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Factors Influencing Urban Heat Island Formation and its Effects on Public Health in Bangladesh

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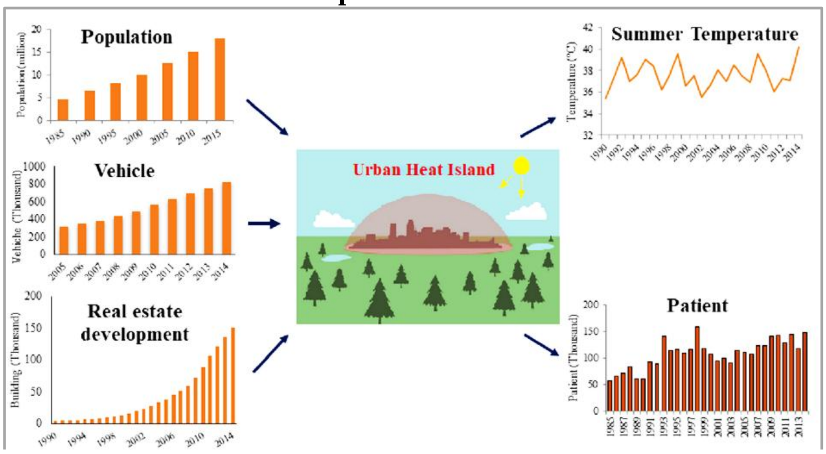
Graphical abstract



Abstract: *Dhaka has emerged as a fast-growing megacity in recent times, which eventually results in urban heat island (UHI) formation. This study showed that during the period 1985-2015 population has increased dramatically and reached to around 18 million in 2014 that increased the temperature of the city. In 2014, the maximum temperature has increased by 3.6°C compared to 1985 when the total population was around 5 million. Rapid infrastructural development (building) under the real estate authorities from 1990 to 2014 occupied the blue-green resources (wetlands and green spaces) in and around the city and results in increased temperature. The total number of the building has increased from 3,702 to150,994 during that period and consequently leads to a higher temperature (40.2°C) in 2014.The vehicular population has also increased significantly over time. It has been observed that in 2005, the vehicle population was 310,408 which increases significantly and reached at 821,186 in 2014 whereas the dominated types were cars (178,828) and motorcycles (373,021).Our study also investigates the influence of UHI on public health. Based on the availability of data regarding the number of patients visited with temperature related illness, the International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b) is only considered in this study. We found that during 1985-2014, the number of the patient visit has increased gradually with the highest number of patient (147,975) visited in 2014 when the summer temperature was the highest (40.2°C).*

Keywords:*Dhaka city, Summer temperature, Urbanization, icddr,b, Vehicle population*

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I. Introduction

Urban heat island (UHI) is defined as a phenomenon when temperature in urban areas become higher compared to the suburban or rural areas in a particular region (Voogt and Oke, 2003; Trenberth, 2004; Ningrum, 2018), which is caused by different factors, for instance higher energy consumption, excessive emissions from industrial processes and households, motor vehicles, increased pavement areas (heat-trapping surfaces), compact urban infrastructures, increased number of buildings, and lack of urban greeneries (Oke, 1987; Landsberg, 1981; Yuan and Bauer, 2007; Ningrum, 2018; Santamouris, 2015; Elsayed, 2012b; Nuruzzaman, 2015; Rizwan, Dennis, & Liu, 2008; Ahmad and Hashim, 2007).

Rapid urbanization and expansion of urban areas are bringing substantial changes in land use through converting natural environment to pavemented areas. These manmade pavemented area can absorb more heat compared to that of natural environment resulting in increased urban temperature, may also responsible for prolonged hot days, especially during the summer. This situation is even worse in different megacities of the tropical countries with higher population density where as a consequence, human health and environmental components are being affected seriously (Memon et al., 2007; Roth, 2007; Tan et al., 2009). Yang et al. (2016) asserted that increased urban temperature resulted from UHI have profound impacts on urban ecology, hydrological functions, local climate, biological habitat, human health, and energy flow in the ecosystem. As UHI is characterized by excessive hot weather and the increased average temperature in cities resulting in frequent heat waves, thus the rate of mortality increased noticeably during this period (Buechley et al., 1972).

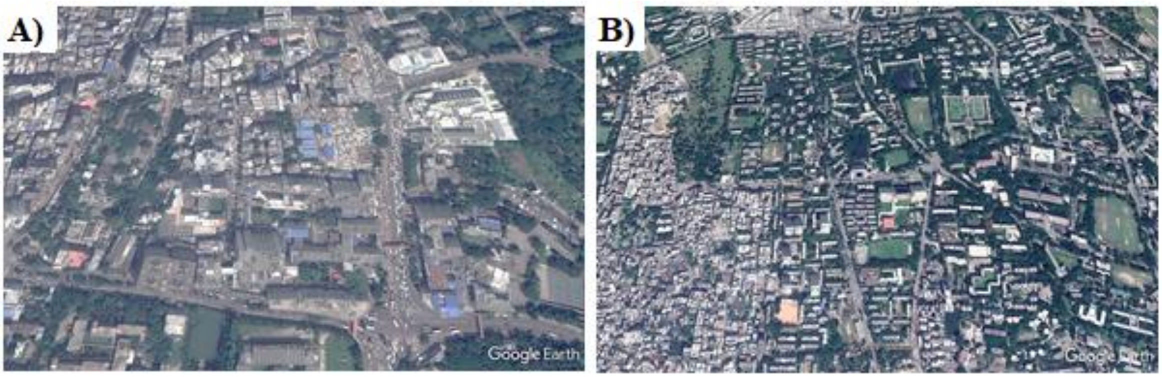
As a rapidly growing urban population and urban expansion,significant changes in the geophysical environment in Dhaka city has occurred in recent times. According to the Bangladesh Bureau of Statistics (BBS) report, the city is confronted with a considerably high rate of urban development and population growth since 1981 (BBS, 1997; BBS, 2003), therefore created terrific pressure on the urban ecosystem and life of city inhabitants. Studies (Mayer et al., 2003; Ifatimehin et al., 2010; Hossain, 2008; Atkinson, 2002; Dewan et al., 2009; Alam and Rabbani, 2007) have found that during the past few years urbanization and urban development in Dhaka was so rapid that it transformed a significant proportion of natural landscape into built-up areas.

