Urbanisation and environmental degradation in Dhaka Metropolitan Area of Bangladesh

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Abstract: Using available data on relevant issues and onsite field visits, this paper documented the environmental problems associated with the unprecedented urbanization in Dhaka Metropolitan Area of Bangladesh. Analyses revealed that a rapid spatial expansion of the city has been taking place alongside the remarkable rise in urban population, simultaneously putting immense pressure on natural resource-base. Substantial changes that were observed in land use and cover are believed to be a significant factor in elevating the risk of natural hazards, particularly flooding during monsoon. In addition, air, water, and noise quality, have all become acute, and are subsequently posing uncertain liabilities to the inhabitants' health of the area. Rapid uncoordinated urbanisation gives rise to a spectacular growth of slums and squatters, making 3.4 million slum dwellers in 2006 from only 1.5 million in 1996. Achieving sustainable urban development in the DMA therefore, requires tackling the environmental problems in a rational manner.

Keywords: Dhaka Metropolitan Area; DMA; urbanisation; environmental degradation; sustainable development; environmental pollution; Bangladesh.

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1 Introduction

Urbanisation has become one of the greatest environmental challenges in the world today. Generally, the term urbanisation refers to the alteration of an agrarian economy to that of an industrial plus service-oriented economy (Mandal, 2000). Worldwide, a strong trend of urbanisation has been observed since 1900. Estimates show that only 10% of the global population was living in urban areas in 1900. This grew to 30% in 1950 and 47% in 2000 (UN, 2002). Projections are that by 2025, the urban population will represent more than two-thirds of the world population (World Bank, 2007). Even though the urban surface area corresponds to only two percent of the world's terrestrial surface, those same areas consume nearly 75% of the world's natural resources and generate an enormous amount of waste (UNFPA, 2007; Redman and Jones, 2004). Currently, the rate of urbanisation is much higher in developing countries than in the developed world; predictions indicate that by 2020, most of the megacities[1] of the world will exist in developing countries (World Bank, 2007).

Urban growth, fuelled by population growth and economic development, has two opposing facets. On the one hand, megacities act as engines of economic and social improvement to countries (Girard et al., 2003), but on the other, urbanisation leads to the destruction of the environment, particularly in developing countries. Numerous studies documented a number of negative impacts of urbanisation on the environment. These include increasing vulnerability to natural hazards (Wenzel et al., 2007; Weng, 2001), channel-bank and road-surface erosion (Nelson and Booth, 2002), habitat destruction (Alphan, 2003), landscape degradation and fragmentation (Dewan et al., 2010; Grimm et al., 2008), climate change (Green and Baker, 2003), species extinction

(McKinney, 2006), and the reduction of net primary productivity (Xian et al., 2007). All of these changes are being identified as decisive factors attributed to global change (Nagendra et al., 2004), which will eventually impact humans (Liu et al., 2003). Effective management of the changing urban environment is considered a prerequisite to achieving sustainability (Wu and Murray, 2003).

