Study on climatic variability induced by urbanization and industrialization in Egypt

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सार – इस शोध पत्र में शहरीकरण और के कारण जलवायु परिवर्तिताओं पर पड़ने वाले प्रभाव की जाँच करने के लिए विख्यात जिलों मिस्र के गेटर कैरो रिजन (GCR) के तीन को लिया गया है। इन तीनों जिलों का चयन शहरीकरण के भिन्न-भिन्न स्तरों को दर्शाने के लिए किया गया हैं जिनके नाम हैः बाहतीम (ग्रामीण क्षेत्र को दर्शाता है) अब्बसिया (शहरी क्षेत्र का दर्शाता है) तथा ड्रेल्वन (औधोगिक क्षेत्र को दर्शाता है)। इस शोध पत्र में सात जलवायविक तत्वों (न्यूनतम, अधिकतम तथा औसत तापमान, पवन गति, सापेक्षिक आर्द्रता, बादल और वर्षा की मात्रा) की मासिक ऋतुनिष्ठ और वार्षिक औसत विसंगतियों को ग्रामीण शहरी और औधोगिक क्षेत्रों में तीन लगातार अवधियों में लेकर के चरणों की गणना की गई। प्रत्येक जिले के विस्तार और विकास को दर्शाने के लिए तीन अवधियों का चयन किया गया है। प्राप्त हुए परिणामों से पता चला है कि प्रत्येक जिले के न्यूतम अधिकतम तथा औसत तापमानों में इसके पूर्व की अवधि के दौरान धीरे-धीरे वृद्धि हुई है जबकि पवन गति के मान सापेक्षिक आर्द्रता बादल एवं वर्षा की मात्रा में अपेक्षाकृत विपरीत लक्षय प्रदर्शित हुए है। शहरीकरण की प्रक्रियाओं के प्रभाव की तुलना में औधोगिकीकरण की प्रक्रिओं का जलवायाविक तत्वों पर अधिक प्रभाव देखा गया है।

ABSTRACT. The present work investigates the effect of urbanization and industrialization processes on climatic variabilities over three distinguished districts in Greater Cairo Region (GCR), Egypt. The three districts have been chosen to represent different degrees of urbanization namely, Bahtim, (represents rural area), Abbasiya (represents urban area) and Helwan (represents industrial area). The monthly, seasonally and annual mean anomalies of seven climatic elements (minimum, maximum and mean temperatures, wind speed, relative humidity, cloud and rainfall amounts) for three successive periods at the rural, urban and industrial areas have been calculated and used in this study. The three periods have been selected to represent stages of growth and development of each district. The results revealed that, for each district, the values of minimum, maximum and mean temperatures were gradually increased from old period to attained maximum values during the last recent period, while the values of wind speed, relative humidity, cloud and rainfall amounts showed fairly opposite behaviour. The effects of industrialization processes on the climatic elements were found stronger than the effects of urbanization processes.

Key words – Climatic variability, Climatic elements, Urbanization, Industrialization, Egypt.

1. Introduction

The impact of the process of urbanization on the climate of cities is well documented in the literature. It is now nearly two hundred years since the first discussion of urban climate based on direct temperature measurements (Luke Howard's thermometer based observations) in London in 1820. It was found that London was warmer than the surrounding countryside (Howard, 1820). Urbanization and industrialization have modified the local city climate, which are often characterized by higher temperature, lower humidity, cloudiness and rainfall, and weaker winds than surrounding rural areas. Now the impact of urbanization and industrialization on air temperature (Urban Heat Island, UHI) has been documented in many cases. In many cities, the increase in urbanization would differentially warm the minimum relative to the maximum temperature and make the trend of the minimum temperature is larger than the maximum. The reason of this difference is apparently linked to associated increases in low cloudiness and to aerosol effects as well as the enhanced greenhouse effect (Qian and Lin 2004). Zhou *et al*. (2004) found that the daily minimum temperature rise faster than the daily maximum temperature in urban areas in China. Annual and seasonal significant increasing trends of maximum and minimum temperature were detected in the Western half of Iran due to urbanization and greenhouse gas emissions from human

activities (Tabari, 2011). The increasing trends in minimum temperature were stronger than those of maximum temperature in the Maharlo watershed, south-western of Iran (Abolverdi, 2014). Also, it has been reported that the rise of temperature in urban districts is steeper than that in other regions because of the urban heat-island effect (Stone, 2007; Fujibe, 2009; McCarthy *et al*., 2010). The magnitude of urban heat island is a function of urban morphology and physical characteristics, urban extent, waste heat release, and other regional climate factors (Oke, 1987; Arnfield, 2003; Kanda, 2007).

Air pollutants and aerosols generally reduce the amount of shortwave radiation reaching the ground surface during daytime, creating a cool effect on the surface. However, they are much more effective in absorbing and emitting radiation than water vapor and greenhouse gases in the long wave atmospheric window (wavelength range 8-11 µm) under specific conditions, thus having the potential to increase the long wave radiation energy received at the surface of the urban land (Jacobson, 1998). The overall effect depends on the initial particle and growth size due to absorption of water vapor, (Rudich *et al*., 2007).

Sundborg (1950) was the first to relate UHI intensity to meteorological elements such as cloudiness, wind speed, temperature, and absolute humidity using a multiple linear regression method. He showed that cloudiness and wind speed parameters are negatively correlated with the UHI intensity in Uppsala, Sweden, and that the total variance explained by the regression model is larger in the night time than in the daytime. After Sundborg's pioneering paper was published, many similar works have followed, using different sets of meteorological parameters for various cities (Duckworth and Sandberg 1954; Oke, 1995; Kuttler, 1998; Juan *et al*., 2000; Morris *et al*., 2001 and Tereshchenko and Filonov, 2001). Also, the effect of urbanization on the humidity field "Urban Humidity Island" has been studied in detail by various investigators (Kratzer, 1956; Nieuwolt, 1966; Padmanabhamurty, 1979; Jauregui, 1986; Oguntoyinbo, 1986; Padmanabhamurty, 1986; Abedayo, 1991; Unkasevic, 1996; Jauregui and Tejeda; 1997 and Unkasevic *et al*., 2001). It has been demonstrated that the central parts of cities are usually warmer and drier than their environs. The impact of urbanization on precipitation has been also studied by various investigators (Atkinson, 1971; Lowry and Probáld, 1978; Yonetani, 1982; Shafir and Alpert, 1990; Changnon *et al*., 1991; Jauregui and Romales, 1996; Changnon, 2001; Bornstein and Lin, 2000). In these investigations, it was found that both, the number of precipitation days and the intensity of precipitation have changed due to urbanization and industrialization processes. Fortuniak *et al*. (2006) analysed data from two automatic stations in Lodz, Poland (one urban and one rural) for the period 1997-2002 and stated that under favourable weather conditions the highest temperature differences between the urban and rural station reached 8.0 °C. These authors also found that relative humidity is lower in the town, sometimes by more than 40%, water pressure differences can be either positive (up to 5 hPa) or negative (up to - 4 hPa) and wind speed at the urban station is on average lower by about 34% at night and 39% during daytime.

Although the effects of urbanization on climatic elements have been studied worldwide so far by many authors (Landsberg, 1981; Oke, 1982; Holmer and Eliasson, 1999; Montavez *et al*., 2000; Arnfield, 2003; Sailor and Lu, 2004; Best, 2005; Best *et al*., 2006; Masson, 2006; Kanda, 2007; Grimmond, 2007; Oleson *et al*., 2008; 2010; 2012; Fujibe, 2009; Flanner, 2009; Parker, 2010; Grimmond *et al*., 2010; Kitha and Lyth, 2011; Kai *et al*., 2012; Qi-xiang *et al*., 2012; Guangyong *et al*., 2013; Jun *et al*., 2013; Yan *et al*., 2013), there are few studies focused especially on the effect of urbanization and industrialization processes on the climatic elements in Egypt. Therefore, this paper deals with the climatic variabilities induced by urbanization and industrialization processes over three distinguished localities represent different degrees of urbanization and how much these processes affect the climatic elements in Egypt.

