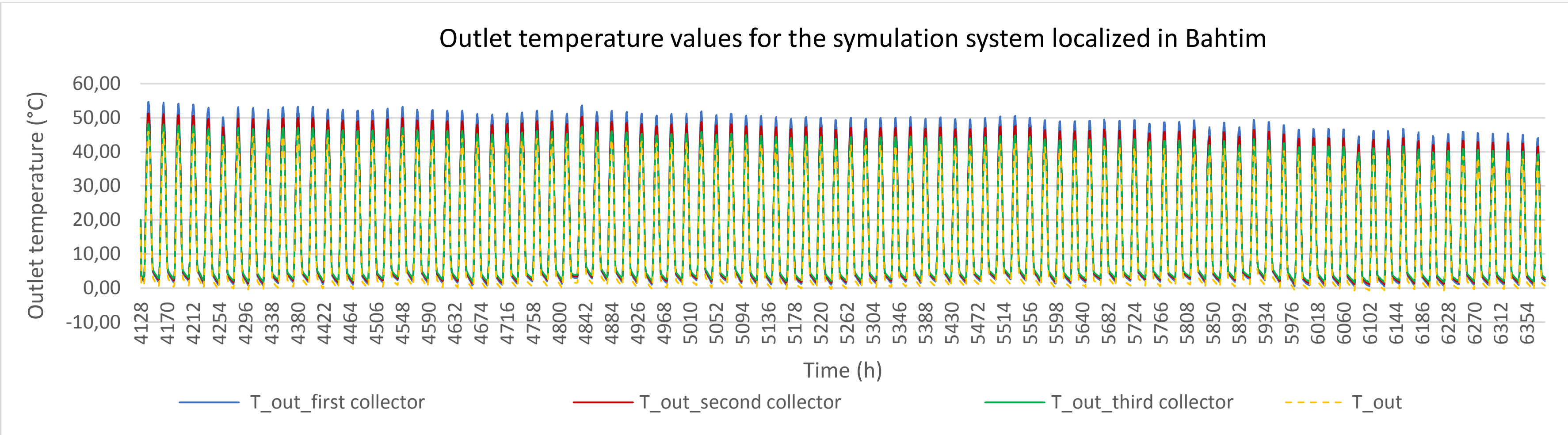

Figure 99 - Outlet temperature values for the symulation system localized in Bahtim.

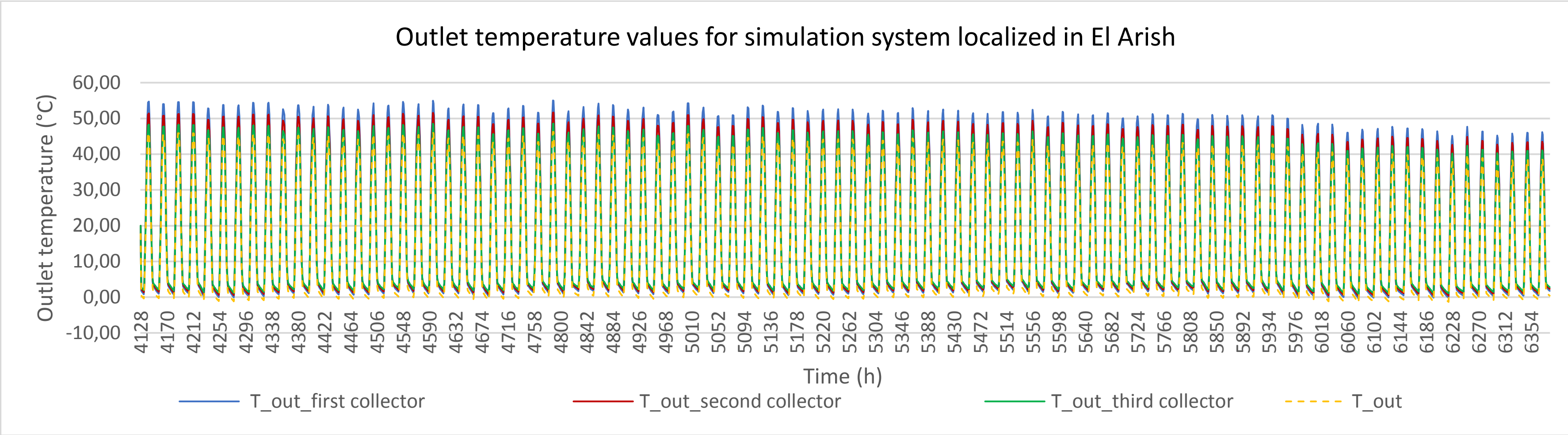

Figure 100 - Outlet temperature values for simulation system localized in El Arish.

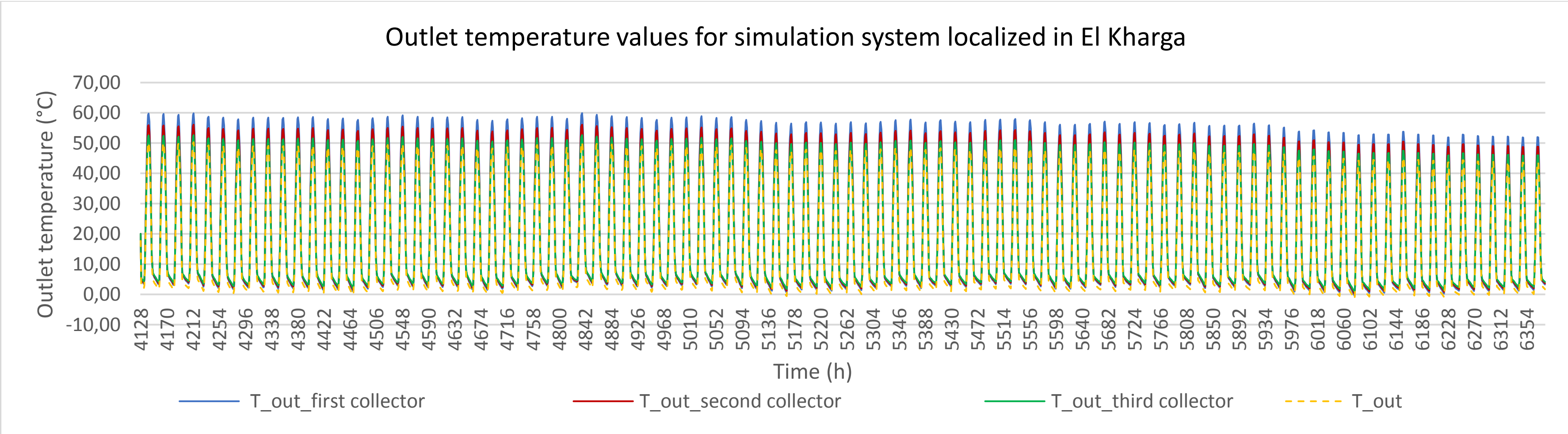

Figure 101 - Outlet temperature values for simulaton system localized in El Kharga.

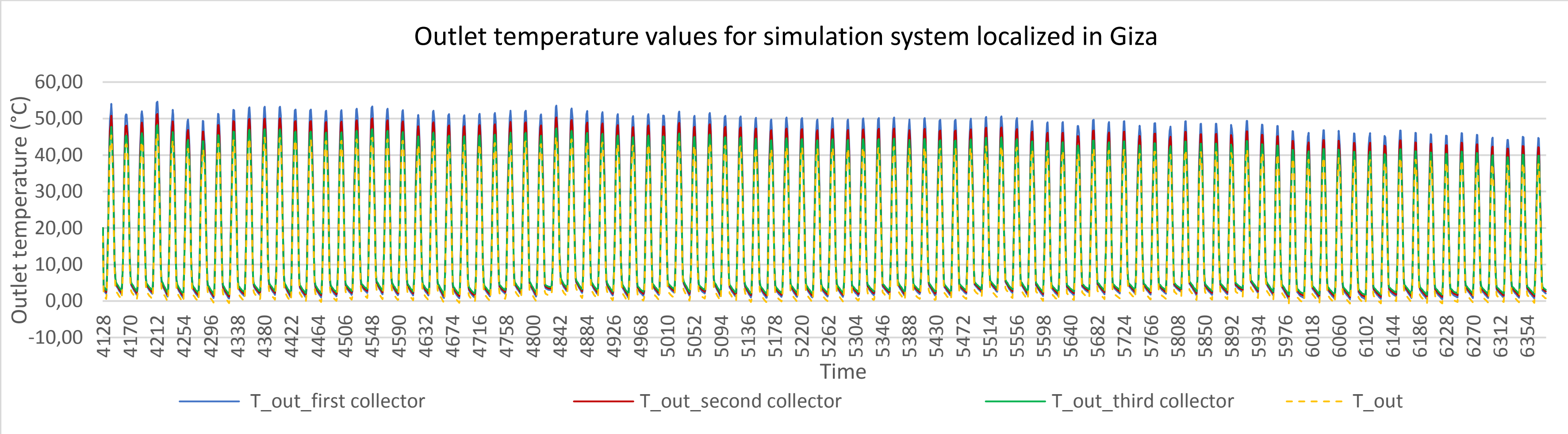

Figure 102 - Outlet temperature values for simulation system localized in Giza.

