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The American University in Cairo

School of Science and Engineering

Impact of Global Warming on Dissolved oxygen Concentrations In River Nile and on the Waste Allocation Plan of the River (Present and Future plan)

By

Rawnaa Imam Yassin

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science in Environmental Engineering

Under the supervision of

Dr. Sherine Ahmed Elbaradei

Assistant Professor at the Construction Engineering Department

The American University in Cairo

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Abstract

Water is the hub of life and driver of nature. That is why water quality is one of the most important concerns nowadays all over the world. Monitoring and improving water quality is considered as one of the key factors in the water quality management strategies.

Water quality is extremely important to all countries and particularly in regions that depend mainly on water as a main source of life, like Egypt. The River Nile is a main source of life in Egypt.

As much as water and water quality are of significant importance also climatic change and global warming have the same importance, it is one of the most investigated issues nowadays and definitely it is going to affect the future of mankind on earth. Global warming affects all aspects of life; i.e. humans, animals, water…etc. and this means it is affecting the ecosystem which in turn affects the whole life on planet earth and the most important that it has a great effect on water quality in rivers.

That is why the aim of this study is to investigate the impact of global warming on river Nile water quality; especially on dissolved oxygen (DO) concentrations. The study is done on the Nile River in Egypt at three monitoring stations; namely at Luxor governorate, at Alexandria governorate and the Capital Cairo.

A mathematical model is constructed to simulate the DO concentrations at different water temperatures. The study is investigating two scenarios; namely it simulates the critical DO concentration in summer (month August) where the Nile reaches its peak discharge in Egypt. Also it simulates the DO values in winter (month February) where the lowest discharge in the Nile in Egypt is reached.

The study used air temperatures over the last 30 years to predict the Nile River water temperatures at the three above mentioned stations. Also in this research a mathematical model was developed to predict air temperatures from 2013 till 2030 and hence predict the values of water temperatures and DO concentrations for the same period of years (2013-2030).Also the further effect of global warming on the location of water and waste water treatment plants on the river Nile was studied.

It was found that the values of the critical DO concentrations decreased over the years according to the global warming effects: at Luxor it decreased in February by 3.99% and by 4.26 % in August, In Cairo it decreased in February by 4 % and in August by 4.8 % whereas at Alexandria it decreased in February by 1.34% and in August by 5.16%.

It is observed that global warming has a negative impact on the DO concentration values in the River Nile, according to the range of initial DO concentration values that were investigated for this study. DO critical concentrations values decreased significantly with the increase of air temperatures. Also it was found that global warming has a considerable effect on the locations of the water and waste water treatment plants on the river and thus on the waste allocation plan.

Chapter 1
Introduction

Water is one of the main sources of Life on earth, all life aspects are mainly depending on water. But just how much water exists on, in, and above our planet? About 71 percent of the Earth's surface is water-covered

The majority of water on the Earth's surface around 96 % is saline water in the oceans. And only 3 % is fresh water (1)

This small percentage of fresh water increases the importance of water and water quality management systems

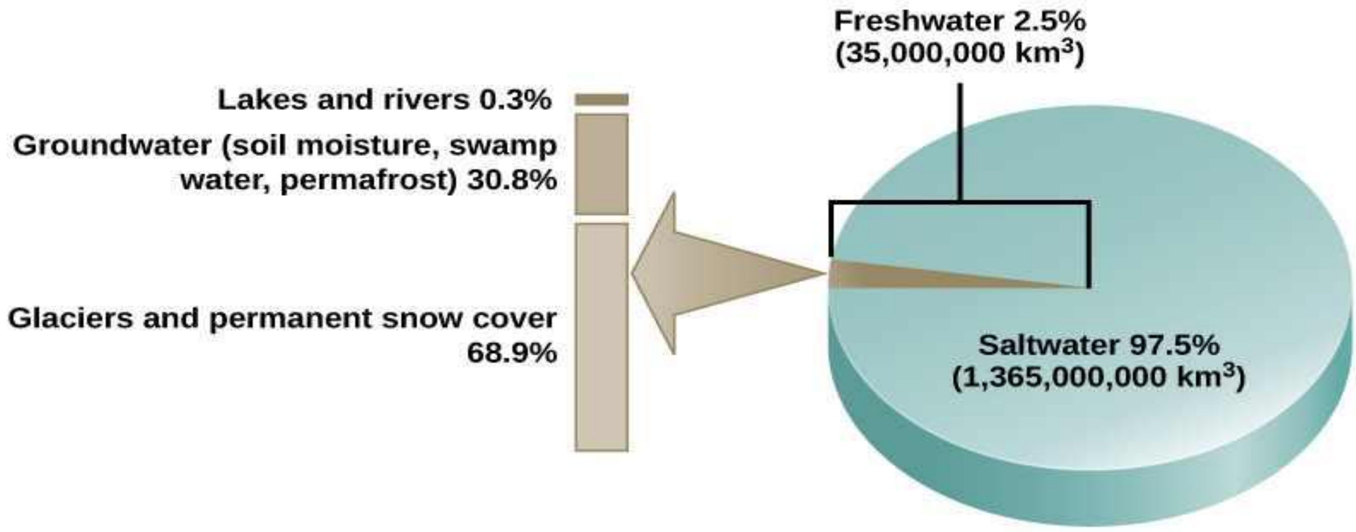

Figure 1.1 water on Earth (2)

A great effort is done in studying water quality and the parameters affecting this quality. The most influent parameters affecting water quality are: the water temperature (Tw) and the dissolved oxygen concentrations (DO).

The DO concentration is an essential indicator of the quality of water used human as well as aquatic flora and fauna. DO is very essential for aquatic life. It is maintained by natural chemical and biological processes that either increase or decrease local oxygen concentrations.

One of the most arising issues that could affect water quality is climate change and global warming. Global warming causes a significant increase in temperature this increase in temperature reduces the solubility of oxygen in water and hence minimizes the oxygen level in water.

Human activities are one of the main causes for the increase in the global temperature which is a great threat to the environment and Mankind. Many studies were carried to show what is Global warming, its causes and dangerous impacts.

1.1 Global warming and Climate Change

Global warming is a gradual increase in the overall temperature of the earth's atmosphere generally attributed to the greenhouse effect caused by increased levels of carbon dioxide, CFCs, and other pollutants(3).

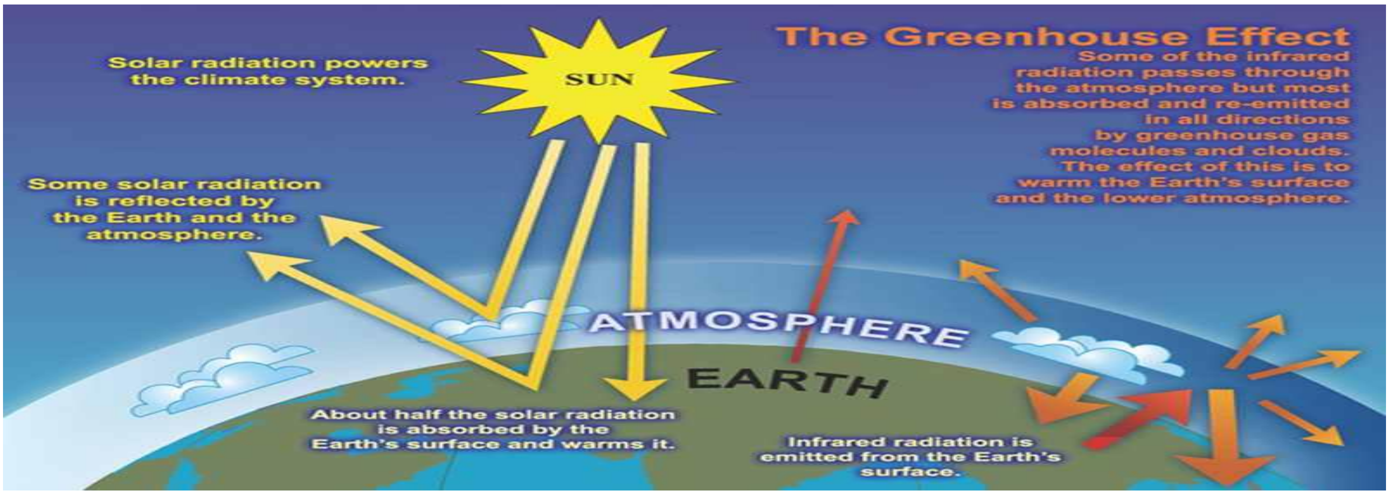

Figure 1.2 Earth and Global warming (3)

Scientists have documented the rise in average temperatures worldwide since the late 1800s. Earth's average temperature has risen by 1.4 degrees Fahrenheit (0.8 degrees Celsius) over the past century, according to the Environmental Protection Agency (EPA) (3).

Temperatures are projected to another rise from 2 to 11.5 degrees F (1.133 to 6.42 degrees C) over the next 100 years. Most of the leading scientific organizations in the world acknowledge the existence of global warming as fact, according to a NASA report. 97 %of climate scientists agree that the rate of global warming trends the planet

is now experiencing is not a natural occurrence, but is primarily the result of human activity. That consensus was made clear in a major climate report released Sept. 27, 2013, by the Intergovernmental Panel on Climate Change (IPCC) (4).
In that report, climate scientists indicated they are more certain that there is a link between human activities and global warming.

In its fifth assessment (AR5) in 2014 the (IPCC) reported that most of global warming is caused by increasing concentrations of greenhouse gases and other human (anthropogenic) activities. Climate model projections summarized in AR5 indicated that during the 21st century the global surface temperature is likely to rise from 0.3 to 1.7 °C (0.5 to 3.1 °F) for their lowest emissions scenario using stringent mitigation and 2.6 to 4.8 °C (4.7 to 8.6 °F) for their highest (4). These findings have been recognized by the national science academies of the major industrialized nations.

Many Studies have discussed the global warming and the climate change and in order to get the full picture we have to go through the causes and effects of global warming as well as the protocols signed to eliminate global warming.

1.2 Causes of Global warming

Climate is responding to various changes, These Change can push the climate system towards warming or cooling among these Causes are: the increased concentration of greenhouse gases, Solar radiation, human activities volcanic eruptions and the rotation of earth around the sun orbital cycles that can take more than ten thousand years but may cause cooling But Scientists and researchers have recorded a significant rise in the earth temperature (5).

We will go through the most important causes of global warming:

1.2.1 Green House gases

Most climate scientists stated that the main cause of the current global warming is human expansion of the "greenhouse effect "warming that result when the atmosphere traps heat radiating from Earth toward space (6)

Certain gases in the atmosphere block heat from escaping. Long-lived gases that remain semi-permanently in the atmosphere and DO not respond physically or chemically to changes in temperature are described as "forcing" climate change, among these are: Water vapor, Carbon dioxide (CO_2), Methane, Nitrous oxide, Chlorofluorocarbons (CFCs).

1.2.2 Human Activities

On Earth, human activities are changing the natural greenhouse. Over the last century the burning of fossil fuels like coal and oil has increased the concentration of atmospheric carbon dioxide (CO_2). This happens because the coal or oil burning process combines carbon with oxygen in the air to make CO_2. To a lesser extent, the clearing of land for agriculture, industry, and other human activities have increased concentrations of greenhouse gases. The industrial activities that our modern civilization depends upon have raised atmospheric carbon dioxide levels from 280 parts per million to 400 parts per million in the last 150 years (7) The panel also concluded there's a better than 90 percent probability that human-produced greenhouse gases such as carbon dioxide, methane and nitrous oxide have caused much of the observed increase in Earth's temperatures over the past 50 years.

1.3 Impacts of Global warming

Global warming has a significant and costly impact on environment and all aspects of life, humans, animals, plants, weather and water. A few of them will be stated, the impact on water quality will be discussed in details later in this study Among the impacts of global warming are:

1.3.1 Accelerating sea water rise and coastal flooding

Global warming is now accelerating the rate of sea level rise, increasing flooding risks to low-lying communities and high-risk coastal properties (9)

1.3.2 More Intense heat waves

Dangerously hot weather is already occurring more frequently than it did 60 years ago—and scientists expect heat waves to become more frequent and severe as global warming intensifies (9). This increase in heat waves creates serious health risks, and can lead to heat exhaustion, heat stroke, and aggravate existing medical conditions.

1.3.3 Costly and growing health impact

Climate change has significant implications for our health. Rising temperatures will likely lead to increased air pollution, a longer and more intense allergy season, the spread of insect-borne diseases, more frequent and dangerous heat waves, and heavier rainstorms and flooding. All of these changes pose serious, and costly, risks to public health.

1.3.4 Disruption to food supplies

Rising temperatures and the accompanying impacts of global warming — including more frequent heat waves, heavier precipitation in some regions, and more severe droughts in others — has significant implications for crop and meat production. Global warming has the potential to seriously disrupt our food supply, drive costs upward, and affect everything from coffee to cattle, from staple food crops to the garden in your backyard.

1.3.5 Impacts of global warming on ecology

Climate change is expected to aggravate current problems for ecosystems. In general, two ecological responses to climate change can be distinguished. These are a shift in the geographical range of species and a changing phenology (the timing of life-cycle events). On a micro scale it is expected that higher temperatures and eutrophication (an existing problem but exacerbated by climate change) will lead to increased phytoplankton blooms. In particular, nuisance cyanobacteria are expected to benefit from climate warming. Changes in the dynamics and composition of hytoplankton lead to food mismatches between zooplankton and phytoplankton. These mismatches might lead to food mismatches higher in the food chain, which would have a strong impact on the ecosystem.

Harmful bacteria, such as Clostridium botulinum and Legionella pneumophilia, are also expected to benefit from climate warming. On a macro scale, climate warming is mainly expected to cause changes in species phenology, physiology and species composition. Increased water temperature is an important cause of changes in aquatic species composition and diversity and lifecycle dynamics. However, changes in aquatic species composition due to climate change are so far not well documented in the Netherlands. Extreme weather events are expected to negatively influence the diversity of macro in vertebrates. Disturbed ecosystems are more vulnerable to invasive species. Invasive species can have devastating impacts on ecosystems, and some are expected to increase due to climate change.

1.3.6 Impacts of global warming on Mankind

Changing water quality due to climate change is expected to affect social functions such as public health, recreation, agriculture and industry. Water- and vector-borne diseases might increase as a result of climate change. Drinking water supply might also be negatively affected. Recreation is expected to increase due to higher temperatures in the summer but cyano bacterial blooms in recreational waters will restrict their recreational value. Agriculture is influenced by climate change in both positive and negative ways.

Crops are sensitive to direct changes (temperature, precipitation) and indirect changes (prevalence of pests, altered water quality). With regard to power plants, problems with cooling water, and therefore energy production, might occur in the future.

1.3.7 Impact on water surfaces

As global temperatures rise, so too DO average sea surface temperatures. These elevated temperatures cause long-term damage to coral reefs. Scientists have documented that sustained water temperatures of as little as one degree Celsius above normal summer maxima can cause irreversible damage.

Global warming has also a very dangerous effect on the water rivers surfaces as the water river temperatures will rise causing the DO (dissolved oxygen) to decrease and thus highly threatens the aquatic life and Human health and this will be the core of this study.

This study will discuss the impact of global warming on river water quality. As one of the major factors affecting dissolve oxygen in streams is high temperatures, the study is developed to discuss this impact on the water of river Nile in Egypt.

1.4 Kyoto Protocol

The world governments have given a great care of the global warming and climate change. They have signed lots of agreements and protocols trying to decrease the effect of global warming through the whole world. The most distinguished protocol is Kyoto protocol (10).

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its Parties by setting internationally binding emission reduction targets. Recognizing that developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity, the Protocol places a heavier burden on developed nations under the principle of "common but differentiated responsibilities"(10).

Chapter2

Literature Review

Impact of Global warming on Water resources

As previously mentioned that global warming has a negative impact on all aspects of life especially water. Once water quality is affected by the global warming; human, animals, plants are all affected too. The relationship between water, energy, agriculture and climate is a significant one. More and more, that relationship is falling out of balance: food, water and energy security.

Climate change is a phenomenon we can no longer deny as its effects have become increasingly evident worldwide. On the list of warmest years on record, almost every year since 1992 is included and, according to NASA and NOAA data, 2015 was the hottest. As the earth's temperature continues to rise, we can expect a significant impact on our fresh water supplies with the potential for devastating effects on these resources (11).

Due to the arising importance of the discussed issue in this chapter we will go through some of the published researches and Papers that studied the impact of global warming on water resources. These published researches and studies investigated the effect of global warming on dissolved oxygen levels in streams and rivers.

2.1 Potential Effect of Climate Change on Surface Water Quality in North America

Murdoch et al. Carried out a research to indicate that changes in climate can have a significant effect on the quality of surface waters. Changes in water quality during storms, snowmelt, and periods of elevated air temperature or drought can cause changes that exceed thresholds of ecosystem tolerance and, thus, lead to water-quality degradation (12).

Warming and changes in available moisture occur, water-quality changes will first occur during phases of climate-induced stress, and in ecosystems where the factors controlling water quality are sensitive to climate variability. Continued climate stress would increase the frequency with which ecosystem thresholds are exceeded and thus results to chronic water-quality changes. Management strategies in a warmer climate will therefore be needed that are depending on local ecological thresholds rather than annual median condition.

As human population and activities on the landscape inevitably increase in the coming years, tensions between the water resource requirements of humans and natural ecosystems will grow. Establishing long-term monitoring of the ecosystem processes is highly needed.