Due to increased impervious land surfaces and loss of urban green spaces and wetlands the UHI phenomena is become severe in the city and therefore, the city is affected by erratic rainfall, increased heat stress in summer, flooding and waterlogging problem due to unreliable rainfall, increased public health problems associated with high temperature, outbreak of diseases, and water scarcity. Only a few qualitative studies were found to assess the urban climate change in Dhaka city but to the best of our knowledge no study has been performed to correlate UHI and public health problems in Dhaka city, Bangladesh. Based on these circumstances this study has been conducted to identify the factors contribute to urban heat island formation, and to determine the influence of UHI on public health in Dhaka city.

II. Materials And Methods

Study area characteristics: The study has been conducted in the capital city (Dhaka) of Bangladesh. It lies between 23°42' and 23°54' N latitudes and 90°20' and 90°28'E longitudes (Banglapedia, 2014). Dhaka is in central Bangladesh on the eastern banks of the Buriganga River. The current population of Dhaka is estimated to be about 17.91 million (UN, 2015). Dhaka District (Dhaka division) with an area of 1463.60 sq. km. is bounded by Gazipur and Tangail districts on the north, Munshiganj and Rajbari districts on the south, Narayanganj district on the east, Manikganj district on the west. The city is bounded by the rivers Buriganga to the south, Turag to the west, Balu to the east and Tongi Khal to the north. The city has three distinct seasons: the winter (November-February), with temperature 10°C to 20°C; the pre-monsoon season (March-May), with temperature reaching up to 40°C; and the monsoon (June-October), with temperatures around 30°C. Dhaka experiences about 2,000 mm rain annually, of which about 80% falls during the monsoon.

Fig.1 illustrates some of the selected urban areas in Dhaka city that shows heterogeneous surface coverage. Areas like Shahbagh, Azimpur, and Uttara consists of many commercial and residential buildings, and institutionswith few green areas compared to Khilgaon. However, urban infrastructures are increasing rapidly in all these areas without proper urban planning that has increased the average temperature of the city and therefore triggering the UHI formation.



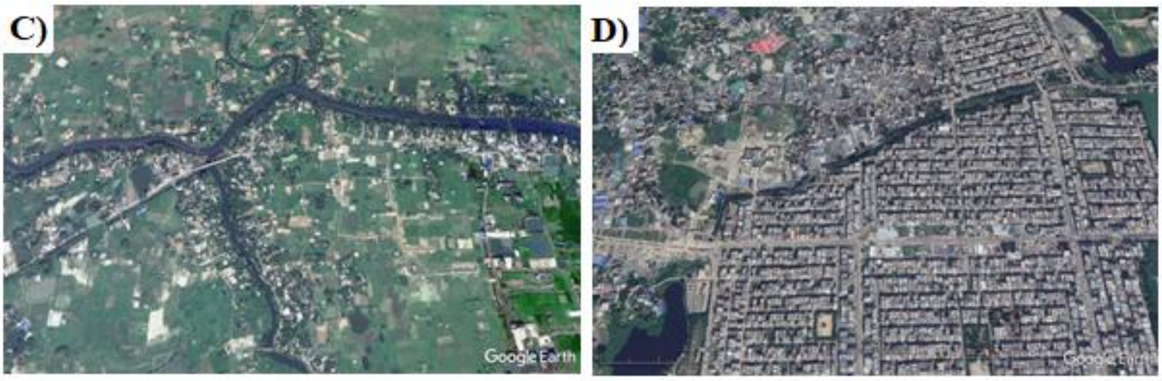


Fig. 1. Selected urban neighborhoods in Dhaka city showing heterogeneous surface coverage. A) Shahbagh, B) Azimpur, C) Khilgaon, and D) Uttara. Source: Google Earth (2018)

Data sources:Both primary and secondary data sources were used in this study. Primary data were collected in an integrated approach using questionnaire survey and key informant interview (KII).A questionnaire survey was conducted in four different urban areas in Dhaka city including Azimpur, Uttara, Khilgaon, and Shahbag(Fig. 1) among the city inhabitants having different professions such as students, workers, and housewife. Different types of questions such as basic knowledge on urban heat island, its causes and consequences, causes and sources of temperature rising, the impact of increasing temperature on public health, vehicle status, development in real estate sector etc. were incorporated in the questionnaire. The key informant interview was mainly conducted among the doctors of *icddr,b* Bangladesh as the study focuses on the impacts of UHI on public health in Dhaka city.