2. Study area and climatic characteristics

The study area of GCR lies south of the delta in the Nile basin. It is considered as one of the world's 15 largest cities in urban and population growth. Its population exceeds 19 million concentrated over an area of about 214 km^2. It is characterized by the presence of Moqattam hills to its east and southeast, and desert areas extending in the west and east directions. Urbanization and industrialization have increased very rapidly in GCR, particularly in the second half of the last century, causing an increase in the pollution of its atmosphere. Climatologically, GCR follows a subtropical climatic. Among the outstanding weather events are dust and sandstorms that frequently blow in the transitional seasons of spring (March to May) and autumn (September to November). In spring, hot desert depressions known as the Khamasin depressions occur. They are always associated with hot and dry winds often laden with dust and sand, increasing the atmospheric pollution. In winter (December to February) the general climate of GCR is cold, moist and rainy, while during summer (Jun to August), its climate is hot, dry and rainless. According to the Climatological Normals of Egypt (EMA, 1982), the average daily mean,

TABLE 1

Coordinates and brief locations description

Stations	Latitude	Longitude	Brief location description
Bahtim	30° 08′	31° 15′	An agrometeorological station, lies on the border between urbanized and cultivated area
Abbasiya	30° 05′	31° 17′	Typical urban site surrounded by overpopulation towns in all directions except SE-direction
Helwan	29° 52′	31° 20′	Heavy industrial and residential site lies in south east of Cairo City in eastern desert

Fig. 1. Growth of the population of Egypt and its capital, Greater Cairo Region (Source: Census of Egypt)

maximum, and minimum temperatures over GCR range from 13.8, 19.7 and 8.8 °C, respectively, in January, to 27.9, 34.9 and 22.3 °C, respectively, in July. Average relative humidity ranges from 38% in May to 65% in January, while cloud cover ranges from 0.1 octa in July to 2.4 octa in January. Rainfall in GCR is generally low throughout the year. The total rainfall ranges from 0.3 mm in October to 6.8 mm during December, while the months from April to September are rainless. Wind speed ranges from 2.8 kt during October to 5.6 kt during May. The prevailing winds are N, NW and W, with percentage of occurrence 31.8, 12.9, 12.8, respectively. These wind directions could cause rapid transportation of pollutants and other urban wastes from the adjacent northern industrial area of Shubra El-Kheima to GCR. In this study, three distinguished districts in GCR have been chosen to represent different degrees of urbanization namely, Bahtim, (represents rural area), Abbasiya (represents urban area) and Helwan (represents industrial area). A brief description and basic information of the three selected districts (Table 1) are given below:

(*i*) Bahtim agro-meteorological station lies about 13 km to the north west of central Cairo near the border between urbanized and cultivated area. It has been established at the end of 1966 in the field of the Agricultural Research Station of the Agricultural Society at Bahtim and is working on routing basis up till now (2014). The observational field at Bahtim included a dry and bare field up to 1970. Afterwards it included a wet field covered with grass (Lippa-Nodiflora). The surrounding area was cultivated land and it was considered to be a good example of the rural area. The irrigation in Bahtim in addition to the Nile water is considered important and good moisture sources. Fortunately, although the population and human activities started increasing rapidly nearby Bahtim area during the last few years, its typical rural conditions is still completely existing till now (2014).
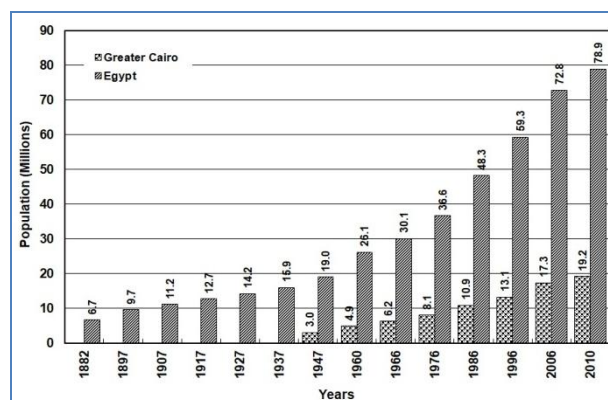
(*ii*) Abbasiya meteorological station (main building of the Egyptian Meteorological Authority, EMA) lies on the east bank of the River Nile near Central Cairo on the road leading from the city to the suburb of Heliopolis, to the northeast part of Cairo city. Many factories exist in the near-by area also, where high density of buildings and high density of population exist in addition to more than 2 millions cars and buses. Streets are covered by asphalt and gardens are not abundant. The local soil is originally desert sand. There are no any moisture sources except River Nile. Generally, air quality in Abbasiya station represents the typical urbanization occurs in and around Cairo City.

(*iii*) Helwan is the heavy industry and residential area, is about 24 km to the south east of the city of Cairo in the eastern desert. Before 1950, this city was an international famous calm place distinguished by its fine and good weather as well as its known natural spring. Peoples from different parts of the country and from different countries usually visited it enjoyed its good weather and exposing themselves to the beneficial solar radiation. From 1950, the urbanization and industrialization processes have been growing very rapid in and around Helwan. The most important factors in this area are the steel, cement, chemical, fertilizer, brick and car industries and power plants. All the above stations were adequately and regularly serviced by EMA.

3. The population growth of Egypt and GCR

Egypt is currently suffering overpopulation. The population growth in Egypt and its capital, GCR, increased several times during the few last decades (Fig. 1). The population of Egypt rose from 6.7 millions in 1882 to over 78.9 millions in 2010. It is expected to increase to about 150 millions in 2050. GCR's population also rose from 3.013 million in 1947 (The start date of

TABLE 2

Normals values of the climatic elements and its corresponding anomalies during the three successive periods (1967-1981, 1982-1996 and 1997-2012) at Bahtim rural area and (1923-1952, 1953-1982 and 1983-2012) at the urban (Abbasiya) and industrial (Helwan) areas

Climatic element	Area	Normal	Anomalies		
			Eldest period	Middle period	Recent period
Minimum temperature, Tmin (^{o}C)	Rural	12.95	-0.81	-0.17	+0.92
	Urban	16.95	-1.36	+0.34	+1.50
	Industrial	17.64	-1.71	+0.12	+1.85
Maximum temperature, Tmax (^{o}C)	Rural	28.62	-0.54	+0.36	+0.73
	Urban	29.37	-0.62	+0.17	+0.98
	Industrial	29.91	-0.82	+0.0.8	+0.99
Mean temperature, T (^{o}C)	Rural	20.74	-0.63	-0.05	+0.58
	Urban	22.14	-1.11	+0.29	+1.23
	Industrial	23.53	-1.58	+0.21	+1.51
Wind speed, V (m/s)	Rural	4.16	+0.62	-0.18	-0.63
	Urban	4.02	+0.75	-0.22	-0.84
	Industrial	3.87	+0.81	-0.16	-0.88
Relative humidity, RH (%)	Rural	62.71	+3.62	+0.82	-4.25
	Urban	57.71	+5.10	-0.19	-6.22
	Industrial	55.86	+5.75	-1.23	-7.11
Cloud amount, CL (octas)	Rural	2.97	+0.70	+0.08	-0.86
	Urban	1.33	+0.81	-0.04	-0.89
	Industrial	1.24	+1.09	+0.11	-1.07
Rainfall, RN (mm)	Rural	2.82	+0.47	+0.07	-0.50
	Urban	1.92	+0.62	-0.25	-0.67
	Industrial	1.83	+0.89	-0.13	-0.65

GCR census) to 19.2 millions in 2010. Currently the population of GCR is estimated to be growing at roughly 2.9 per cent annually and accordingly, it is expected to increase to about 60 millions in 2050. Currently, the population of GCR represents almost a quarter of Egypt's population and it is the most populated city in Egypt at about 2136.1 person per square kilometer against 63.7 person per square kilometer in Egypt as a whole, (Egypt Human Development Report, 2003). Overpopulation of Egypt and its capital causes many problems including air pollution, rapid spread of disease and climate change. Therefore, the population problem in Egypt is extremely severe and needs to be solved.