2.2 Impact of Climate Change on Water Quality in the Netherlands;

Verweij et al. did a research that focused on the expected impact of climate change on water quality, including effects on ecology, human health and some economic sectors. RIVM therefore recommends authorities not to develop new policy but to incorporate what is the incoming possible impact of climate change into existing policy (13).

This research described the impact of climate change on water quality in the Netherlands. The report was based on a literature study and interviews with experts. The effects of a changing climate on water quality are shown in terms of changing physical and chemical processes, changing ecology and the influence on humans.

The Dutch Meteorological Institute (KNMI) developed four climate scenarios (G/G+ and W/W+) for the Netherlands. Recent scientific developments have led to the belief that the worst-case scenarios W/W+ are most likely for the Netherlands.

In all the scenarios it was discovered that climate change will reduce the physico-chemical water quality. Ecosystems in Netherlands are under great pressure due to eutrophication, pollution and habitat fragmentation. Climate change is expected to aggravate current problems for ecosystems.

2.3 Use of Air-Water Relationships for Predicting Water Temperature

V. Kothandaraman and R. L. Evans did this study to investigate the nature of seasonal and non-seasonal variations in the daily mean water temperatures of the Illinois River at a given location and to develop a method for predicting water temperatures based on observed meteorological data (14). Such a model for water temperature variations would be invaluable for predicting the responses of water bodies to any additions caused by power plant operations. This research didn't study the effect of varying temperatures on water quality in rivers.

Fourier analysis applied to the observed average daily ambient air and Illinois River water temperatures at Peoria, Illinois, indicates that the harmonic with a periodicity of one year is about 80% of the total variance in the average daily dry air temperatures and about 95% of the total variance in the water temperatures.

A mathematical model is done to predict the annual cyclic trend in the water temperatures from the air temperature records. Values for the parameters of the mathematical model were evaluated by the use of the 1969 water and air temperature records for Peoria. These parametric values, in conjunction with the ambient air temperature records for Havana, were used to predict Illinois River water temperatures at Havana for the years 1968 and 1969 excellent agreement was found between the predicted and observed water temperatures.

2.4 Stream Temperature Estimation From Air Temperature

Heinz G. Stefan & Eric B. Preud carried out this research to conclude an equation that relates air temperature to water temperature in streams. Mississippi river was their case study(15).

They were able to drive theses general equations: Tw= 5.0 + 0.75 Ta and Tw= 2.9 + 0.86 Ta with temperatures in °C, were derived for daily and weekly water temperatures, respectively, for the 11 streams studied. The simulations had a standard deviation between measurements and predictions of 2.7°C (daily) and 2.1°C (weekly).

They didn’t study the effect of the temperatures on water quality. None of the water quality parameters were examined after detecting the equations relating air and water temperatures.

2.5 Effects of Global warming on Critical Dissolved Oxygen Concentrations and on DO Sag Curve in the Nile River

This research was done to investigate the effect of global warming on the DO critical concentrations in the Nile River in Egypt (16). Two stations were chosen: Alexandria and Luxor (both are Egyptian governorates). Luxor is at the upstream of the Nile River in Egypt; whereas Alexandria is at the downstream of the Nile River in Egypt.

El Baradei and El Baz did this study to calculate the effect of global warming DO concentrations in the river Nile over a period of 23 years from 1990 to 2013. A mathematical model was developed on a spreadsheet to calculate the water temperature from air temperature and then calculating the critical DO concentrations as a result of the water temperatures.

From the previous examples and so many unmentioned researches it could be seen that researches didn't directly relate the effect of air temperatures and hence water temperatures on the water quality in a quantifying manner addressed via equations and predictive mathematical model. The only research did this was EL Baradei and El Baz but this research didn't predict the future impact and only calculated the critical Do concentrations.

Chapter 3

Methodology and Model Formulation

The objective of this thesis is to study the impact of air and water temperatures on the values of critical Dissolves Oxygen (DO) concentrations in Nile River. The DO concentration is the most important parameter when it comes to examining and detecting the water quality because living fauna and flora can't survive without DO. Also the water quality deteriorates significantly if DO drops below certain values (in rivers this value is 5 mg/l).

In order to satisfy the objective of this thesis a mathematical model of 3 sub models was developed to calculate the air temperatures, water temperatures and finally the Critical Dissolved oxygen concentrations.

This Chapter we will discuss the three parts of the mathematical model starting with air Temperature part, next to the water temperatures thus ending up with critical dissolved oxygen concentrations.

3.1 Air temperature Sub-model

Global warming and the significant rise of air temperatures in the last years was studied by many papers and researches, it was proven by many scientists and as previously mentioned many international agreements, conventions and conferences were held to discuss global warming and trying to reduce all the emissions that cause global warming.

Although this thesis didn't depend only on the previous investigations, a mathematical sub model was constructed to detect the air temperature rise since year 1983 till year 2013 and also predicting air temperature rise from year 2013 till year 2030 for the studied period and destinations.

3.1.1 Procedure of air temperature sub-model.

This model depends on credible information extracted from different weather forecast websites which all had nearly the same reading of temperatures for the time period 1983-2013. One of the main sources of this model is weatheronline.co (17) which had a daily air temperature for the periods and destinations studied in this research, will be discussed later in the case study.

The first component of the sub-model was extracting the maximum and minimum daily air temperature for both the months and Nile reach studied.

Daily air temperatures were extracted from weatheronline.co (17) to get the average of the maximum and minimum temperature. Below is a screen shot from the website graphs the daily air temperature was extracted from as an example.

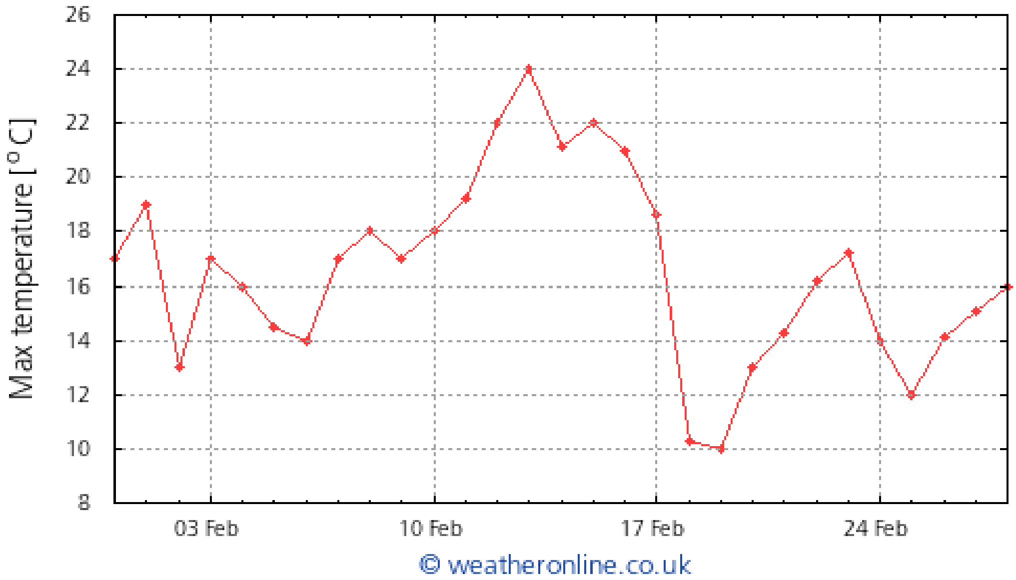

Figure 3.1 Maximum daily air temperatures for February

The second component of the sub- model after extracting the daily temperatures from all graphs, was calculating an average for both the maximum and the minimum temperature for the months and Nile reach studied during the years 1983-2013.

The Third Component of this model is predicting the maximum and minimum air temperatures for the time length and destinations studied starting from year 2013 till year 2030. This was developed on excel spread sheet; a curve was concluded from the previous average air temperatures calculated then an equation was developed for each curve with the best regression fit to give the results.

3.2 Water temperature Sub-model

In this part water temperature will be predicted from the previous air temperatures. Many papers and researches developed equations to calculate water temperature from air temperature. In this thesis water temperatures were calculated using the equation of Heinz (15) which takes in consideration the lag time between air and water temperature.

Also Heinz equation was designed to estimate the water temperature of the Mississippi river which has the same climatic, hydrology and hydraulic conditions as river Nile (15).

The equation gives a linear relationship between daily air temperatures and daily water temperatures and the lag time.

The model for calculating water temperature is developed on excel spread sheet using Heinz equation and previous calculated air temperature from 2009 till 2030 for the Nile reach and months under consideration. Real life data for water temperature and DO values were only available for 2009 and 2010.Those available real life measurements (19) were used as initial values and also to calibrate and validate the model.

3.2.1 The governing Linear equation between air and water temperature (Heinz equation):

$$Tw = A + B\ Ta\ (t - \delta) \quad \text{......................equation 1 (15)}$$

Tw: water Temperature in degree Celsius

A: is the first regression coefficient, it is estimated by substituting 2 real life measurements of air temperature and water temperature for years 2009 and 2010 (available data as mentioned before) for Luxor, Cairo and Alexandria during February and August. So this leaves us with 4 values of the regression coefficient for each city; 2 values for February and 2 values for August.

Then the average coefficient “A” between year 2009 and year 2010 was taken to calculate the water temperatures for the successive years.

B: is the second regression coefficient it represents the slope of the line linking the water temperature with the air temperature and it can be calculated through the following equation:

$$\frac{\Delta Twater}{\Delta Tair} = \frac{1}{\sqrt{1 + \left(\frac{2 * \pi * depth}{\tau * \alpha}\right)^2}} \quad \text{......................equation 2}$$

Ʈ= is the cyclic period here it is 29 days

ą = is the thermal diffusivity coefficient alpha

ą = K/Cp*ῥ

K= Surface heat exchange coefficient between the water surface and air in W/m2.℃ and it is a function of wind speed and average water temperature and is obtained from charts and tables (19)

Cp = Specific heat Constant of water and it is constant, 4200 W.S/Kg. C

ῤ = Water density and it is 1000kg/m3

δ = Ʈ/ 2*Π * tan-1 (2 Π* depth/ Ʈ* ᾳ) this is the lag time for example if lag time is calculated to be 3 hours then the water temperature at 1 pm is a function of the air temperature at 10 am

Depth= h it is the water depth at each of the 3 cities and it is as follows:

At Luxor h is = 8m in February and 11m in August

At Cairo h is = 5m in February and 8m in August

At Alex. h is = 2.5m in February and 5.5 m in August

By fulfilling all these parameter and plugging those into equation 1, water temperatures can be calculated for the 3 cities during February and August from 2009 till 2030 and this can be shown through the case study.

3.3 Dissolved oxygen Calculations

DO is the most important parameter for water quality assessment, if it reached its critical value it is very dangerous to the aquatic life and also for Mankind (20).

Dissolved Oxygen concentration is inversely proportion to water temperature if water temperature is low the DO is high which is healthy But if the temperature is high the DO concentrations are low which gives very poor water quality.

In this section the values of the critical dissolved oxygen concentrations will be calculated to determine the direct impact of the increasing air and water temperature on the critical dissolved oxygen concentration.

Critical dissolved oxygen concentrations are very vital to the water quality management process; it is very fatal if dissolved oxygen concentrations went below this value.

3.3.1 Procedure of Calculating Critical Dissolved Oxygen Concentration

To calculate the Critical Dissolved Oxygen concentrations the critical time should be calculated first by the following equation:

Tc=1 /(k2-k1)*ln*(k2/k1(1- DO*(k2-k1)/K1*lo)…………..equation.3

Tc = is the critical time in days

Lo= is the biological oxygen demand in water (real life measurement) in mg/L

DO= is the initial deficit dissolved oxygen concentration (DO) in mg/L

K1= Decomposition rate, in day-1, it is measure any at any temperature by the following equation:

$K1= (K_1)_{20^\circ c}*(1.047)^{T-20}$

Where $(K_1)_{20^\circ c}$ = 0.052/day and T is stream temperature which is the water temperature (Tw)

K2= Re-aeration rate, in day-1, it is measure any at any temperature by the following equation:

$K_2= (k_2)_{20^\circ c} *(1.024)^{T-20}$

Where $(k_2)_{20^\circ c}$ = 0.048/day and T is the stream temperature which is the water temperature (Tw).

After calculating the critical time at which the value of dissolved oxygen is critical the Tc will be used in Streeter-Phelps equation to get Dc which is the critical deficit dissolved oxygen concentration.

Streeter Phelps equation:

$$\mathbf{D_{t} = K_1*Lo/K_2-K_1*(e^{-k1t}- e^{-k2t}) + DOe^{-k2t}} \quad \text{.................... eq. (4)}$$

Streeter Phelps equation is used to calculate for point source waste load where t here will be the t_c so D_c can be calculated for the 3 cities during February and august and then D_c will be plugged in the following equation to get C_c which is the Critical dissolved oxygen concentration:

$$\mathbf{D_c= C_s- C_C} \quad \text{.. eq. (5)}$$

Where Cs is the DO saturation Concentration in mg/l, As DO concentration values it depends on water temperature values accordingly

Summing up the three sub models, calculating and predicting the air temperature then using Heinz equation to calculate the water temperature in River Nile depending on the calculated air temperatures Finally calculating the DO concentration values to prove the direct effect of global warming on water quality. This can be shown in the following figure:

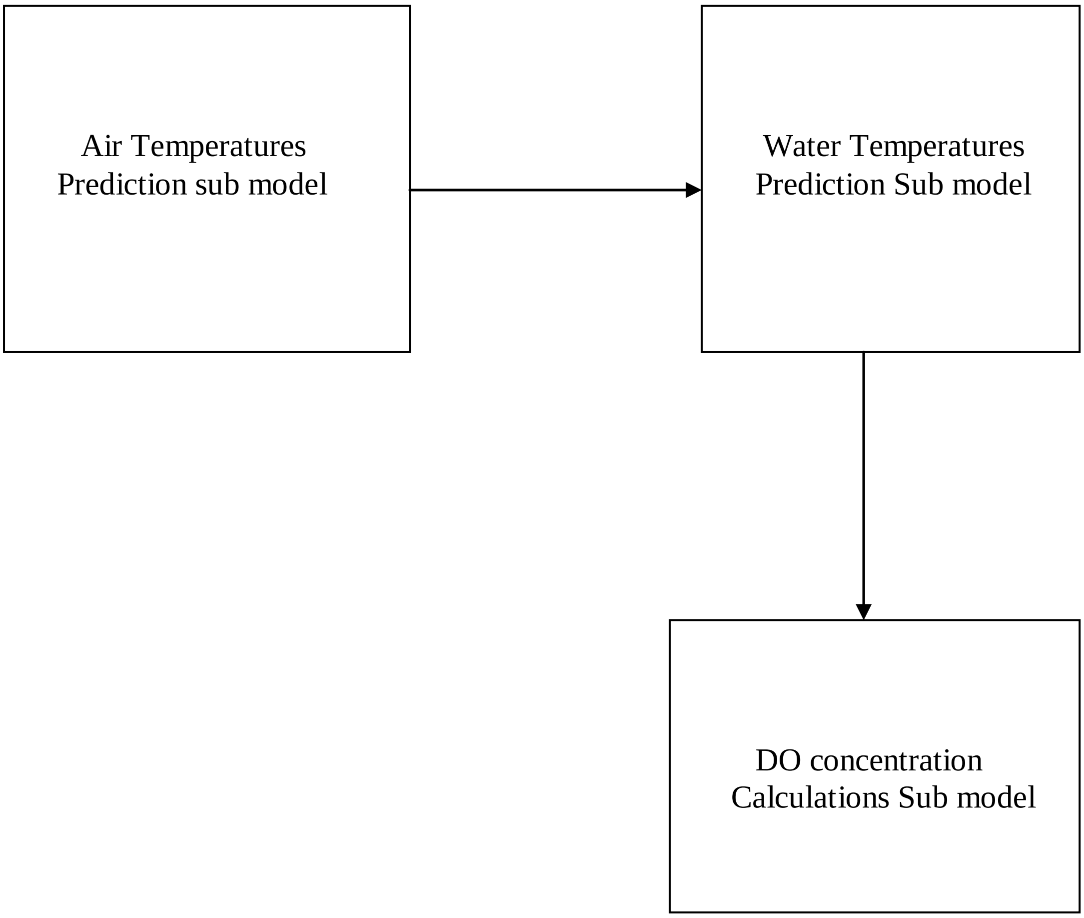

Figure 3.2 Mathematical model flow chart

Chapter 4

Case Study Nile River :(Luxor, Alexandria, Cairo reach)

In this chapter the 3 mathematical sub model mentioned in the previous chapter will be applied to the case study River Nile in 3different cities: Luxor, Cairo and Alexandria during summer and winter from year 1983 till year 2030.

In this research those three main stations were taken along Egypt; one in the South of Egypt which is Luxor governorate, the other one is in the North of Egypt which is Alexandria governorate and the Capital Cairo which is nearly in the middle of Egypt. February and March were the months taken in this simulation as February represent winter when the lowest discharge of River Nile happens and August represent summer when the peak discharge or river Nile occurs.

The following tables and charts will represent the calculations and results for each sub model.

4.1 Air temperature calculations and results

The maximum and minimum air temperatures are calculated for the 3 cities: Luxor, Cairo and Alexandria during moths February and August starting from year 1983 till year 2013, then a curve was drawn for each city in each month to conclude the equation governing the air temperature rise in each case and hence this equation is used to predict the future air temperatures from year 2013 till year 2030 as shown in the following tables and charts. Table 4.1 is shown as an example and the rest of tables from table 4.2 till 4.12 are in the Appendix.