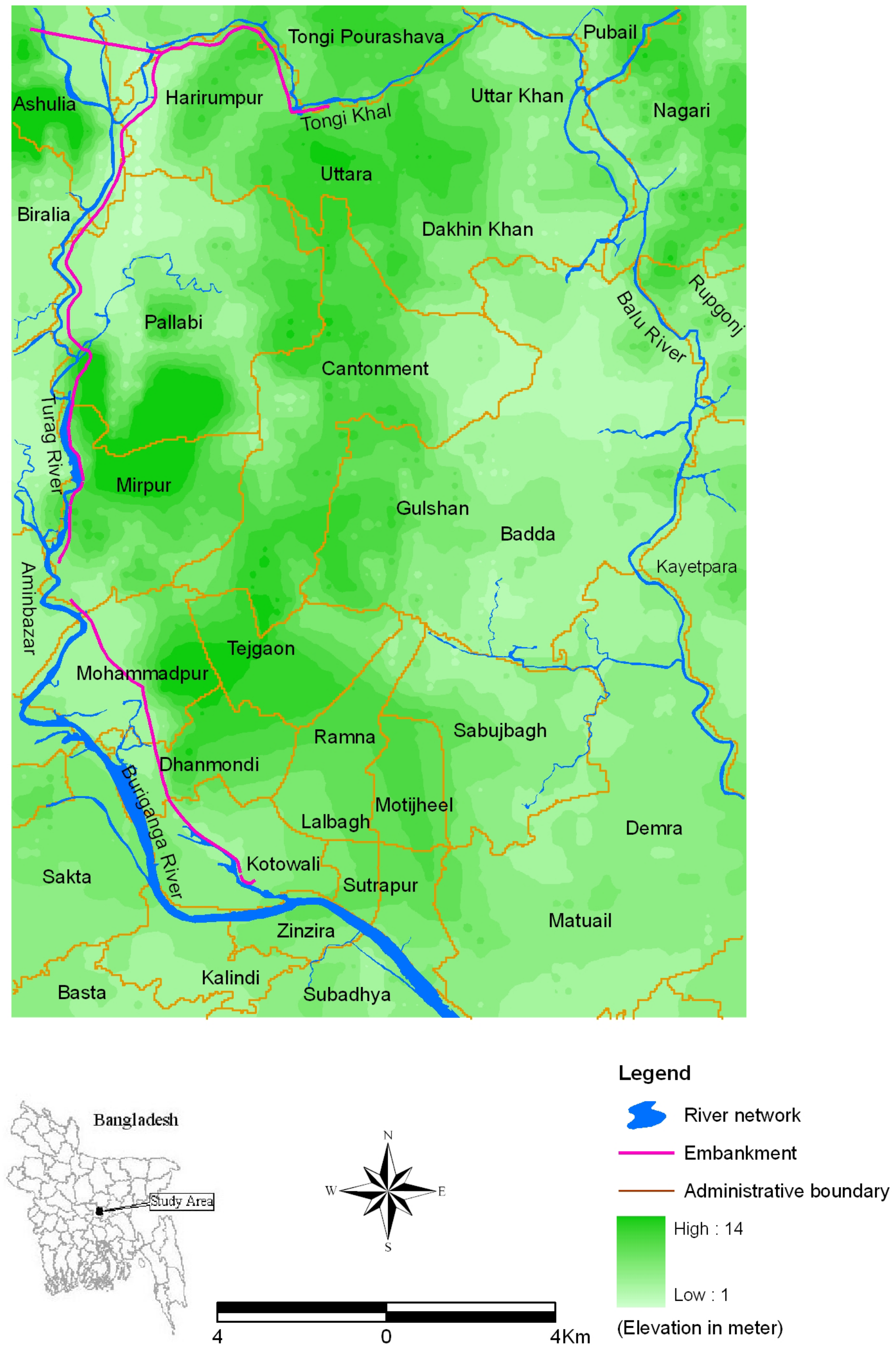
Bangladesh is one of the most densely populated countries in the world. With an extremely low per capita income ($440 US), until the 1970s, the bulk of the gross domestic product (GDP) was from agriculture. Contributing about 60% to the GDP (BBS, 2005a), the service sector currently replaces agriculture. In contrast, industrial growth is extremely steady and shares only 16%. This has resulted in considerable loss of arable lands. It also exerts tremendous pressure on limited resources, predominantly on cultivated areas and forest cover. For example, every year, more than 809 km^2 of agricultural/rural land is transformed into cities, roads, and infrastructure in Bangladesh (BBS, 1996). In addition, agricultural expansion in areas with a higher population density has progressively depleted the forest coverage of the country (Giri and Shrestha, 1996). Consequently, urban growth is exceedingly conspicuous, and the urban population of the country rose from 14.1 million in 1981 to 35 million in 2005, and around 45 million in 2011 [Centre for Urban Studies, National Institute of Population, Research and Training (NIPORT) and Measure Evaluation, 2006; BUF, 2011]. One of the most important reasons for the population explosion in the cities of Bangladesh is a large scale rural to urban migration caused by the collapse of a sustainable rural economy (Rouf and Jahan, 2006).