Apart from primary data collection secondary data was also very important to conduct the study, which was collected from different authentic and related authorities and institutions. For instance, meteorological data were collected from Bangladesh meteorological department (BMD). The 25 years daily temperature data were collected on an annual basis from the year 1990 to 2014 in order to observe the temperature trend during that period. Demographic data was collected from the Bangladesh Bureau of Statistics (BBS).Data on housing status and status of motor vehicles in Dhaka city were collected from the Center for Urban Studies (CUS). In order to understand and evaluate the causal factors of UHI and to estimate the relative contribution of each causal factors, its effect on public health throughout the period of 1985-2014, the analysis work is devoted to recognize the recent trend of variation of climatic parameter, population growth, real estate development, and patient visit in hospital (*icddr,b*). The data were analyzed on a year basis. The collected data were tabulated and coded and then MS Excel and SPSS-14 software were used for calculation and analysis.

III. Results AndDiscussion

Trend of annual maximum summer temperature in Dhaka city: Temperature is one of the most important primary indicators for the climate. The temperature distribution of the study area shows the annual maximum summer (March-June) temperature during the period ranged from 1990-2014, which was hot and humid in general. For instance, maximum summer temperatures range between 30°C to 40°C during that period. However, April is the warmest month in most parts of the country (BMD, 2015).The line diagram indicates the increasing trend of summer temperature where the highest summer temperature (40.2 0C) was found in 2014 and the lowest (35.4 °C) was found in1990. The value of the coefficient of determination is 0.019 (Fig.2) . Faysal et al., (2014) asserted that the annual maximum temperature of Dhaka city for the last 60 years was increased at 1.3°C in every 100 years, which clearly revealed that maximum temperature is increasing rapidly.The average maximum temperature during the period of 1995-2014 was also analyzed in our study where from 1995 to 2004 the average maximum temperature was 33.9 °C and in the following 10 years period (i.e. 2005-2014) it increased to 34.2 °C.

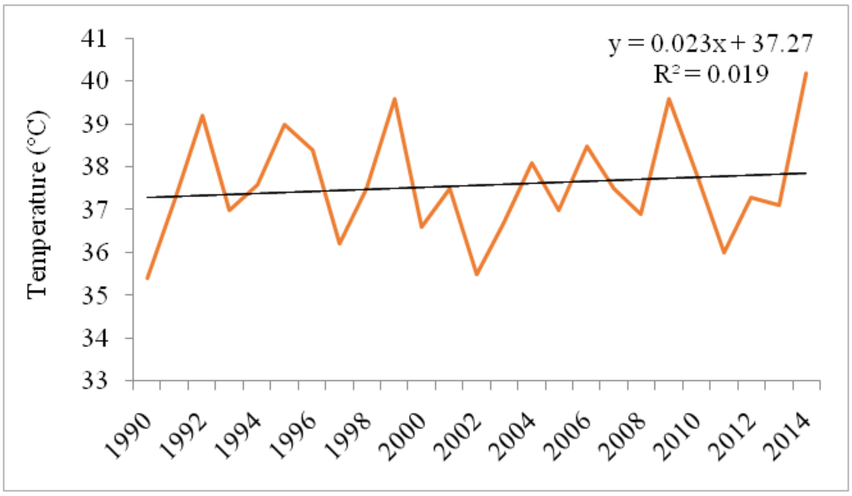


Fig. 2. Trend of annual maximum summer temperature in Dhaka city

Factors influencing urban heat island (UHI) formation:

Increasing population trend in Dhaka City: Dhaka City has emerged as a fast-growing megacity in recent times. According to the UN (1998), the population growth rate was 6.9 percent during the period of 1974-2000. In 1985, the city had a population of 4,630,000, which increased to 17,910,000 in 2015 (BBS, 2015). This indicates a nearly four-fold increase in population during the last 30 years (Fig. 3) and it is projected that population will continue to increase in the coming decades.This accelerated growth in urban population results in profound changes in microclimatic factors such as temperature, humidity, and heat balance.

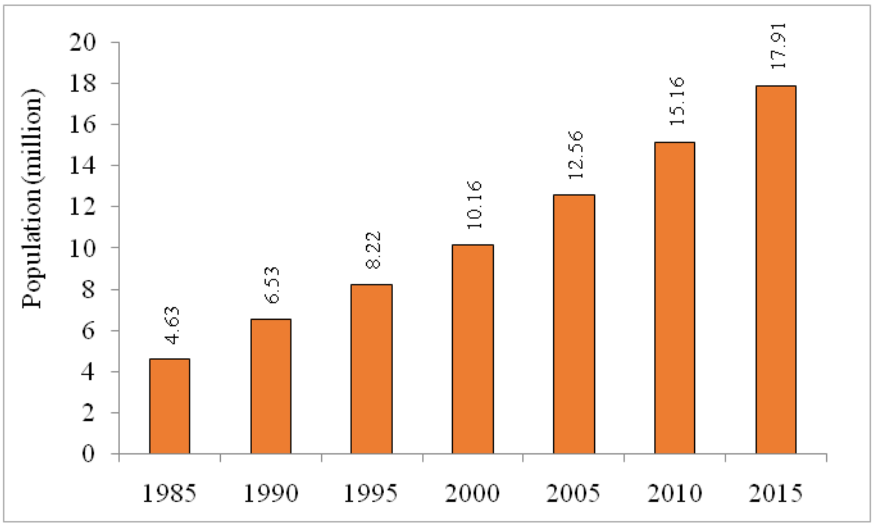


Fig. 3. Population growth in Dhaka city (BBS, 2015).

