Monitoring and Description of Annual Accumulative Growing Degree Days Changes in Nile Delta Governorates

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Abstract: In this study daily maximum and minimum air temperature were used to calculate GDD at ten governorates in Nile Delta and presents a description for the development of seasonal accumulated Growing degree-days GDD for three selected base temperatures 0, 5 and 10 °C through the period from 2000 to 2012. The mentioned selected base temperature were chosen because the growing degree-days (GDD) above these base temperatures provide a useful indicator for assessing seasonal crops development for a group of important crops such like wheat, corn, tomato and potato which are cultivated heavily in Nile delta governorates. In addition, lots of other seasonal crops however, field or vegetables crops have the same base temperature or within this selected three base temperature. Annual accumulation of GDD in all studied Nile Delta governorates record increasing polynomial trend. Ismailia was the government out of ten studied governments, which keep presenting the first highest GDD in all studied years (2000-2012). In addition, prediction equations were implemented to predict annual accumulative GDD for the three studied base temperature for any desirable year were found and presented. Moreover, to estimate GDD's above "0 °C" and "10°C" from the mean of "5°C" GDD's a regression analysis were applied and the strong relationship were found by R^2 above 0.96. Statistics results of calculated GDD and its development through the span-period can be useful for crop management decisions, like determinate the most suitable time for cultivation, suitable locations or the ideal mix between time and location to obtain the best yield from both sides quantity and quality.

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Key words: Annual accumulative Growing Degree Days (GDD), Base temperature (0, 5 and 10 °C), Nile Delta governorates, regression equations, agro-climatic indicator.

1. Introduction

Temperature is considered as the most influential element such as chemical, physiological and biological process in plants. Plants of different species vary quite widely in their adaptability to temperature. Most plants survive and grow in a temperature range between 0 to 50°C. The occurrence of different phonological events during a growing season of any crop and the effect of temperature on plant growth can be concluded using accumulated heat units (growing degree days). The idea is based on the fact that, plants have a certain temperature requirement before they attain certain phonological stages and they need a specific amount of accumulated heat to meet their requirements for phonological development (Sunil and Sarma, 2005). In addition, Wang 1960 reported that, growing degree days (GDD) is based on the idea that the development of a plant or other organisms first of all poikilotherms will occur only when the temperature exceeds a specific base temperature for a certain number of days.

Temperature and GDD represent two important factors, both play vital roles in influencing crops development by affecting plant functions such as evapotranspiration, photosynthesis, plant respiration, and in plant water and nutrient movement (Bourque *et al*., 2000; Hassan *et al*., 2007).

Growing degree days is used as a method to predict the growth stages of major crops such as soya bean, maize, wheat particularly moderate crops; also is useful in taking precautionary measures against insect and diseases attack crops (Roltsch *et al*., 1999; Cesaraccio *et al*., 2001; Førland *et al*., 2004; Matzarakis *et al*., 2007; Fealy and Fealy, 2008). Moreover, GDD was also calculated on the basis of long-term average daily mean temperature or it computed on data of a given year and in this case it will take into account weather variability.

There are several methods of GDD calculation including model estimation with their advantages and short comings (Roltsch *et al*., 1999). Assumption of GDD with mean temperature calculated as average of minimum and maximum daily temperatures is the most common in agricultural and phenological researches as reported by Gilmore and Rogers, 1958; Bootsma, 1994; McMaster and Wilhelm, 1997; Matzarakis *et al*., 2007; Fealy and Fealy, 2008.

The Nile Valley and Delta are the main agricultural areas of Egypt and is the food basket of

Egypt. The Nile Delta region considered as highly fertile and productive agricultural land in Egypt. It has one half of the total cultivated area (about 4.3 million Feddan). About 93% of the total Nile Delta land is "old land" and contribute 65% of the total national agriculture production. Also present a unique example for mixed crop pattern whereas, field crops, vegetables and fruits are grown continuously.

Major cultivated field crops in this region are cotton, maize and rice during the summer season. However, during the winter season wheat and berseem are the major cultivated field crops. The base temperatures for those crops are 10 °C for maize (Gordon and bootsma, 1993), rice (Sandhu *et al.* 2013) and cotton (Landivar and Benedict, 1996). Base temperature of 0°C was considered for wheat (McMaster and Smika, 1988 and Kharel *et al.,* 2011).

In addition many kinds of vegetables and fruits are grown in this region during summer or winter season. Such like cabbage, carrot, cauliflower, celery, parsley, peas and spinach (base temperature = 4 °C according to Elnesr *et al.,* 2012). Another group of vegetables grown above 10 °C base temperature are cultivated in Nile Delta, for example, common beans, cucumber, melon, mulukhiyah, okra and tomato (Elnesr *et al.,* 2012). Moreover, potato also cultivated heavily in this region (base temperature = 6 °C).

Illustrated wide range of cultivated species at the studied region, however, field crops or vegetables crops varied in its heat needs and its base temperature. That is creating a difficult situation to study every crop and the availability of its need from heat units. So, in these work three base temperatures were selected to present most or all cultivated species. The chosen base temperature are 0, 5 and 10 °C because it have stable meanings as warm period; heat supply of the vegetation period and heat supply for the period of active plant growth (Gordeev *et al.,* 2006).