Dhaka, the capital of Bangladesh is expanding at an average rate of 4.24%/year. If this rate continues, projections are that Dhaka will be the third largest megacity of the world by 2020 (World Bank, 2007). Its growth has been phenomenal since the independence of the country in 1971 (Chowdhury and Faruqui, 1989). The population increased from 0.34 million in 1951 to more than 12 million in 2005 (World Bank, 2007). Apart from population growth, the increasing contribution of Dhaka's GDP to the national economy has made the city a nerve centre for socioeconomic as well as cultural development. Hence, the city area expanded immensely during the last few decades to accommodate its ever-increasing population (Dewan and Yamaguchi, 2008, 2009a, 2009b; Islam, 1996, 2005).

Rapid urban growth has simultaneously induced many adverse impacts on the environment of Dhaka Metropolitan Area (hereinafter, DMA). Some of the notable impacts are – an increase of flood risk potential, severe environmental pollution (e.g., the high lead level in DMA's air has been recognised as a neurotoxin and considered a threat to children's brain development), uncontrollable growth of informal settlements, massive urban poverty, and the enormous problems of solid and hazardous waste disposal. In addition, inappropriate physical planning and mismanagement of the scarce resources have been blamed for further aggravating the socio-environmental parameters of Dhaka. So that a greater understanding can be developed and the path made clear toward achieving a sustainable urban environment, there is the need for a more systematic and comprehensive study on urban expansion and environmental degradation in the area.

The goal of this paper is to document the environmental problems that result from the physical development of DMA. The paper is primarily based on published literature, secondary data, and related statistics from relevant organisations and onsite field visits. It systematically addresses the source, the dimensions, and the implications of the environmental problems in DMA. Finally, a discussion and recommendation of possible measures for the mitigation and management of environmental problems are put forward.

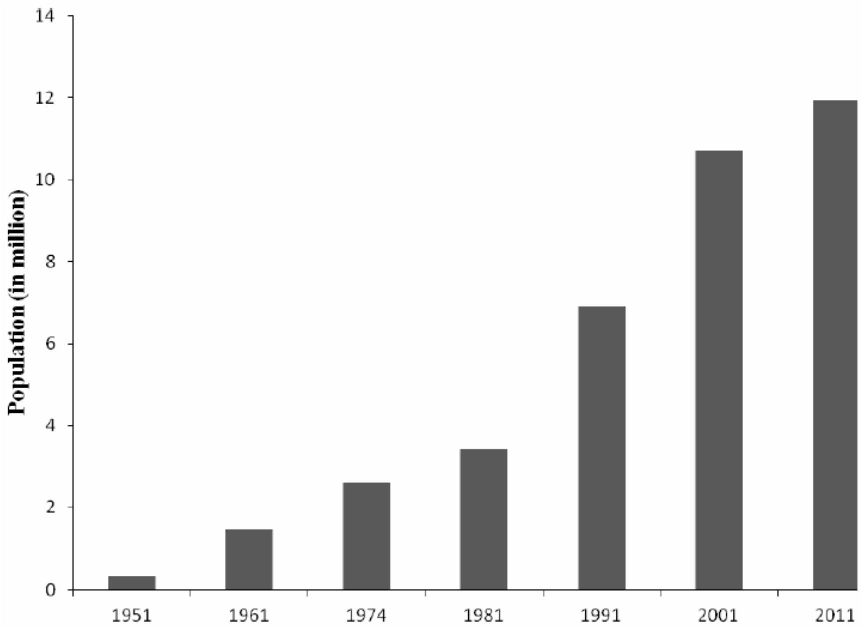
Figure 1 Location of the study area (see online version for colours)



2 The study area

The DMA is located at the centre of Bangladesh, between latitudes 23.58°N and 23.90°N, and longitudes 90.33°E and 90.50°E (Figure 1). Topographically, the area is a flat land situated mainly on an alluvial terrace, popularly known as the Madhupur Terrace, which was formed during the Pleistocene epoch. The surface elevation of the area ranges from 1 to 14 m, whereas most of the built-up areas are at elevations between 6 and 8 m (FAP 8A, 1991). Four major river systems surround the DMA. These include the Buriganga, Turag, Tongi Khal, and Balu, which flow to the south, west, north, and eastern part of the city, respectively. The study area lies in the sub-tropical monsoon zone under humid climatic conditions and annually receives 2000 mm of rainfall, of which more than 80% occurs during the monsoon season (July–October).