The study also identified the correlation between population growth and five years moving maximum temperature. It is revealed that in 1985, the maximum temperature in Dhaka city was 37.1 °C and population was 4.63 million with an area of 1463.60 sq. km. while in 2015,the maximum temperature was observed 40.7 °C and the population of 17.91 million,respectively with the same amount of landmass. The trend line in Fig.4 indicates that temperature was increased with five years moving population growth and there was a strong positive correlation between population growth and temperature during 1985-2015. Oke (1987) argued that population and UHI intensity are directly related as urban temperature increases significantly due to the increase in urban population.

Fig. 4. Temperature variation with urban population growth

Real estate development in the housing sector:The unprecedented growth in urban population in Dhaka city increases the demand forland units for housing or building construction. The development of urban infrastructures in recent decades is undoubtedly considered as the primary cause of UHI formation. During the period 1990 to 2014, infrastructural developments (building) in Dhaka city has increased dramatically under real estate development authorities as shown in Fig.5. The total number of the building has increased from 3,702 to150,994 during this period, which eventually leads to increased temperature in the city. This is mainly because of the expansion of urban built-up areas by occupying the existing blue-green resources (i.e. wetlands and green spaces) in and around the city. For instance, our study found that the annual maximum temperature was increasedconsiderablyduring the period of 1990 to 2014 where maximum temperaturewas recorded as in 2014 with the highest number of buildings. Mallick and Mourshed (2012) asserted that during the last two decades open spaces and water bodies have been converted to cemented areas at an alarming rate to meet the growing demands of housing and infrastructures, resulting in higher temperature and change in energy balance as well as affecting the human environment.

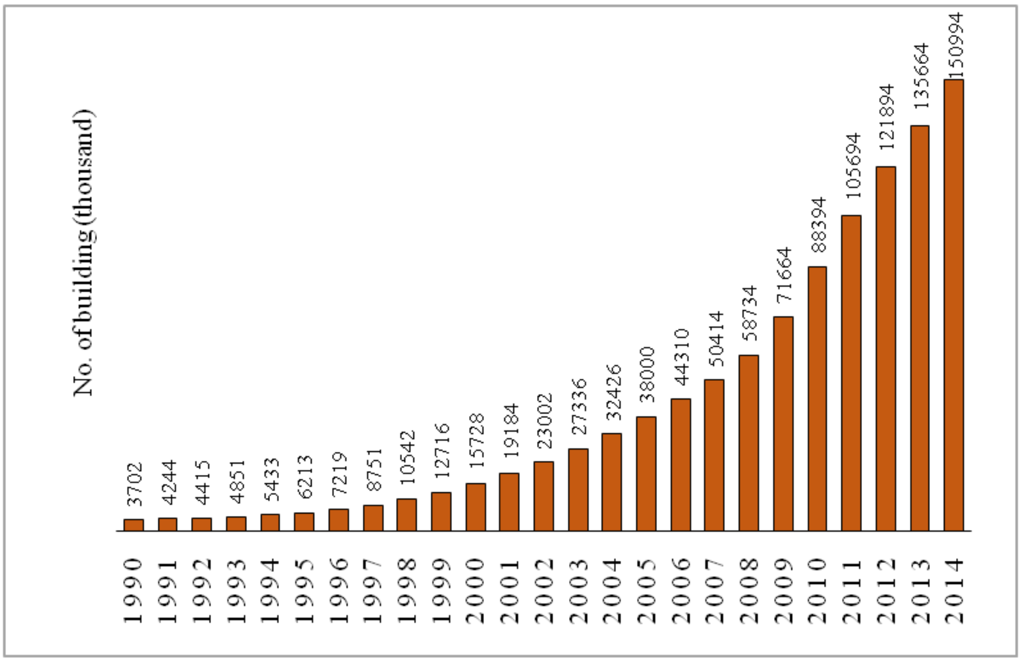


Fig. 5. Real estate development in the housing sector (1990-2014)

Increasing trend of vehicle population:Figure6 shows the growth of the vehicle population in Dhaka city during the period 2005-2014. In 2005,the vehicle population was 310408, which increases significantly over time and reached at 821,186 in 2014 out of which cars nearly 178,828 and motorcycles 373,021 as shown in

Fig.7. Thus it is revealed that over a period of 10 years, the vehicle numbers in Dhaka have increased remarkably and in 2014 it increased by 3-folds.Annual vehicle registration data of Bangladesh Road Transport Authority (BRTA) 2008 showed that the total vehicle population in Dhaka have been growing at an accelerating rate for the last several years especially after 2010 as shown in Fig.6.

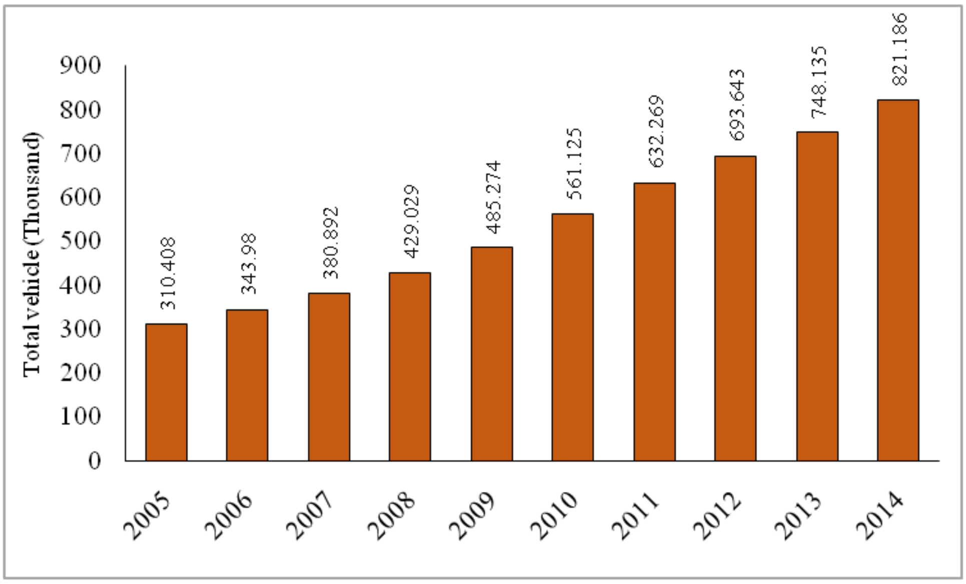


Fig. 6. Motorized vehicles population in Dhaka city (2005-2014).