Highlighting the climatic statues inside the Nile Delta, a clear fact will appear through results of many studies. Such results confirm that Nile Delta are varied in its climate and contain more than agro-climatic zone. Eid *et al.,* 2006 divided Egypt into 9 agro- climatic zones; three of those 9 were inside the delta (1- Central Delta; 2- East Delta and 3-West Delta). Later, Medany, 2007 developed another classification, four agro- climatic zones appear inside the Delta as follow: (1) North Delta (Dakhlia, Gharbia, Damietta and Kafr El-Sheikh); (2) West Delta (Alexandria and Behira); (3) Middle Delta,

(Ismailia, Kalubia, Minofia, Port-Said and Sharkia); (4) South Delta (Giza, Cairo, Beni Suef and Fayom). Recently, Khalil *et al.,* 2011 presented eight different agro-climatic zones in Egypt concerning five of them in Delta i.e. (1) Kafr El-Sheikh and Garbia; (2) Alexandria and Damiatta; (3) Ismailia, Sharkia and Monofia; (4) Kalubia, Beni sweif and Minia and (5) Behira and Fayoum.

From all illustrated information about wide range of crops that cultivated in Delta beside the great reported different in the climate distribution in this area, it will be important to understand the annual spatial distribution of GDD in this area. Such understanding is relates to the integration of growth and crucial to the practice of agriculture activities. Also, it will be helpful in designing the crop rotation according to the available GDD at each governorate.

The objectives of this study are:

(1) Present specific information about GDD for different agro-climatic areas Nile Delta during the studied period for the three selected base temperatures 0, 5 or 10 °C.

(2) Establish the probability approaches to estimate GDD accumulations from known meteorological data at station all delta governorates.

(3) Establish rule of thumb measures to estimate the accumulation of GDD's above a specific base temperature from the accumulation above another base temperature for all studied delta governorates.

Materials and Methods

Daily maximum and minimum air temperature measurements starting from 2000 to 2012 were obtained from 18 automatic weather stations distributed in Nile Delta governorates (Figure 1). Some data were estimated by a weighting algorithm based on actual measurements from nearby weather stations to ensure completeness of necessary record to cover the study need. The station data were available from Central Laboratory for Agricultural Climate (CLAC), Agricultural Research Center.

The data were used to calculate GDD for each year in each governorate from the ten selected governorates in the Nile Delta region. The studied span period was considered enough to provide meaningful probability analyses while not too long to be significantly influenced by climatic change. Three base temperatures (0, 5 and 10°C) were selected based on the most presented base temperature for the some cultivated crops in Nile Delta region.

Daily GDD's of each station for the three studied base temperature were calculated based on measured daily maximum (T_{max}) and minimum (T_{min}) air temperatures and base temperature (T_{base}) as follows:

$$GDD= [(T_{max} + T_{min})/2 - T_{bas}]$$

One assumption constraint was used in the GDD as follow: If the minimum temperature is less than T_{base}, then it is set to T_{base}.

The ArcGIS 10.1 software was used to create classified maps by using Quantities graduated color methods. In addition, the location of meteorology station was generated from longitude and latitude of each location by the same software.

To estimate the annual accumulative GDD above both 0 and 10 °C using the available information about GDD above 5 °C . Data of various T_{bas} for each governorate were analyzed deterministically once with years and again together (i.e. between accumulative GDD_0 &GDD_5, GDD_0 &GDD_{10} and GDD_{10} &GDD_5) using the REG procedure (SAS, 2002).

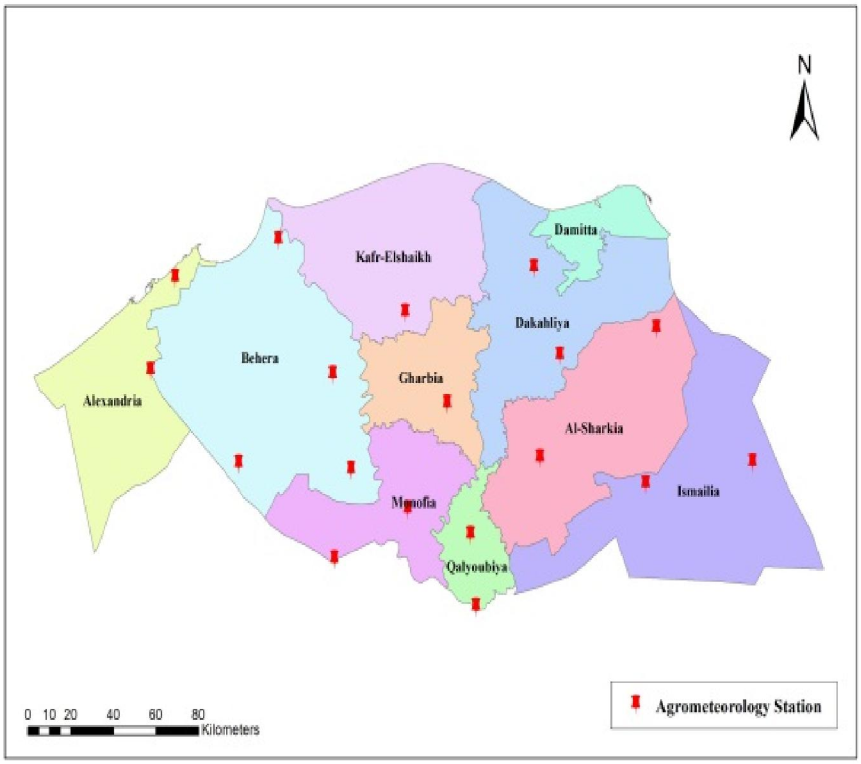

Figure (1): Locations of automatic weather stations.

3. Results and Discussion

Illustrated data in Figure (2) concluded that, yearly accumulative GDD were increasing according to polynomial trend for the period starting from 2000 to 2012. The polynomial trend for yearly GDD was confirmed in the cases of using 0, 5 and 10 °C as a base temperature (T_{bas}).