4.   Data used

Monthly measured values of seven climatic elements at the three selected stations of Bahtim, Abbasiya and Helwan for ninety years period (1923-2012) have been obtained from EMA and used in this study. Only forty-six years period (1967-2012) is available for Bahtim whereas its agro-meteorological station has been established at the end of 1966. The seven climatic elements that used in this study are minimum temperature (Tmin, °C), maximum temperature (Tmax, °C), mean temperature (T, °C), wind speed (V, kt), relative humidity (RH, %), cloud amount (CL, octas) and rainfall amount (RN, mm). The three selected stations were adequately and regularly serviced by EMA and the sites of data collection have remained the same, with almost negligible change since the beginning of the measurements. The three stations were selected to represent different degrees of urbanization namely, Bahtim, (represents rural area), Abbasiya (represents urban area) and Helwan (represents industrial and residential area). The Kolmogoroff-Smirnoff (KS-test) and the Shortcut Barlet homogeneity tests
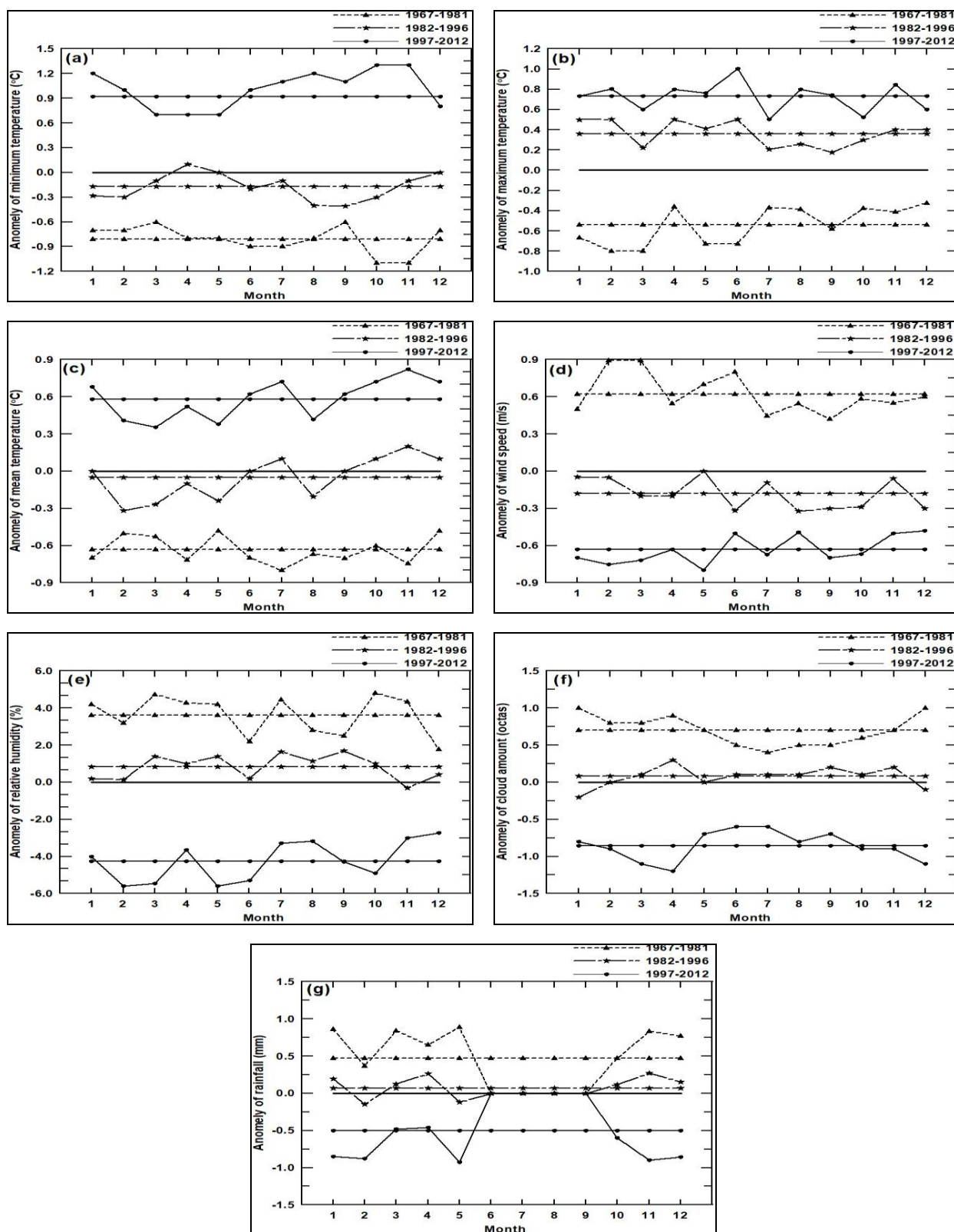
Figs. 2(a-g). Variation of monthly mean anomalies of (a) minimum temperature, Tmin; (b) maximum temperature, Tmax; (c) mean temperature, T; (d) wind speed, V; (e) relative humidity, RH%; (f) cloud amount, CL and (g) rainfall amount, RN during the three different periods, (1967-1981), (1982-1996) and (1997-2012) at the rural area of Bahtim

(Aesawy and Hasanean, 1998) were carried out and adjustments were made to filter out the in homogeneities due to instruments and observational errors. The tests established that the data for all the three stations were homogenous. Analysis of variance is also used and the significance levels tested are less than 0.05. Minitab software version 16 was used to apply the test.   The monthly, seasonally and annual mean anomalies values of the seven climatic elements for three successive periods, (1967-1981), (1982-1996) and (1997-2012) at Bahtim and (1923-1952), (1953-1982) and (1983-2012) at Abbasiya and Helwan have been calculated and used in this study. This study has been performed for the available three different periods representing different stages of growth and development of the study areas and to show the behavior of the different climatic elements before and after urbanization and industrialization established in GCR since 1950 and to identify the characteristics of these climatic elements associated with simple development occurred at Bahtim area since establishment of its agro-meteorological station by the end of 1966 year.

5.   Results and discussion

Analysis of the annual mean anomalies of the seven climatic elements over the three selected areas have been presented and discussed in detail in the following section.

5.1. *Bahtim station (rural area)*

The monthly and annual mean anomalies of the climatic elements; [minimum temperature (Tmin, °C), maximum temperature (Tmax, ℃), mean temperature (T, °C), wind speed (V, kt), relative humidity (RH, %), cloud amount (CL, octas) and rainfall amount (RN, mm)] for three successive periods (1967-1981), (1982-1996) and (1997-2012) at the rural of Bahtim are given in Table 2 and illustrated by Figs. 2 (a-g). It was found that the annual mean anomalies of Tmin have been increased from -0.81 °C during the eldest period (1967-1981), to -0.17 °C in the middle period (1982-1996), and again increased to +0.92 °C in the recent period (1997-2012) [Fig. 2(a) and Table 2].

The same pattern has been found for Tmax and T. The annual mean anomalies of Tmax have been increased from -0.54 °C in the eldest period (1967-1981) to +0.36 °C in the middle period (1982-1996) and then again increased to +0.73 °C in the recent period (1997-2012). Regarding the mean temperature (T), the annual mean anomalies have been distinctly increased from -0.63 °C in the eldest period (1967-1981) to -0.05 °C in the middle period (1982-1996), thereafter, it increased to +0.58 °C in the recent period (1997-2012), [Figs. 2(b & c) and Table 2]. The same behavior is generally observed for the

variations of the seasonal mean anomalies of Tmin, Tmax and T with highest (lowest) variation during spring (autumn) season. The seasonal mean anomalies of Tmin have been increased from -0.93 °C (-0.73 °C) during spring (autumn) of the eldest period to +1.23 °C (+0.70 °C) in spring (autumn) of the recent period. While, the seasonal mean anomalies of Tmax have been increased from -0.63 °C   (-0.46 °C) during spring (autumn) of the eldest period to +0.77 °C (+0.70 °C) in spring (autumn) of the recent period. Similarly, the seasonal mean anomalies of T have been increased from -0.72 °C (-0.56 °C) during spring (autumn) of the eldest period to +0.72 °C (+0.42 °C) in spring (autumn) of the recent period, (Table 3).

It is noticed that all monthly mean values of Tmin, Tmax and T at the rural area have negative anomaly during the eldest period (1967-1981), while they have positive anomaly during the recent period (1997-2012). During the middle period (1982-1996), the monthly mean values of Tmin and T fluctuated between the negative and positive anomaly while all monthly mean values of Tmax have positive anomaly, [Figs. 2(a-c)]. This gradual increase in Tmin, Tmax and T is due to the effect of transport huge amounts of air pollutants into the rural area from its north in addition to the actual population and human activities that recently increased rapidly around Bahtim area. Furthermore, it is clear that the process of urbanization has insignificant effect on Tmax and T compared to Tmin [Figs. 2(a-c) and Table 2). This result agrees with the findings of Chandler (1967), Oke (1982), Katsoulis and Theoharatos (1985), Harmon *et al*. (2004), Runnalls and Oke (2006), Hale *et al*. (2008).