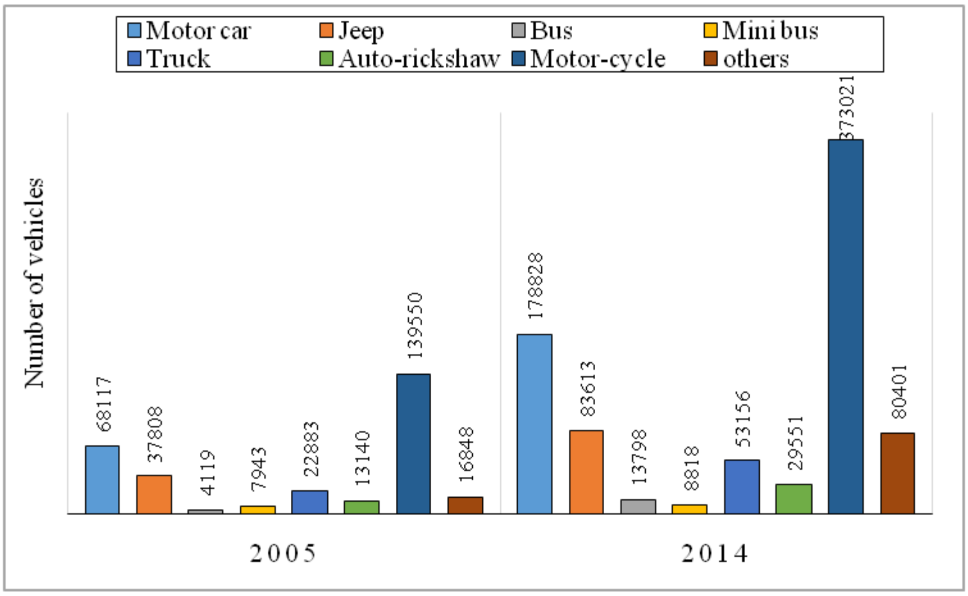


Fig. 7. Vehicle composition in 2005 and 2014 in Dhaka city

It should be noted that these vehicle population generally consists of mix composition as shown in Fig.8, which increased remarkably in the last few years. For instance, Fig.7 shows a comparative scenario in terms of increasing number of vehicle composition in two different years. However, based on the registered vehicle population data from the Centre of Urban Studies (CUS, 2015) up to 2014 it is observed that among the total number of registered vehicles in Dhaka the percentage of the motorcycle was the highest (45%) in 2014. However, apart from motorcycle, the vehicle composition also includes motor car (22%), jeep/microbus (10%), bus (2%), minibus (1%), truck (6%), auto-rickshaw (4%), and others (10%) as shown in Fig.8. The present findings is similar to the findings of the Department of Environment (DoE), Bangladesh wherein the total vehicle composition the percentage of motorcycles was the highest (43%), followed by rotor car (27%), jeep/microbus (10%), Others (8%), trucks (6%), auto-rickshaws (3%), bus (2%), and minibus (1%) (DoE, 2012).

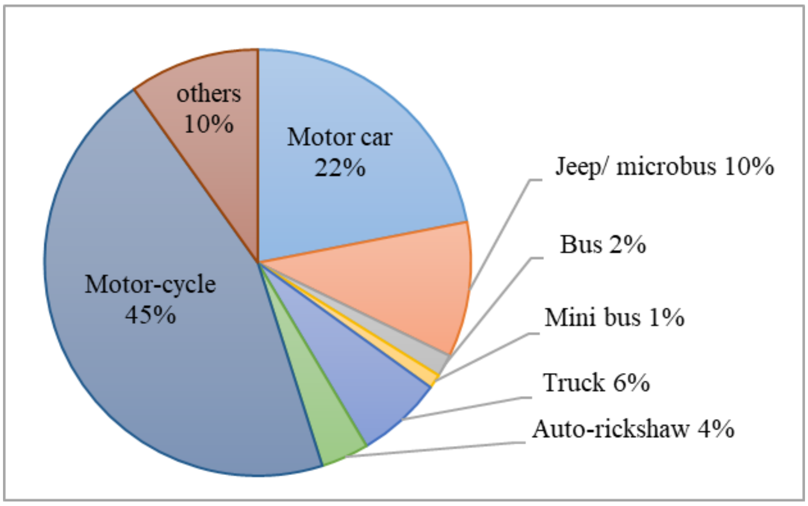


Fig.8. Composition of the totalvehicle population in Dhaka city in 2014.

