Impact of Climate change on Dissolved Oxygen Concentrations and on Waste Allocation Plan of Nile River in Egypt

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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. As much as water and water quality are of significant importance also climatic change has the same importance. This Study investigates the impact of climate change on dissolved oxygen (DO) concentrations in Nile River. The study is done on Nile River in Egypt at two monitoring stations: Luxor governorate governorate and the Capital Cairo.
A mathematical model is developed to predict air temperatures from 2013 till 2030 and hence predict values of water temperatures and resulting DO concentrations. Furthermore, the effect of global warming on locations of water and waste water treatment plants on river Nile was studied. The study investigated temperatures and DO values in summer (peak discharge of Nile River In Egypt) and in winter (lowest discharge in the Nile in Egypt).
It was found that values of critical DO concentrations were negatively impacted as a result of the Climate change effects and thus decreased over the years by the following amounts: at Luxor 3.99% in February and 4.26 % in August, at Cairo 4% in February and 4.8% in August Furthermore, global warming has a considerable effect on locations of water and waste water treatment plants on rivers and thus on the waste allocation plan.

Keywords—– global warming, dissolved oxygen concentration, rivers, water quality, water quality modeling, waste allocation, water treatment plant, waste water treatment plant.

1.INTRODUCTION

Water is one of the main sources of life on earth, all life aspects are mainly depending on water. About 71%of the Earth's surface is water-covered. The majority of water on the Earth's surface is saline water around 96% 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.

The most influential environmental 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 by 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 significant factors that could affect water quality and dissolved oxygen concentrations 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.

Global warming is due to the increase of greenhouse gases and human activities that raised the global temperature. Global warming has a great threat to the environment and Human. Many researchers have investigated the impacts of global warming, Among these impacts: seawater rise and coastal flooding, more intense heat waves, health impacts, disruption especially on the ecology and ecosystems such as the deterioration of river water quality, a shift in the geographical range of species and a changing phenology (the timing of life-cycle events) and 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 (2)(3).

Although Egypt produces less than 1% of the world total emissions of greenhouse gasses but it is highly affected by the global warming and climate change impacts (3) (18).

Numerous studies showed that River Nile is very sensitive to temperature and precipitation changes (3). But very limited studies discussed the effect of global warming on quality of River Nile, particularly dissolved oxygen levels.

Global warming might increase the stress on River Nile and decline its water quality as high water temperatures reduce dissolved oxygen levels especially if the concentrations went below 5 mg/l that definitely will affect the water quality and aquatic life (4) (11).

Published researches studied the effect of global warming on dissolved oxygen levels in streams and rivers but none of them studied the effect of high temperatures on dissolved oxygen concentrations and on the waste allocation plan of the River Nile. This paper is the first one that studies the Impact of Global Warming on dissolved oxygen concentrations and on waste allocation plan of Nile River in Egypt.

2. MATHEMATICAL MODEL

The objective of this paper is to study the impact of global warming on the values of critical Dissolved Oxygen (DO) concentrations and waste allocation plan in Nile River.

In order to satisfy the purpose of this paper a mathematical model that is divided into three sub models were developed on an excel spread sheet to calculate the air temperatures, water temperatures and finally the Critical Dissolved oxygen concentrations.

The first mathematical sub model is the air temperature sub model that 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 via using regression techniques for the studied period and destinations.

The first component of the sub-model was extracting the maximum and minimum daily air temperature for both months: February and August from 1983-2013 at Two stations on the River Nile namely; first station is at Luxor, second one is Cairo (17).

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.

The Second mathematical sub model is the water temperature sub model where water temperature will be predicted from the previous air temperatures. Water temperatures were predicted from air temperatures using the equation of Heinz (15) which takes in consideration the lag time between air and water temperature. 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.

The Third mathematical sub model is the dissolved oxygen sub model; the simulated water temperatures of the Nile were used to calculate the critical dissolved concentrations using Streeter-Phelps equation. 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 final mathematical sub model 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.