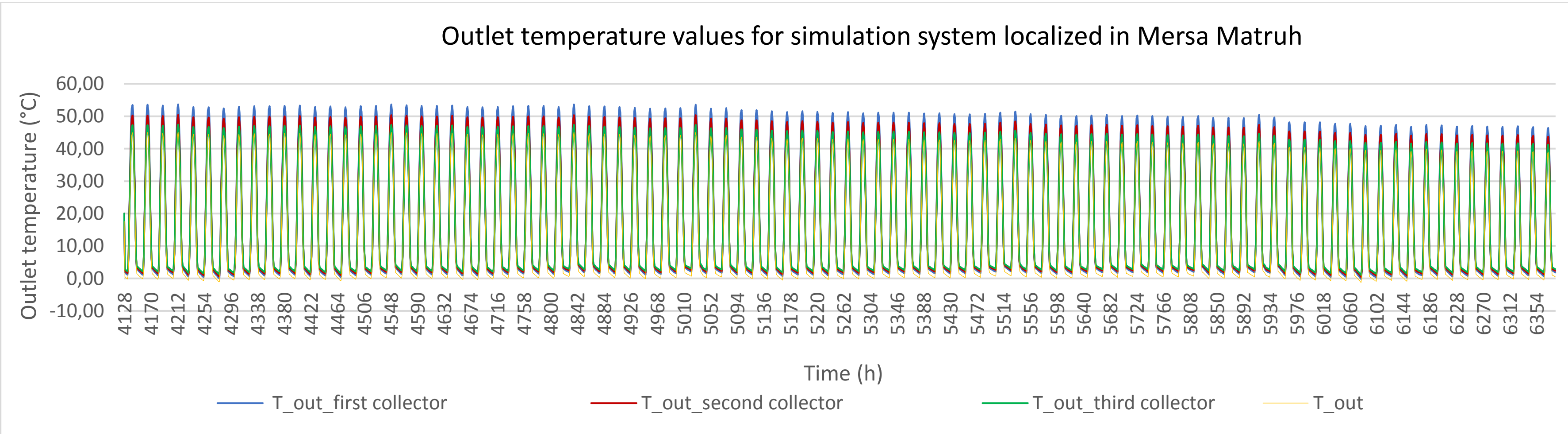

Figure 103 - Outlet temperature values for simulation system localized in Mersa Matruh.

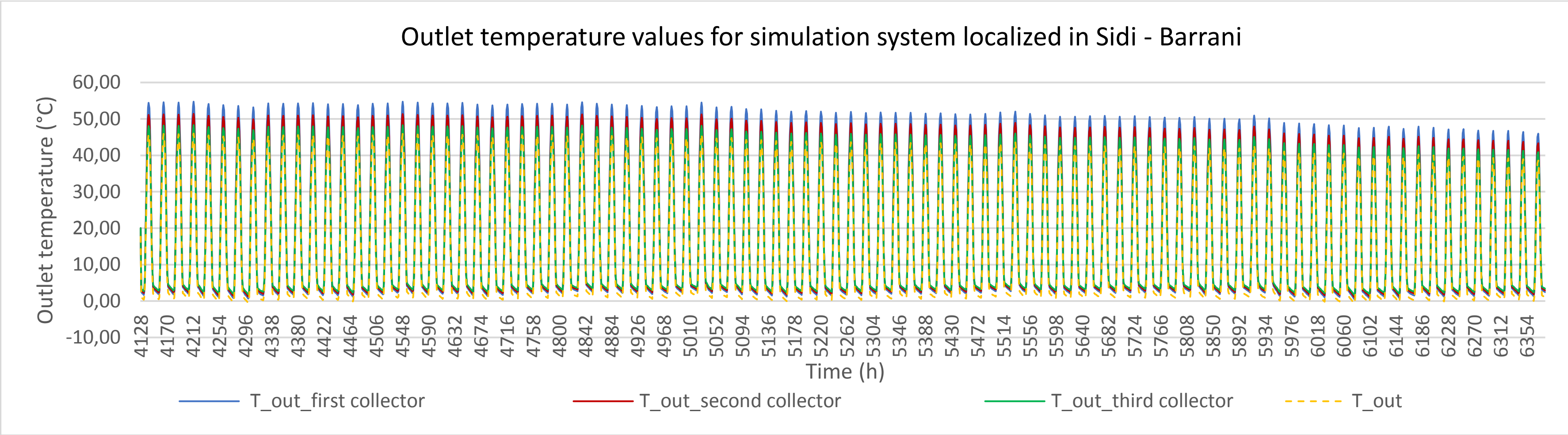

Figure 104 - Outlet temperature values for simulation system localized in Sidi - Barrani.

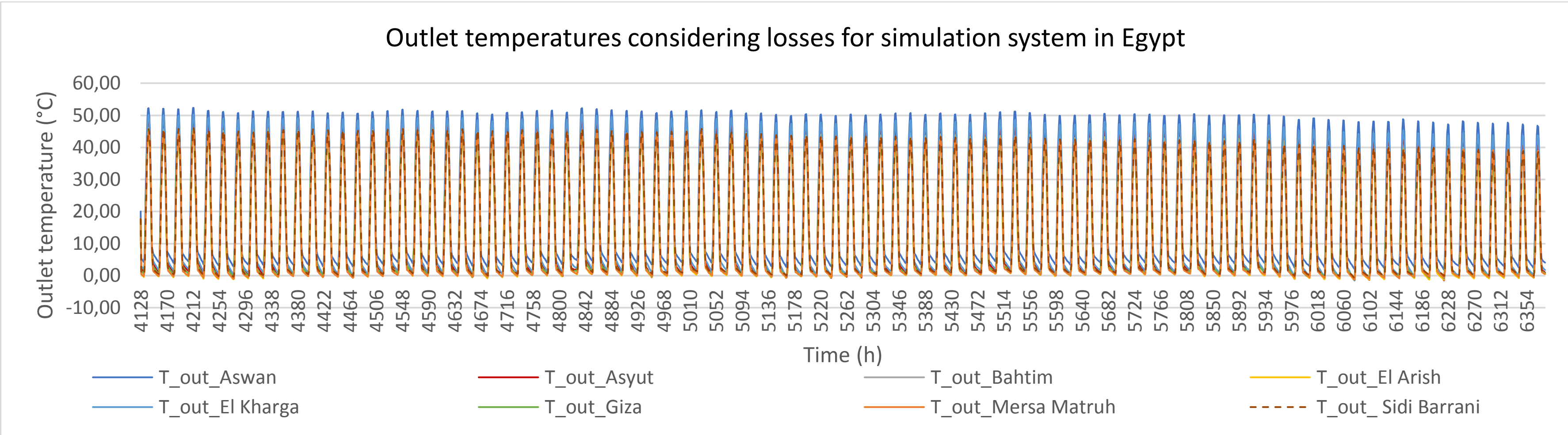

Figure 105 - Outlet temperatures considering losses for simulation system in Egypt.

4.4 Results of Trnsys for Libya

Libyan locations listed in *Table 111* for which are available weather data are:

- *Kufra*, a southeastern city in the Libyan desert;
- *Sebha,* an oasis city in southwestern Libya;
- *Tripoli Internation Airport,* the weather station is in the airport of the capital, Tripoli.