Some exceptions were recorded in some years. Such exceptions appear as a far points from the trend line. Such far points divided into two groups.

First group presented years that were lower than the general trend (down the trend line). This group appears in governorates Damietta, Ismailia, Kafr El Sheikh, Qalyubiya, Sharkia, Alexandria, Behera in 2000, but, Gharbia governorate appear in years 2000 and 2011 and finally Dakahlia appear in years 2000 and 2012.

Second group presented years that were higher than the general trend (above the trend line). Governorates that presented the second group were Damietta in 2011, Gharbia in 2012, Menofia, Behera and Qalyubia in 2010, Sharkia and Dakahlia in 2010 and 2011. Nominated exceptions were recorded for the three tested base temperature.

Observed results in figure (2) confirmed that annual accumulative GDD above 0°C base temperature was the highest compared to 5 and 10 °C following a clear descending order. Presented value trend of results could be summarized, the lowest base temperature the higher accumulative GDD.

According to the mentioned result, yearly calculated GDD's (2000 to 2012) above base temperature 0°C was the highest followed by GDD's above base temperature 5°C and finally, GDD's above 10°C was the lowest.

Results in figures (3, 4 and 5), compare annual accumulative GDD for each of the studied governorates. Inside each of the studied governorate calculated GDD recorded a wide range of differences from year to the other within the studied period for the three studied base temperature.

Generally, highest calculate GDD's was found in Ismailia governorate during the studied period from 2000 to 2012 for the three studied base temperature. On the other side, Damietta governorate was the lowest in calculated GDD's in the same mentioned period. However, in the last two years (2011 and 2012) Behira governorate was the lowest in calculated GDD's.

Highlighting on each governorate, the characterization, behavior and changes in annual accumulative GDD are discussed as follow:

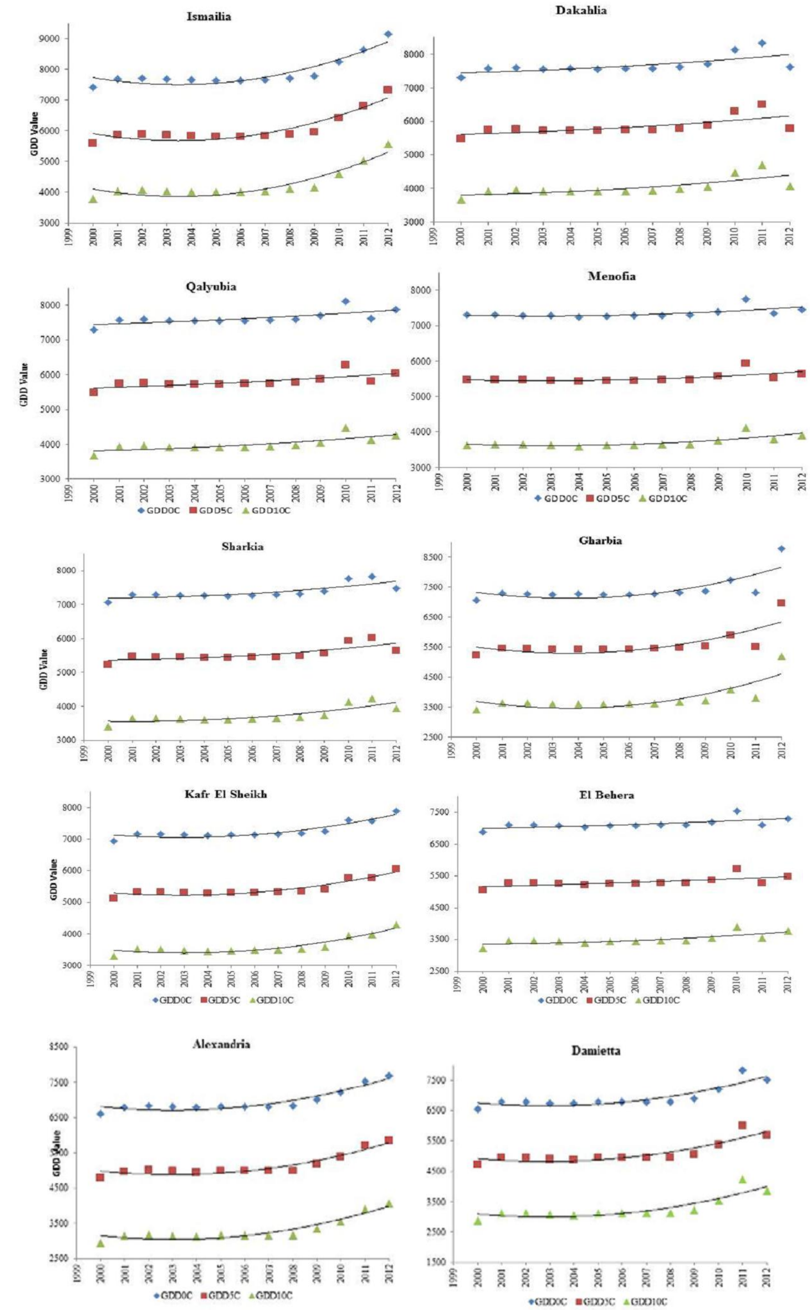

Figure (2): Yearly accumulative growing degree days (GDD) at Sharkia, Gharbia, Kafr El Sheikh, El Behera, Ismailia, Dakahlia, Qalyubia and Menofia from 2000 to 2012 for three base temperatures 0, 5 and 10 °C.