Figure 2 Population growth of DMA between 1951 and 2011



The city has extensive administrative and infrastructural facilities, as well as widespread road and telecommunication networks. Hence, it has become a hub of urban growth and a centre of economic activity. Due to its economic, educational, and socio-political significance, marginalised rural people are attracted to the area for better employment opportunities and improved life styles. For instance, DMA's population was 0.34 million in 1951 and 0.56 million in 1961. By 1974, it rose 2.6 million, averaging an annual growth rate of 9.32% between 1961 and 1974 (Islam, 1996, 1999, 2005). In 1981, the population increased to 3.44 million when the annual growth rate surpassed all its previous records. In 1991, the population of Dhaka increased to 6.92 million; in 2001, it reached 10.7 million (BBS, 2001). Currently, the population of Dhaka is nearly 12 million (Figure 2) with an annual average growth (1991–2001) of 3.5%, which has already outpaced the country's annual growth rate of 1.3% (World Bank, 2007; BBS, 2005a, 2011). Studies indicate that the rapid growth of the urban population is primarily driven by rural-urban migration. Islam (1991) for example, reported that more than 60% of the people in DMA are migrants. Understandably, these additional people have created tremendous pressure on land for housing and other urban services, which in turn has profound environmental implications.

3 Environmental consequences

The majority of the literature suggests that urbanisation introduces many environmental adversities. The DMA is no exception to this. The following section describes the magnitude of the environmental problems, resulting from the rapid urban expansion in the study area.

3.1 Land use and land cover change

At the present, land use/cover change, and consequent urban growth in response to increasing human activity, particularly in developing countries, is unprecedented (Grimm et al., 2008) and Dhaka is no exception to this reality. Table 1 presents the land use and land cover statistics between 1960 and 2005. It shows that urban built-up areas occupied only 11.1% in 1960; this figure increased to 26.1% in 1988, and 49.4% in 2005, revealing significant changes in land use/cover in the DMA (Dewan and Yamaguchi, 2009a, 2009b). The bare soil/landfill[2] category has also increased exponentially. Observations collected during field visits indicate that urban expansion onto natural lands is extremely rapid, leading to the destruction of natural habitats and rural lands (Figure 3). Essentially, the low-lying lands are under tremendous pressure of development for housing since these areas are significantly cheaper than any other land (e.g., elevated land). In contrast, other land use/cover classes such as, water bodies, cultivated land, low-lying lands, and vegetation, have all been significantly reduced. Estimates of land cover conversion using a transition matrix revealed that from 1960 to 2005: agricultural land decreased by 55%, wetlands by 47%, vegetation cover by 38%, and water bodies by 29% (Table 1). Further statistical analysis revealed that between 1960 and 1988, agricultural land decreased by 34% whereas built-up land increased by 134%. In order to accommodate the increasing demand for urban lands, nearly 43% of available low-lying lands were converted to built-up areas during the period between 1988 and 2005. This result is consistent with other cities in the world. For example, the rate of urban expansion in Ajmer, a city of India, over the periods of 1977 to 1989 and 1989 to 2002 was 29.2 ha yr^{-1} and 32.4 ha yr^{-1}, respectively (Jat et al., 2008). On the other hand, the city of Istanbul, Turkey exhibits a higher rate of urban expansion than DMA. The rate of urban expansion was 1,000 ha yr^{-1} over the period between 1987 and 2001 (Kaya and Curran, 2006). Thus, the results of this study characterise urban growth patterns in DMA and subsequent land use changes in a country with lower per capita income and a different set of demographic regimes.