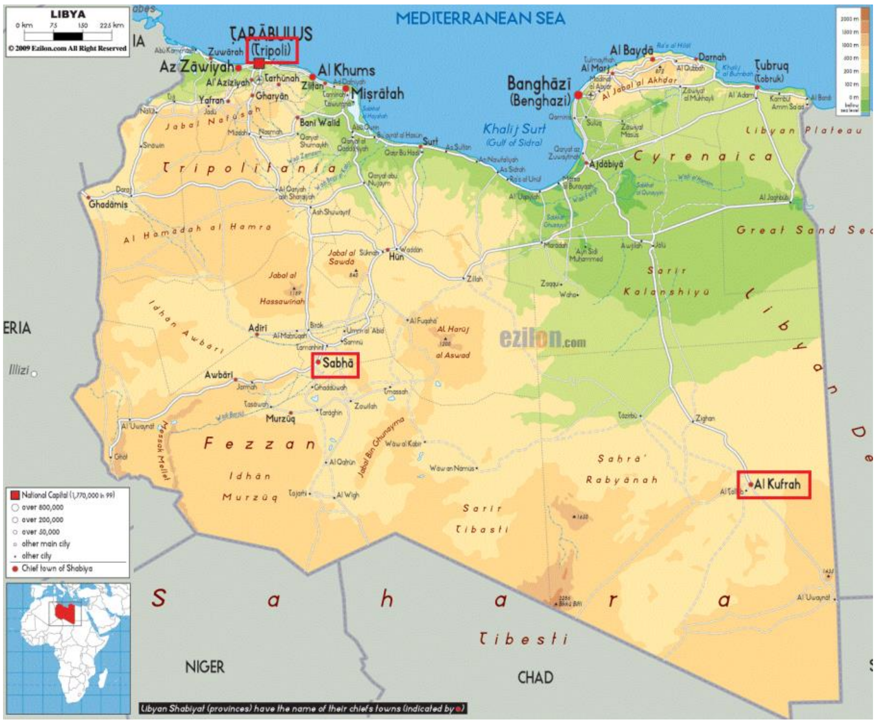

Figure 106 - Physical map of Libya with locations with meteorological stations of Trnsys.

In *Figure 107*, there are the *humidity ratio* trend in all three locations in Libya during the time period established.

In *Table 115*, there the *monthly average temperature* for each Libyan locations:

Temperature [°C]				
Location	June (21st-30th)	July	August	September (1st - 23rd)
Kufra	30,5	30,7	30,5	28,1
Sebha	30,8	30,5	30,5	28
Tripoli Int. Air.	25,8	27,1	27,9	25,8

Table 115 - Monthly average temperature in Libyan locations.

Starting the simulation system, in *Figure 86*, for each location in Libya for which are available weather data, it is possible to obtain four *outlet temperature* values: out the three collectors and the outlet temperature considering the dissipated power. Plotting all data from 21st June to 23rd September every 1 hour (*Figure 108*, *Figure 109*, *Figure 110*).

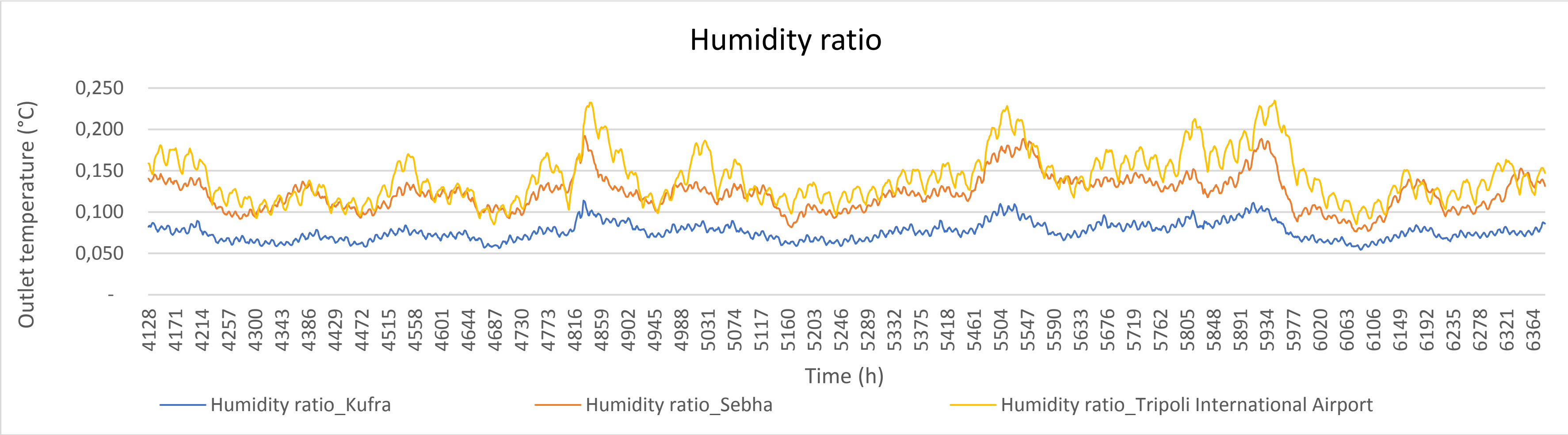

Figure 107 - Humidity ratio in Libyan locations.

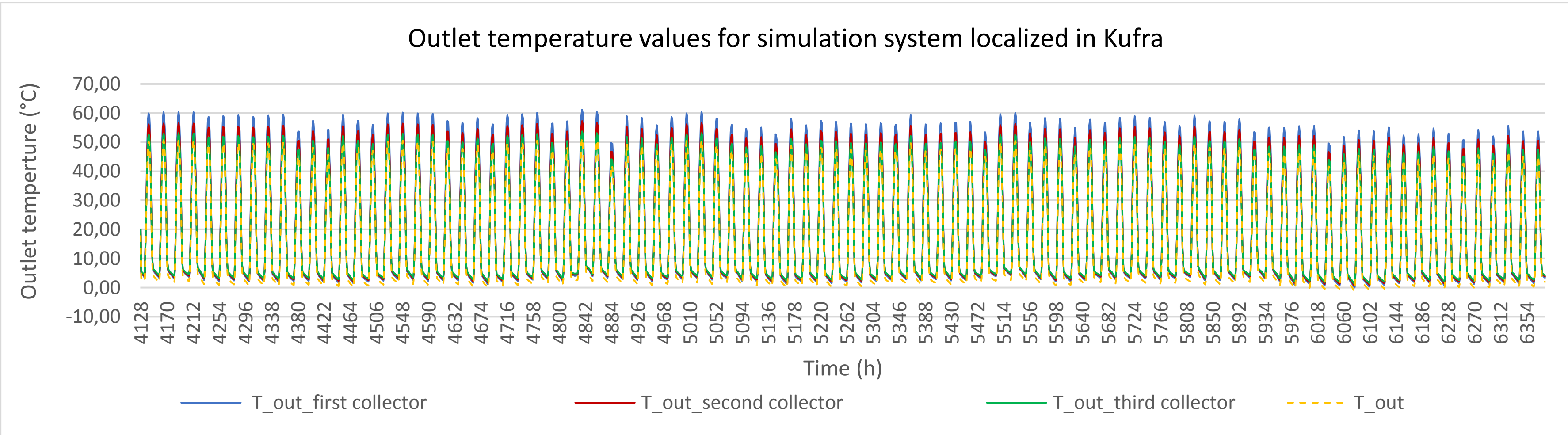

Figure 108 - Outlet temperature values for simulation system localized in Kufra.

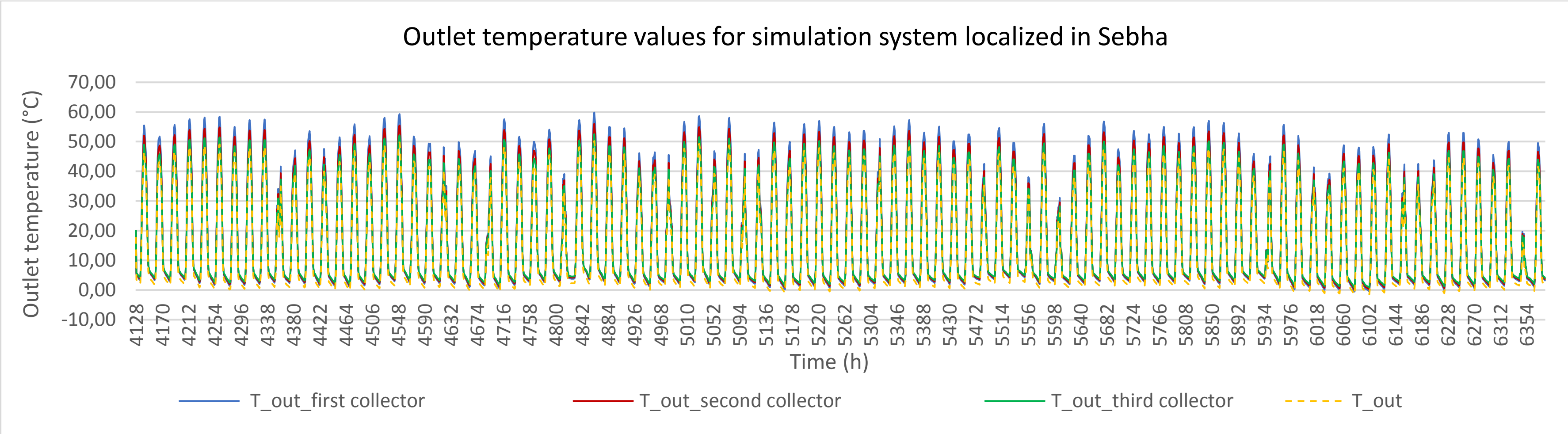

Figure 109 - Outlet temperature values for simulation system localized in Sebha.