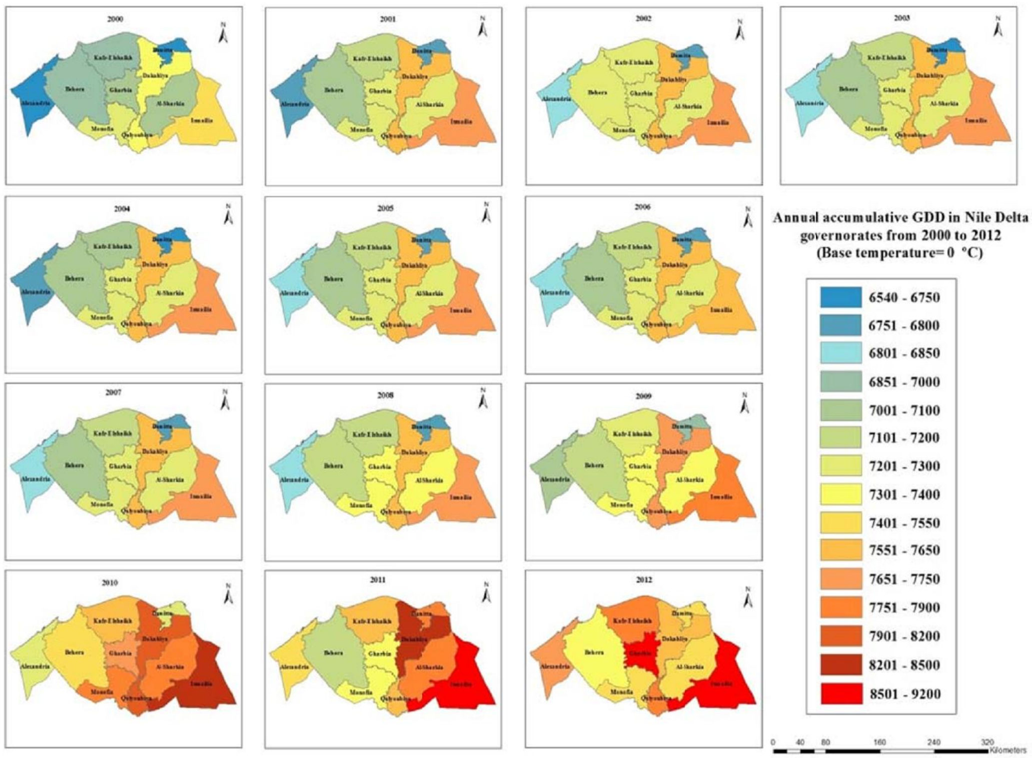

Figure (3): Distribution of annual accumulative growing degree days (GDD) in Nile Delta governorates from 2000 to 2012 at base temperature 0°C.

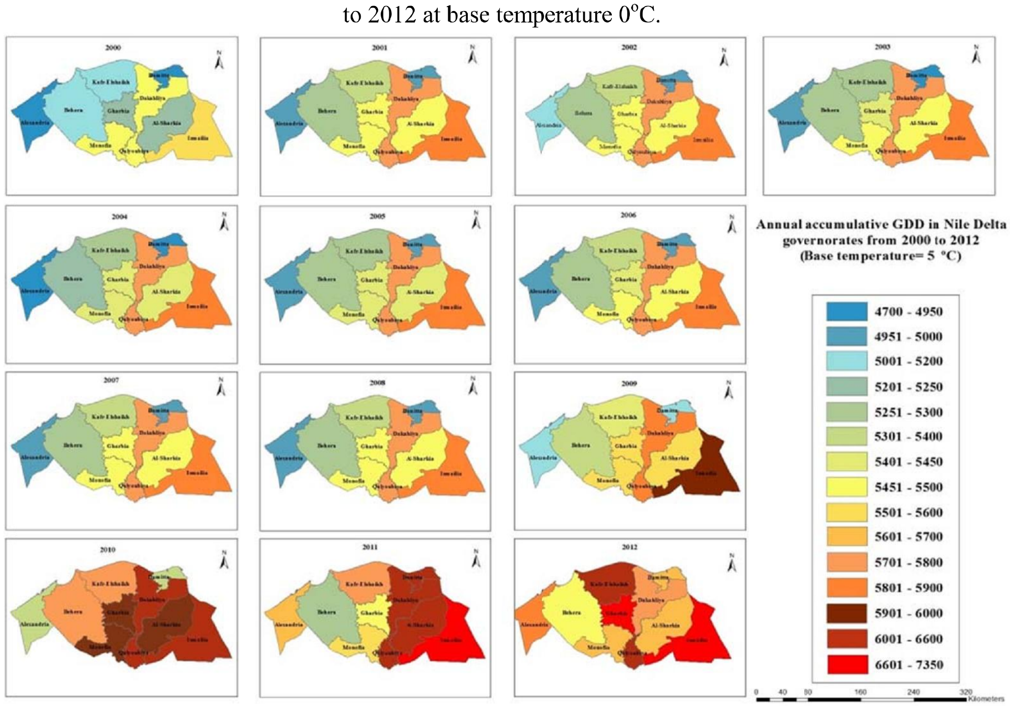

Figure (4): Distribution of annual accumulative growing degree days (GDD) in Nile Delta governorates from 2000 to 2012 at base temperature 5°C.