Table 4.1 Luxor February Maximum air Temperatures

Maximum Temperature	-													
February														
Luxor														
Year	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14
1983	21.0	21.0	23.0	20.0	21.0	22.0	20.0	21.0	24.0	25.7	26.0	26.0	28.0	29.7
1984	26.0	31.0	30.0	28.0	28.0	27.0	22.0	22.0	23.0	27.0	28.0	26.5	21.0	22.0
1985	22.5	18.5	19.0	21.0	22.0	22.0	21.0	22.0	23.5	24.0	25.5	28.0	28.0	30.0
1986	24.0	27.0	27.0	30.0	29.0	24.0	22.0	24.0	27.0	22.5	23.0	25.0	27.0	28.5
1987	30.0	32.0	34.0	23.7	23.0	24.0	25.0	26.0	21.8	22.0	21.0	23.0	28.0	30.0
1988	22.0	19.8	20.0	22.0	26.0	30.0	25.0	24.0	24.0	25.0	24.0	30.0	22.0	23.0
1989	20.0	20.0	20.0	22.0	20.0	22.0	23.0	24.0	24.0	20.5	20.0	20.5	19.0	17.0
1990	27.8	22.0	22.0	21.0	21.5	20.0	20.0	20.3	22.0	21.0	20.0	21.0	22.0	25.0
1991	20.0	21.0	21.0	21.0	21.0	22.2	23.0	20.0	22.0	22.2	23.0	23.5	23.7	24.2
1992	18.3	20.0	20.0	15.0	17.0	19.0	19.0	18.5	17.9	14.0	16.3	18.5	19.8	21.0
1993	21.0	20.0	14.5	18.0	15.0	16.2	19.0	21.0	22.0	16.0	17.0	18.0	21.0	20.0
1994	17.0	17.0	21.0	21.0	23.0	24.0	26.0	27.0	21.7	23.0	22.8	21.0	21.5	22.0
1995	23.0	26.0	25.9	19.0	21.7	20.5	21.0	19.0	19.0	18.5	21.0	23.0	26.0	25.8
1996	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1997	20.5	20.0	20.5	21.0	20.0	17.8	20.0	21.5	21.5	22.0	20.5	21.0	22.0	22.0
1998	28.0	28.5	30.5	29.7	30.0	31.8	27.8	24.3	23.0	20.5	21.0	21.0	21.5	21.5
1999	26.0	27.8	29.0	32.0	31.0	26.0	22.5	26.0	27.9	27.0	27.0	28.0	29.9	29.9
2000	22.0	24.0	24.5	25.0	20.5	20.5	20.5	14.2	21.8	22.0	21.8	23.7	23.0	23.7
2001	28.5	27.8	28.5	21.7	22.0	23.5	23.0	23.5	23.5	22.0	24.5	26.5	26.5	25.7
2002	25.7	25.9	26.3	26.3	27.8	28.0	30.5	28.2	28.4	31.0	31.2	22.3	23.0	20.3
2003	24.0	26.2	29.0	20.0	20.3	20.5	23.7	27.8	19.8	20.2	20.0	19.0	27.0	21.8
2004	19.0	21.0	21.0	22.0	20.0	21.7	23.0	27.0	28.3	31.0	25.7	26.0	26.0	17.8
2005	28.0	23.0	24.0	24.0	21.0	21.2	21.0	22.0	20.0	20.0	24.0	23.0	20.0	18.5
2006	26.0	29.0	28.0	24.0	25.7	26.0	26.2	26.0	22.0	19.0	23.0	25.7	25.7	24.0
2007	22.2	22.4	24.0	23.0	19.0	22.2	21.7	21.0	23.8	26.2	28.0	27.8	28.0	24.2
2008	19.8	23.0	24.2	17.0	27.8	28.2	23.8	23.8	25.0	25.0	24.5	24.5	24.0	21.5
2009	24.0	23.8	25.0	26.0	29.8	32.0	31.0	28.2	29.8	32.5	21.0	23.0	27.0	29.7
2010	32.2	27.9	25.9	23.0	19.8	29.8	20.0	22.0	25.0	28.2	22.0	31.0	31.8	32.2
2011	24.2	27.8	25.8	28.0	32.2	30.5	31.0	30.0	25.7	25.7	29.0	25.0	25.0	27.8
2012	20.0	20.0	25.0	25.0	27.7	29.0	22.0	22.0	22.0	24.5	24.0	26.4	31.9	33.0
2013	20.0	22.0	22.0	25.0	30.5	30.5	22.0	24.0	26.2	26.2	25.8	26.2	24.0	25.0

Table 4.1 Luxor February Maximum air Temperatures continued

Year	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29	**Average**
1983	30.0	27.0	27.0	23.0	26.0	19.8	20.0	19.8	22.0	24.5	23.7	20.0	17.0	18.0	21.0	23.0
1984	25.0	25.0	26.0	27.0	27.0	25.5	24.0	24.0	25.0	28.0	26.0	27.0	27.0	27.0	29.0	26.0
1985	30.0	20.5	20.0	25.5	27.0	28.0	30.0	27.0	20.5	24.0	28.0	19.8	17.0	20.0	22.0	23.7
1986	20.0	21.0	23.0	27.0	25.0	28.0	30.0	30.0	29.8	31.0	29.0	27.0	28.0	32.0	32.0	26.6
1987	31.0	32.0	27.0	27.0	26.0	28.0	28.0	29.0	30.0	33.0	34.0	23.0	23.0	23.0	34.0	27.3
1988	24.0	22.0	20.0	20.0	22.0	25.7	26.0	22.0	18.0	20.0	22.0	26.0	30.0	33.7	36.0	24.3
1989	18.0	21.0	24.0	24.0	23.0	22.0	23.0	22.0	21.0	24.0	26.0	28.0	30.0	31.0	33.0	22.8
1990	28.2	25.0	26.5	28.2	27.0	20.0	21.0	20.5	21.0	22.0	21.0	20.0	24.0	25.8	27.0	22.9
1991	26.0	28.0	29.0	28.0	28.0	32.0	31.0	29.0	33.0	23.0	21.0	26.0	24.3	23.0	22.5	24.5
1992	24.0	25.0	20.0	24.0	23.7	24.0	25.0	29.0	21.7	13.7	18.0	17.0	18.0	19.8	22.0	20.0
1993	17.8	18.2	20.0	25.0	25.0	24.0	23.0	23.0	21.0	22.0	24.3	30.0	31.0	33.0	29.7	21.6
1994	23.0	23.5	25.0	23.7	27.8	29.0	29.0	24.0	22.0	21.8	22.0	24.0	28.0	23.0	24.0	23.4
1995	20.5	22.0	24.0	25.0	25.0	27.0	26.3	24.5	20.0	23.0	26.0	25.0	25.5	27.0	28.0	23.4
1996	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1997	22.2	23.7	24.5	27.7	29.0	25.8	23.0	19.7	19.0	19.7	23.8	23.8	23.0	22.2	25.8	22.2
1998	23.0	23.0	24.5	23.0	24.5	24.3	24.3	24.0	26.2	24.4	24.0	23.7	26.2	27.5	26.0	25.1
1999	22.0	22.0	25.8	26.5	25.0	23.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	26.7
2000	26.0	26.0	26.3	25.0	22.2	21.0	25.5	21.8	23.0	23.8	NA	NA	NA	NA	NA	22.8
2001	24.5	23.0	24.0	22.0	21.0	25.5	22.3	20.0	22.0	22.0	25.7	26.7	27.9	28.9	39.0	24.9
2002	23.8	25.8	27.8	27.8	25.0	25.5	26.2	30.0	31.0	32.0	24.0	24.2	25.7	25.7	26.0	26.7
2003	22.0	23.8	25.8	28.5	34.0	24.0	21.0	22.0	25.0	27.0	20.0	17.8	20.0	22.0	24.5	23.3
2004	18.0	20.2	25.7	27.0	23.0	23.5	24.2	25.0	26.0	32.0	33.0	34.0	36.0	34.0	34.0	25.7
2005	22.0	25.8	26.0	31.7	34.0	33.8	33.8	30.0	32.0	32.5	32.0	27.8	28.2	32.0	28.2	26.2
2006	27.9	22.0	20.0	20.2	24.2	28.2	29.0	32.0	28.3	28.0	33.8	33.0	33.9	34.0	36.0	26.9
2007	24.5	26.0	25.0	27.0	23.7	24.5	31.0	31.8	30.0	31.0	30.7	26.0	25.0	26.3	26.2	25.6
2008	20.0	22.3	25.7	20.0	17.8	22.0	26.2	28.0	22.0	27.8	22.0	22.2	26.0	28.2	31.0	23.9
2009	28.0	26.3	23.7	23.7	26.0	32.0	26.0	23.5	23.7	24.0	26.2	28.0	30.0	21.9	21.7	26.5
2010	33.8	35.0	36.2	36.5	37.0	35.0	35.0	37.0	34.2	31.0	31.8	33.0	24.0	25.0	30.2	29.8
2011	32.0	24.5	24.5	26.3	31.7	31.5	26.2	22.3	25.7	26.2	NA	NA	NA	NA	NA	27.4
2012	33.7	25.0	20.2	19.8	22.0	22.5	27.0	28.0	31.0	34.2	23.0	24.5	27.0	24.5	23.0	25.4
2013	28.0	25.0	24.0	25.0	24.5	25.7	26.5	26.2	31.7	26.4	27.7	32.0	33.0	34.0	32.0	26.6

The tables are summarized in the 4 following Figures to show the trend of each city in every month during the past 30 years:

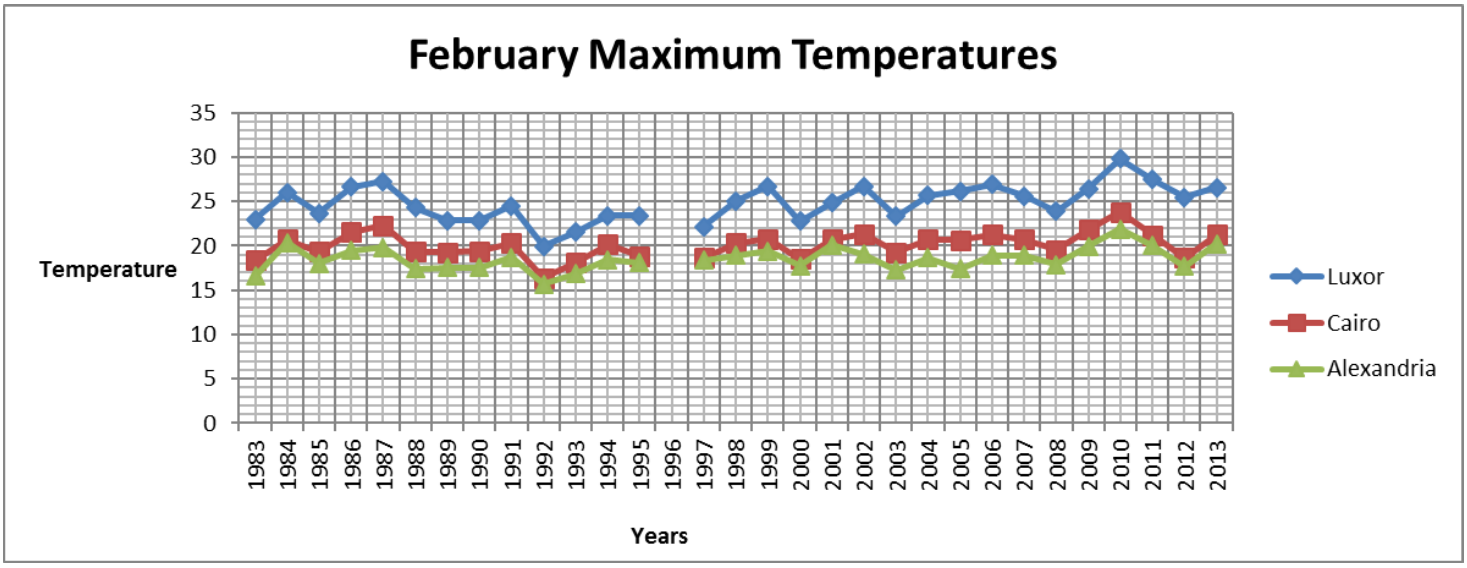

Figure 4.1 February Maximum air temperatures

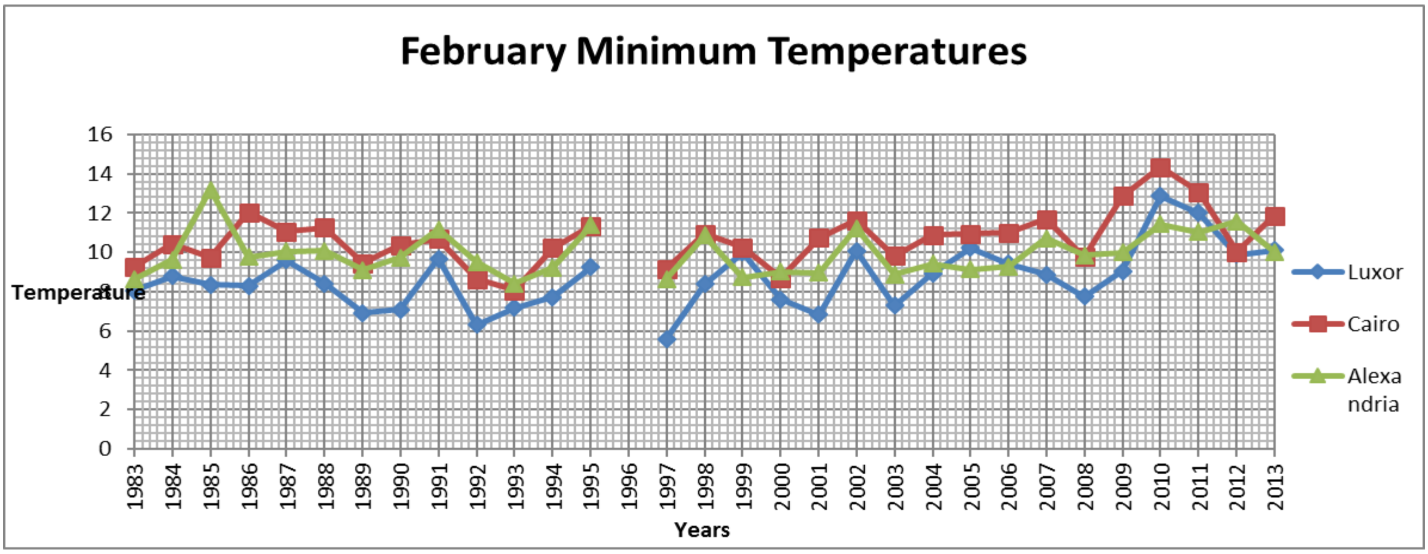

Figure 4.2 February Minimum air temperatures

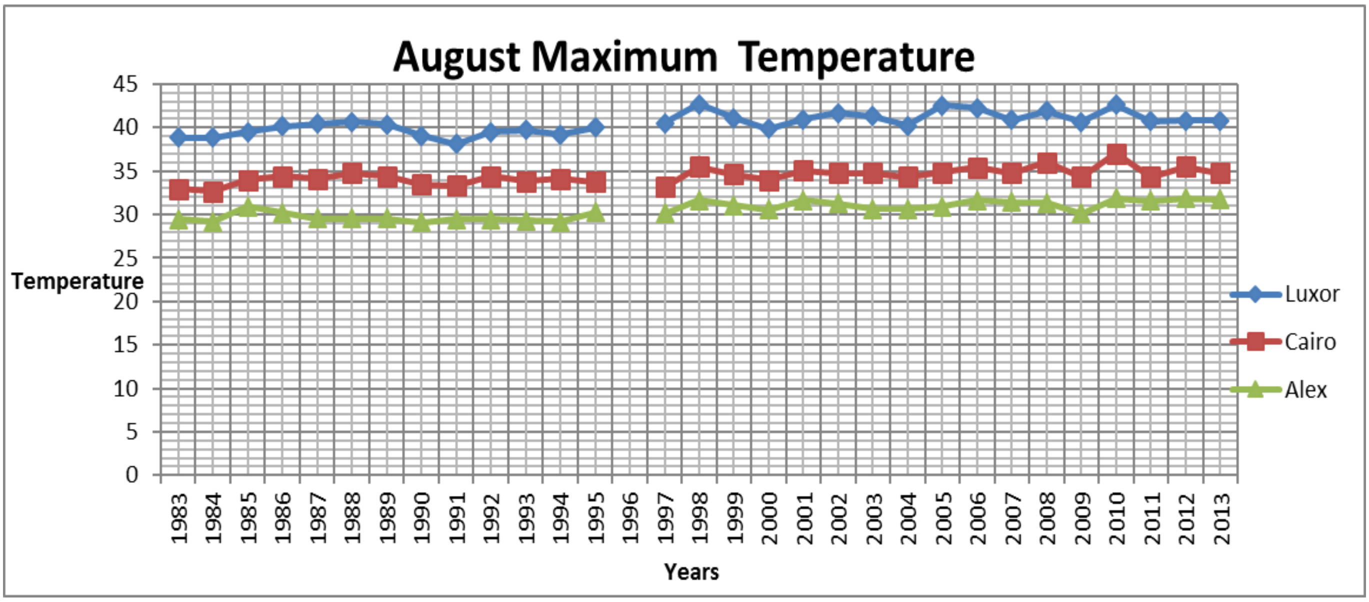

Figure 4.3 August Maximum air temperatures

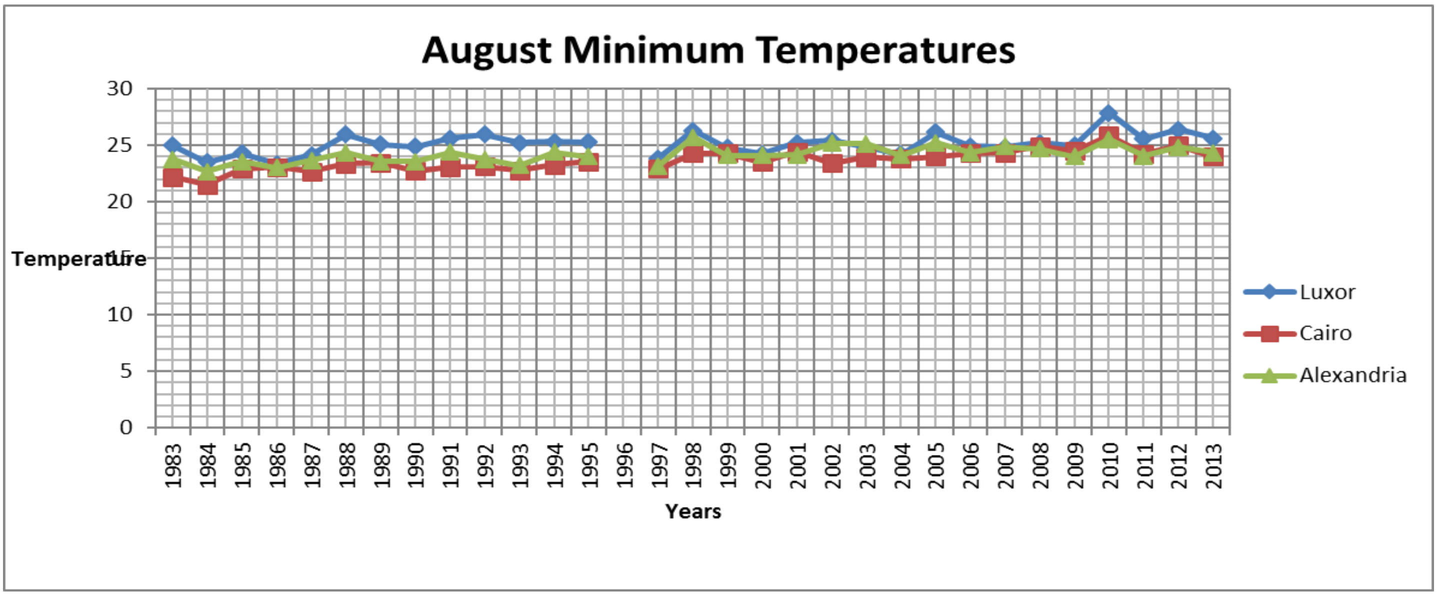

Figure 4.4 August Minimum air temperatures

From the previous Tables and figures it can be concluded that temperatures curves for the 3 cities in February and August during the 30 years from 1983 till 2013 has always been in a rising trend. The average of increasing through the whole time length is from (1.7- 2.5) degree Celsius which matches to a great extent the previous researches that investigated air temperatures (16)(18) that will be discussed later on Calibration and Validation Chapter.

The second component of the air temperature sub model developed for calculating the air temperatures, uses the previous figures (fig. 4.1 – fig 4.4) to detect a trend line for the curves and hence deduce an equation that represent the relationship between time and air temperatures to able to calculate and predict the air temperatures from 2013- 2030 for Luxor, Cairo, Alexandria during February and August.

The upcoming Figures represent the above mention step of procedure and also will show the whole trend starting from 1983 till 2030.

Luxor Governorate

The following curve 4.5 shows the trend line concluded from Figure 4.1 For Luxor on month February and the shown equation above the curve is calculated from this trend and thus the air temperatures from 2013- 2030 were calculated accordingly and the figure 4.6 shows the temperatures calculated from 1983-2013 and it also plugged into table 4.2 the total increase from 1983- 2030 is between 3-4 degree Celsius and it is accepted one according to the % of increase predicted by many weather researchers(6)

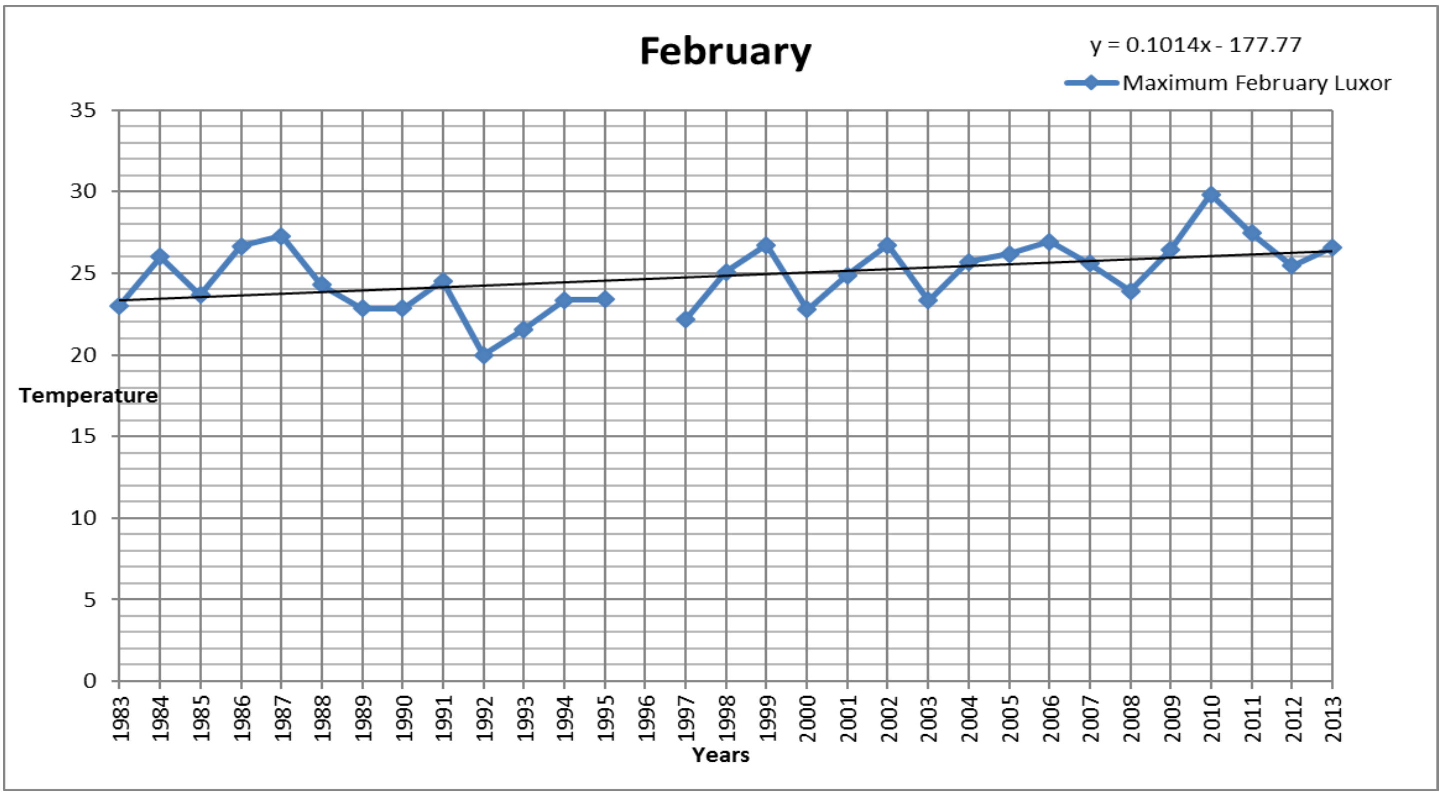

Figure 4.5 Luxor air temperatures 1983-2013

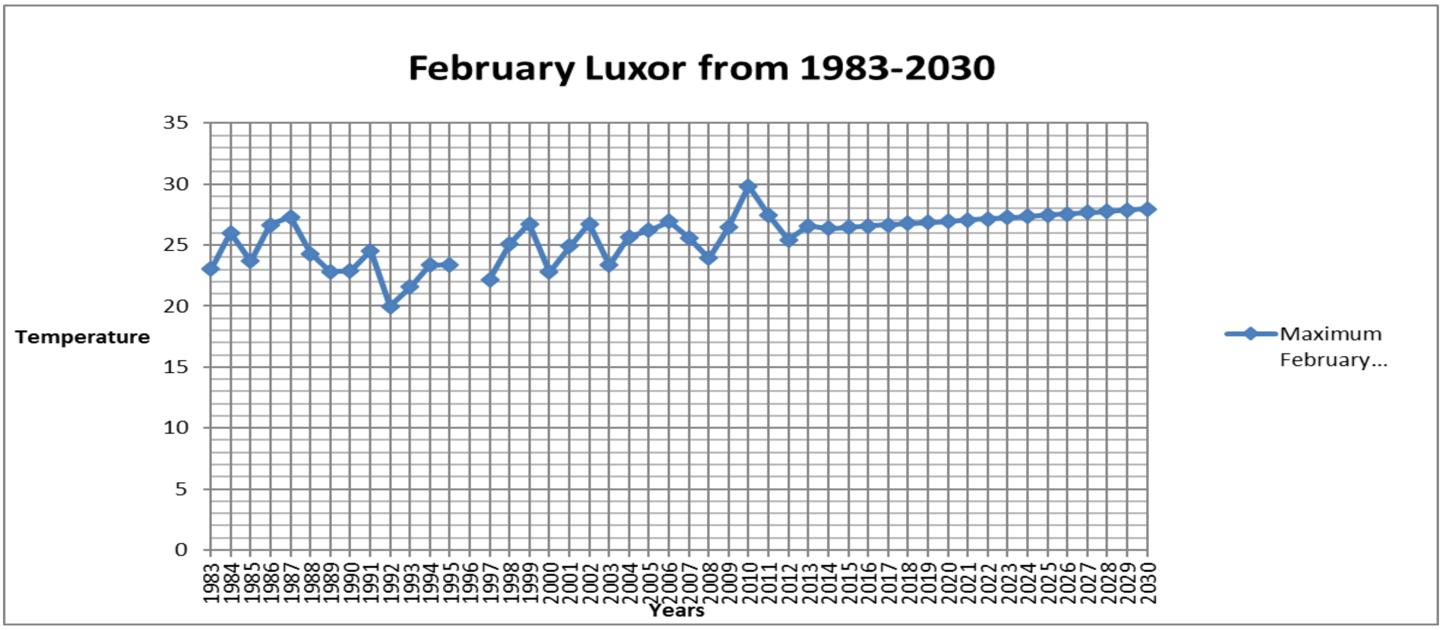

Figure 4.6 Luxor February air temperatures 1983-2030

Table 4.2 Luxor February air temperatures 1983-2030

Temperature	-								
February									
Luxor									
Year	Average	Year	Average	Year	Average	Year	Average	Year	Average
1983	23.0	1993	21.5	2003	23.3	2013	26.5	2023	27.2
1984	26	1994	23.3	2004	25.6	2014	26.3	2024	27.3
1985	23.6	1995	23.3	2005	26.1	2015	26.4	2025	27.4
1986	26.6	1996		2006	26.9	2016	26.5	2026	27.5
1987	27.2	1997	22.1	2007	25.5	2017	26.6	2027	27.6
1988	24.2	1998	25.0	2008	23.9	2018	26.7	2028	27.7
1989	22.8	1999	26.7	209	26.4	2019	26.8	2029	27.8
1990	22.8	2000	22.7	2010	29.8	2020	26.9	2030	27.9
1991	24.5	2001	24.8	2011	27.4	2021	27.0		
1992	19.9	2002	26.7	2012	25.4	2022	27.1		

The same happens here for Luxor but on August, appears obviously in the coming Figure 4.7, 4.8 and table 4.3

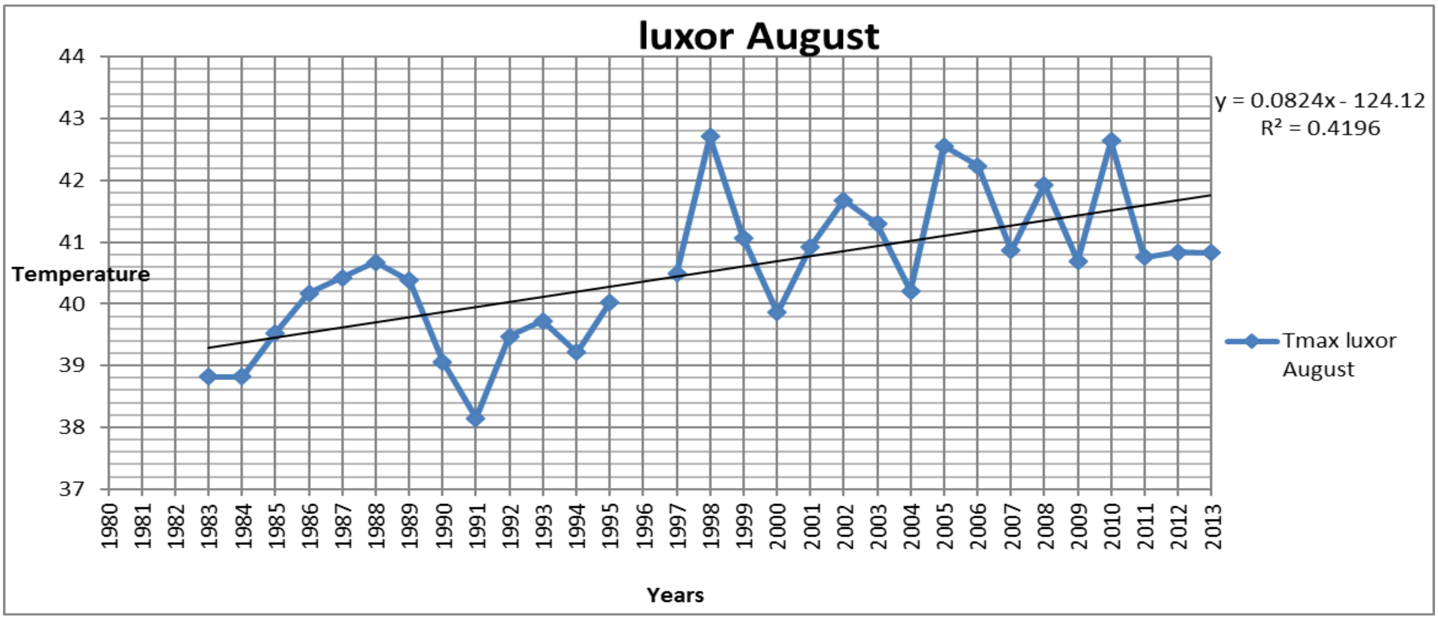

Figure 4.7 Luxor August air temperatures 1983-2013

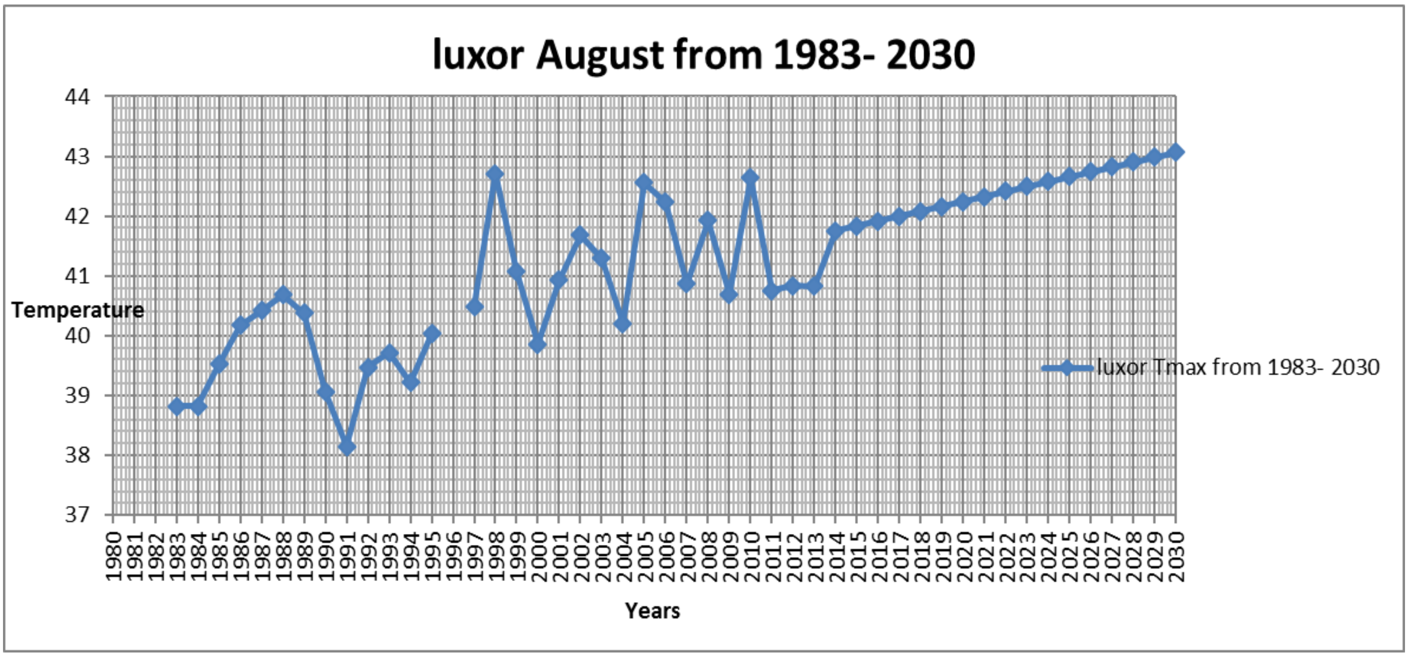

Figure 4.8 Luxor August air temperatures 1983-2030

Table 4.3 Luxor August air temperatures 1983-2030

Temperature	-								
August									
Luxor									
Year	Average	Year	Average	Year	Average	Year	Average	Year	Average
1983	38.8	1993	39.7	2003	41.2	2013	40.8	2023	42.4
1984	38.8	1994	39.2	2004	40.2	2014	41.7	2024	42.5
1985	39.5	1995	40.0	2005	42.5	2015	41.8	2025	42.6
1986	40.1	1996		2006	42.2	2016	41.9	2026	42.7
1987	40.4	1997	40.4	2007	40.8	2017	41.9	2027	42.8
1988	40.6	1998	42.7	2008	41.9	2018	42.0	2028	42.9
1989	40.3	1999	41.0	209	40.6	2019	42.1	2029	42.9
1990	39.0	2000	39.8	2010	42.6	2020	42.2	2030	43.0
1991	38.1	2001	40.9	2011	40.7	2021	42.3		
1992	39.4	2002	41.6	2012	40.8	2022	42.4		

After extracting the equation from graph 4.7and plugging it into the following graph 4.8.The results are put into a tabulated form and the increase in temperature is seen as temperature started with 38.8 and reached 43 at the end of the time length studied.