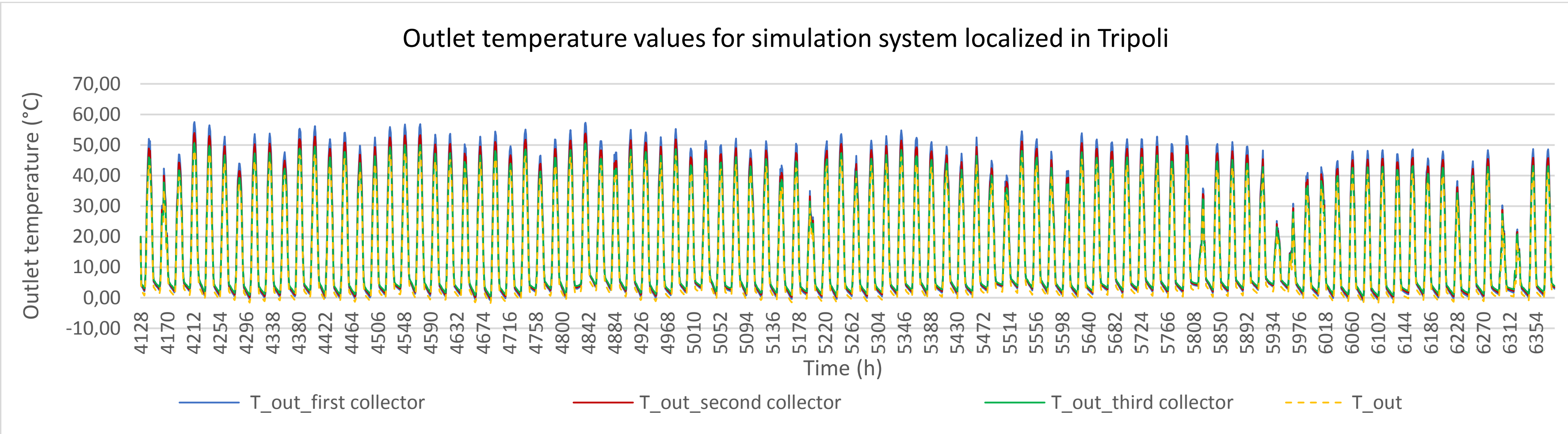

Figure 110 - Outlet temperature values for simulation system localized in Tripoli.

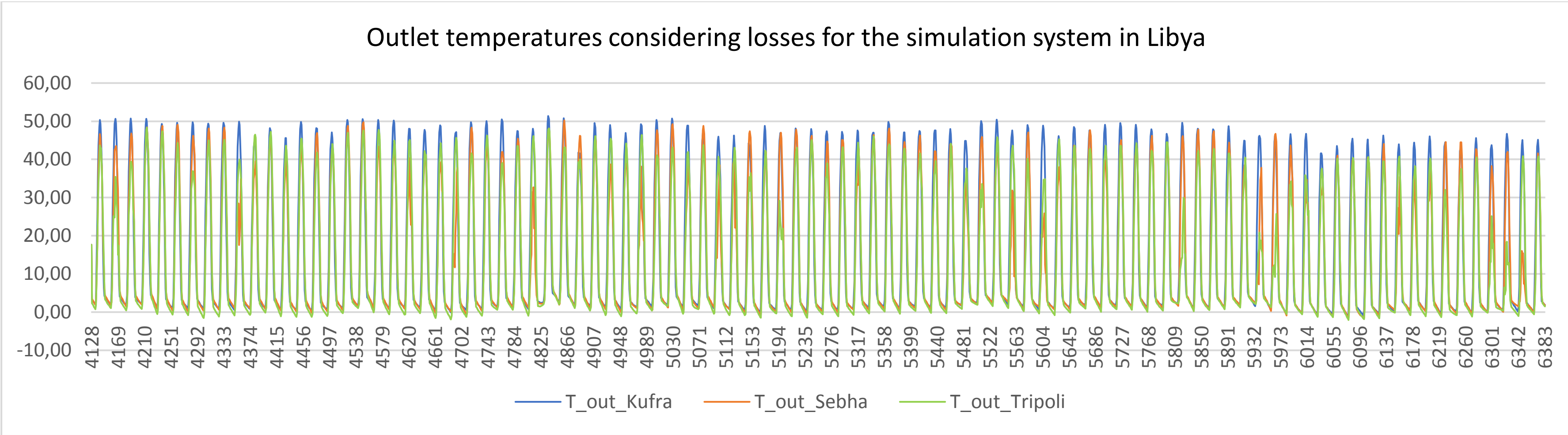

Figure 111 - Outlet temperatures considering losses for the simulation system in Liby

4.5 Results of Trnsys for Morocco

Moroccan location listed in *Table 111* for which are available weather data is the capital *Casablanca* on the Atlantic Ocean coast.

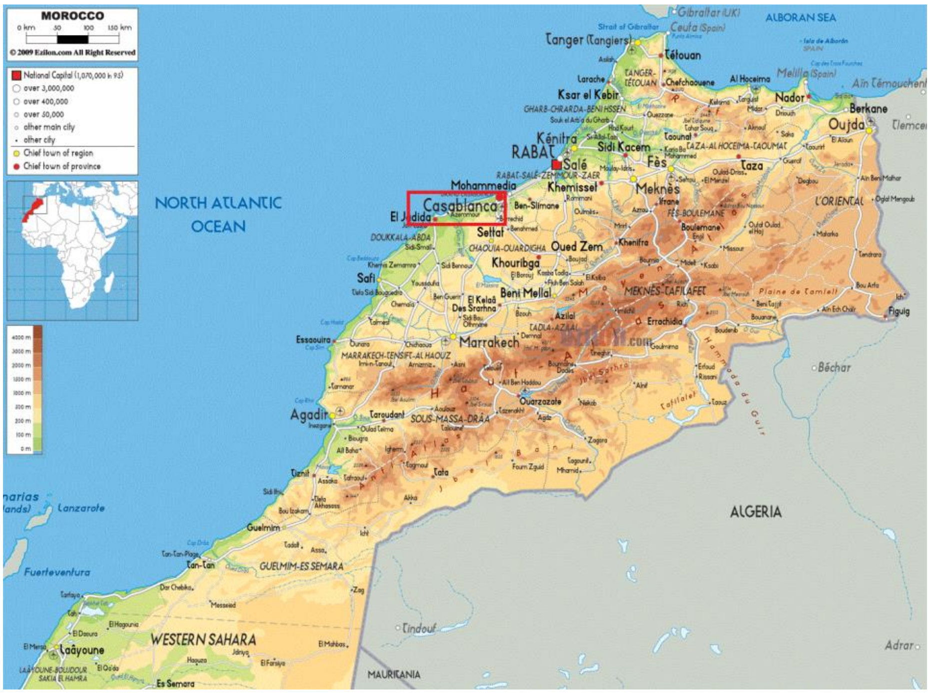

Figure 112 - Physical map of Morocco with locations with meteorological stations of Trnsys.

In *Figure 113*, there are the *humidity ratio* trend in the only one location in Morocco during the time period established.
In *Table 116*, there the *monthly average temperature* for the Moroccan location:

Temperature [°C]				
Location	June (21^{st}-30^{th})	July	August	September (1^{st} - 23^{rd})
Casablanca	19,9	22,4	22,7	21,4

Table 116 - Monthly average temperature in Moroccan locations.

Starting the simulation system, in *Figure 86*, for each location in Morocco for which are available weather data, it is possible to obtain four *outlet temperature* values: out the three collectors and the outlet temperature considering the dissipated power. Plotting all data from 21^{st} June to 23^{rd} September every 1 hour (*Figure 114*).