The study also identified the correlation between increasing motor vehicles and maximum temperature during the period 2005-2014. Although Fig.9 shows a fluctuating pattern of annual maximum temperature during the period, however, the increasing trend was observed in 2006, 2009, 2010 and 2014 onward with increased vehicle population. For instance, the highest annual maximum temperature (40.2 °C) was observed in 2014 with total vehicle population of 821,186. Rahman (2009) asserted that the number of motorized vehicles is increasing at an alarming rate and it is expected to be continuing in the future. This accelerated growth in vehicle population also contributes to greenhouse gases (GHG) emissions, therefore, have profound impacts on climate change and higher temperature. However, apart from vehicle population, anthropogenic heat generation through industrialization, increasing urbanization, clearing urban greeneries, and overpopulation have substantial effects on UHI. Yuan and Bauer (2007) and Coutts et al. (2007) asserted that UHI is exacerbated by the anthropogenic heat, which is producedthrough transportation, car engines, industrial activity,air conditioners, overpopulation and domestic and commercial buildings, therefore affecting the microclimate.

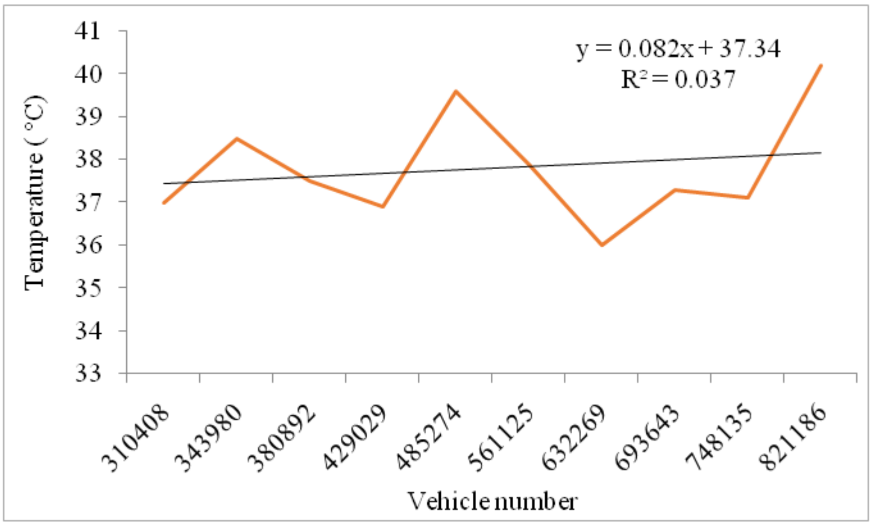


Fig. 9. Annual variation of maximum temperature in response to vehicle population

UHI effects on public health:

To understand the relationship among higher temperature influencing UHI and public health impacts this study applied the survey approach among the local inhabitants in some selected parts of the city (Fig. 1). Moreover, an in-depth interview was conducted among the doctors of the International Centre for Diarrhoeal Disease Research, Bangladesh (*icddr*,b) to explore the information regarding the number of patients visit in *icddr*,b as a consequence of temperature rising in Dhaka city during the period1985-2014. In our study, only*icddr*,b is considered to determine the influence of UHI on public health. This is because no statistical data or records are available in other government hospitals such as Dhaka Medical College and Hospitals and Dhaka Shishu Hospital regarding the number of patients visited or admitted with temperature-related illness.

The high temperature is highly responsible for the outbreak of various diseases. The study identified that anthropogenic factors such as industrialization, increasing urbanization, deforestation, transportation, and overpopulation are mainly responsible for rising temperature in the city, which eventually affect the public health and therefore leads to increased number of patients visit annually (Table S2). Fig.10 shows the trend of yearly patient visit in *icddr,b* during the period 1985-2014. It is apparent that in the last few years the number of patient visits has increased gradually with the highest number of patient (147,975) visited in 2014 (except for 1998 when the patient visit was the highest due to prolonged period of flooding) while the summer temperature was the highest (40.2°C) (Table S3).