Capital Cairo

The same procedure done with Luxor Governorate will be done with capital Cairo using the curve and the governing equation concluded from the curve to calculate the temperature and observe the temperature rise and global warming through 1983-2030.

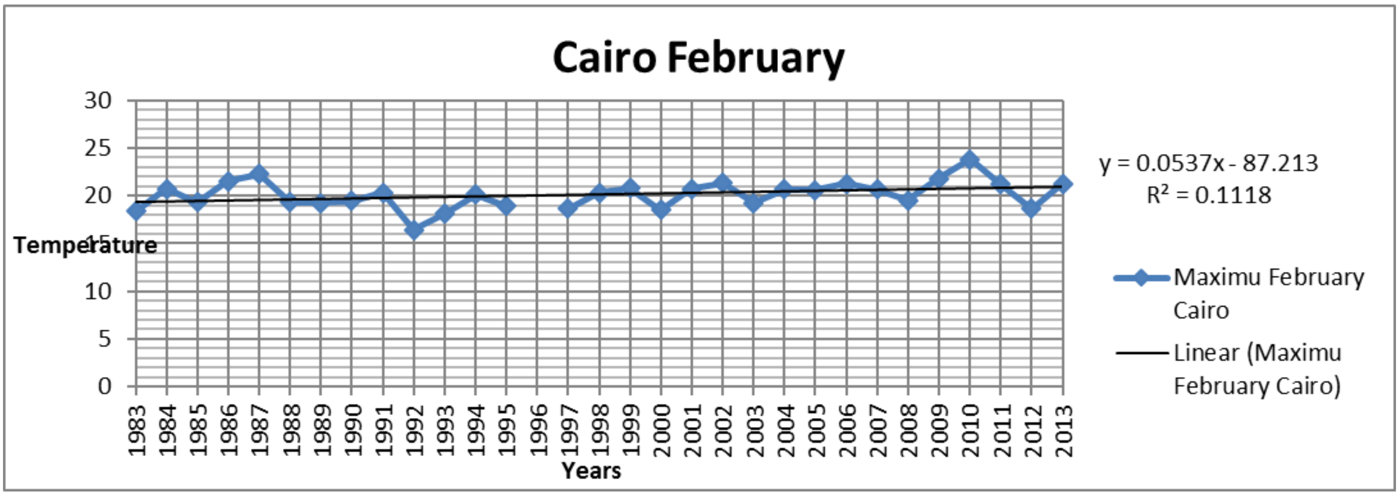

Figure 4.9 Cairo February air temperatures 1983-2013

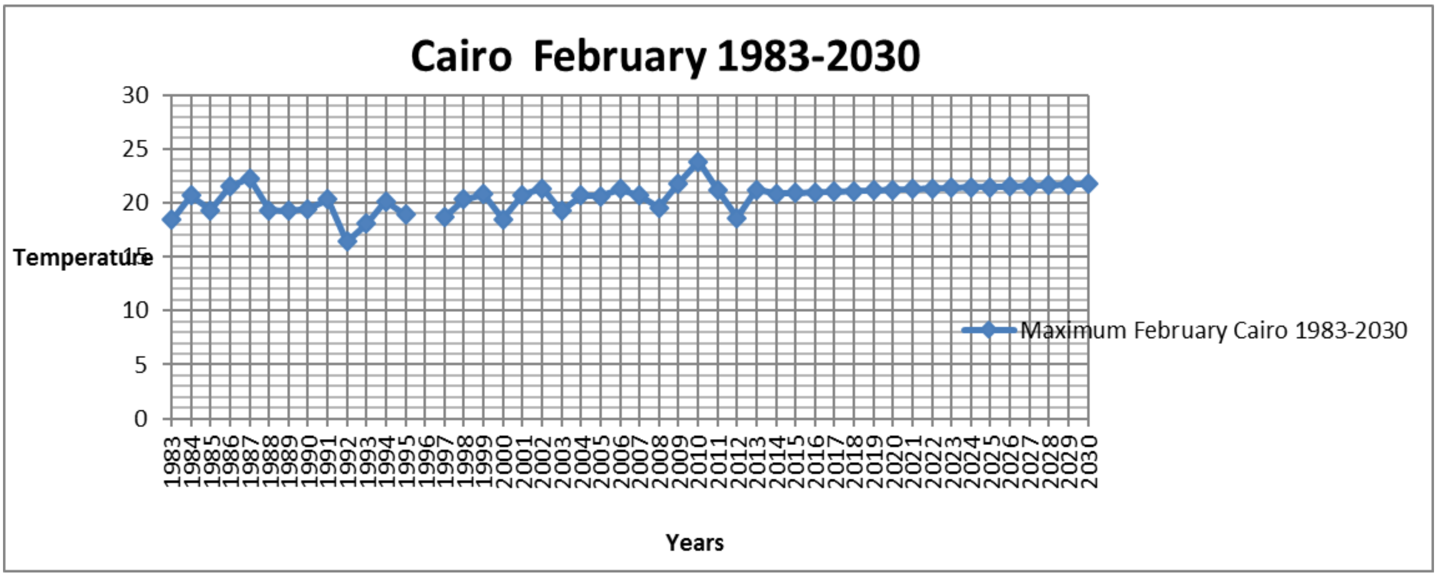

Figure 4.10 Cairo February air temperatures 1983-2030

Table 4.4 Cairo February air temperatures 1983-2030

Temperature	_								
February									
Cairo									
Year	Average	Year	Average	Year	Average	Year	Average	Year	Average
1983	18.3	1993	18.0	2003	19.2	2013	21.2	2023	21.3
1984	20.7	1994	20.1	2004	20.6	2014	20.8	2024	21.4
1985	19.3	1995	18.8	2005	20.6	2015	20.9	2025	21.4
1986	21.5	1996		2006	21.2	2016	20.9	2026	21.5
1987	22.3	1997	18.6	2007	20.6	2017	21.0	2027	21.5
1988	19.3	1998	20.3	2008	19.5	2018	21.0	2028	21.6
1989	19.2	1999	20.8	209	21.7	2019	21.1	2029	21.6
1990	19.4	2000	18.4	2010	23.8	2020	21.2	2030	21.7
1991	20.3	2001	20.7	2011	21.2	2021	21.2		
1992	16.4	2002	21.3	2012	18.6	2022	21.3		

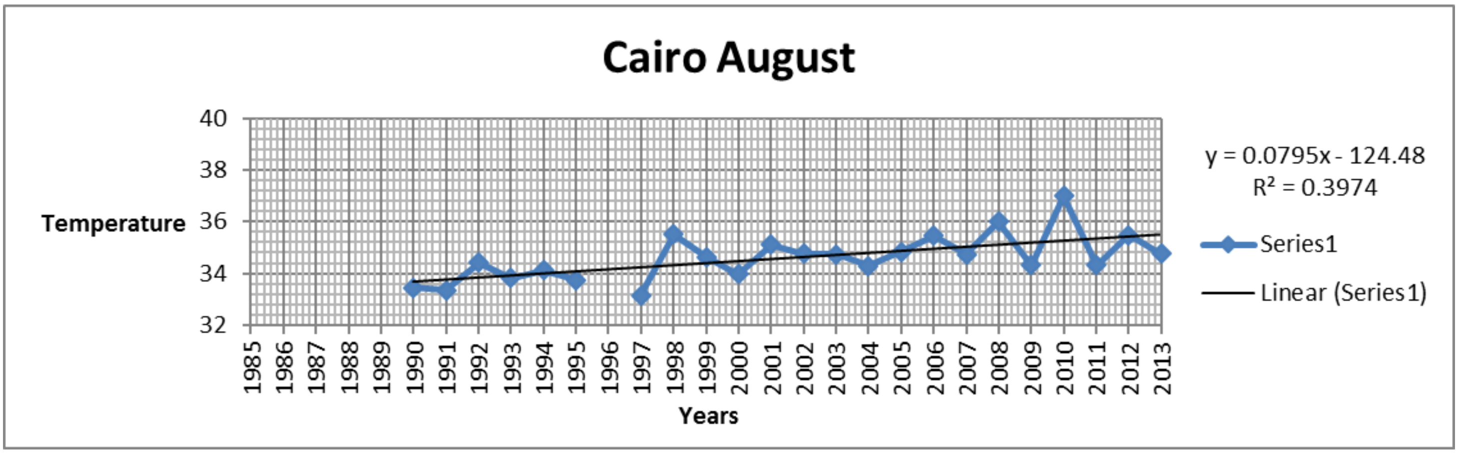

Figure 4.11 Cairo August air temperatures 1983-2013

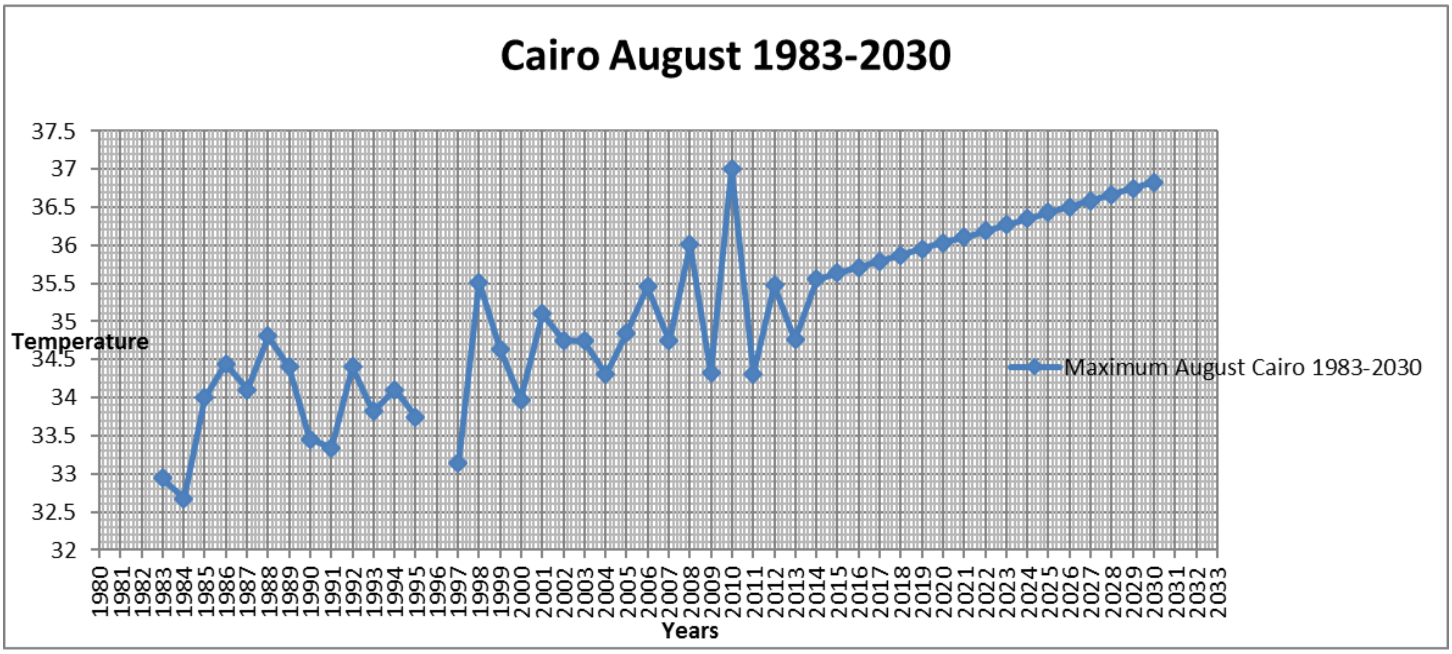

Figure 4.12 Cairo August air temperatures 1983-2030

Table 4.5 Cairo August air temperatures 1983-2030

Temperature	-								
August									
Cairo									
Year	**Average**	**Year**	**Average**	**Year**	**Average**	**Year**	**Average**	**Year**	**Average**
1983	32.9	1993	33.8	2003	34.7	2013	34.7	2023	36.2
1984	32.6	1994	34.1	2004	34.3	2014	35.5	2024	36.3
1985	33.9	1995	33.7	2005	34.8	2015	35.6	2025	36.4
1986	34.4	1996		2006	35.4	2016	35.7	2026	36.5
1987	34.1	1997	33.1	2007	34.7	2017	35.7	2027	36.5
1988	34.8	1998	35.5	2008	36.0	2018	35.8	2028	36.6
1989	34.4	1999	34.6	209	34.3	2019	35.9	2029	36.7
1990	33.4	2000	33.9	2010	37.0	2020	36.0	2030	36.8
1991	33.3	2001	35.1	2011	34.3	2021	36.1		
1992	34.4	2002	34.7	2012	35.4	2022	36.1		

Referring to the previous table it could be noticed that Cairo has less temperatures than Luxor as Luxor lies in the south and it is known by its hot dry weather although Cairo has Kept the rising trend in air temperature, From 1983- 2013 the temperature rise was around 1.818 degrees and from 2013- 2030 it was from 2- 2.5 degrees.

Alexandria Governorate

As previously mentioned the Alexandria graph for air temperature from 1983 to 2013 is also extracted alone and an equation is formulated from the graph on excel spread sheet to explain the raising trend from this graph. This equation was used to predict the air temperature from 2013 to 2030.