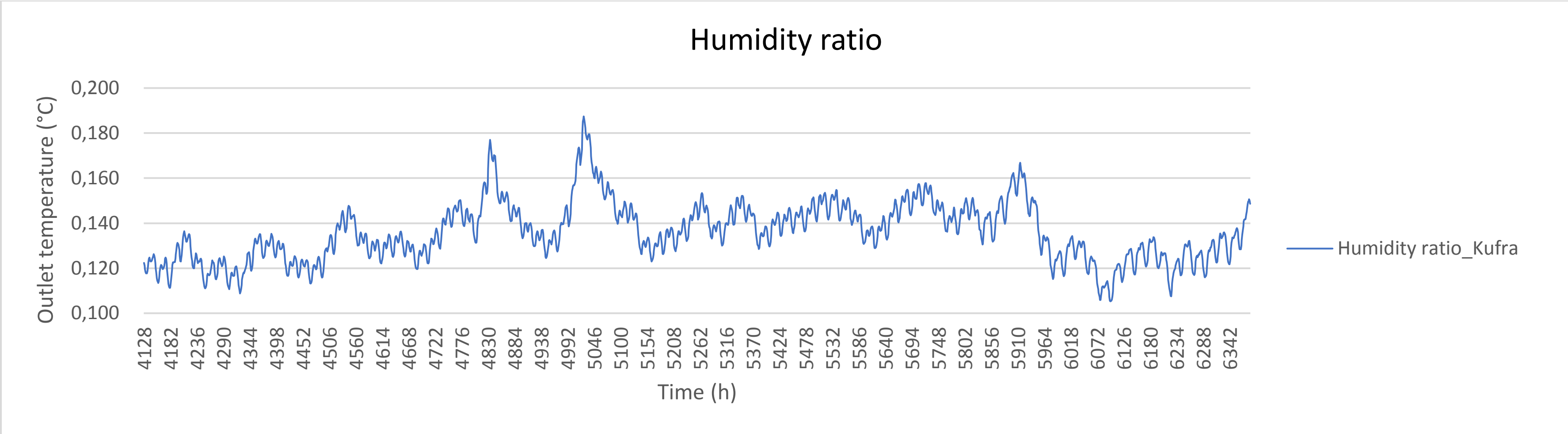

Figure 113 - Humidity ratio in Moroccan location.

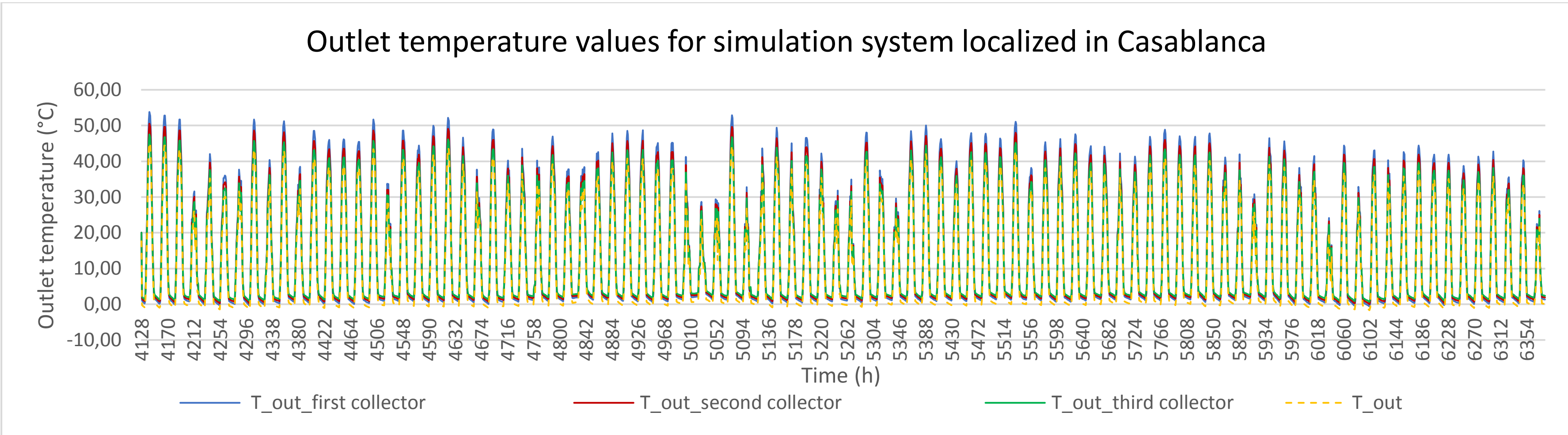

Figure 114 - Outlet temperature values for simulation system localized in Casablanca.

4.6 Results of Trnsys for Sudan

Sudan locations listed in *Table 111* for which are available weather data are:

- *Dongola*, a city in northern – intern of Sudan near the Nile river;
- *Hudeiba*, a suburb of the capital Khartoum;
- *Khartoum*, the Sudan capital situated in the intern of the country near the Nile river;
- *Nyala*, a city in the western Sudan near the Darfur region;
- *Port Sudan*, a city on the Red Sea coast;
- *Shambat*, a suburb of the capital Khartoum.

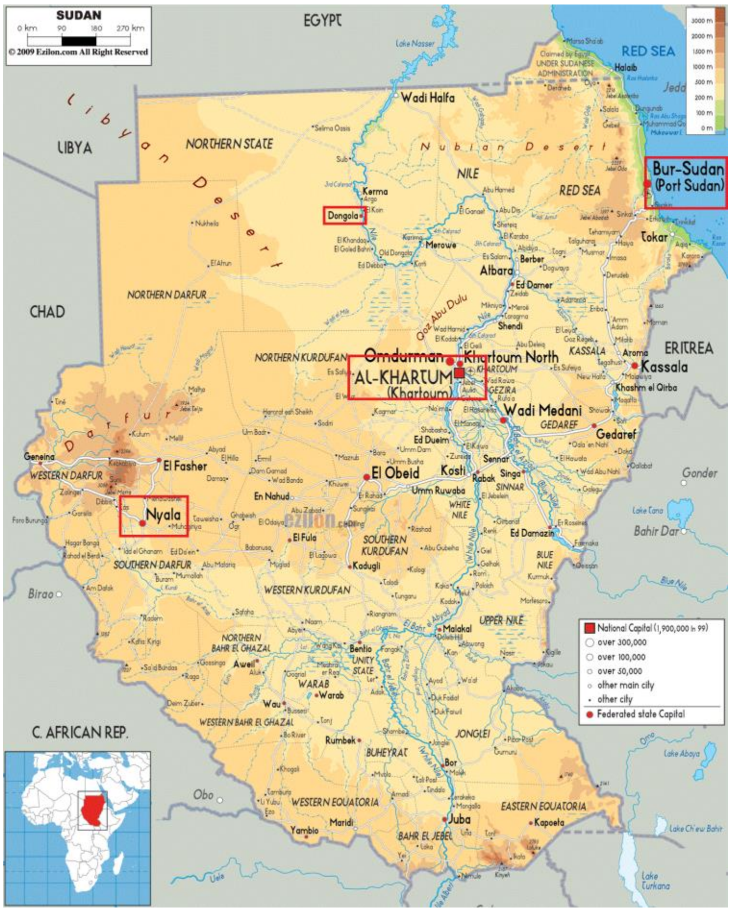

Figure 115 - Physical map of Sudan with locations with meteorological stations of Trnsys.

In *Figure 116*, there are the *humidity ratio* trend in the only one location in Sudan during the time period established.

In *Table 117*, there the *monthly average temperature* for the Sudan location:

Temperature [°C]				
	June (21^{st}-30^{th})	July	August	September (1^{st} - 23^{rd})
Dongola	33,6	33,7	33,5	31,8
Hudeiba	34,4	34	33,3	33,2
Khartoum	33,9	32,2	31,5	32
Nyala	28,7	27,8	27,1	26,5
Port Sudan	31,8	34,2	34,5	31,7
Shambat	33,3	32	31,3	31,5

Table 117 - Monthly average temperature in Sudan locations.

Starting the simulation system, in *Figure 86*, for each location in Sudan for which are available weather data, it is possible to obtain four *outlet temperature* values: out the three collectors and the outlet temperature considering the dissipated power. Plotting all data from 21^{st} June to 23^{rd} September every 1 hour (*Figure 117, Figure 118, Figure 119, Figure 120, Figure 121, Figure 122*).