Fig. 2(d) and Table 2 show monthly and annual mean anomalies of wind speed (kt) for the three selected periods. It was found that the variations of annual mean anomalies of wind speed from the eldest period (1967-1981) to the recent period (1997-2012) opposite to the corresponding variations of air temperature [Figs. 2(a-d)], whereas the annual mean anomalies of wind speed have been gradually decreased from +0.62 kt during the eldest period (1967-1981) to -0.18 kt in the middle period (1982-1996), and again decreased to -0.63 kt in the recent period (1997-2012). It could be noticed that all monthly mean values of wind speed have positive anomaly during the eldest period (1967-1981), while they have negative anomaly during both middle and recent periods, [Fig. 2(d) and Table 2]. This lesser values of wind speed may be attributed to gradually increase of buildings number and growing up of high establishments results in an increase of the roughness parameter (assumed to be grown from 0.01 m to 0.20 m). Therefore, wind velocity has been decreased in recent years compared to both eldest and middle periods. Regarding the variations of the seasonal mean anomalies of wind speed (kt), it was found that the highest

TABLE 3

Seasonal anomalies of the climatic elements during the three successive periods (1967-1981, 1982-1996 and 1997-2012) at Bahtim rural area and (1923-1952, 1953-1982 and 1983-2012) at both urban (Abbasiya) and industrial (Helwan) areas

Climatic element	Season	Area	Anomalies		
			Eldest period	Middle period	Recent period
Minimum temperature, Tmin (ºC)	Winter	Rural	-0.76	-0.19	+1.00
		Urban	-1.33	+0.59	+1.45
		Industrial	-1.59	+0.15	+1.80
	Spring	Rural	-0.93	-0.27	+1.23
		Urban	-1.45	+0.09	+1.70
		Industrial	-1.89	-0.14	+2.09
	Summer	Rural	-0.87	-0.23	+1.10
		Urban	-1.36	+0.39	+1.51
		Industrial	-1.79	+0.44	+1.83
	Autumn	Rural	-0.73	0.00	+0.70
		Urban	-1.31	+0.29	+1.37
		Industrial	-1.56	+0.03	+1.67
Maximum temperature, Tmax (ºC)	Winter	Rural	-0.60	+0.47	+0.71
		Urban	-0.69	+0.16	+1.13
		Industrial	-0.83	+0.14	+0.97
	Spring	Rural	-0.63	+0.38	+0.77
		Urban	-0.71	+0.13	+1.07
		Industrial	-0.97	+0.17	+1.07
	Summer	Rural	-0.49	+0.32	+0.72
		Urban	-0.69	+0.30	+0.95
		Industrial	-0.75	+0.09	+1.01
	Autumn	Rural	-0.46	+0.29	+0.70
		Urban	-0.60	+0.09	+0.93
		Industrial	-0.73	-0.07	+0.93
Mean temperature, T (ºC)	Winter	Rural	-0.68	-0.03	+0.60
		Urban	-1.07	+0.39	+1.21
		Industrial	-1.62	+0.12	+1.44
	Spring	Rural	-0.72	+0.10	+0.72
		Urban	-1.27	+0.38	+1.41
		Industrial	-1.63	+0.14	+1.58
	Summer	Rural	-0.57	-0.20	+0.59
		Urban	-1.30	+0.32	+1.22
		Industrial	-1.54	+0.20	+1.57
	Autumn	Rural	-0.56	-0.07	+0.42
		Urban	-0.80	+0.09	+1.08
		Industrial	-1.53	+0.38	+1.43
Wind speed, V (m/s)	Winter	Rural	+0.66	-0.13	-0.65
		Urban	+0.64	-0.30	-0.86
		Industrial	+0.86	-0.22	-0.84
	Spring	Rural	+0.71	-0.13	-0.72
		Urban	+0.87	-0.28	-0.93
		Industrial	+0.96	-0.15	-0.97
	Summer	Rural	+0.60	-0.25	-0.56
		Urban	+0.85	-0.15	-0.81
		Industrial	+0.71	-0.09	-0.86
	Autumn	Rural	+0.52	-0.22	-0.62
		Urban	+0.59	-0.08	-0.77
		Industrial	+0.69	-0.19	-0.83

Table 3 (*Contd.*)

Climatic element	Season	Area	Anomalies		
			Eldest period	Middle period	Recent period
Relative humidity, RH (%)	Winter	Rural	+3.06	+0.24	-3.92
		Urban	+4.43	-0.63	-5.59
		Industrial	+6.13	-2.32	-7.10
	Spring	Rural	+4.40	+1.27	-4.90
		Urban	+6.80	+0.37	-7.75
		Industrial	+6.23	-1.26	-7.69
	Summer	Rural	+3.15	+0.99	-4.11
		Urban	+5.09	+0.80	-5.88
		Industrial	+6.03	-1.08	-7.08
	Autumn	Rural	+3.88	+0.80	-4.07
		Urban	+3.92	-1.34	-5.57
		Industrial	+4.60	-0.27	-6.56
Cloud amount, CL (octas)	Winter	Rural	+0.47	-0.10	-0.67
		Urban	+0.72	-0.13	-0.86
		Industrial	+1.08	-0.40	-1.03
	Spring	Rural	+0.93	+0.13	-1.00
		Urban	+0.98	+0.03	-1.11
		Industrial	+1.15	-0.03	-1.13
	Summer	Rural	+0.80	+0.10	-0.93
		Urban	+0.85	+0.07	-0.81
		Industrial	+1.10	+0.03	-1.10
	Autumn	Rural	+0.60	+0.17	-0.83
		Urban	+0.70	-0.13	-0.78
		Industrial	+1.04	-0.03	-1.01
Rainfall, RN (mm)	Winter	Rural	+0.67	+0.07	-0.62
		Urban	+1.23	-0.45	-1.18
		Industrial	+1.49	+0.07	-1.11
	Spring	Rural	+0.79	+0.09	-0.86
		Urban	+0.71	-0.29	-0.87
		Industrial	+1.20	+0.23	-1.03
	Summer	Rural	0.00	0.00	0.00
		Urban	0.00	0.00	0.00
		Industrial	0.00	0.00	0.00
	Autumn	Rural	+0.43	+0.13	-0.50
		Urban	+0.54	-0.27	-0.64
		Industrial	+0.86	+0.23	-0.45

variation occurred during spring while the lowest variation occurred during autumn season. The seasonal mean anomalies of wind speed have been decreased from +0.71 kt (+0.52 kt) during spring (autumn) of the eldest period to -0.72 kt (-0.62 kt) in spring (autumn) of the recent period, (Table 3).

According to Georgii (1970), the higher velocity and turbulence of the surface wind increases ventilation condition which cause greater mixing of the highly polluted low level air with cleaner air flowing above the urban canopy, while lower wind velocity decreases ventilation condition which in turn does not change the pollutants concentration at urban canopy. Then the decreasing wind speed from the eldest to recent period at

Bahtim area results in an increased concentration of transposed pollutants coming from adjacent northern industrial area of Shubra El-Kheima and surrounding urban areas and in turn, it will transform Bahtim area gradually from typical rural to suburban, then urban area.

Concerning RH%, it could be clearly seen that the annual mean anomalies of RH% have been decreased gradually from +3.62% in the eldest period (1967-1981) to +0.82% in the middle period (1982-1996) and again decreased to takes -4.25% in the recent period (1997-2012), [Fig. 2(e) and Table 2]. It is also noticed that all monthly mean values of RH% have positive anomaly during both eldest and middle (except November) periods while they have negative anomaly during the recent

period, [Fig. 2(e)]. The observed decrease in RH% is attributed to gradual decrease of the agricultural activities as well as removal of the different trees for buildings construction purpose and in turn decrease the irrigation processes and evapo-transpiration in Bahtim area. Concerning the variations of the seasonal mean anomalies of RH%, it could be clearly seen the highest variation occurred during spring while the lowest variation occurred during winter season. They have been decreased from +4.40% (+3.06%) during spring (winter) of the eldest period to -4.90% (-3.92%) in spring (winter) of the recent period (Table 3).

Also, it was found that maximum difference between the anomaly values of RH% for the eldest and recent periods occurred in March while minimum difference occurred in December [Fig. 2(e)]. This may be attributed to usual invasion of hot dry Khamsin depressions over Egypt during March (spring season) in addition to the artificial heat resulting from recent urbanization processes around Bahtim, favors evaporation and evapo-transpiration processes and leads to more humid air over Bahtim during March of the recent period. While December (winter season) already characterizes by high values of RH% according to Egypt's climate.

It could be clearly seen that the annual mean anomalies of CL (octas) have been decreased gradually from +0.70 in the eldest period (1967-1981) to +0.08 in the middle period (1982-1996), then to -0.86 in the recent period (1997-2012), [Fig. 2(f) and Table 2]. Seasonally, they have been decreased from +0.93 octas (+0.47 octas) during spring (winter) of the eldest period to -1.00 octas (-0.67 octas) in spring (winter) of the recent period, (Table 3). This goes along with the decrease of RH% at rural Bahtim area as mentioned above. It is also noticed that all monthly mean values of the cloud amount at the rural area have positive anomaly during the eldest and middle (except January and December) periods while they have negative anomaly during the recent period [Fig. 2(f)]. The observed decrease in CL is attributed to gradual decrease of the atmospheric water vapor content resulting from decreasing the agricultural activities as well as removal of the different trees for buildings construction purpose and in turn decrease the irrigation processes and evapo-transpiration in Bahtim area.