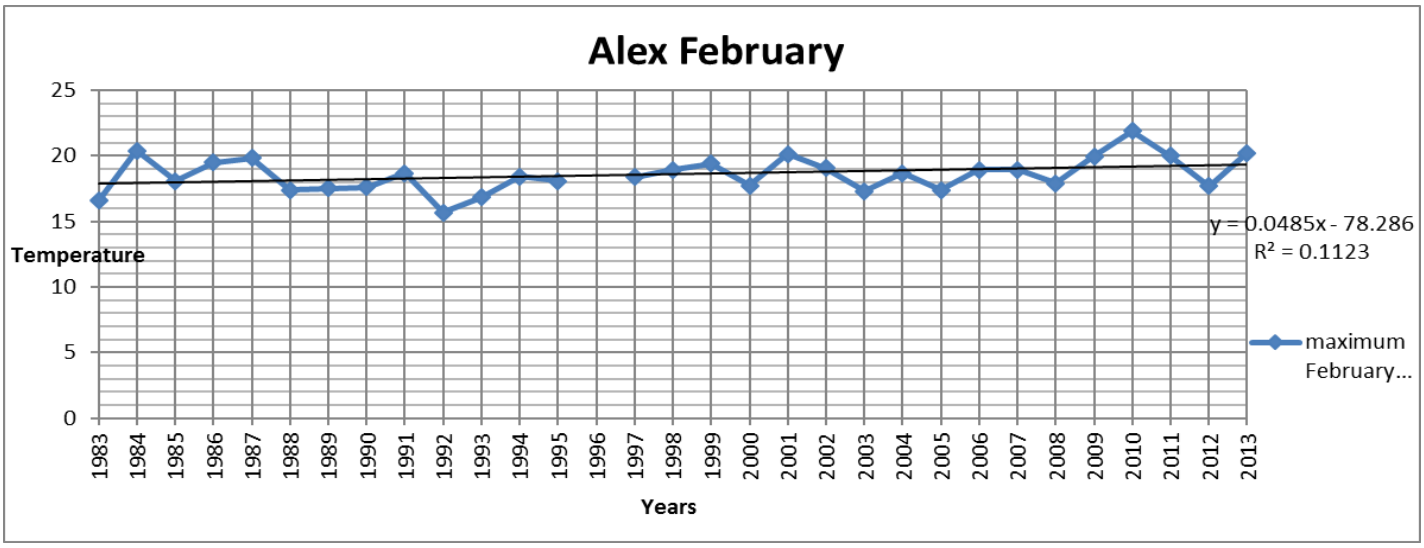

Figure 4.13 Alex. February air temperatures 1983-2013

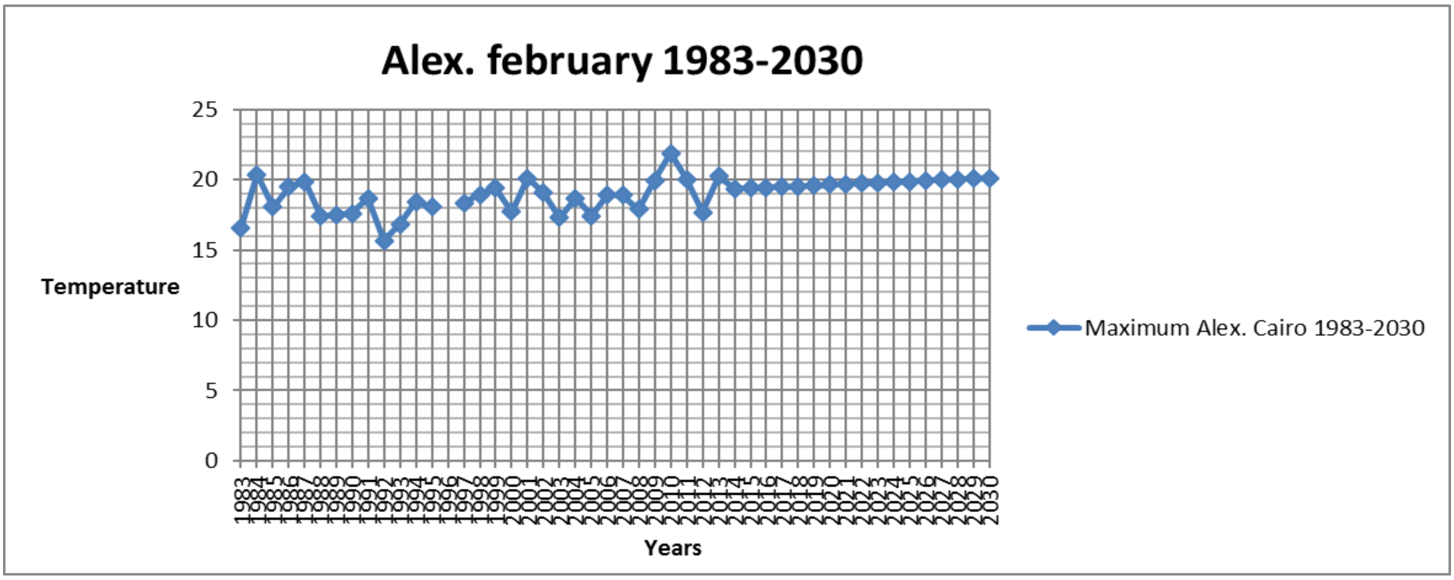

Figure 4.14 Alexandria February air temperatures 1983-2030

Table 4.6 Alex. February air temperatures 1983-2030

Temperature	-								
February									
Alexandria									
Year	**Average**	**Year**	**Average**	**Year**	**Average**	**Year**	**Average**	**Year**	**Average**
1983	16.5	1993	16.8	2003	17.2	2013	20.2	2023	19.7
1984	20.3	1994	18.4	2004	18.6	2014	19.3	2024	19.8
1985	18.0	1995	18.0	2005	17.4	2015	19.3	2025	19.8
1986	19.5	1996		2006	18.9	2016	19.4	2026	19.9
1987	19.8	1997	18.3	2007	18.9	2017	19.4	2027	19.9
1988	17.3	1998	18.9	2008	17.8	2018	19.5	2028	20.0
1989	17.5	1999	19.3	209	19.9	2019	19.5	2029	20.0
1990	17.5	2000	17.7	2010	21.8	2020	19.6	2030	20.1
1991	18.6	2001	20.1	2011	20.0	2021	19.6		
1992	15.6	2002	19.0	2012	17.6	2022	19.7		

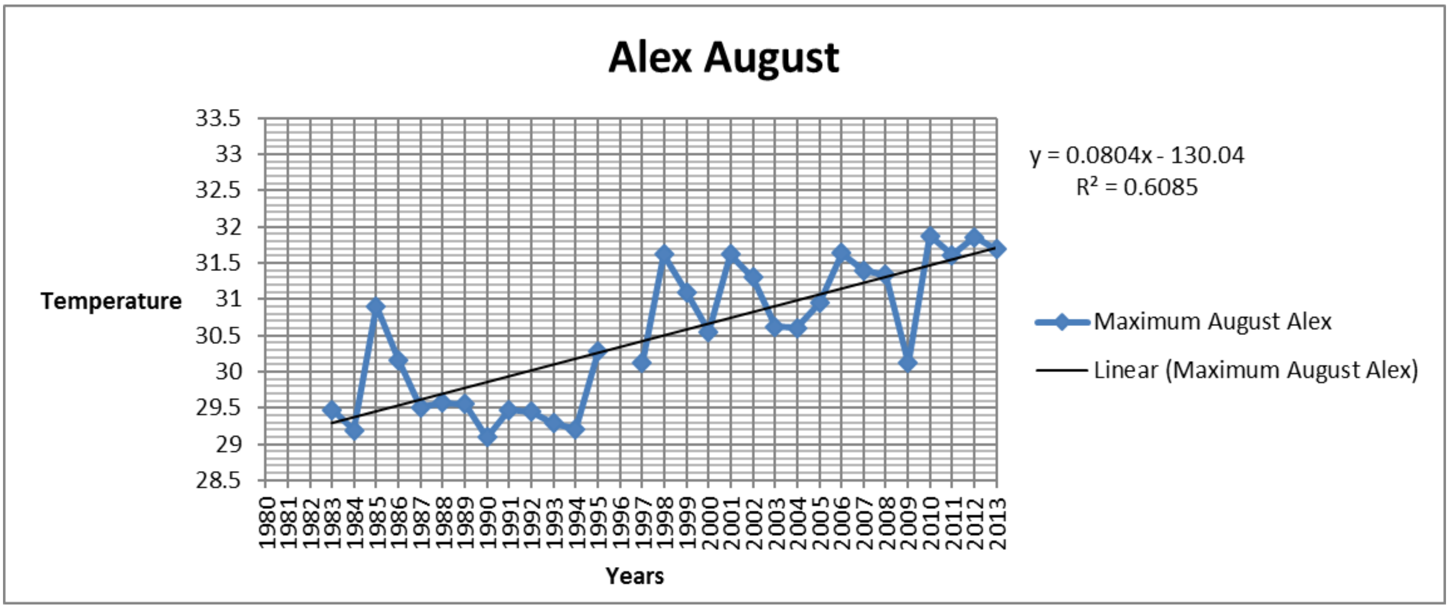

Figure 4.15 Alex. August air temperatures 1983-2013

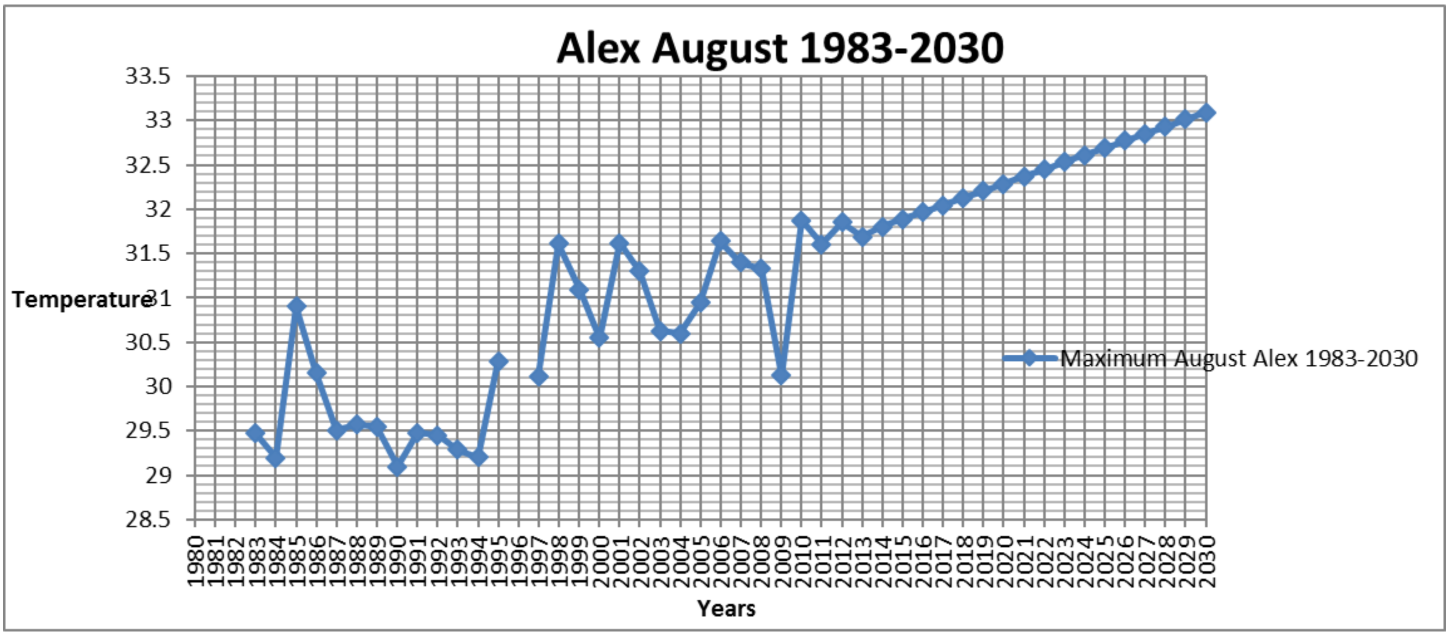

Figure 4.16 Alex. August air temperatures 1983-2030

Table 4.7 Alex. August air temperatures 1983-2030

Temperature	-								
August									
Alexandria									
Year	**Average**	**Year**	**Average**	**Year**	**Average**	**Year**	**Average**	**Year**	**Average**
1983	29.4	1993	29.2	2003	30.6	2013	31.6	2023	32.5
1984	29.1	1994	29.2	2004	30.6	2014	31.8	2024	32.6
1985	30.9	1995	30.2	2005	30.9	2015	31.8	2025	32.6
1986	30.1	1996		2006	31.6	2016	31.9	2026	32.7
1987	29.5	1997	30.1	2007	31.4	2017	32.0	2027	32.8
1988	29.5	1998	31.6	2008	31.3	2018	32.1	2028	32.9
1989	29.5	1999	31.0	209	30.1	2019	32.2	2029	33.0
1990	29.0	2000	30.5	2010	31.8	2020	32.2	2030	33.0
1991	29.4	2001	31.6	2011	31.6	2021	32.3		
1992	29.4	2002	31.3	2012	31.8	2022	32.4		

It could be observed that Alexandria has lower temperature than Luxor and Cairo due to its geographic site in Egypt north coast although it also has a rising trend of temperature throughout the whole period of time. It raised 2 degrees from year1983 till year 2013 and 2.5 degrees from year 2013 till year 2030.

4.2 Water temperature Calculations

As mentioned in Chapter 3; to calculate the water temperatures Heins equation (15) will be used. Heins equation is mainly depending on daily air temperatures which are calculated in section 4.1 for the months and Nile reach under consideration. Also other parameters and coefficients governing and modifying Heins equation to be used on River Nile as elaborated in Chapter 3are calculated .The following tables and charts show the water temperature calculations and results

Luxor Governorate

Water temperature is calculated using Heins equation with all the previous mentioned parameter and the air temperatures.

Table 4.8 Luxor February water temperatures 2009-2030

Luxor Feb. water data			
B	0.89		
s	0.085625		
A	2		
Year	Temperature	Year	Temperature
2009	19.53	2020	21.93
2010	19.56	2021	21.94
2011	19.67	2022	21.97
2012	19.7	2023	21.99
2013	19.71	2024	22
2014	21.44	2025	22.9
2015	21.52	2026	23.5
2016	21.6	2027	24.5
2017	21.68	2028	24.5
2018	21.77	2029	24.6
2019	21.85	2030	24.7

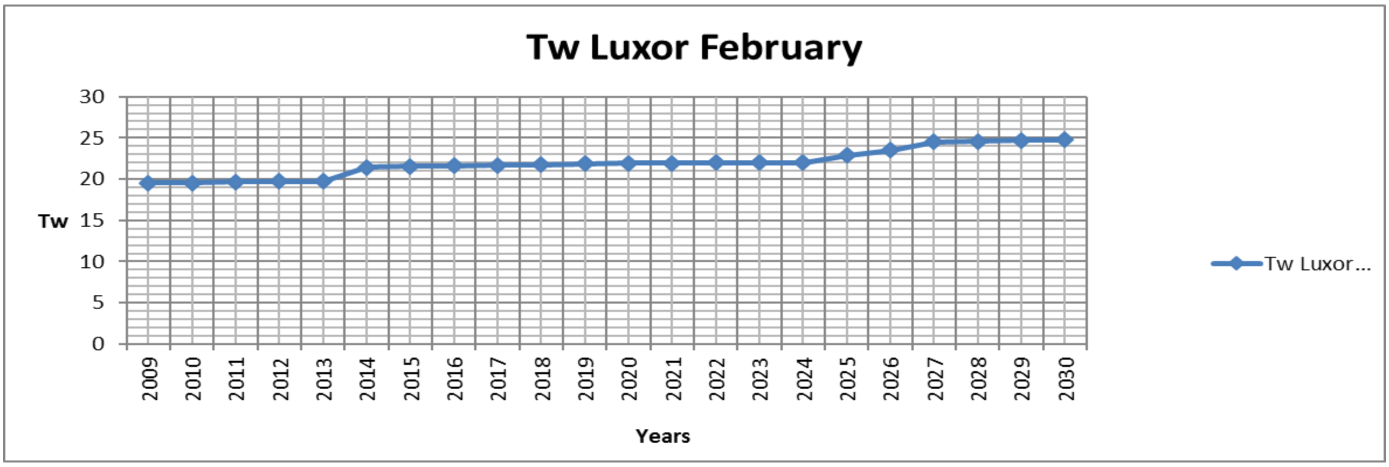

Figure 4.17 Luxor February Water Temperatures 2009-2030

Table 4.9 Luxor August water Temperatures 2009-2030

Luxor August. water data			
B	0.6		
s	0.1875		
A	9		
Year	**Temperature**	**Year**	**Temperature**
2009	24.6	2020	26.5
2010	24.7	2021	26.6
2011	24.8	2022	26.6
2012	24.9	2023	26.7
2013	24.9	2024	26.7
2014	26.3	2025	27.7
2015	26.3	2026	27.8
2016	26.4	2027	28.8
2017	26.4	2028	28.9
2018	26.5	2029	29.9
2019	26.5	2030	29.9

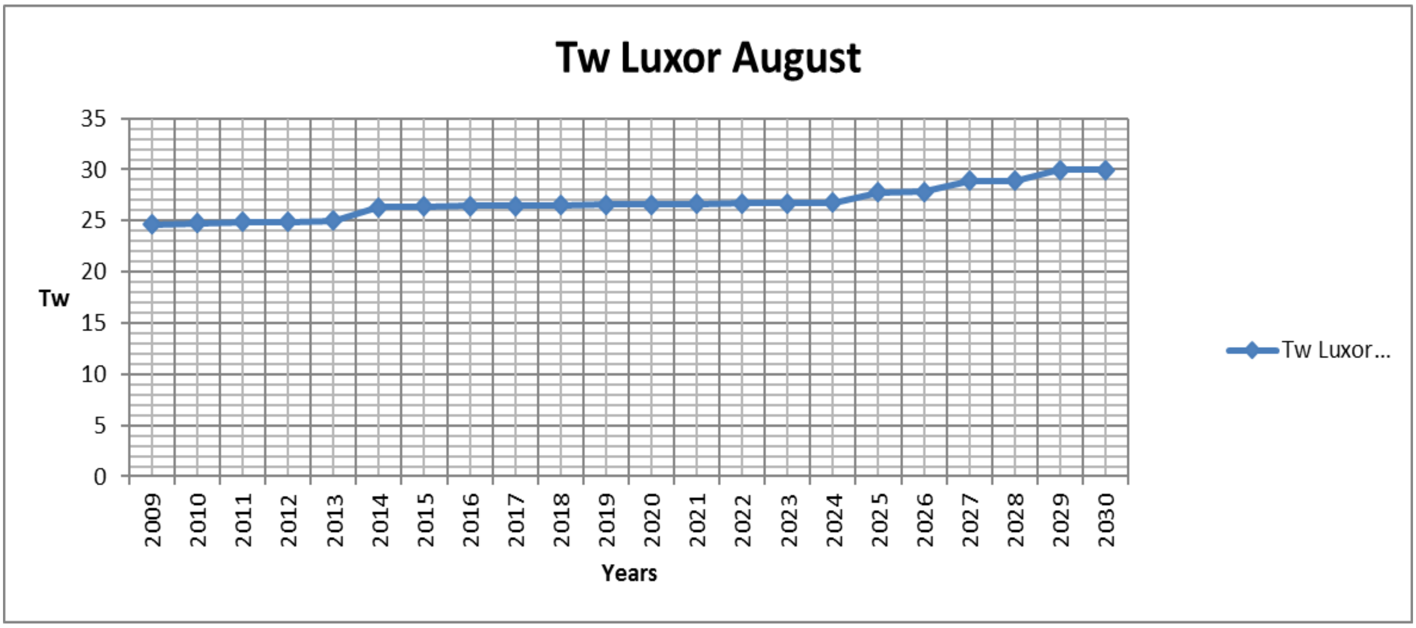

Figure 4.18 Luxor August water Temperatures 2009-2030

From the above tables and graphs it can be noticed that water temperature has a rising trend through the years. The rise ranges from 3-5 degrees through 21 years which can be acceptable range. This increase can be linked to the increase of air temperatures and parameters used in calculating air temperatures. As the equation governing the relation between Water River and air is a linear one, thus any rise in air temperature is accompanied by rise in the stream temperatures.