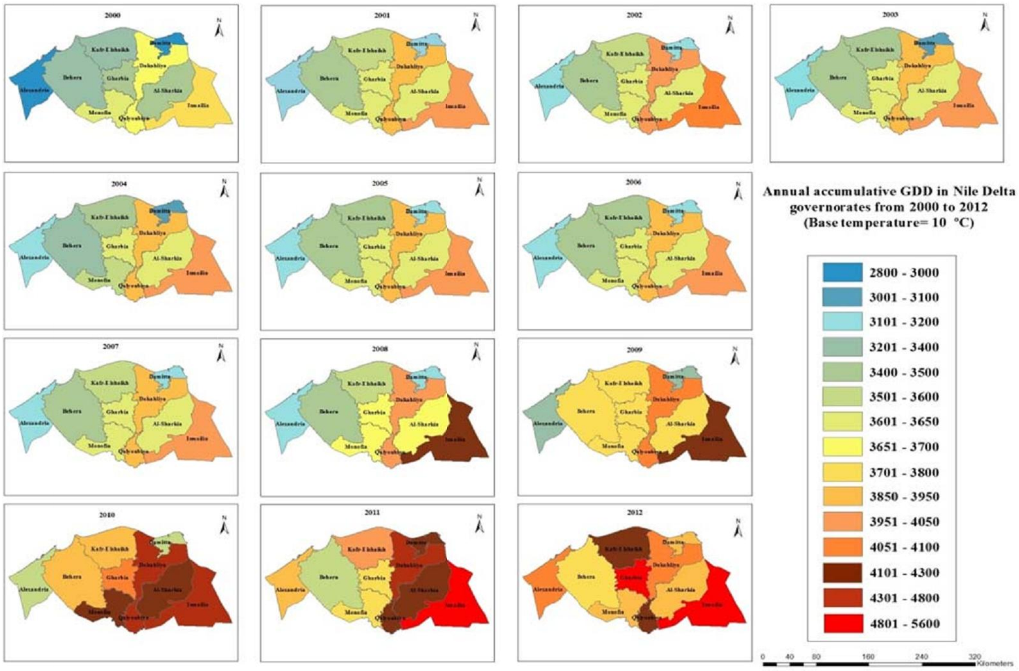

Figure (5): Distribution of annual accumulative growing degree days (GDD) in Nile Delta governorates from 2000 to 2012 at base temperature 10°C.

***Ismailia Governorate*:**

Ismailia governorate during the studied period ranked the first highest annual accumulative GDD compared to other studied governorates as shown in Table (1), this rank was completely true for the three studied base temperature 0 °C (Figure 3), 5 °C (Figure 4) and 10 °C (Figure 5). Such rank is meanly due to the high recorded maximum and minimum air temperature at this governorate, which are the main factors to calculate the GDD as mentioned before.

In addition, the annual accumulative GDD for the same respective base temperature were increased through the studied period and recorded the highest value at the end of the period (2012, when highest maximum and minimum air temperature were recroded), compared to the year 2000. Regarding the different between accumulative GDD inside the governorate, it's concluded form Figures (3, 4 and 5) that, from 2000 to 2001 and from "2001 to 2002" a slight higher in annual accumulative GDD was happened and noticed for the three studied base temperatures. Meanwhile, during the period from 2003 to 2006, annual accumulative GDD kept to be in the same range (whereas, annual maximum and minimum air temperature kept to record 28 and 15 °C at these three years) compared to years 2000, 2001 and 2002, whereas, annual maximum air temperature appears to be different and record 27, 29 and 28 °C at these years. Starting from the year 2007 to the year 2012, annual accumulative GDD has been increased to record the highest increments in years 2010 (because of the high recorded maximum air tempetarure (30 °C)), 2011 and 2012.

In this regard, it is noted that, annual accumulative GDD in Ismailia was 7424, 5594 and 3790 for the three studied base temperature through 2000. However, in the end of the studied period (2012) annual accumulated GDD were recorded 9146, 7320 and 5566.The results reflect a higher increment obtained of annual accumulative GDD governorate.

***Dakahlia Governorate*:**

Data in Table (1), indicated that, Dakahlia governorate was the second highest annual accumulative GDD, compared to other studied governorates except in years 2001, 2003, 2004 and 2007, it was the third highest accumulative annual GDD. The mentioned results due to the highest recorded maximum and minimum air temperature which was the second high air temperature after Ismailia However, in the year 2012 annual accumulative GDD decreased to be the sixth highest governorate (at this year both maximum and minimum air temperature were decreased). Studying the development of the noticed differences in GDD inside the governorate, it was noted that annual accumulative GDD recorded a continuous increment starting from

2006 and continue to record the highest value in 2011. In addition, annual accumulative GDD recorded a decrement in the year 2012 compared to the year 2011 (Figures 3, 4 and 5).

Generally, annual accumulative GDD increases in Dakahlia from 7309, 5479 and 3671 through 2000 and recorded 7615, 5788 and 4074 in 2012. Illustrated results concluded that, annual accumulative GDD in Dakahlia changes and such changes does not appear as a stable trend. From the last discussed results; it's clear that annual prediction for the accumulative GDD in this governorate should be done to determinate the suitable crop pattern in the governorate.

***Qalyubia Governorate*:**

Qalyubia governorate ranked the third highest annual accumulative GDD compared to other studied governorates. In years 2001, 2003, 2004 and 2007; the governorate ranked the second highest annual accumulative GDD (Table 1). Meanwhile, it ranked the fifth highest annual accumulative GDD in the year 2012. The discussed rank was confirmed for the three studied base temperature 0°C (Figure 3), 5°C (Figure 4) and 10 °C (Figure 5). Such mentioned different in the rank was mainly because of the different in recoded both maximum and minimum air temperature from year to another.