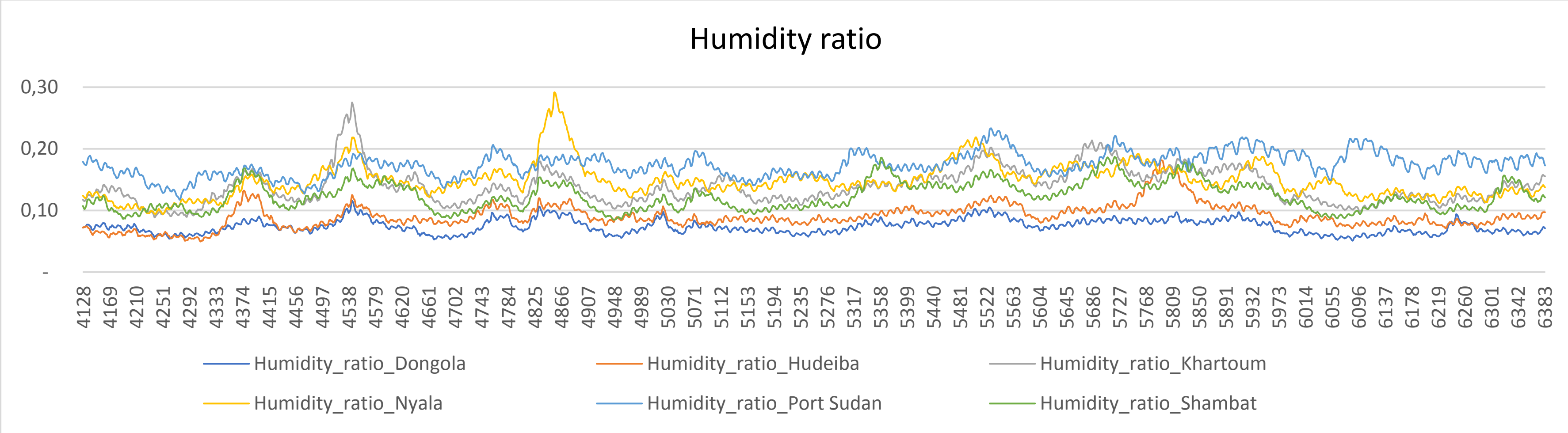

Figure 116 - Humidity ratio in Sudan locations.

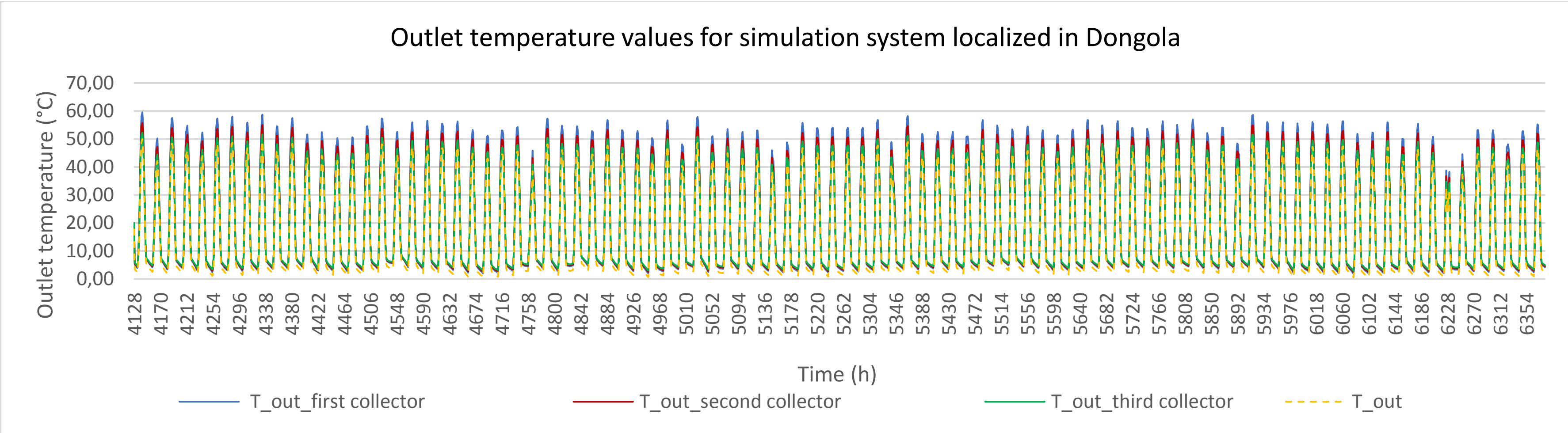

Figure 117 - Outlet temperature values for simulation system localized in Dongola.

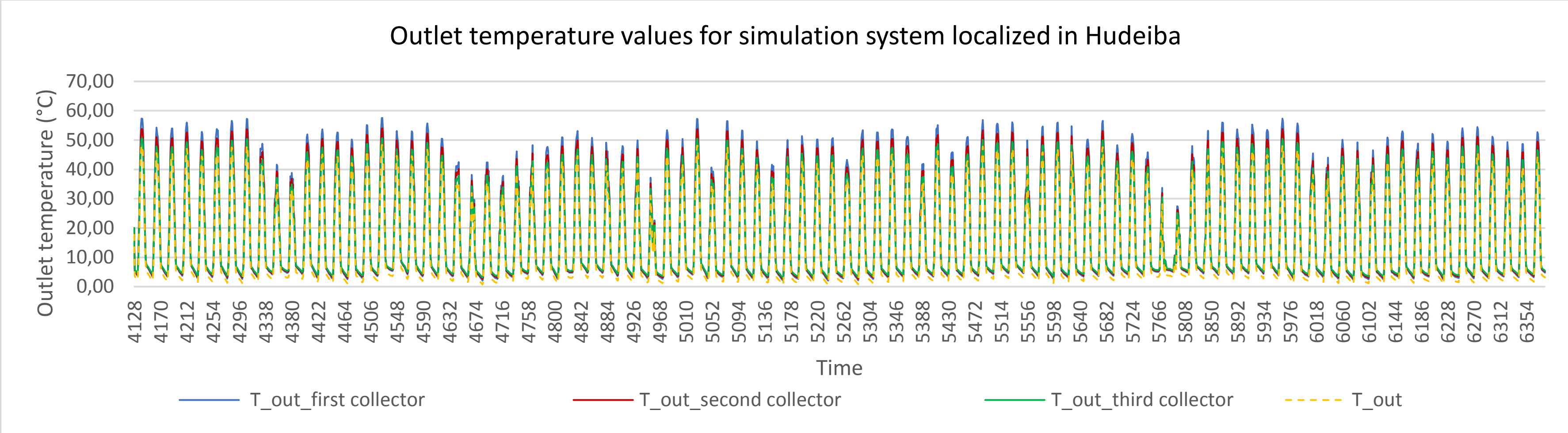

Figure 118 - Outlet temperature values for simulation system localized in Hudeiba.

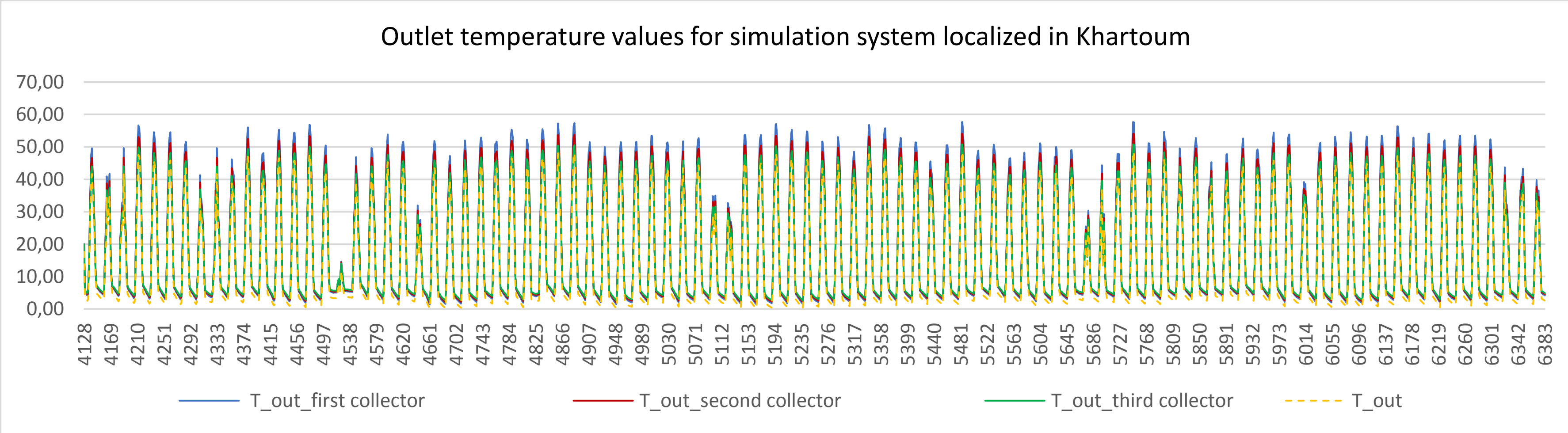

Figure 119 - Outlet temperature values for simulation system localized in Khartoum.