Capital Cairo

The same procedure is carried to calculate the water temperatures in Capital Cairo during February and August as it will appear in the coming tables and graphs:

Table 4.10 Cairo February water temperatures 2009-2030

Cairo February water data			
B	0.75		
s	0.145833333		
A	5.2		
Year	Temperature	Year	Temperature
2009	17.1	2020	18.7
2010	17.4	2021	18.8
2011	17.7	2022	18.8
2012	18.3	2023	18.9
2013	18.4	2024	18.9
2014	18.5	2025	18.9
2015	18.6	2026	18.9
2016	18.6	2027	19.0
2017	18.6	2028	19.0
2018	18.7	2029	19.0
2019	18.7	2030	19.1

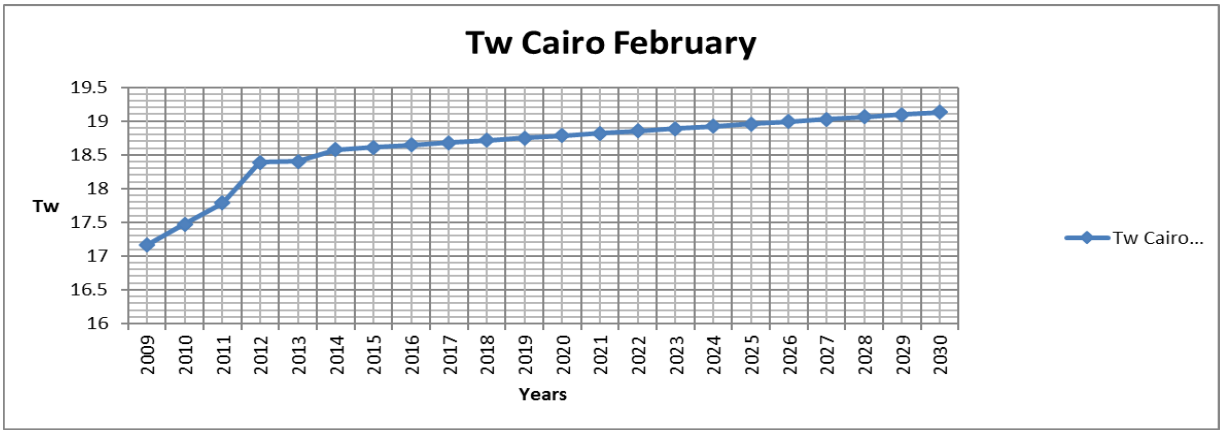

Figure 4.19 Cairo February water temperatures 2009- 2030

Table 4.11 Cairo August water temperatures 2009-2030

Cairo August water data			
B	0.6		
s	0.196		
A	11.6		
Year	Temperature	Year	Temperature
2009	22.2	2020	25.0
2010	22.5	2021	25.1
2011	22.6	2022	25.1
2012	22.8	2023	25.2
2013	22.8	2024	25.2
2014	22.9	2025	25.2
2015	23.9	2026	26.3
2016	23.9	2027	27.3
2017	23.9	2028	28.4
2018	24.02	2029	29.4
2019	24.9	2030	29.4

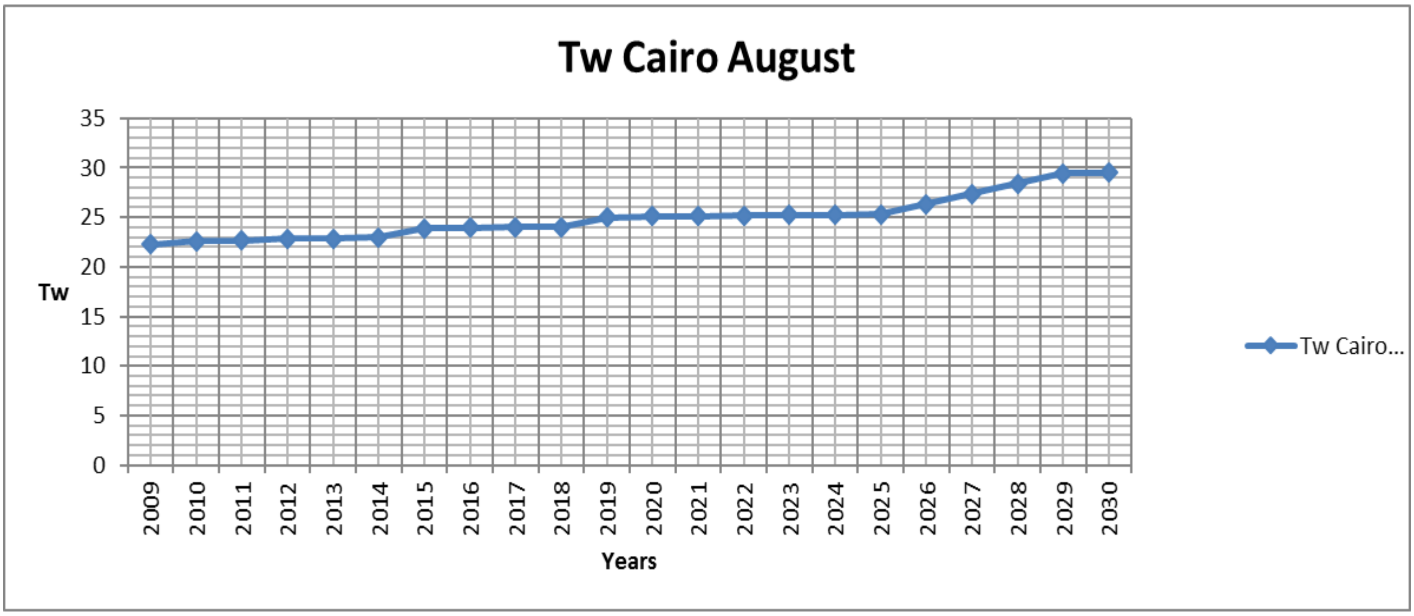

Figure 4.20 Cairo August Water Temperatures 2009-2030

For Cairo the water temperature also has a rising trend ,it is not high as Luxor but this due to geographic site of Luxor in south and higher air temperature than Cairo. As for February the water temperature rise for 2 degrees only through the whole period of study while in August it has raised for 5 degrees for the same period, this could be related to the high rise in air temperatures during August.

Alexandria Governorate

The following tables and graphs show the water temperature during February and August through the years 2009- 2030 using Heins equation (15):

Table 4.12 Alex. February water Temperatures 2009-2030

Alex February water data			
B	0.547		
s	0.1906		
A	9		
Year	Temperature	Year	Temperature
2009	16.8	2020	18.6
2010	17.6	2021	18.7
2011	17.8	2022	18.7
2012	17.8	2023	18.7
2013	17.9	2024	18.7
2014	17.9	2025	18.8
2015	18.5	2026	19.8
2016	18.6	2027	19.8
2017	18.6	2028	19.8
2018	18.6	2029	19.8
2019	18.6	2030	19.9

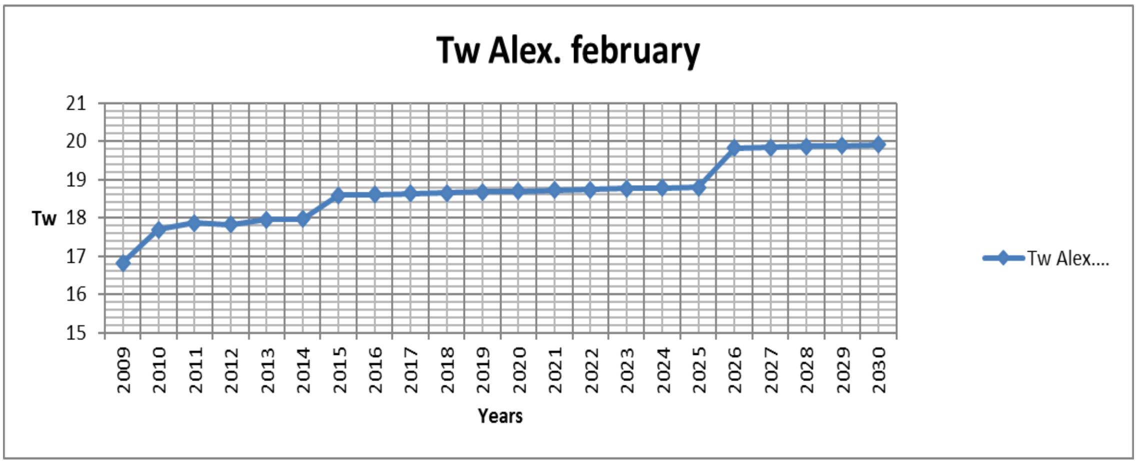

Figure 4.21 Alexandria February water temperatures 2009- 2030

Table 4.13Alex. August water temperatures 2009-2030

Alex August water data			
B	0.43		
s	0.21625		
A	16.79		
Year	Temperature	Year	Temperature
2009	20.9	2020	24.6
2010	20.9	2021	24.6
2011	20.9	2022	24.7
2012	20.9	2023	24.7
2013	21.4	2024	25.7
2014	21.5	2025	25.8
2015	21.5	2026	26.8
2016	21.5	2027	26.8
2017	22.5	2028	27.8
2018	23.6	2029	27.9
2019	24.6	2030	27.9

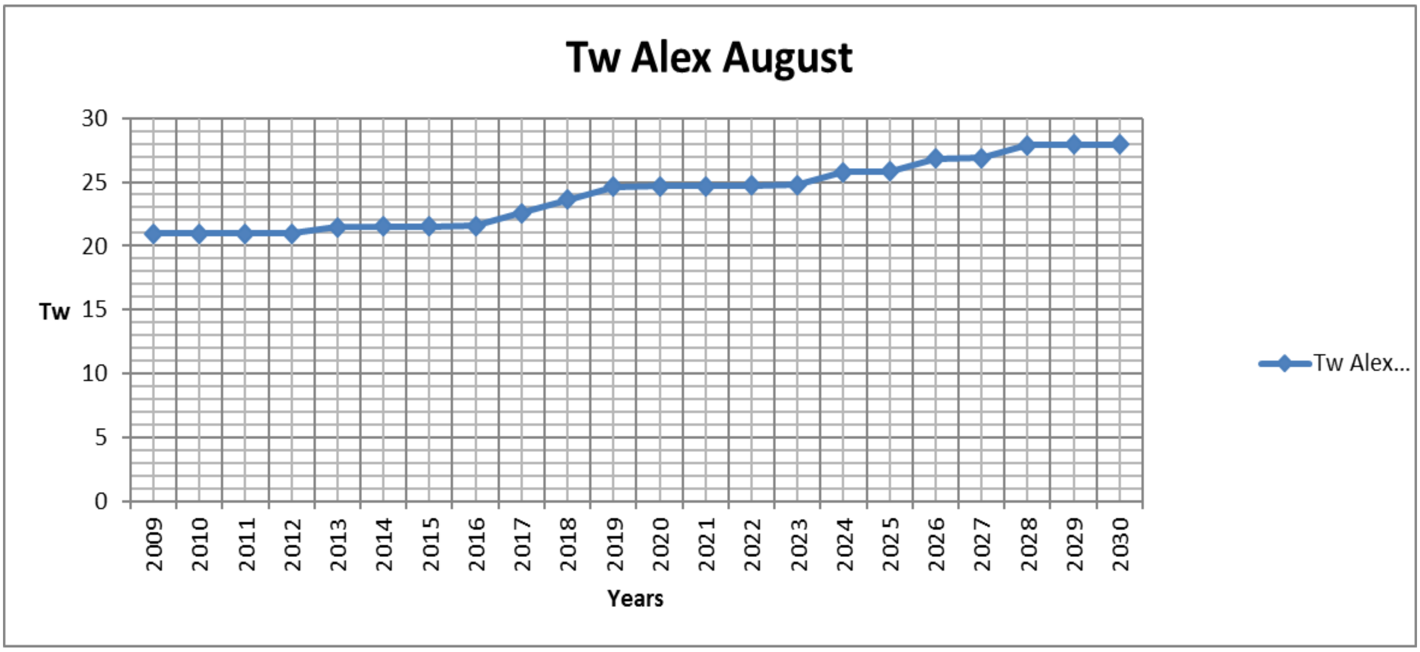

Figure 4.22 Alex. August water temperatures 2009-2030

The water temperature in Alexandria has a temperature rise range of 3 degrees during February through the whole time length hence it had 7 degrees rise in August through the same time length although it is still has a lower water temperature other than Luxor and Cairo due to geographic conditions and lesser air temperature.

4.3 Dissolved Oxygen Calculations

After calculating all the air and water temperatures in the previous sections for the 3 cities during February and August for the time length under consideration. The Do sub model elaborated in chapter 3 is used. All the needed parameters previously mentioned in the methodology and sub model chapter are calculated and plugged in equation (2) to get Tc (critical time), the following results are obtained:

Table 4.14 Critical Time for the Months and Nile reach studied

	Water Temperature T_w (degree Celsius)	Critical Time T_C (days)
Luxor February	19	4.3
	21	4.6
Luxor August	24	4.8
	26	4.9
Cairo February	18	5.5
	19	5.7
Cairo August	22	6
	25	6.2
Alexandria February	17	6.3
	18	6
Alexandria August	20	7.2
	24	7

After calculating the critical time for the months and Nile reach considered, the critical dissolved oxygen should be calculated. Streeter Phelps equation (eq.3) is used to calculate the deficit oxygen concentration, then the deficit DO oxygen is plugged into equation 4 (eq.4) to get the critical DO oxygen concentrations Cc.

To get the values of the DO saturation Cs in mg/l the following table 4.26 is used as Cs depends on water temperature (16).

Table 4.15 Cs concentration Values

Temperature(˚c)	DO mg/l	Temperature(˚c)	DO mg/l	Temperature(˚c)	DO mg/l	Temperature(˚c)	DO mg/l
1	14.6	23	8.56	12	11.01	34	7.16
2	14.19	24	8.4	13	10.76	35	6.93
3	13.81	25	8.24	14	10.52	36	6.82
4	13.44	26	8.09	15	10.29	37	6.71
5	13.09	27	7.95	16	10.07	38	6.61
6	12.75	28	7.81	17	9.85	39	6.51
7	12.43	29	7.67	18	9.65	40	6.41
8	12.12	30	7.54	19	9.26	41	6.41
9	11.83	31	7.41	20	9.07	42	6.22
10	11.55	32	7.28	21	8.9	43	6.13
11	11.27	33	7.16	22	8.72	44	6.04

After getting the Values of Cs from the previous table and plugging them into equation 4 as stated before, the Cc values can be calculated as shown in the following table:

Table 4.16 Critical Do concentration Values

	Water Temperature (degree Celsius)	BOD (mg/l)	Dc (mg/l)	Cs mg/l	Cc mg/l	% decrease in Cs
Luxor February	19	6	2.75	9.26	6.51	3.99
	21	6	2.65	8.9	6.25	
Luxor August	24	6	2.54	8.4	5.86	4.26
	26	6	2.48	8.09	5.61	
Cairo February	18	3	2.47	9.65	7.18	4.038
	19	3	2.37	9.26	6.89	
Cairo August	22	2.3	2.09	8.72	6.63	4.82
	25	2.3	1.93	8.24	6.31	
Alexandria February	17	3.7	2.24	9.65	7.41	1.34
	18	3.7	2.14	9.45	7.31	
Alexandria August	20	3	1.573	9.07	7.497	5.16
	24	3	1.29	8.4	7.11	

Referring to table 4.14, 4.16 it can be noticed that each city for each month has two different temperatures these are the lowest and highest water temperature occurred more than once in the water temperature calculations tables and accordingly the Cs was calculated between theses 2 temperatures to the % of decrease in Cs could be noticed.

It can be concluded that the critical dissolved concentrations are decreased once the water temperature increase and the water temperature increased with the increase of the air temperatures according to equation 1.

This gives a direct relationship between global warming and the decrease of critical dissolved oxygen concentration and results in the deterioration of water quality through years.

The previous model with all its 3 components will be calibrated and validated in the following chapter

Chapter 5

Calibration and Validation

In order to Calibrate and validate the mathematical model developed, First the definition of Calibration and Validation must be mentioned.

5.1 Calibration

Calibration is a comparison between measurements – one of known magnitude or correctness made or set with one device and another measurement made in as similar a way as possible with a second device. The device with the known or assigned correctness is called the standard . The second device is the unit under test, test instrument, or any of several other names for the device being calibrated. (20)

The formal definition of calibration by the International Bureau of Weights and Measures is the following: "Operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties (of the calibrated instrument or secondary standard) and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.