The research was done for the previously mentioned months February and August, As February is the month in the winter at which the river Nile has the lowest discharge. As for August it is the month in the summer where the Nile reaches its peak discharge. The Two destinations chosen: Luxor as it is upstream end of the Nile, south of Egypt Alexandria is the downstream end of the Nile, north of Egypt and Cairo it is the middle

3. Calculations

For the air temperature sub model; Daily air temperatures were extracted from weatheronline.co (17) to get the average of the maximum and minimum temperature for February and August months during the period from 1983-2013.Then 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.And finally 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.

For the water temperature sub model: The governing Linear equation between air and water temperature (Heinz equation):

$$T_w=A+BT_a(t-\delta) \ldots\ldots \text{Eq. 1 (15)}$$

Tw: water Temperature in degree Celsius
Ta: air temperatures in degree Celsius
t: is the time
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:

$$\Delta T_{water}/\Delta T_{air} = 1/\sqrt{1}+(2\pi*\text{Depth}/\alpha*Ʈ)^2 \ldots\ldots\text{Eq.2}$$

Ʈ= is the cyclic period here it is 29 days
α = is the thermal diffusivity coefficient alpha
$\alpha = K/C_p*\rho$
K= Surface heat exchange coefficient between the water surface and air in $W/m^{2\cdot}C$
and it is a function of wind speed and average water temperature and is obtained from
charts and tables (19)
C_p = Specific heat Constant of water and it is constant, 4200 W.S/Kg. C
ρ = Water density and it is 1000kg/m3

$\delta = \quad \Tau / 2*\Pi * Tan-1 (2 *\Pi* depth/ \Tau * \alpha)$

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 2 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

By fulfilling all these parameters and plugging those into equation 1, water temperatures can be calculated for the 2 cities during February and August from 2009 till 2030.

For the calculations for the critical dissolved oxygen concentrations the critical time should be calculated first by the following equation:

$D_O*(k_2-k_1)/K_1*l_o)$ ………………………. Eq.3

Where:

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

K_1= Decomposition rate, in day-1, it is measure any at any temperature by the following equation:

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

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

K_2= 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:

$D_t = K_1*Lo/K_2-K_1*(e-k1t- e-k2t) + D_{Oe} -k_2t$ ……………………………… Eq. (4)

Streeter Phelps equation is used to calculate for point source waste load where "t" here will be the t_c so Dc can be calculated for the 2 cities during February and august and then Dc will be plugged in the following equation to get Cc which is the Critical dissolved oxygen concentration:

Dc=Cs-Cc…………………………… Eq. (5)

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

The initial BOD values were taken from real life readings for Luxor, Cairo at February and August (19).

4. Results and Discussions

After doing the simulation the following results for air temperatures, water temperatures and dissolved oxygen concentration were obtained. The following tables and graphs shows the results of the mathematical model carried to obtain air temperatures from 1983-2030 in Luxor and Cairo, water temperatures in Luxor and Cairo and Finally the critical dissolved Oxygen Concentrations

The Following figures illustrates the air temperatures trends at Luxor and Cairo from 1983-2030