Concerning the recorded differences in annual accumulative GDD inside the governorate through the studied period, Figures (3, 4 and 5) indicated that annual accumulative GDD increased gradually starting from 2006 to 2010. During 2011 the annual accumulative GDD was lower than the calculated in 2010. Through 2012 annual accumulative GDD increased again, but, the increment was not enough to be equal to that recorded 2010 (still less than 2010). The mentioned trend was confirmed for the three studied base temperature.

Generally, annual accumulative GDD in Qalubia governorate increased from 7308, 5478 and 3670, during 2000 has reached the highest GDD 8121, 6296 and 4474 in the year 2010 for the same respective base temperature.

***Menofia Governorate*:**

Menofia governorate recorded a continuous reduction in the annual accumulative GDD through the span-period from 2000 to 2012 (Table 1). The governorate ranked the fourth highest in years 2000, 2001, 2003, 2005, 2006 and 2009. More reduction was recorded in the annual accumulative GDD which was enough to move the governorate for the fifth order in years 2002, 2007 and 2010. Another reduction in GDD was happened in years 2004 and 2008 while the governorate ranked the sixth order among the studied governorates. More reduction in annual accumulative GDD was found in 2011 and 2012, which reflected in the governorate order to be eighth and ninth governorate, respectively compared to other studied governorates.

The discussed order for the Menofia governorate among studied governorates reflected a low level of annual accumulative GDD compared to other studied governorates for the (Figures 3, 4 and 5).

Annual accumulative GDD at the governorate started with 7298, 5468and 3638 during 2000, but the last calculated values during 2012 were 7464, 5635 and 3907 above 0 °C, 5 °C and 10 °C, respectively. Through those values of GDD in this governorate, a slight increment was noticed. But, when comparing such increments with the recorded increment at other studied governorate it's clear that, the noticed increments at Menofia were lower than the recorded increments in other studied governorates. This status reflected in the rank of this governorate among all studied governorates. On the other hand, within the studied period the year 2010 recorded highest annual accumulative GDD.

Result could be beneficial in case of select the suitable place for crops that require relatively low annual accumulative GDD. In this respect, it is noted that this governorate is classify as one of the coolest studied governorate is mainly because of 1-the low recorded maximum and minimum air temperature at this area (which is translated to low GDD) and 2-because of continuous increment in both maximum and minimum air temperature at other studied governorates (which is reflect a late rank between other governorates).

***Sharkia Governorate*:**

Data in Table (1) confirmed that, Sharkia governorate presents a semi stable example within the studied governorates. Annual accumulative GDD for the three studied base temperature in this governorate was almost in fourth or fifth order. Sharkia was the fourth highest annual accumulative GDD in years 2002, 2004, 2007, 2008, 2009, 2010, 2010 and 2011. But, it ranked the fifth in years 2000, 2001, 2003, 2005 and 2006. Hence, year 2012 was the only recorded exception case, whereas the governorate ranked the eighth highest annual accumulative GDD. Obtained results were true for the three studied base temperature.

Focusing on the performance of annual accumulative GDD within the studied years (2000-2012), annual accumulative GDD increased in 2001 compared to 2000 and thin it decreased gradually from 2002 to 2005. These movements in values of GDD were mainly in harmony with the movement of recorded maximum and minimum air temperature.

On the other hand, Sharkia annual accumulative GDD started to take increasing trend from 2006 to record the highest annual accumulative GDD in 2011 (7835, 6014 and 4234 for the three studied base temperature (0, 5 and 10 °C; respectively). Finally, GDD decreased again in 2012. In spite of the mentioned reduction, annual accumulative GDD keep highest than the low recorded GDDs in years from 2002 to 2005. Due to the clear stability in this governorate, it could recommend to use the same crop pattern with more attention to the prediction results to be ready for any change.

***Gharbia Governorate*:**

Gharbia governorate ranked sixth order within the studied governorates during years 2000, 2001, 2002, 2003, 2005, 2006, 2007, 2009 and 2010. However; in 2004 and 2008 the governorate ranked the fifth highest annual accumulative GDD. Moreover, annual accumulated GDD in 2011 was decreased compared to other studied governorates, which make Gharbia ranked number nine among the studied governorates (Table 1).The highest annual accumulative GDD in Gharbia was found in 2012 (8786, 6963 and 5212 compared to 7059, 5229 and 3401 in 2000 for the three studied base temperature 0, 5 and 10 °C; respectively. High GDD was not only higher than other years in the same governorate but, it was also the second highest GDD compared to other studied governorates.

***Kafr El Sheikh Governorate*:**

Staring from the year 2000 to the year 2010, Kafr El Sheikh appears as the seventh highest annual accumulative GDD for the three base temperatures. However, in 2011 and 2012 it ranked sixth and fourth highest annual accumulative GDD, respectively.

Studying carefully the annual accumulative GDD inside the governorate, its noticed that, from 2000 to 2010 annual accumulative GDD kept to be in a certain range even if it reduced or decreased but, it present values in the same range.

Discussing example for a reduction in the annual accumulative GDD, it decreased slightly from "7151, 5326 and 3503" in 2002 to be "7123, 5298 and 3474" in 2003, another slight reduction was found in 2004 to be "7100, 5270 and 3442" for the three studied base temperature 0, 5 and 10 °C, respectively.

Moreover, another example for increment in the annual accumulative GDD in the governorate also was presented. In the year 2005, annual accumulative GDD recorded "7123, 5298 and 3475" and then it increased to be "7232, 5407 and 3582" in the year 2009.