Concerning rainfall variability, a decrease from +0.47 mm in the eldest period (1967-1981) to +0.07 mm in the middle period (1982-1996) then -0.50 mm during the recent period (1997-2012) was found in the annual mean anomalies of rainfall amount (mm), [Fig. 2(g) and Table 2]. This decrease in rainfall amount was found parallel to the decrease in both relative humidity and cloud amounts, as mentioned above [Figs. 2(e-f)], due to the

gradual increase of the urbanization processes occurred around Bahtim area. Seasonally, they have been decreased from +0.79 mm (+0.67 mm) during spring (winter) of the eldest period to -0.86 mm (-0.62 mm) in spring (winter) of the recent period (Table 3).

It could be also noticed that all monthly mean values of the rainfall amount have positive anomaly during the eldest period while they have negative anomaly during the recent period. The anomalies in rainy months of the middle period are subjected to fluctuations from positive to negative values [Fig. 2(g)]. This is attributed to weakening of urbanization processes occurred around Bahtim in (1982-1996) period. Therefore, the effects of the urbanization during this period on cloud amounts and in turn the amount of rainfall was very weak compared to the recent period (1997-2012) which is characterized by heavy urbanization processes around Bahtim area.

5.2. *Abbasiya station (typical urban area)*

Regarding the urban area, the monthly and annual mean anomalies of the climatic elements; Tmin, Tmax, T, V, RH%, CL, RN for the three successive periods (1923-1952), (1953-1982) and (1983-2012) at Abbasiya urban area are also given in Table 2 and illustrated by Figs. 3(a-g). It was found that the annual mean anomalies of Tmin have been increased gradually from -1.36 °C in the first period (1923-1952) to +0.34 °C in the middle period (1953-1982), and again increased to +1.50 °C in recent period (1983-2012), [Fig. 3(a) and Table 2]. The annual mean anomalies of both Tmax and T have similar behavior to Tmin, whereas Tmax values distinctly increased from -0.62 °C in the first period (1923-1952) to +0.17 °C in the middle period (1953-1982), thereafter its values increased to +0.98 °C in recent period (1983-2012), [Fig. 3(b) and Table 2]. While the annual mean anomalies of T have been increased from -1.11 °C in the first period to +0.29 °C in the middle period, thereafter its values increased to +1.23 °C in the recent period, [Fig. 3(c) and Table 2]. The same behavior is noticed for the variations of the seasonal mean anomalies of Tmin, Tmax and T with highest (lowest) variation during spring (autumn) season. The seasonal mean anomalies of Tmin have been increased from -1.45 °C (-1.31 °C) during spring (autumn) of the eldest period to +1.70 °C (+1.37 °C) in spring (autumn) of the recent period. While, the seasonal mean anomalies of Tmax have been increased from -0.71 °C (-0.60 °C) during spring (autumn) of the eldest period to +1.07 °C (+0.93 °C) in spring (autumn) of the recent period. Similarly, the seasonal mean anomalies of T have been increased from -1.27 °C (-0.80 °C) during spring (autumn) of the eldest period to +1.41 °C (+1.08 °C) in spring (autumn) of the recent period (Table 3).
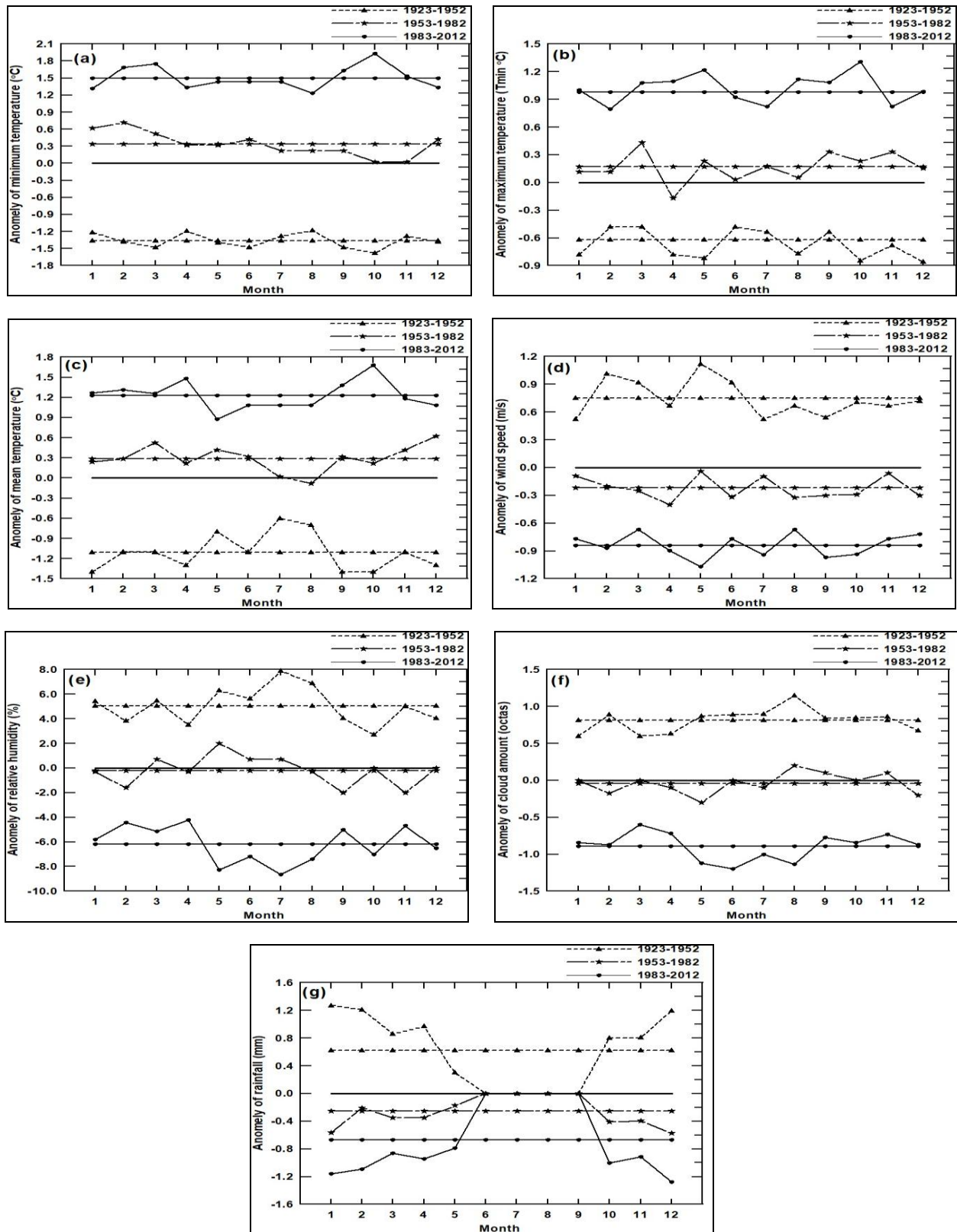
Figs. 3(a-g). Variation of monthly mean anomalies of (a) minimum temperature, Tmin; (b) maximum temperature, Tmax; (c) mean temperature, T; (d) wind speed, V; (e) relative humidity, RH%; (f) cloud amount, CL and (g) rainfall amount, RN during the three different periods, (1923-1952), (1953-1982) and (1983-2012) at the urban area of Abbasiya

It is also noticed that all monthly mean values of Tmin, Tmax and T have negative anomaly at Abbasiya urban area during the eldest period, while they have positive anomaly during the middle (except April for Tmax and August for T) and recent periods, [Figs. 3(a-c)]. This gradual increase in Tmin, Tmax and T points to the recent increased intensity of air pollution and greenhouse effect in the urban atmosphere induced by the very rapid growth of population in GCR (Fig. 1). This huge increase of population is followed by rapid increase in traffic density and the industrial activity. In addition, during the last three decades, new industrial cities have been established around GCR such as 10th Ramadan, 6th October, and 15th May Cities etc. These cities are considered one of the major sources of air pollution in GCR (Robaa and Hafez, 2002). A relatively distinct increase in Tmin, Tmax and T has been also observed during October of the recent period (1983-2012), [Fig. 3(a-c)]. This increase could be attributed to recently combined effects of urbanization processes with the severe air pollution episodes referred to as ''black cloud'' that invaded the urban area during October month of the last few years (Sivertsen *et al*., 2000; EL-Shahawy and Hanna, 2003). It could be noticed that the effect of urbanization processes at the urban area of Abbasiya is more significant on Tmin than on both Tmax and T (Table 2). This result confirms the findings of Oke (1982); Katsoulis and Theoharatos (1985); Katsoulis (1987); Runnalls and Oke (2006); Hale *et al*. (2008).