Figure 1 Air temperatures at Luxor on February August from 1983-2030

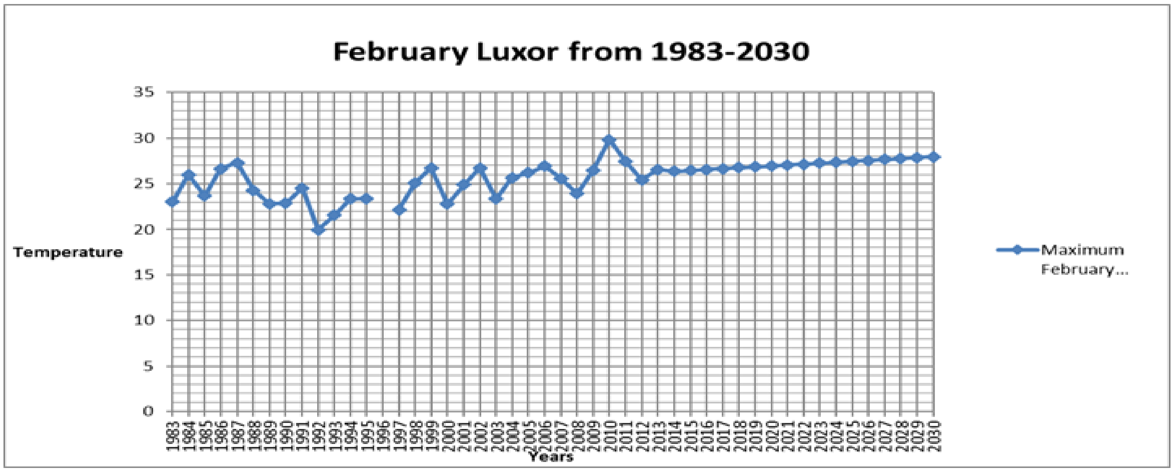

Figure 1 Air temperatures at Luxor on August from 1983-2030

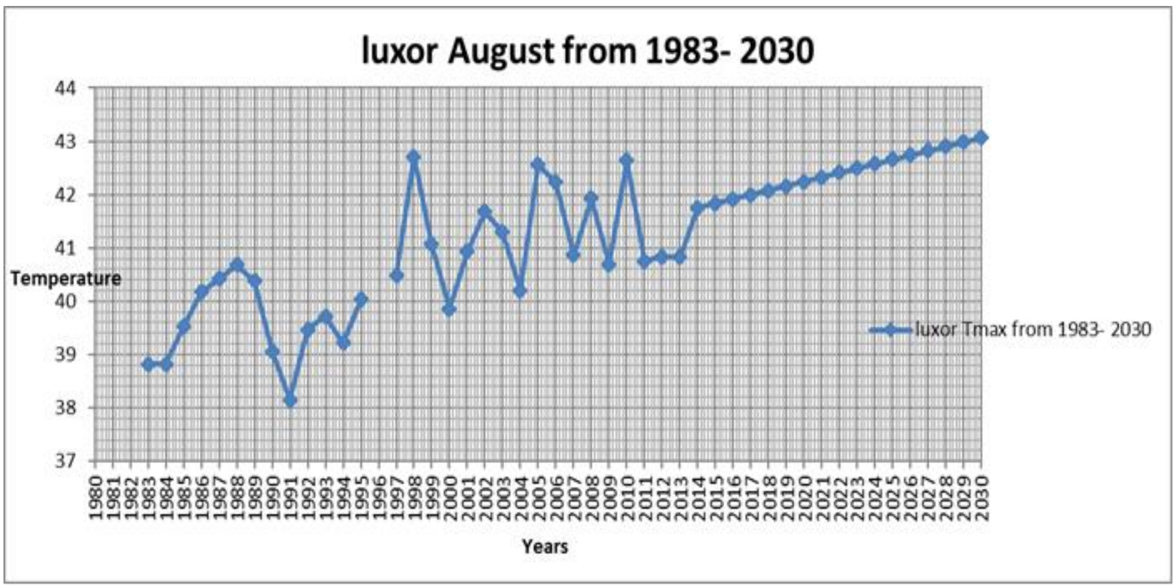

Figure 2 Air temperatures at Cairo on February from 1983-2030

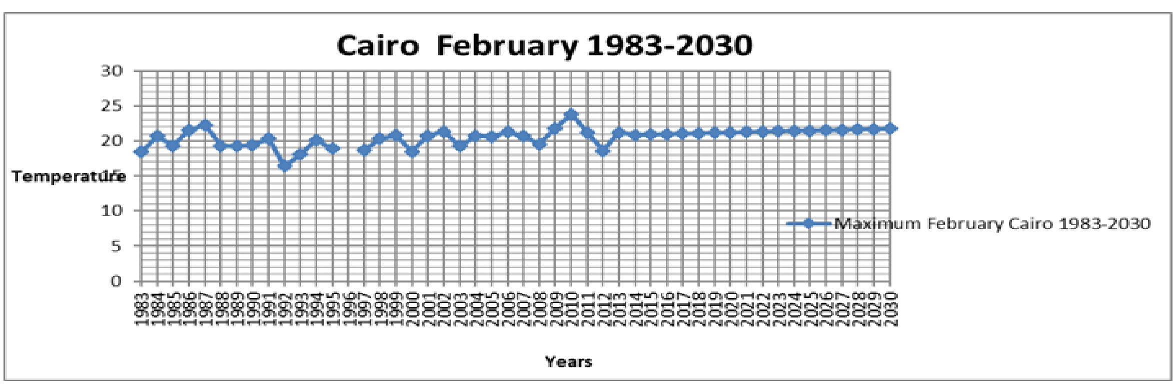

Figure 3 Air temperatures at Cairo on August from 1983-2030

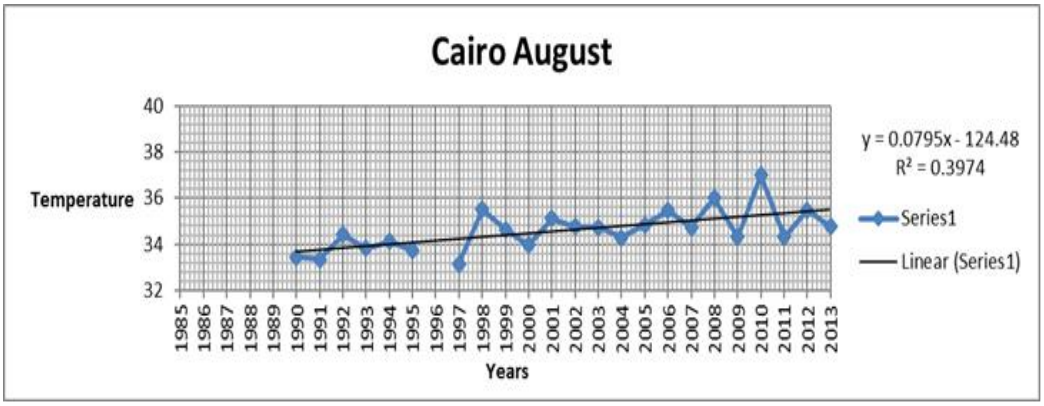

Figure 4 Water Temperatures at Luxor in August from 2009-2030

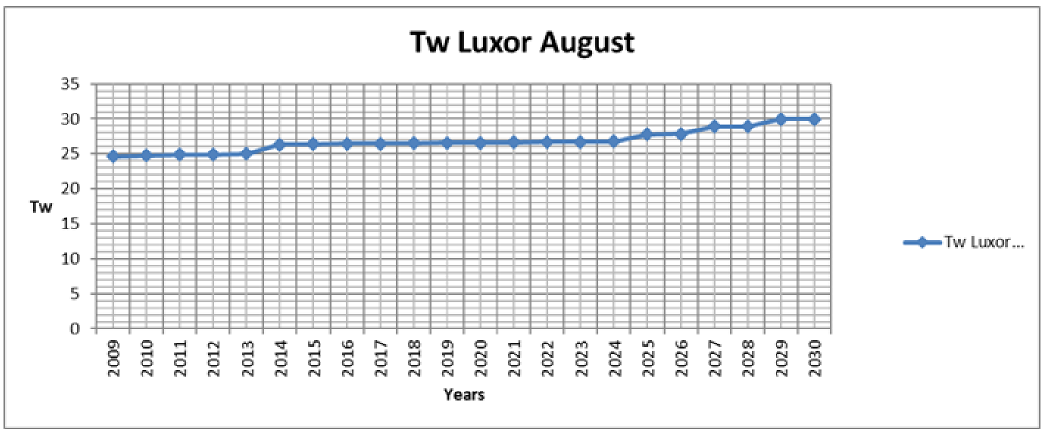

Figure 5 Water Temperatures at Luxor in February from 2009-2030

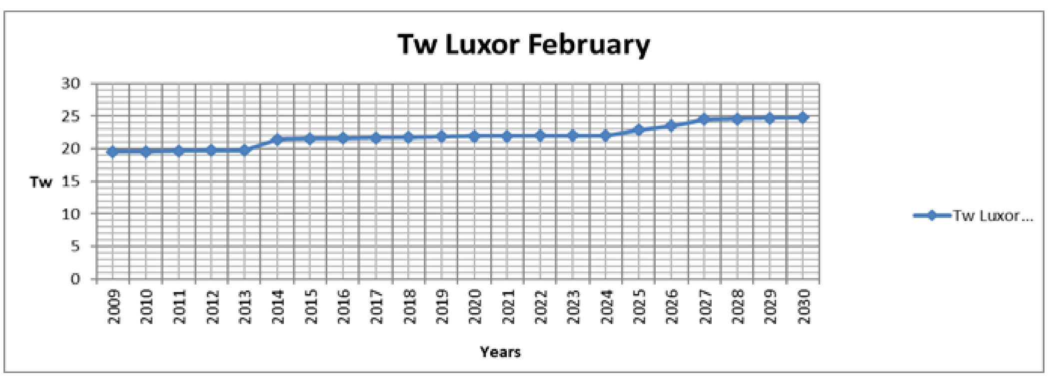

Figure 6 Water Temperatures at Cairo in August from 2009-2030

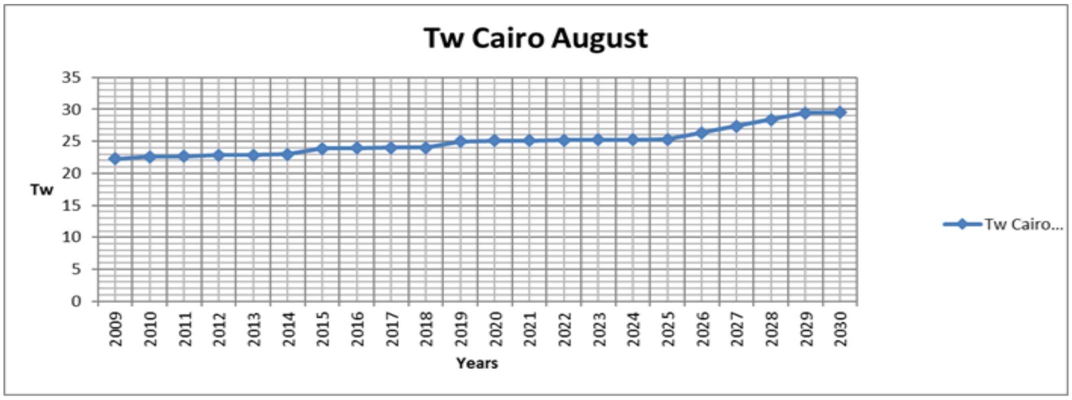

Figure 7 Water Temperatures at Cairo in February from 2009-2030

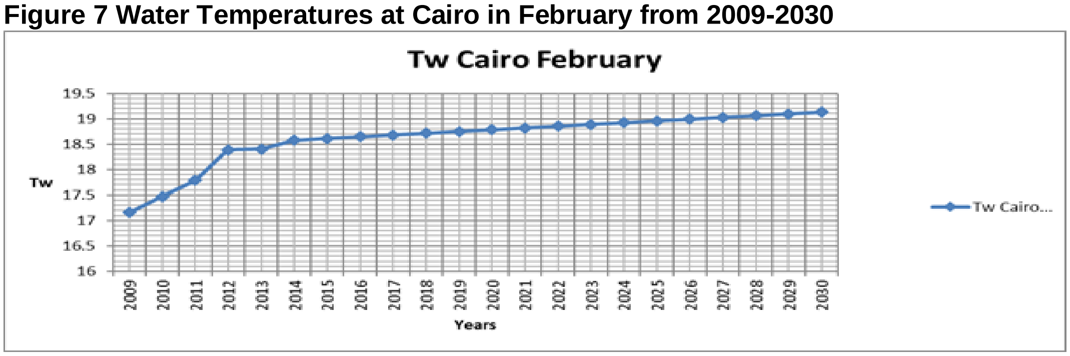

Table 1 Critical Time results

	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

Table 2 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	

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.

5. CONCULUSION

The research was done to investigate the impact of global warming on the critical dissolved oxygen concentrations of River Nile in Egypt. Two stations were chosen at which the simulation was done; namely Luxor, Cairo Luxor is at the upstream 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. 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. 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 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.

6. Calibration and Validation

The mathematical model was calibrated and validated by comparing its results with real life measurements. In the Air temperature model 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).For The water temperature model % of error between water temperatures calculated and that measured in real life for Luxor, Cairo 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). DO calibration model 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 .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 %compared with real life measurements available.

7. Waste allocation plan

By calculating the critical time at which DO reaches its critical values (Table 1&2) for Luxor, Cairo 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

8. Limitations

This research did the work needed to investigate the impact of global warming on DO concentration**s** 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 research 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 and Cairo that were the reach studied in the thesis to investigate if they will face the same impact due to global warming.

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