In addition; during the last studied two years more increment in annual accumulative GDD was recorded to reach "7580, 5755 and 3977" in the year 2011. As mentioned before, this recorded GDD was enough to rank the governorate in the sixth order.

But, absolute highest GDD in this governorate was observed in 2012 (7876, 6047 and 4283 (FigureS 3,4 and 5) Which, was enough to qualify the governorate to rank in the fourth order.

***Behera Governorate*:**

Behera was the eighth highest governorate in annual accumulative GDD compared to other studied governments in the period from 2000 to 2010. Moreover, in 2011 and 2012 the governorate became coldest so, it ranked number ten.

From another point of view, Behera presented the third lowest governorate regarding the annual accumulative GDD from 2000 to 2010, and then during years 2011 and 2012 it became the lowest governorate for the three studied base temperature.

Although the stable rank for the governorate as mentioned before from 2000 to 2010, but, annual accumulative GDD at this governorate generally took increment trend through the studied years.

This results is explained on two bases: 1-the continuous increment in both maximum and minimum air temperature at this governorates (which is reflect the increment trend), 2- increment in recorded maximum and minimum air temperature at other studied governorates (which is reflect the reason for the stability in the rank)

The peak of the mentioned increasing trend was found 2010 (7537, 5712 and 3888).

The mentioned increment in GDD was true for all the studied years except years 2003 (7073, 5248 and 3425), 2004 (7041, 5211 and 3383) and 2011(7116, 5291 and3538) which, represent the only three reduction years (like a bottom area in a curve) in annual accumulative GDD in the governorate compared to other years which represent increments years (like a top area in a curve).

***Alexandria Governorate*:**

Alexandria governorate presented the second lowest annual accumulative GDD compared to other studied governorates from 2000 to 2010. Hence, annual accumulative GDD increased enough to reach the level that moved the government to ranked seventh and fifth order during 2011 and 2012; respectively.

The trend of annual accumulative GDD in Alexandria through the studied years appeared to be increasing trend from 2000 (6606, 4776 and 2946) to record highest value in 2012 (7673, 5846 and 4070 for the three studied base temperature 0, 5 and 10 °C) as shown in Figures (3, 4 and 5). Moreover, a continuous increasing in annual accumulated GDD was observed from 2008 to 2012.

***Damietta Governorate*:**

Damietta governorate registered the lowest annual accumulative GDD compared to other studied governorates starting from 2000 to 2010. In the last studied two years the rank of the governorate moved to be third and seventh in years 2011 and 2012; respectively. Starting from 2008 annual accumulative

GDD increased gradually to record the highest value in 2011 (7836, 6011and 4231for the same respective base temperature).

Summary of governmental rank according to its annual accumulative growing degree days (GDD) in years from 2000 to 2012 is shown in Table (1).

Table (1): Governmental rank according to its annual accumulative growing degree days (GDD) during years 2000 to 2012

years	Governorates									
	Ismailia	Dakahlia	Qalyubia	Menofia	Sharkia	Gharbia	Kafr El Sheikh	El Behera	Alexandria	Damietta
2000	1	2	3	4	5	6	7	8	9	10
2001	1	3	2	4	5	6	7	8	9	10
2002	1	2	3	5	4	6	7	8	9	10
2003	1	3	2	4	5	6	7	8	9	10
2004	1	3	2	6	4	5	7	8	9	10
2005	1	2	3	4	5	6	7	8	9	10
2006	1	2	6	4	5	6	7	8	9	10
2007	1	3	2	5	4	6	7	8	9	10
2008	1	2	3	6	4	5	7	8	9	10
2009	1	2	3	4	5	6	7	8	9	10
2010	1	2	3	5	4	6	7	8	9	10
2011	1	2	5	8	4	9	6	10	7	3
2012	1	6	3	9	8	2	4	10	5	7

Prediction the annual accumulative growing degree days:

The tabulated data in Table (2) show concluded equations which could be used to predict annual accumulative GDD for each governorate under different base temperature 0, 5 and 10 °C for any desirable year (2050 for example). Moreover, adjusted R^2 for each equation was presented in the same table, which, make it possible to evaluate degree of trust for using each of the given equations results.

Therefore, one equation was presented for each of the studied T_{base} for every studied governorate. Meanwhile, the three concluded equations for Alexandria are the most trusted equations with high adjusted R^2(0.89 for the same respective base temperatures compared to other concluded equations for other studied governorates. Moreover, equations with high adjusted R^2 were found in Kafr El-Sheikh (0.87, 0.86 and 0.87 for the same respective base temperatures, respectively).In addition, the equation for Ismailia ranked the third trusted with adjusted $R^2$0.86for the three tested base temperature 0, 5 and 10 °C, respectively and Damietta was the fourth trusted equation (0.79, 0.79 and 0.78 for the same respective base temperature).

On the other hand, equations for Dakahlia, Menofia and Behera recorded the lowest adjusted R^2 for the same respective base temperatures. Menofia was the lowest with R^2 0.40 followed by Dakahlia with R^2 0.45 and finally Behera governorate ranked the last low trusted equation with R^2 0.47 for the both base temperature 0 and 5°C.

Estimating GDD_0 & GDD_{10} using GDD_5:

To conclude GDD's for both “0 °C” and “10 °C” base temperature, a regression equations were developed and are given in Table (3) to estimate the mean GDD's above “0 °C” and “10°C” from the mean “5°C” GDD's. A strong relationship between above both “0 °C” and “10°C” appears to be exist with the mean “5°C” GDD as evident by both R^2 values exceeding 0.96.