5.2 Validation

Verification and validation are independent procedures that are used together for checking that a product, service, or system meets requirements and specifications and that it fulfills its intended purpose. (20)

Calibration of the mathematical model against real life values was done and the following results were obtained:

5.3 Air Temperature Model calibration:

Table 5.1 Air temperature calibration model Luxor 1983-2005

Maximum August Luxor(1983-2005)			
Year	Extracted from website	Calculated from graph	% of Error
2006	42.2	41.3	2.02
2007	40.8	41.4	-1.51
2008	41.9	41.5	0.79
2009	40.6	41.7	-2.4
2010	42.6	41.8	1.93
2011	40.7	41.9	-2.85
2012	40.8	42.0	-2.91
2013	40.8	42.1	-3.20

Table 5.2 Air temperature calibration model Luxor 1990-2005

Maximum August Luxor(1990-2005)			
Year	Extracted from website	Calculated from graph	
2006	2006	42.2	0.67
2007	2007	40.8	-3.129
2008	2008	41.9	-0.98
2009	2009	40.6	-4.51
2010	2010	42.6	-0.22
2011	2011	40.7	-5.3
2012	2012	40.8	-5.60
2013	2013	40.8	-6.10

Table 5.3 Air temperature calibration model Luxor 1990- 2000

Maximum August Luxor(1990-2000)		
Year	Extracted from website	Error %
2000	40.59	-1.85
2001	40.68	0.59
2002	40.76	2.199
2003	40.84	1.085
2004	40.92	-1.79
2005	41.00	3.64
2006	41.09	2.70
2007	41.17	-0.755
2008	41.25	1.59
2009	41.33	-1.57
2010	41.42	2.84
2011	41.50	-1.84
2012	41.58	-1.84
2013	41.66	-2.06

Table 5.4 Air temperature calibration model Cairo 1983-2005

Maximum August Cairo(1983-2005)			
Year	Extracted from website	Calculated from graph	% of Error
2006	35.45	34.91	1.52
2007	34.74	34.99	-0.72
2008	36.00	35.07	2.58
2009	34.32	35.15	-2.42
2010	37.00	35.23	4.77
2011	34.31	35.31	-2.92
2012	35.47	35.39	0.21
2013	34.75	35.47	-2.05

Table 5.5 Air temperature calibration model 1990-2005

Maximum August Cairo(1990-2005)			
Year	Extracted from website	Calculated from graph	% of Error
2006	35.45	34.85	1.70
2007	34.74	34.93	-0.55
2008	36.00	35.02	2.73
2009	34.32	35.10	-2.28
2010	37.00	35.19	4.89
2011	34.31	35.27	-2.81
2012	35.47	35.36	0.31
2013	34.75	35.44	-1.97

Table 5.6 Air temperature calibration model Cairo 1990-2000

Maximum August Cairo(1990-2000)			
Year	Extracted from website	Calculated from graph	% of Error
2001	35.1	34.49	1.73
2002	34.75	34.57	0.50
2003	34.74	34.66	0.22
2004	34.30	34.75	-1.32
2005	34.84	34.84	0.008
2006	35.45	34.93	1.47
2007	34.74	35.02	-0.80
2008	36.00	35.11	2.48
2009	34.32	35.20	-2.5
2010	37.00	35.28	4.63
2011	34.31	35.37	-3.11
2012	35.47	35.46	0.015
2013	34.75	35.55	-2.29

Table 5.7 Air temperature calibration model Alex 1983-2005

Maximum August Alex(1983-2005)			
Year	Extracted from website	Calculated from graph	
2006	31.63	31.16	1.50
2007	31.41	31.24	0.50
2008	31.33	31.32	0.026
2009	30.12	31.40	-4.25
2010	31.87	31.48	1.23
2011	31.60	31.5	0.13
2012	31.85	31.64	0.66
2013	31.68	31.72	-0.12

Table 5.8 Air temperature calibration model Alex. 1990-2005

Maximum August Alex(1990-2005)			
Year	Extracted from website	Calculated from graph	
2006	31.63	31.41	0.70
2007	31.41	31.55	-0.50
2008	31.33	31.69	-1.17
2009	30.12	31.83	-5.7
2010	31.87	31.98	-0.32
2011	31.60	32.12	-1.62
2012	31.85	32.26	-1.28
2013	31.68	32.40	-2.26

Table 5.9 Air temperature calibration model Alex.. 1990-2000

Maximum August Alex(1990-2000)			
Year	Extracted from website	Calculated from graph	%error
2001	31.62	31.08	1.70
2002	31.30	31.28	0.037
2003	30.62	31.49	-2.84
2004	30.62	31.70	-3.61
2005	30.94	31.91	-3.13
2006	31.63	32.12	-1.53
2007	31.40	32.33	-2.96
2008	31.33	32.53	-3.85
2009	30.12	32.74	-8.71
2010	31.87	32.95	-3.38
2011	31.60	33.16	-4.92
2012	31.85	33.37	-4.76
2013	31.68	33.58	-5.97

From the previous tables it could be noticed that % of error is low between the calculated air temperature from the equation extracted from the graph and the air temperatures obtained from the real life measurements of (17).

The air temperature rise throughout the whole study period was in range from 3-4 degrees. For the period from 1983- 2013 it was from 2- 2.5 degrees for the 3 cities and for the time period from 2013-2030 it had a temperature rise range from 2.5- 3.5 degrees.

Other than that % of error didn’t exceed 7 % for the period we have a real life measurements for, the percent of increase is accepted and it was stated in the UN annual report for Climate change (4). Also this % of increase in air temperatures was stated by many researchers studied the climate change in their researches (15) (18)

In the light of the above mentioned errors and previous researches it could be concluded that that the results of the air mathematical model could be reliable.

That % of errors could be due to inaccuracy of real life measurements also the temperatures calculated are approximated to whole numbers although this won’t affect the model as the % of error is minor and in the accepted range.

5.4 Water Temperature Model

It is also needed to calibrate and Validate the mathematical model developed on excel spread sheet to calculate the water temperature for the three cities using equation 1.

This done through comparing the values calculated against real life measurement.

It wasn't available to get real life measurements for water temperatures except for years 2009 and 2010, so Calibration was done through these years:

Table 5.10 Water Temperature Calibration model

	Water Temperature Calculated	Water Temperature from real life	%Error
Luxor February			
2009	19	20	5
2010	19.7	20.5	3.9
Luxor August			
2009	23.9	24.5	2.4
2010	25.7	25	2.8
Cairo February			
2009	17.7	17	4.1
2010	18	17.7	1.6
Cairo August			
2009	21.5	21.9	1.8
2010	21.9	22.5	2.6
Alexandria February			
2009	16.5	16	3
2010	16.7	16.4	1.8
Alexandria August			
2009	15	15.5	3.2
2010	15.7	15.9	1.25

Referring to Table 5.10 it could be concluded that % of error between water temperatures calculated and that measured in real life for Luxor, Cairo and Alexandria for years 2009 and 2010 didn’t exceed the 5 % which makes the, mathematical model credible and the results obtained from are reliable.

Also the % of increase of water temperature through the whole period of study was in an accepted range from 3- 5 degrees depending on previous paper that studied the rise of water temperature due to global warming(16)(21).

That % of error could be due to real life measurement inaccuracy also Heins equation was developed for Mississippi river not for river Nile and some minor climatic and hydraulic conditions might affect the accuracy of temperatures, yet are the error % are below than 10 % so it could be concluded that this sub model is reliable.

5.5 **Dissolved Oxygen Calibration model**

As For the DO calibration model it faced the same problem as water calibration model which is the lack of real life measurements, DO values was only available for years 2009 and 2010 (19)so the calibration was done using the data for these 2 years as shown in the following table:

Table 5.11 Do Concentrations calibration model

	Water Temperature (degree Celsius)	Cc mg/l	Average Cc mg/l	Real life DO values mg/l	% of Error
Luxor February	19	6.51	6.38	6	6.3
	21	6.25			
Luxor August	24	5.86	5.735	6.1	5.8
	26	5.61			
Cairo February	18	7.18	7	6.7	5
	19	6.89			
Cairo August	22	6.63	6.47	6.45	0.3
	25	6.31			
Alexandria February	17	7.41	7.3	7.46	1.3
	18	7.31			
Alexandria August	20	7.497	7.4	6.8	7.35
	24	7.11			

For Table 5.11 the average of DO concentrations for February and August was calculated so it is compatible with the average Cc calculated from the mathematical model. The % of error was from 0.3 % to 7.35 %. These percent of errors could as the real life measurements are not the critical values although it is compared to critical values.

A possible error can be found in real life measurements, also the air and water temperatures value used are approximated to whole number and this can be another source for this % of error.

The % of error is in the acceptable range they are all below 8 % and this percent of error is small and therefore the results of this mathematical model could be accepted.

The output of the three components of the mathematical model has a small % of error compared to the available real life measurements and they are all in the acceptable range according to previous published papers and researcher concerning the issue of study. In light of this the results are accepted and the mathematical model is reliable.

Chapter 6

Waste Allocation of water and waste water treatment plants

Along the river Nile there are many waste water treatment plant and water treatment plant stations placed at different locations. This thesis can be used to determine the future and possible locations of waste water treatment and water treatment plants.

By calculating the critical time at which DO reaches its critical values (Table 4.25) for Luxor, Cairo and Alexandria during the highest discharge of the Nile (August months) and the lowest discharge of the Nile (February months) it is possible to know when and where the critical DO concentrations (Cc) will occur for each city during each year for the upcoming years. The Critical dissolved Oxygen concentrations is very dangerous for Mankind and aquatic life in the river, the minimum value for DO in river is 5 mg/l.(19)

To allocate the waste water treatment plant and the water treatment plant it should be taken in consideration when and where the critical dissolve oxygen concentration will take place due to global warming through the coming years.

Referring to table 4.14, Tc is calculated for each city so the critical time Tc can be used to determine the convenient distance for the waste water treatment plant (WWTP) and water treatment plant (WTP) for the months and Nile reach considered in the case study.

For Luxor governorate during the lowest discharge of the Nile (February months) it will has the lowest water temperature 19°c and the highest water temperature 21°c and the critical time Tc for these 2 water temperatures are 4.3 and 4.6 days respectively i.e. that the value of Cc (critical dissolved oxygen concentrations) will be reached after 4.3 days when water temperature is 19°c and 4.6 days when water temperature is 21°c While Luxor during the highest discharge of the Nile (August months) has a lowest water temperature of 24°c and highest water temperature of 26°c and the critical time Tc is 4.8 and 4.9 respectively, therefore the distance needed to allocate water treatment plant can calculated using the Tc and the velocity of the river Nile. The water treatment plant should be placed after the location where the Cc will happen.

For Capital Cairo during the lowest discharge of the Nile (February months) it will has the lowest water temperature of 18°c and the highest water temperature of 19°c and the critical time Tc for these 2 water temperatures are 5.5 and 5.7 days respectively i.e. means that the value of Cc (critical dissolved oxygen concentrations) will be reached after 5.5 and 5.7 days .While Cairo during the highest discharge of the Nile (August months) has a lowest water temperature 22°c and highest water temperature 25°c and the critical time Tc is 6 and 6.2 respectively, therefore the distance needed to allocate water treatment plant can calculated using the Tc and the velocity of the river Nile. The water treatment plant should be placed after the location where the Cc will happen.

For Alexandria governorate during the lowest discharge of the Nile (February months) it will has the lowest water temperature 17°c and the highest water temperature 18°c and the critical time Tc for these 2 water temperatures are 6.3 and 6 days respectively i.e. means that the value of Cc (critical dissolved oxygen concentrations) will be reached after 6.3 and 6days .While Alexandria during the highest discharge of the Nile (August months) has a lowest water temperature 20°c and highest water temperature 24°c and the critical time Tc is 7and 7.2 respectively, therefore the distance needed to allocate water treatment plant can calculated using the Tc and the velocity of the river Nile. The water treatment plant should be placed after the location where the Cc will happen.

It can be concluded that the water treatment plant should be placed after the location where the Cc occurs to assure the best water quality but this location varies from one city to another according to critical time Tc .

Chapter 7

Conclusion

The aim of this thesis is to investigate the impact of global warming on the critical dissolved oxygen concentrations of River Nile. Nile River is the main source of fresh water in Egypt .DO is the most significant parameter and an indication of the water quality status and thus affecting human life, agriculture and aquatic life.

Three stations were chosen at which the simulation was done; namely Luxor, Cairo and Alexandria. Luxor is at the upstream of the Nile River in Egypt; whereas Alexandria is at the downstream of the Nile River in Egypt, Cairo is the capital in the middle of river Nile stream The simulation was done From 1983 to 2030 and the two months on which the study focused were February (lowest discharge of the Nile in Egypt) and August (highest discharge of the Nile in Egypt). A mathematical model was done on a spreadsheet to calculate the air temperature; water temperature and finally calculating the critical DO concentrations due to water temperatures.

First a mathematical model was developed to calculate the air temperature from 1983 till 2013 to detect the rise in temperature through years and it was found that there is a rise in temperature from 1983 till 2013 by average 2 degrees Celsius. There results were used as calibration to the model and to predict the temperatures From 2013 till 2030 which showed an average increase by 2.5- 3 degree Celsius and this highly showed the global warming and climate change that the world is facing.

This model was calibrated by real life measures and previous published work and it showed an acceptable % of error as previously discussed in the chapter of calibration and validation

According to the rise of air temperatures the surface water must be affected by the atmosphere and to prove this a mathematical model was constructed to calculate the water temperature using equation 1 that depended on the calculated air temperature and other parameters stated before in the Methodology chapter. The calculated water temperature showed an average rise in temperature through the period of study from 3-5 degrees and this model was calibrated by real life measurements and it had an acceptable range of error that didn't exceed the 5 %.

The Last component in the model was calculating the critical dissolved oxygen concentrations by using the water temperatures calculated, the critical time calculated and the Streeter Phelps equation. The critical dissolved concentration showed a significant decrease in high water temperature and thus there was also a decrease the DO saturation concentrations as shown in table 4.16 and this will definitely affect the water quality

This decrease in critical DO concentrations is going to affect all values of DO concentration and thus the time needed for DO recovery in rivers is going to increase which will make the water quality of a poor condition for long periods of time and hence negatively affect the fauna and flora in rivers and also it will affect the waste allocation management plan on that river.

It is observed that the percentage decrease is higher in August than in February. This is so because the critical DO concentration in the denominator over which we divide the % decrease equation is less in August than in February (this is because August is hotter than February) and thus the % decrease is higher in the summer (August) than the winter

In light of the previous discussion it could be concluded that global warming has a negative effect on DO concentrations in general and critical DO concentrations in particular in Rivers. This is important to know because in the future this will cause a threat because the air and hence the water temperatures will continue rising and thus the DO concentrations in rivers will continue decreasing. This decrease in DO concentrations as well as the raise in water temperature will negatively affect the aquatic life and some species of them could be endangered or more seriously could vanish which in turn will affect the ecosystem.

Recommendations for Further work

The thesis did the work needed to investigate the impact of global warming on DO concentrations in river Nile, however there is still further work can be done. Among this further work include the Photosynthesis and Respiration factor, COD, SOD factors in Heins equation (eq.1) that relates the air temperature with water temperature; this can give different values for water temperatures.

Also the effect of the minimum air temperatures on water temperatures and hence on the DO concentrations can be studied as this thesis studied the effect of the maximum air temperatures on water temperatures and DOES concentrations values.

The effect of global warming on the whole DO sag curve can be studied in another research.

Different Nile reach can be studied other than Luxor, Cairo and Alexandria that were the reach studied in the thesis to investigate if they will face the same impact due to global warming.

References

1- http://water.usgs.gov/edu/earthhowmuch.html

2-Brian C. back and Gary J.Weisel, Global warming,Greenwood,2010

3- Spencer R.Weart, Discovery of Global Warming, Oxford Press,2009

4- Thomas F. Stocker&AL. , Climate Change physical science basis, Cambridge University Press,2013

5-Jim Motavalli, Feeling the Heat: Dispatches from the frontlines of Climate Change, Routledge,2004

6- http://climate.nasa.gov/effects/

7- http://www.epa.gov/climatechange/impacts-adaptation/water.html

8-Schroeder&Christophe H,Global warming and the problem of policy Innovation,Enviromental law,Vol 39,No.2, spring 2009

9-Rowland&Michael J, Will the Sky Fall In? , Antiquity, vol.84, No.326, December 2010

10- Koyoto Protocol to the united nations framework, United Nations 1998, http://unfccc.int/kyoto_protocol/items/2830.php

11- M. Radwan, "Global warming impacts on water quality in the Nile Delta, Egypt," Nile Basin Water Engineering Scientific Magazine, Vol.2, 2009.

12-Peter S. Murdoch, Jill S. Baron, and Timothy L. Miller2,Potential effects of climate change on surface water quality in North America, Journal of the American water resources Association Vol. 36,No 2 April 2000

13-W. Verweij, J. van der Wiele, I. van Moorselaar, E. van der Grinten; Impact of climate change on water quality in the Netherlands, summary of the Dutch report 'Effecten van Klimaatverandering in Nederland: 2012, Netherlands Environmental Assessment Agency, The Hague2013

14- V. Kothandaraman and R. L. Evans, Use of Air-Water Relationships for Predicting Water Temperature, Printed by authority of the State of Illinois-Ch. 127, IRS, Par. 58.29 (3-72-1000)
15- S.G. Heinz, and E.B. Preudhomme, "Stream temperature estimation from air temperature," Water Resources Bulletin Vol.29, No.1, 1993, pp. 27-45.

16- Sherine El Baradei& Amro El Baz, Effects of Global warming on Critical Dissolved Oxygen Concentrations and on DO Sag Curve in the Nile River, International Conference on Biological, Civil and Environmental Engineering (BCEE-2014) March 17-18, 2014 Dubai (UAE)

17- http://www.weatheronline.co.uk/weather/maps

18- El Baradei, S. A., Imam, E. H. (2011), "Impact of Barrages on Water Quality of Rivers Upstream and on Air Entrained in the Hydraulic Jump Downstream", ”. International Conference on Water, Energy and the Environment (ICWEE), Sharjah (UAE).

19- Egyptian Ministry of Health, "Water parameters measurement in Nile River", 2010

20- EPA (United States Environmental Protection Agency), Water: Monitoring, http://water.epa.gov/type/rsl/monitoring/vms52.cfm, 2012.

21- R. Thomann, Principles Of Surface Water Quality Modelling and Control. Harper Collins, 1987