Fig. 3(d) and Table 2 show the monthly and annual mean anomalies of wind speed, V (kt) for the three selected periods. It was found that the annual mean anomalies of V have been gradually decreased from +0.75 kt during the eldest period (1923-1952) to -0.22 kt in the middle period (1953-1982), and again distinctly decreased to -0.84 kt in the recent period (1983-2012). Seasonally, it was found that the highest variation occurred during spring while the lowest variation occurred during autumn season. The seasonal mean anomalies of wind speed have been decreased from +0.87 kt (+0.59 kt) during spring (autumn) of the eldest period to -0.93 kt (-0.77 kt) in spring (autumn) of the recent period (Table 3).

The recently lower value of wind speed at the urban area may be attributed to the fact that wind speeds are generally lower in the built up areas than in their surroundings resulting from the increase in surface roughness within cities. The surface roughness increase is associated with accelerations produced by a well-developed urban heat island. This result agree with the findings of Chandler (1965) and Jauregui (1986) and the recent work of Coceal and Belcher (2005) who noted that an increase in canopy density is usually associated with a

decrease in the mean wind speed in the urban canopy. Furthermore, the recently lower value of wind speed at the urban area of Abbasiya decreases ventilation condition which in turn increase the pollutants concentration at urban canopy as well as the increased concentration of transposed pollutants coming from adjacent northern industrial area of Shubra El-Kheima and surrounding urban areas. This could be represent an important reason to seriously increase the air pollution problem over Abbasiya urban area. It is also noticed that all monthly mean values of V at Abbasiya urban area have positive anomaly during the eldest period (1923-1952), while they have negative anomaly during both middle (1953-1982) and recent (1983-2012) periods, [Fig. 3(d)]. This is attributed to high recently increase of roughness parameter values resulting from increased numbers of very high buildings and growing up of high establishments.

Fig. 3(e) and Table 2 show the monthly and annual mean anomalies of relative humidity, (RH %) for the three selected periods. It could be clearly seen that the annual mean anomalies of RH% decreased gradually from +5.10% in the eldest period (1923-1952) to -0.19% in the middle period (1953-1982) and again decreased to -6.22% in the recent period (1983-2012). Concerning the variations of the seasonal mean anomalies of RH%, it could be clearly seen the highest variation occurred during spring while the lowest variation occurred during autumn season. They have been decreased from +6.80% (+3.92%) during spring (autumn) of the eldest period to -7.75% (-5.57%) in spring (autumn) of the recent period (Table 3). It is also noticed that all monthly mean values of RH% at the urban area of Abbasiya have positive anomaly during the eldest period while they have negative anomaly during the recent period (1983-2012). During the middle period (1953-1982), the monthly mean values of RH% slightly fluctuated between the negative and positive anomaly [Fig. 3(e)]. The observed decreasing trend of RH% is due to increase in T that should increase the water holding capacity of air. Furthermore, the rarity of gardens and trees as well as smaller release of water vapor from anthropogenic sources in Abbasiya urban area are also contribute to the observed decreasing trend of RH%. It is also noticed that the behavior of RH% is reverse to the behaviour of air temperature at the urban area [Figs. 3(a-c)]. This means that relative humidity is a sensitive function of temperature and strongly affected by the degree of urbanization (Hage, 1975; Lee, 1979; Landsberg, 1981; Unkasevic *et al*., 2001; Chow and Roth, 2006). Furthermore, the results revealed that the maximum difference between the anomaly values of RH% during eldest period (1923-1952) and recent period (1983-2012) occurred during the warm season of the year (From May to August) [Fig. 3(e)]. This may be attributed to the gradual decrease of atmospheric water vapour content,

induced by higher air temperature of warm season, from the eldest period to the recent period. The recent decrease of moisture sources is due to replacement of the gardens, trees and cultivated land by high density of buildings.

Fig. 3(f) and Table 2 show the monthly and annual mean anomalies of cloud amount (CL, octas) for the three selected periods. It was found that the annual mean anomalies of CL decreased gradually from +0.81 octas in the eldest period (1923-1952) to -0.04 octas in the middle period (1953-1982), then to -0.89 octas in the recent period (1983-2012), [Table 2 and Fig. 3(f)]. Seasonally, they have been decreased from +0.98 octas (+0.70 octas) during spring (autumn) of the eldest period to -1.11 octas (-0.78 octas) in spring (autumn) of the recent period, (Table 3). This goes along with the decrease of relative humidity at urban area of Abbasiya ([Fig. 3(e)]. It is also noticed that all monthly mean values of CL have positive anomaly at the urban area during the eldest period while they have negative anomaly during the recent period. During the middle period, the monthly mean values of CL fluctuated between the positive and negative anomaly, [Fig. 3(f)]. The recently observed decrease in cloud amount in the urban area of Abbasiya is attributed to gradual decrease of the atmospheric water vapor content resulting from the urbanization processes. In fact, one potential cause for the increase in cloud amount over urban areas could be the likely increase in the concentration of condensation nuclei in the air that favoured the formation of clouds, which is known to be associated with urbanization and human activities in the urbanized areas. However, in the present study, this effect is not seen at Abbasiya due to the recent dryness of its atmosphere induced by urbanization processes. This may be attributed to the fact that the formation of clouds needs high atmospheric water vapor content beside the condensation nuclei. It could be noticed that, as in case of relative humidity, the maximum difference between the anomaly values of CL during the eldest and recent periods occurred during the warm season of the year (May-August) [Fig. 3(f)]. This is attributed to the recent atmospheric dryness due to urbanization processes over the urban area of Abbasiya.

A decrease from +0.62 mm in the eldest period (1923-1952) to -0.25 mm in the middle period (1953-1982) then to -0.67 mm during the recent period (1983-2012) was found in the annual mean anomalies of rainfall amount (mm) over the urban area of Abbasiya [Table 2 and Fig. 3(g)]. Seasonally, they have been decreased from +1.23 mm (+0.54 mm) during winter (autumn) of the eldest period to -1.18 mm (-0.64 mm) in winter (autumn) of the recent period (Table 3). This decrease in rainfall amount was found parallel to the decrease in both relative humidity and cloud amounts [Figs. 3(e&f)], due to the

rapidly increase of the urbanization processes occurred in Abbasiya, as mentioned above. Also, it has been found that all monthly mean values of RN at Abbasiya urban area have positive anomaly during the eldest period while they have negative anomaly during both middle and recent periods, [Fig. 3(g)]. This is attributed to strong effect of urbanization processes, which started at Abbasiya urban area around the middle period. It could be also noticed that all monthly mean values of RN equal zero during the four months from June to September of the eldest, middle and recent periods. This is due to these months (June to September) are not rainy in the whole country of Egypt.

5.3. *Helwan station (typical industrial and residential area)*

Before, 1950, the town of Helwan was an international famous calm clean city. It enjoyed fine and good weather as well as its known natural spring. Peoples from different parts of the country and from different countries usually visited it enjoyed its good weather and exposing themselves to the beneficial solar radiation. From 1950, industrialization has been growing very rapid in and around Helwan. Therefore, it is believed that significant amount of solar radiation is diffused there as a result of the increasing air pollution in its atmosphere (Higazy, 1973).

The monthly and annual mean values of anomalies of Tmin, Tmax and T °C for the three different periods, (1923-1952), (1953-1982) and (1983-2012) at Helwan station are given in Table 2 and illustrates by Figs. 4(a, b & c) respectively. These periods were chosen from the available data to show the behavior of surface air temperature and other meteorological elements before and after industrialization established in Helwan area since 1950.