Conclusion

Overall the obtained results from this study, it’s clear that GDD could be used as an agro-climatic indicator for thermal extreme Nile Delta climate. The study area (Nile Delta) is containing more than agro-climatic area. So, this study makes it possible to identify how these different agro-climatic areas related to needed mean temperature of each growing season. Results show that calculated GDD for the three studied base temperatures 0, 5 and 10 °C vary considerably from one governorate to another one. The highest calculated GDD was found at the south east part of the Delta (Ismailia governorate). While the lowest GDD observed at north eastern corner of the Delta (**Damietta** governorate).

Generally, values of various categories of GDD increased from west to the eastern parts of the studied region considering Damietta governorate as exception case, whereas, it located to the north eastern part of Delta and record extremely the lowest accumulated GDD.

Because of the diversity of climatic conditions in Nile Delta from one side and the quite diverse range of crops cultivated in the study area from the other side, it's concluded that all the plants cultivated in the studied region could not need to be changed. But, the distribution of the already cultivated plants needs to be re-distributed to the studied governorates. Such re-distribution is highly recommended because of the differences in GDD that appear inside each governorate through the studied period.

Table (2): Concluded equations for predicting annual accumulative GDD for Nile Delta governorates.

	Governorates			
T_{base}	**Ismailia**	**R^2**	**Dakahlia**	**R^2**
0°C	$19.20X^2$ - 76,934.66X + 77,075,695.59	0.86	$2.05X^2$ - 8,183.61X + 8,169,995.05	0.45
5°C	$19.17X^2$ - 76,831.85X + 76,970,648.10	0.86	$2.02X^2$ - 8,058.55X + 8,042,651.78	0.45
10°C	$19.86X^2$ - 79,577.74X + 79,720,412.57	0.86	$3.10X^2$ - 12,395.57X + 12,387,415.33	0.53
	Qalyubia		**Menofia**	
0°C	$1.15X^2$ - 4,592.50X + 4,578,691.94	0.51	$2.92X^2$ - 11,705.06X + 11,727,646.66	0.40
5°C	$1.11X^2$ - 4,422.77X + 4,406,524.56	0.51	$2.93X^2$ - 11,717.06X + 11,737,786.66	0.40
10°C	$1.87X^2$ - 7,477.70X + 7,464,916.03	0.63	$4.35X^2$ - 17,426.46X + 17,456,552.27	0.61
	Sharkia		**Gharbia**	
0°C	$3.18X^2$ - 12,717.51X + 12,721,781.11	0.61	$14.97X^2$ - 59,981.81X + 60,098,682.07	0.59
5°C	$3.18X^2$ - 12,729.65X + 12,731,896.70	0.61	$15.00X^2$ - 60,089.99X + 60,205,069.14	0.59
10°C	$4.64X^2$ - 18,581.59X + 18,594,433.89	0.70	$16.46X^2$ - 65,950.50X + 66,075,280.61	0.64
	Kafr El Sheikh		**El Behera**	
0°C	$8.81X^2$ - 35,272.85X + 35,330,875.12	0.87	$0.66X^2$ - 2,619.52X + 2,607,792.74	0.47
5°C	$8.75X^2$ - 35,048.67X + 35,104,185.43	0.86	$0.65X^2$ - 2,576.85X+ 2,563,017.39	0.47
10°C	$9.66X^2$ - 38,692.37X + 38,753,598.97	0.87	$2.24X^2$ - 8,945.48X + 8,943,186.53	0.60
	Alexandria		**Damietta**	
0°C	$11.18X^2$ - 44,799.46X + 44,873,367.20	0.89	$11.71X^2$ - 46,901.83X + 46,975,746.28	0.79
5°C	$11.16X^2$ - 44,704.36X + 44,776,048.63	0.89	$11.65X^2$ - 46,661.57X + 46,732,940.17	0.79
10°C	$11.83X^2$ - 47,378.17X + 47,453,579.74	0.88	$12.03X^2$ - 48,186.21X + 48,258,498.20	0.78

* "X" is the targeted year.

Table (3): Regression equations to estimate GDD for "0 °C" and "10°C" using "5°C" GDD's.

	Governorates			
Y	**Ismailia**	**R^2**	**Dakahlia**	**R^2**
Y_0	= 140.45 + 1.26 * GDD_5	0.998	=127.26 + 1.28 * GDD_5	0.999
Y_{10}	= -129.39 + 0.73* GDD_5	0.994	= -113.44 + 0.71 * GDD_5	0.997
	Qalyubia		**Menofia**	
Y_0	= 124.73 + 1.28 * GDD_5	0.999	= 125.69 + 1.30 * GDD_5	0.999
Y_{10}	= -108.70 + 0.712 * GDD_5	0.998	= -115.05 + 0.69 * GDD_5	0.997
	Sharkia		**Gharbia**	
Y_0	= 124.72 + 1.30 * GDD_5	0.999	= 135.63 + 1.29 * GDD_5	0.998
Y_{10}	= -116.53 + 0.70 * GDD_5	0.996	= -128.8 + 0.71 * GDD_5	0.991
	Kafr El Sheikh		**El Behera**	
Y_0	= 130.99 + 1.30 * GDD_5	0.999	= 120.83 + 1.31 * GDD_5	0.999
Y_{10}	= -125.98 + 0.69 * GDD_5	0.996	= -114.60 + 0.68 * GDD_5	0.997
	Alexandria		**Damietta**	
Y_0	=118.35 + 1.33 * GDD_5	0.998	= 117.74 + 1.33 * GDD_5	0.998
Y_{10}	=116.28 + 0.67 * GDD_5	0.993	= -117.31 + 0.66 * GDD_5	0.991

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