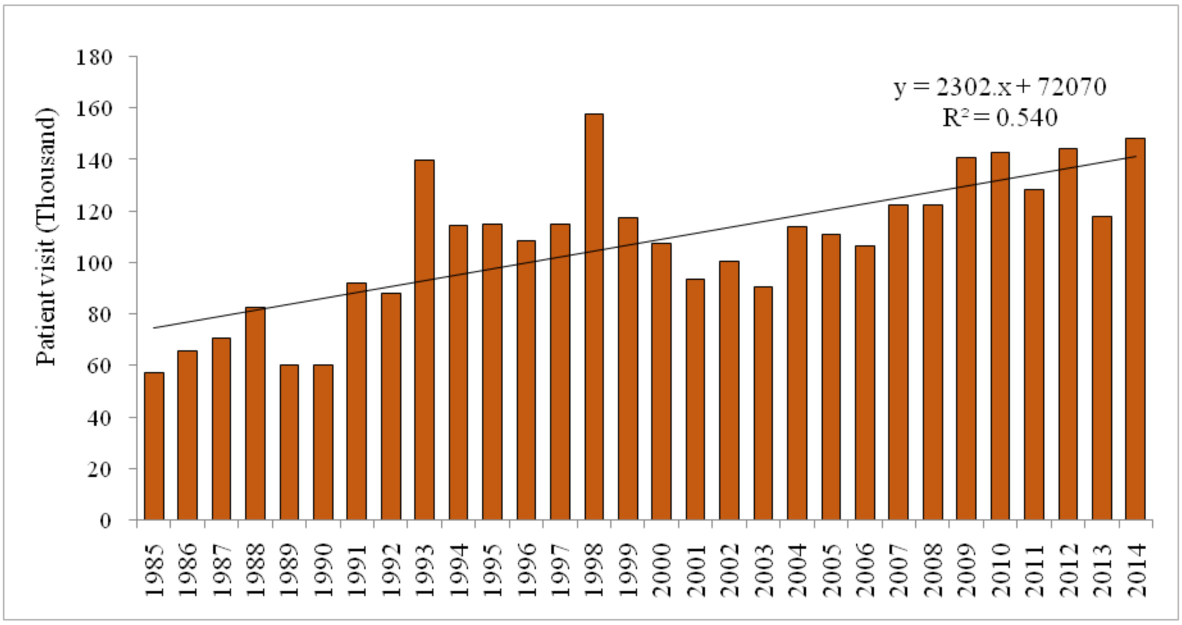


Fig. .10 Annual patient visits in icddr,b

Our study focused on summer season temperatures from March to June. The monthly average maximum temperature in Dhaka city was determined using historical data from the Bangladesh meteorological department (BMD). Fig.11 shows the higher temperature during the month from March to June with a peak of 40.2 °C during April. During this period, the total number of patient visit in the *icddr,b* was also observed higher compared to other months (Table S1). However, the frequency and intensity of UHI and heat-related problems are expected to increase continuously in this period due to uncontrolled anthropogenic activities in the city.

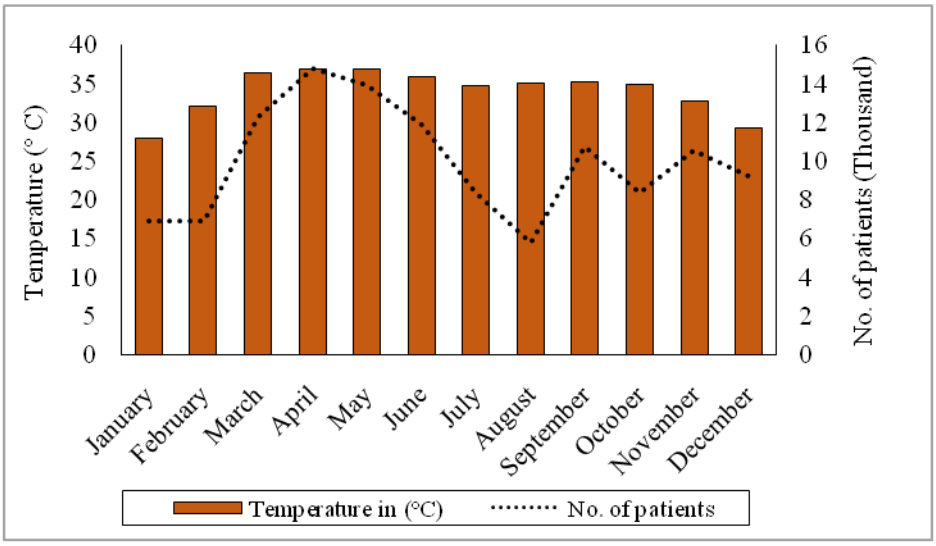


Fig. 11. Monthly patient visits in *icddr, b* in relation with average maximum temperature.

The study revealed that due to the gradualincreasein temperature, the frequency of diseases increased and thus people suffered from various diseases in the city. The surveyed results showed that around 83% of people are suffered from high temperature related diseases almost every year. Among them,38% reported that diarrhea is more prevalent during the high-temperature period in the city, followed by cholera, hypertension, skin disease, asthma, and heat stroke (Fig. 12). Khan (2010) reported that diarrhea is more frequent during the extreme temperature periods. Besancenot, (2002); Luber and McGeehin, (2008) stated that high-temperatureperiodsassociated with UHI can cause discomfort, weakness, disturbances of consciousness, cramps, fainting, heat stroke, and hypertension.

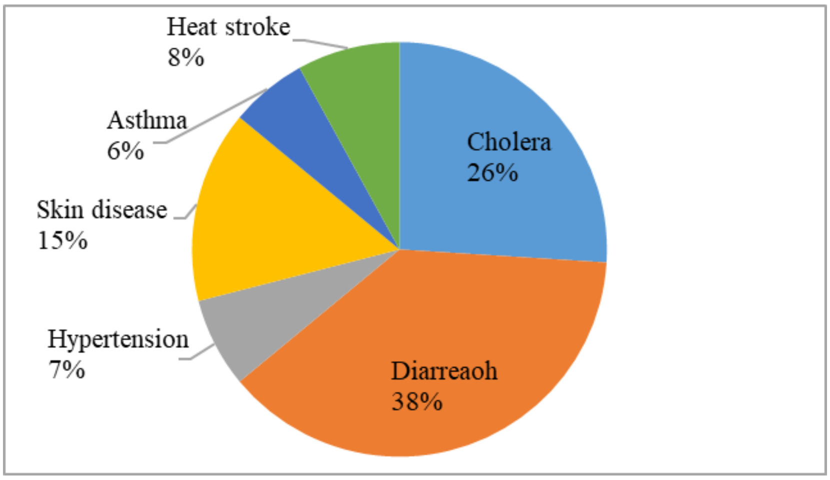


Fig. 12. Impacts of urban heat island on public health

IV. Conclusion

UHI is considered as one of the major urban environmental problems resulted from anthropogenic activities facing the 21st century. The formation of UHI has profound impacts on the city environment including public health as it leads to a higher temperature and the impacts are considered as the key indicator that reflects the severity of urbanization. This study identified rapid population growth, increased vehicular population, uncontrolled development in infrastructures (buildings) under the real-estate authorities as the key factors responsible for UHI formation in Dhaka city. The study found that during the last 30 years all these factors increased noticeably resulted in increased temperature and number of patients visit due to higher temperature-related diseases,especially in the summer. For instance, during March to June,the total number of patient visited in the *icddr,b* was observed much higher while the temperatures were also observedhigher.Based on the present circumstances it is expected that UHI and heat-related problems will increase continuously in the coming decades if these factors continue to increase instead of controlling. However, the study suggests the necessity of further works to determine the UHI impacts on public health by taking into consideration other government hospitals and private clinics that are not covered in this study due to unavailability of information.