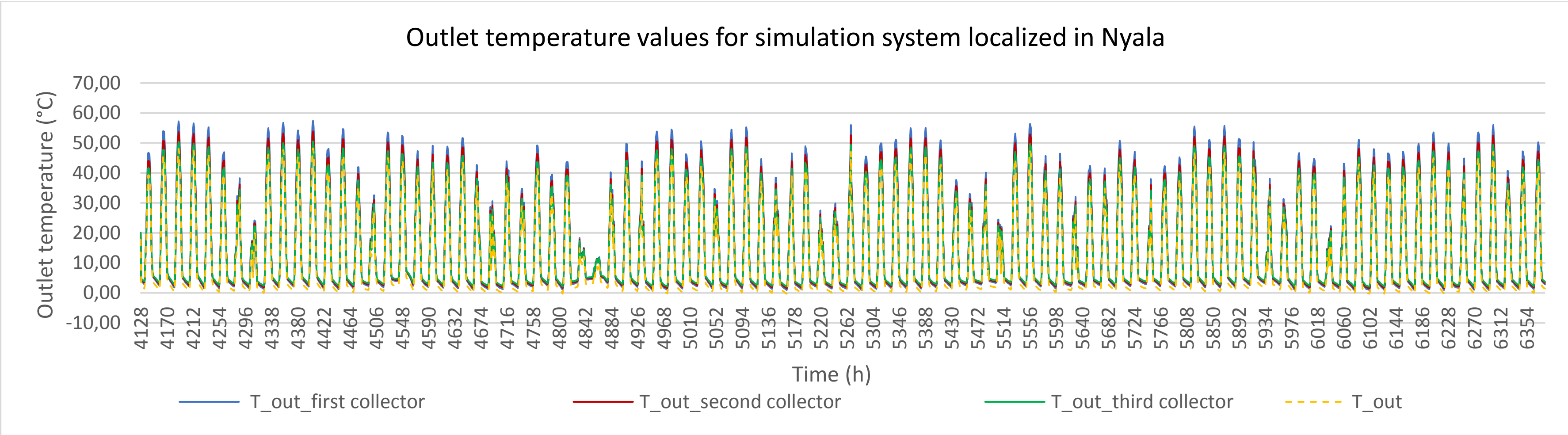

Figure 120 - Outlet temperature values for simulation system localized in Nyala.

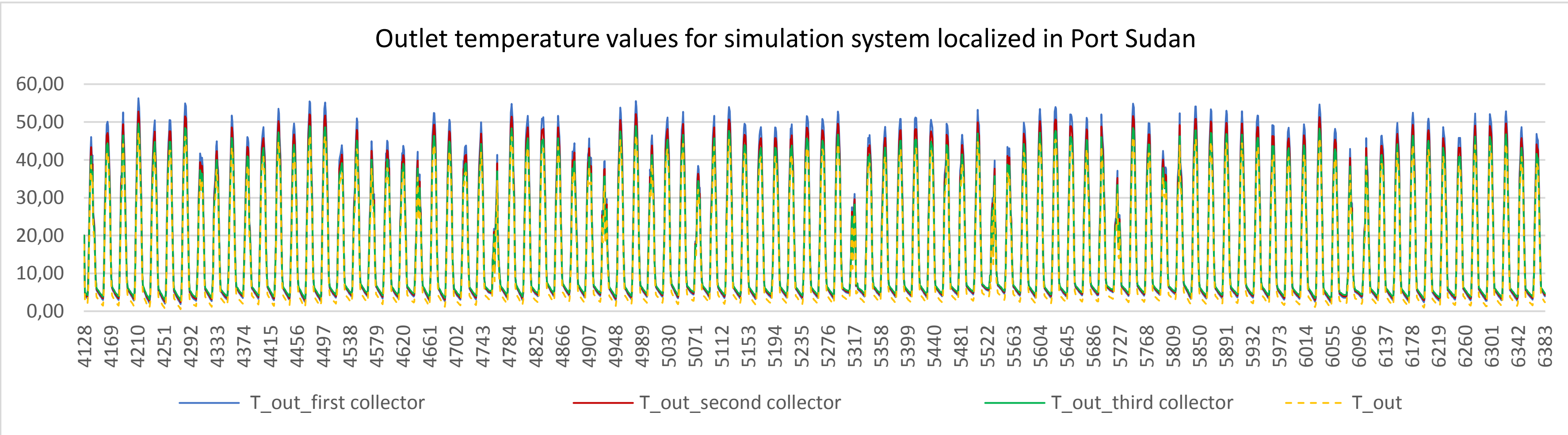

Figure 121 - Outlet temperature values for simulation system localized in Port Sudan.

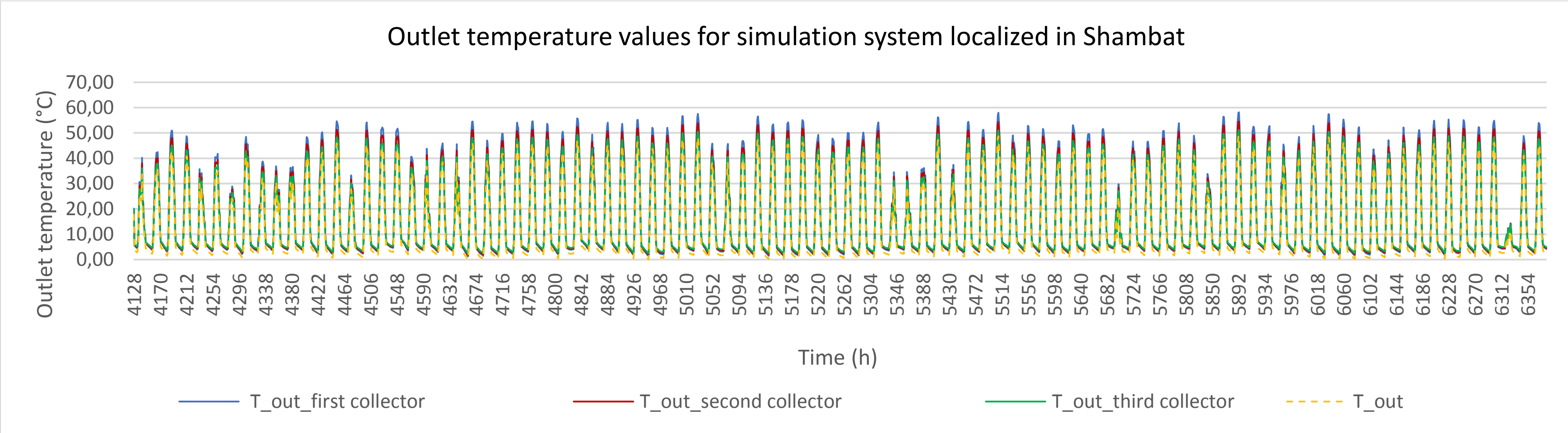

Figure 122 - Outlet temperature values for simulation system localized in Shambat.

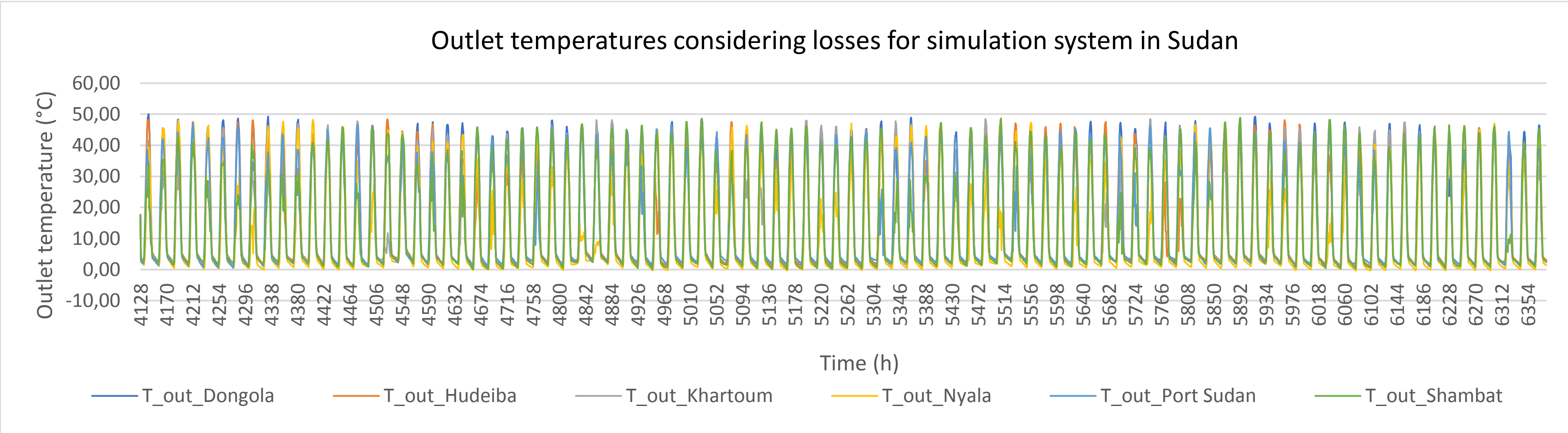

Figure 123 - Outlet temperature considering losses for simulation system in Sudan

4.7 Results of Trnsys for Tunisia

Tunisian location listed in *Table 111* for which are available weather data is the capital *Tunis* on the Atlantic Ocean coast.