It was found that the annual mean values of anomalies of Tmin increased gradually from -1.71 °C in the eldest period (1923-1952) to +0.12 °C in the middle period (1953-1982), and again increased to +1.85 °C in recent period (1983-2012), [Table 2 and Fig. 4(a)]. The annual mean anomalies of both Tmax and T have similar behavior to Tmin, whereas Tmax values increased from -0.82 °C in the eldest period (1923-1952) to +0.08 °C in the middle period (1953-1982), thereafter its values increased to +0.99 °C in recent period (1983-2012), [Table 2 and Fig. 4(b)]. While the annual mean anomalies of T increased from -1.58 °C in the first period to +0.21 °C in the middle period, thereafter its values increased to +1.51 °C in the recent period [Table 2 and Fig. 4(c)]. The same behavior is noticed for the variations of the seasonal mean anomalies of Tmin, Tmax and T with highest (lowest) variation during spring (autumn)
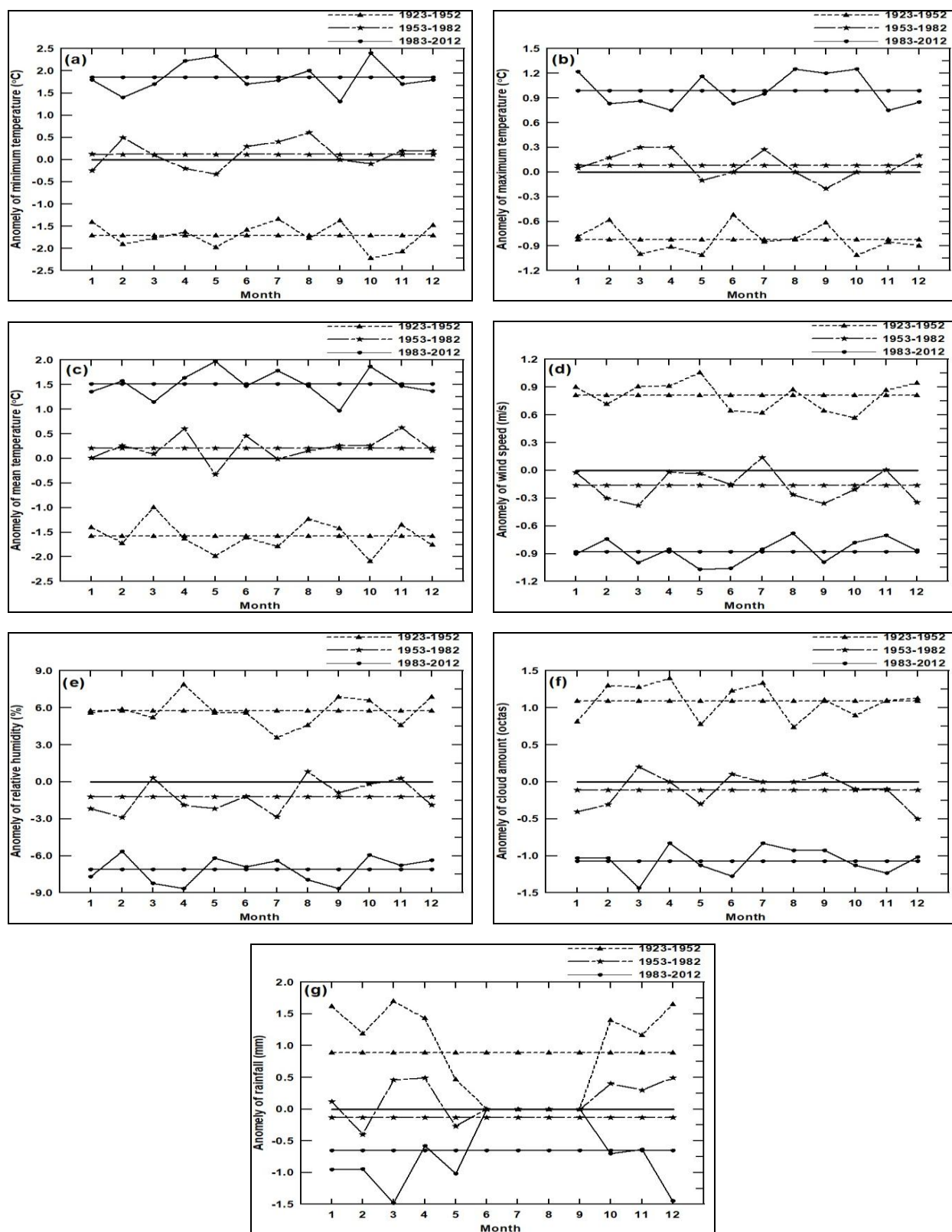
Figs. 4(a-g). Variation of monthly mean anomalies of (a) minimum temperature, Tmin; (b) maximum temperature, Tmax; (c) mean temperature, T; (d) wind speed, V; (e) relative humidity, RH%; (f) cloud amount, CL and (g) rainfall amount, RN during the three different periods, (1923-1952), (1953-1982) and (1983-2012) at the industrial area of Helwan

season. The seasonal mean anomalies of Tim have been increased from -1.89 °C (-1.56 °C) during spring (autumn) of the eldest period to +2.09 °C (+1.67 °C) in spring (autumn) of the recent period. While, the seasonal mean anomalies of Tmax have been increased from -0.97 °C (-0.73 °C) during spring (autumn) of the eldest period to +1.07 °C (+0.93 °C) in spring (autumn) of the recent period. Similarly, the seasonal mean anomalies of T have been increased from -1.63 °C (-1.53 °C) during spring (autumn) of the eldest period to +1.58 °C (+1.43 °C) in spring (autumn) of the recent period (Table 3).

The gradual increase of Tmin, Tmax and T values at the industrial area (Helwan) is due to the heavy industrial collection at Helwan and highly polluted air causing greenhouse effect leading to rising surface air temperature during all months of the year. It could be also noticed that, as at urban area of Abbasiya, all monthly mean values of Tmin, Tmax and T at Helwan have negative anomaly during the eldest period, while they have positive anomaly during the middle (except January, April, May, September and October which have slight negative anomaly) and recent periods [Figs. 4(a-c)]. This gradual increase in Tmin, Tmax and T points to the recent increased intensity of air pollution and greenhouse effect over the industrial area of Helwan.

As mentioned above, severe air pollution episodes always invade GCR (including the industrial area of Helwan) during October month of the last few years and combine with the recent emissions resulting from heavy industrial activities at Helwan. These episodes may be the real cause of the highest increase in Tmin, Tmax and T values that have been observed during October of the recent period (1983-2012). It could be also noticed that relatively high departures from the normal of Tmin, Tmax and T (4.3, 2.2 and 4.0 °C respectively) occurred in May of the recent period, [Figs. 4(a-c)]. This could be attributed to the recent increase of intensity and frequency of sandstorms and Khamsin hot waves prevailing during spring season (March-May) over Egypt, especially at Helwan which lies in the eastern desert of Egypt (Hasanean, 1992). On the other hand, Figs. 4(a, b & c) respectively illustrate that the mean monthly departures of Tmin, Tmax and T are somewhat regular and slightly variated during all study periods. This may be attributed to the study area is characterized by homogeneous weather and urban conditions during most months of the study periods.

It could be also noticed that industrial activities at Helwan has insignificant effect on Tmax and T compared to Tmin (Table 2). This result confirms the findings of Katsoulis and Theoharatos, (1985) and Katsoulis, (1987), Harmon *et al*. (2004), Hale *et al*. (2008). Also, it was found that the normal values of Tmin, Tmax and T at the industrial area (Helwan) are higher than those at the urban (Abbasiya) and rural (Bahtim) areas, and that urban values are also higher than those of the rural area (Table 2). It could be also noticed that the effects of industrialization processes on Tmin, Tmax and T values at the industrial area of Helwan are stronger as compared to the effects of urbanization processes at the urban area of Abbasiya through all study periods (Table 2).

Fig. 4(d) and Table 2 show monthly and annual mean anomalies of wind speed (kt) for the three selected periods at the industrial area of Helwan. It was found that the annual mean anomalies of wind speed have been gradually decreased from +0.81 kt during the eldest period (1923-1952) to -0.16 kt in the middle period (1953-1982), and again distinctly decreased to -0.88 kt in the recent period (1997-2012). Seasonally, it was found that the highest variation occurred during spring while the lowest variation occurred during autumn season. The seasonal mean anomalies of wind speed have been decreased from +0.96 kt (+0.69 kt) during spring (autumn) of the eldest period to -0.97 kt (-0.83 kt) in spring (autumn) of the recent period (Table 3).

It could be noticed that all monthly mean values of wind speed at the industrial area of Helwan have positive anomaly during the eldest period, while they have negative anomaly during both middle (except July) and recent periods [Fig. 4(d)]. This is attributed to high recent increase of roughness parameter values resulting from increased numbers of factors and high buildings and growing up of many establishments. The gradual decrease of the wind speed values at the industrial area of Helwan may be attributed to the fact that wind speeds are generally lower in the built up areas than in their surroundings resulting from the increase in surface roughness within cities (Chandler, 1965; Lee, 1979; Jauregui, 1986; Korzeniewski *et al*., 1991; Klysik, 1998).