Acknowledgement

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Supplementary Material

Table S1. Monthly patient visits in *icddr,b* (1995-2014)

Year	Monthly patient visit											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1995	5612	5833	13776	17379	12967	10963	7404	5501	9864	7647	10020	7763
1996	6354	6669	12711	15753	11534	10807	7351	5014	9080	7025	8860	7408
1997	6927	6548	12304	10587	16413	11893	7622	5422	9880	7965	10843	8583
1998	9377	9074	14522	16247	21004	16983	10910	7262	14779	10968	14099	12286
1999	6564	6790	16932	12960	12069	10292	7684	5737	10114	8727	10359	9137
2000	6311	6017	9435	11040	14746	11639	7231	5070	10305	8271	8988	8721
2001	5077	5556	9928	13506	9064	8063	6646	4181	88353	6681	8074	7689
2002	5885	5878	13455	9067	10928	10195	9828	4621	7505	6065	9717	7036
2003	5507	5080	8161	8066	9545	12310	7345	5339	7555	6358	8005	8073
2004	7047	6900	11926	10890	17485	10010	8210	5110	9070	7296	8990	8993
2005	7640	6301	11520	15886	11895	9020	8153	5210	9286	7080	9577	9420
2006	6240	6244	14480	11692	10926	9223	7047	5316	10280	7086	9975	8022
2007	7130	7173	11232	15170	16174	10525	8407	8765	11064	8853	1592	9041
2008	7100	7138	10125	16377	16147	10350	8612	5460	11369	8940	11395	9151
2009	8218	7381	12924	18982	15191	14247	10582	6565	13239	9834	12593	11104
2010	8013	8687	14672	19501	13371	14600	9493	6844	13894	9346	12742	11332
2011	7399	7343	11792	17302	14843	14162	7730	7164	11152	1772	10656	10015
2012	7310	8578	13024	18320	15553	14787	10008	7925	12653	10060	13095	11263
2013	6800	7032	9660	16827	12737	13110	7031	5671	11181	10724	8070	9224
2014	8531	8813	13368	19830	15964	15170	10064	7106	14008	10123	13436	11562

Source: icddr,b (2014)

Table S2. Yearly total patient visits in icddr, b (1985-2014)

Year	Patient Visit
1985	57350
1986	65415
1987	70739
1988	82721
1989	60083
1990	59950
1991	92148
1992	88028
1993	139750
1994	114151
1995	114279
1996	108566
1997	114987
1998	157441
1999	117365
2000	107474
2001	93300
2002	100380
2003	90344
2004	133941
2005	110994
2006	106531
2007	122126
2008	122191
2009	140860
2010	142495
2011	128330
2012	144176
2013	118067
2014	147975

Source: icddr, b (2014)

Table S3. Monthly maximum temperature in Dhaka city (1995-2014)

Year	Monthly maximum temperature in (°C)											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1995	29.2	30.8	38.8	39	38	36.6	33.5	34.7	35.6	34.6	34.2	28.6
1996	29.2	32	37.6	38.4	36.5	35.5	34.1	35.5	37.5	35.4	33.7	30.3
1997	27.6	31.3	35.6	34.7	36.2	35.5	34.4	37.5	34	34	33.7	29
1998	27.3	30.8	34.8	35.7	37.5	35.8	34.1	34.6	36.2	35.7	33.6	30.3
1999	29.4	35.7	39.6	37.6	37.5	36.6	35.6	34	34.6	34.6	32.4	29.7
2000	28.7	28.2	34	35.1	36.6	35.2	35.2	35	34.4	34.9	32.5	27.3
2001	28	31.4	35.8	37.5	35	33.8	34	34	34.2	34.8	32	28.4
2002	28.2	33.5	35.5	34.3	35.4	34.4	35.2	34.1	35	34.2	33	29.5
2003	27.5	31.6	34	36.2	36.3	36.7	35.3	35.1	34.2	34	32.1	29.2
2004	27.5	32.8	35.8	35.2	38.1	35.2	34.5	34.6	34	34.5	31.1	29.4
2005	28.5	32.1	35.6	37	36.4	36.6	37.3	34	35.1	34.6	31.4	29
2006	28.2	35.9	38.5	37.1	36.8	35	35.6	35.2	35.7	34.7	32.6	30.1
2007	28.8	30.8	36.7	35.9	37.5	35.9	34.8	35.9	34.9	35.6	31.8	28.2
2008	29	30.6	34.6	36.9	36.7	35.4	34	36	34.8	34.8	32.3	29
2009	28.1	33.9	36	39.6	37.8	36.5	35.7	34.3	35.3	35.8	33.9	29
2010	29	31.1	37.3	37.9	36.9	35.8	35.1	35.1	34	35.7	33.2	29.7
2011	27.8	31	34.5	35.8	35.3	36	35.4	35	36.2	34.5	32.4	30
2012	28.5	33	37.3	37.1	36.2	36.7	34.3	34.5	36.5	34.4	32.4	28.5
2013	28.1	32.4	36	37	37.1	36.4	34.6	35	35.7	35.2	32.1	30.5
2014	28.5	30.4	38	40.2	38	37	35.8	35.7	37	35.5	34	30

Source: BMD (2015)

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