Figure 124 - Physical map of Tunisia with locations with meteorological stations of Trnsys.

In Figure 125*, there are the* humidity ratio *trend in the only one location in Morocco during the time period established.*

In *Table 118*, there the *monthly average temperature* for the Moroccan location:

Temperature [°C]				
Location	June (21^{st}-30^{th})	July	August	September (1^{st} - 23^{rd})
Tunis	22,9	26,4	26,8	24,2

Table 118 - Monthly average temperature in Tunisian location.

Starting the simulation system, in *Figure 86*, for each location in Tunisia for which are available weather data, it is possible to obtain four *outlet temperature* values: out the three collectors and the outlet temperature considering the dissipated power. Plotting all data from 21st June to 23rd September every 1 hour (*Figure 126*).

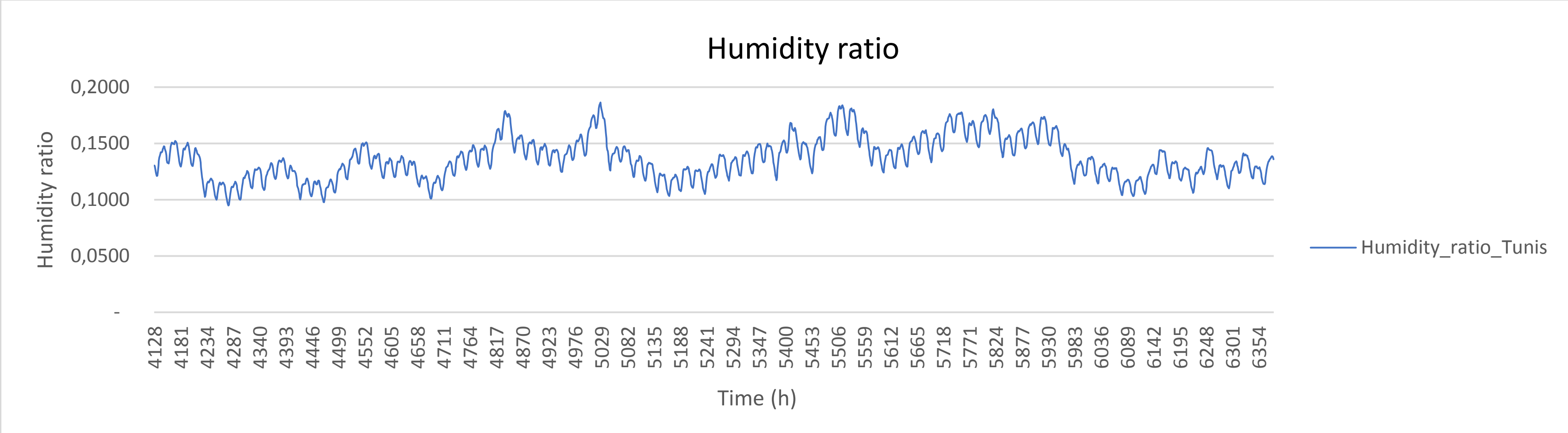

Figure 125 - Humidity ratio in Tunisian location.

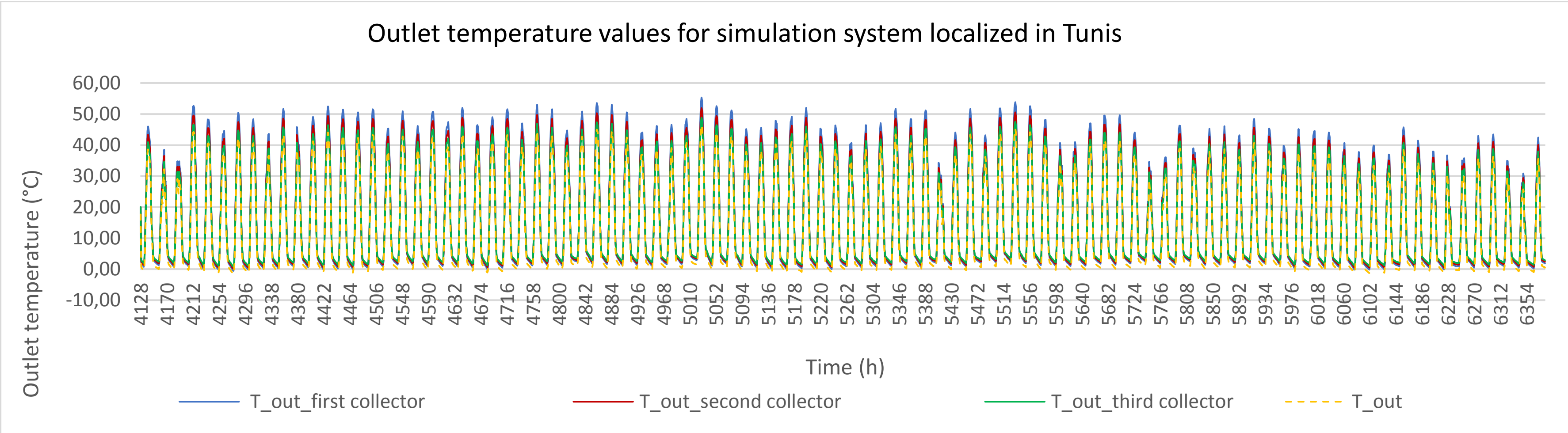

Figure 126 - Outlet temperature values for simulation system localized in Tunis

CHAPTER 5

5. Conclusion

The analysis presented in the previous chapters shows that for the countries of Northern - Africa there is the need to find new technologies for the production of fresh water. In fact, water is essential for local agriculture, especially during periods of the year when it is particularly scarce and difficult to find it. Agriculture for the countries of Northern - Africa represents an important part of the economy and livelihood of the population. New sources of fresh - water production would guarantee a better crop, an increase in national employment and new life prospects for the peoples of Northern - Africa.

The need for new sources of water production is also due to the sharp increase in the population of the Africa area analyzed, the low availability of natural water and the growing population have led Algeria, Libya, Sudan and Tunisia being under the absolute water scarcity threshold of 500 m^3/year per capita. Given that the population of Northen - Africa will tend to increase more and more, it is essential to find a rapid solution for the production of fresh water by new technologies. The geographical position and the presence of wide expanses can help to find a possible solution to the lack of water.

In this scenario, in fact, it is possible to introduce the assembled prototype in the laboratory of the Energy Department (DENERG) of the Politecnico di Torino. It is composed by an adsorption heat exchanger and a condenser with a heat recovery system. The adsorption system contains about 20.5 kg of silica gel grain with an average diameter of 3 mm. The heat is supplied to that system by a water circulation between 50-80 °C, produced by an electric resistance of 1.25 kW. The condenser is composed by an air to air heat recovery system and an air to water radiator which is used to condense the hot and humid stream, through cold water taken from water network, at around 20°C (*V.Gentile,M.Simonetti,P.Finocchiaro,G.V.Fracastoro).* The aim of prototype is to catch the water vapor from air and the water vapor condenses with a low range temperature, 50 – 80 °C.

In chapter 4, with the help of Trnsys, different locations were considered in the six countries of Northern - Africa where it could install solar collectors connected to this prototype. The period of time considered combines with the summer (June 21 - September 23) the period of greatest drought and minor water precipitations. The geographical position, very close to the equator, and

the meteorological conditions help to suggest a possible installation of the prototype. A risk could be that the water that is produced could be used for the maintenance and cleaning of the collectors. In fact, all the countries of North Africa border or have in their borders the Sahara desert.
A system of this type can be useful in a rural area and in an area close to the municipalities even if the main problem could be that of the space given the high density of population of the countries of Northern - Africa.

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