A relatively decrease in wind speed values has been observed during autumn season especially October month of the recent period (1983-2012) [Fig. 4(d)]. This decrease could be contribute in creating severe air pollution episodes referred to as ''black cloud'' that recently formed over Helwan during October month of the last few years (Sivertsen *et al*., 2000; EL-Shahawy and Hanna, 2003). On the other hand, a relatively increase in wind speed values has been also observed during spring season (mainly May) of the recent period (1983-2012) [Fig. 4(d)]. This could be attributed, as mentioned above, to the recent increase of intensity and frequency of hot desert Khamsin depressions prevailing during spring season (mainly May) over Egypt, especially at Helwan, which lies in the eastern desert. These depressions are always associated with hot and dry winds often laden with dust & sand, increasing the atmospheric pollution (Hasanean, 1992).

It has been found that the normal value of wind speed at the industrial area are lower than those at the urban and rural areas, and that urban values are also lower than those of the rural area. Furthermore, the effects of industrialization processes on wind speed at the Industrial area are stronger than the effects of urbanization processes at the urban area through all study periods (Table 2).

It could be clearly seen that the annual mean anomalies of relative humidity (RH%) at Helwan decreased gradually from +5.75% in the eldest period (1923-1952) to -1.23% in the middle period (1953-1982) and again decreased to -7.11% in the recent period (1983-2012), [Table 2 and Fig. 4(e)]. It is also noticed that all monthly mean values of RH% at the industrial area of Helwan have positive anomaly during the eldest period while they have negative anomaly during the middle (except March, August and November months) and recent periods [Fig. 4(e)]. Concerning the variations of the seasonal mean anomalies of RH%, it could be clearly seen the highest variation occurred during spring while the lowest variation occurred during autumn season. They have been decreased from +6.23% (+4.60%) during spring (autumn) of the eldest period to -7.69% (-6.56%) in spring (autumn) of the recent period, (Table 3). The gradual decrease of RH% at Helwan is due to increase in T that should increase the water holding capacity of air. Furthermore, the lower urban evapo-transpiration as a consequence of gradual reduction in vegetation cover, rarity of cultivated plants and moisture sources as well as smaller release of water vapor from anthropogenic sources in the industrial area of Helwan are also contribute to the observed decreasing trend of RH%. It could be also noticed that the mean monthly departures of RH% are regular and slightly variated during the three study periods. This may be attributed to Helwan area is characterized by homogeneous weather during most months of the study periods. It is also noticed that the behavior of RH% is contrary to the behaviour of air temperature at Helwan [Figs. 4(a, b, c & e)]. This emphasize, as mentioned above, the fact that relative humidity is a sensitive function of temperature and strongly affected by the degree of urbanization.

As in case of wind speed, the normal value of relative humidity at the industrial area are lower than those at the urban and rural areas, and that urban values are also lower than those of the rural area (Table 2). Furthermore, it could be noticed that the effects of industrialization processes on the relative humidity at the industrial area (Helwan) are stronger than the effects of urbanization processes at the urban area (Abbasiya) through three study periods (Table 2).

Fig. 4(f) and Table 2 show monthly and annual mean anomalies of cloud amount (CL, octas) for the three

selected periods at the industrial area of Helwan. It was found that the annual mean anomalies of CL decreased gradually from +1.09 octas in the eldest period (1923-1952) to +0.11 octas in the middle period (1953-1982), then to -1.07 octas in the recent period (1983-2012). Seasonally, they have been decreased from +1.15 octas (+1.04 octas) during spring (autumn) of the eldest period to -1.13 octas (-1.01 octas) in spring (autumn) of the recent period (Table 3). This goes along with the decrease of relative humidity at Helwan (Table 2 and Figs. 4(e & f)].

It is also noticed that all monthly mean values of CL at the industrial area have positive anomaly during the eldest period while they have negative anomaly during the middle (except March, June and September) and recent periods [Fig. 4(f)]. The recent observed decrease in cloud amount at the industrial area of Helwan is attributed to gradual decrease of the atmospheric water vapor content as a consequence of the removed agricultural plants as well as rapid growth of urbanization and industrial processes at Helwan.

It is also noticed that the normal value of cloud amounts at the industrial area are lower than those at the urban and rural areas and that urban values are also lower than those of the rural area (Table 2). Furthermore, it could be clearly seen that, as mentioned above, the effects of industrialization processes on the cloud amounts at the industrial area are stronger than the effects of urbanization processes at the urban area through three study periods.

Monthly and annual mean values of anomalies of rainfall amount (mm) during the periods (1923-1952), (1953-1982) and (1983-2012) are given in Table 2 and illustrated by Fig. 4(g). The annual mean anomalies of rainfall amount decreased from +0.89 in the eldest period (1923-1952) to -0.13 in the middle period (1953-1982). Then continuously decreased to -0.65 during the recent period (1983-2012). Seasonally, they have been decreased from +1.49 mm (+0.86 mm) during winter (autumn) of the eldest period to -1.11 mm (-0.45 mm) in winter (autumn) of the recent period (Table 3). These goes along with the decrease in cloud amount occurred over Helwan from the old period to the recent period [Fig. 4(f)].

Also, it has been found that all monthly mean values of RN at the industrial area of Helwan have positive anomaly during the eldest period while they have negative anomaly during the recent period and fluctuated between the positive and negative anomaly during the middle period [Fig. 4(g)]. This is attributed to strong effect of the industrial processes, which started at Helwan with middle period start. It could be also noticed that all monthly mean values of RN equal zero during the four months from June

to September of the eldest, middle and recent periods [Fig. 4(g)]. This is due to these months (June to September) are not rainy in the whole country of Egypt.

It is noticed that, as in case of all above climatic elements, the normal value of rainfall amounts at the industrial area are lower than those at the urban and rural areas, and that urban values are also lower than those of the rural area (Table 2). Furthermore, the effects of industrialization processes on the rainfall amounts at the industrial area (Helwan) are stronger than the effects of urbanization processes at the urban area (Abbasiya) through three study periods (Table 2).

6. Summary and conclusion

GCR is one of the world's mega cities with a population of more than 19 million. The urbanization and industrialization have increased very rapidly in GCR, particularly in the second half of the last century causing an increase in the pollution of its atmosphere. Detailed studies on the effect of urbanization and industrialization on meteorology parameters over GCR have been performed. The data of measured seven meteorology parameters [Minimum temperature Tmin (°C), maximum temperature Tmax (°C), mean temperature T (°C), wind speed V (kt), relative humidity RH (%), cloud amount CL (octas) and rainfall amount RN (mm)] at three selected stations for the study periods (1923-2012) and (1967-2012) have been used. Three stations have been chosen to represent different degrees of urbanization namely, Bahtim, (represents rural area), Abbasiya (represents urban area) and Helwan (represents industrial area). The monthly mean values and the annual mean anomalies of the used climatic elements for three successive periods, (1967-1981), (1982-1996) and (1997-2012) at Bahtim and (1923-1952), (1953-1982) and (1983-2012) at Abbasiya and Helwan have been calculated and used in this study. This study has been performed for the available three different periods representing different stages of growth and development of the study areas and to show the behavior of the different climatic elements before and after urbanization and industrialization established in GCR. Final results and conclusions could be summarized in the following points:

(*i*) The annual mean anomalies of minimum, maximum and mean air temperature have been gradually increased from minimum values during the eldest period to maximum values during the recent period at the three localities.

(*ii*) All monthly mean values of minimum, maximum and mean air temperature have negative anomaly during the eldest period while they have positive anomaly during the recent period at the three sites.

(*iii*) The annual mean anomalies of wind speed, relative humidity, cloud and rainfall amounts have been gradually decreased from maximum values during the eldest period to minimum values during the recent period at the three localities.

(*iv*) All monthly mean values of wind speed, relative humidity, cloud and rainfall amounts have positive anomaly during the eldest period while they have negative anomaly during the recent period at the three sites.

(*v*) The arrangement of the used climatic elements values agree with the degree of urbanization for each station, *i.e.*, whenever urbanization increases, the values of minimum, maximum and mean temperatures increase while the values of wind speed, relative humidity, cloud amount and total rainfall amounts decrease.

(*vi*) The urbanization and industrialization processes cause increasing the values of the minimum, maximum and mean air temperatures, while they cause decreasing the values of wind speed, relative humidity, cloud amount and total rainfall amounts.

(*vii*) The normal value of air temperatures (wind speed, relative humidity, cloud & rainfall amounts) at the industrial area are higher (lower) than those at the urban and rural areas with higher (lower) values of urban than rural areas.

(*viii*) The effects of industrialization processes on the used climatic elements are stronger, at the industrial area, than the effects of urbanization processes at the urban area through the three study periods.

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