Table 1 Area and percentage of different land use/cover types from 1960 to 2005

Land use/cover types	*1960*		*1988*		*2005*	
	Area (ha)	*%*	*Area (ha)*	*%*	*Area (ha)*	*%*
Water bodies	2,965.2	7.1	2,101.5	5.1	2,101.1	5.1
Wetland/lowlands	13,514.4	32.5	12,715.6	30.6	7,128.8	17.2
Cultivated land	13,851.2	33.3	9,024.9	21.7	6,236.6	15.0
Vegetation	6,109.8	14.7	5,793.8	13.9	3,773.1	9.1
Built-up areas	4,625.4	11.1	10,858.9	26.1	20,549.7	49.4
Bare soil/landfill sites	498.0	1.2	1,069.4	2.6	1,774.6	4.3
Total	*41,564*	*100*	*41,564*	*100*	*41,564*	*100*

Source: Dewan and Yamguchi (2009a, 2009b)

Figure 3 Encroachment of low-lying areas by filling-up with sands (see online version for colours)

Source: Field Study (2009)

It may be noted that the construction of a 32-km embankment in the western part of the city accelerated the encroachment of low-lying areas in recent years (Chowdhury and Sato, 2000; Chowdhury et al., 1998); field visits also support this finding (Figure 3). In contrast, the real estate agencies propagate the very recent development (especially residential areas) in the North-Eastern part of the city through in-filling of wetlands and low-lying areas (Alam and Ahmad, 2010; Field Study, 2009). Apart from private agencies, The Capital Development Authority (RAJUK) is also largely responsible for converting agricultural land to built-up areas for housing purposes. Field visits also confirmed that the construction of two bridges over the Buriganga River fostered lowland encroachment in the southerly and North-Westerly directions, mostly in an unplanned and haphazard manner.

3.2 Vulnerability to natural hazards

The unplanned urbanisation made DMA more vulnerable to natural hazards, particularly to flooding and water logging during monsoon. Historically, the most devastating natural disaster in the city of Dhaka was the Great Assam Earthquake in 1897 (Oldham, 1899). However, at present, flooding has become the most pervasive and damaging phenomenon. The DMA experienced many devastating floods in the past; those in 1954, 1987, 1988, 1998, and 2004 were considered the worst (Dewan et al., 2004; Faisal et al., 1999). Flood estimation by remote sensing during three biggest flood events revealed that 47.1% of Dhaka was flooded in 1988, while in 1998 and 2004, the inundation areas were 53.2% and 43%, respectively (Dewan and Yamaguchi, 2007, 2008). Figure 4 illustrates the spatial distribution of flooding during the recent three events. An assessment of flood damage in terms of urban areas under flood during those events indicated that the 1988 flood engulfed 1,484 ha of urban land; whereas, in 1998, the figure was 2,991 ha. It is interesting to note that the moderate flood of 2004 (compared to the 1998 flood) engulfed 4,503 ha of urban land (Dewan and Yamguchi, 2007), which clearly indicates that flood damage is on the rise due to the progressive construction of additional infrastructure. Further analysis indicated that the growth of impervious surfaces resulting from land use/cover change clearly enhanced river peak flows, intensifying the flood risk potential (Dewan and Yamaguchi, 2008). Inappropriate physical planning of the city further aggravated this risk (Mohit and Akther, 2002). For example, a geographic information system (GIS)-based flood hazard map of the 1998 flood revealed that more than 55% of the city area is within the high hazard zone (Dewan et al., 2006, 2007a, 2007b). In contrast, the structural measures of flood control have amplified the flood risk in DMA (e.g., increasing flood duration due to flood embankment, dykes, etc.) (Chowdhury, 2003; Maathuis et al., 1999) and contributed to severe water logging, particularly during monsoon (Alam and Rabbani, 2007) (Figure 5). Field visits suggest that a significant amount of the wetlands and low-lying areas, which previously served as retention ponds during the wet season, is now being developed in housing areas without consideration of the potential consequences of recurrent flooding.

Figure 4 Inundation maps of DMA during the three largest flood events (see online version for colours)

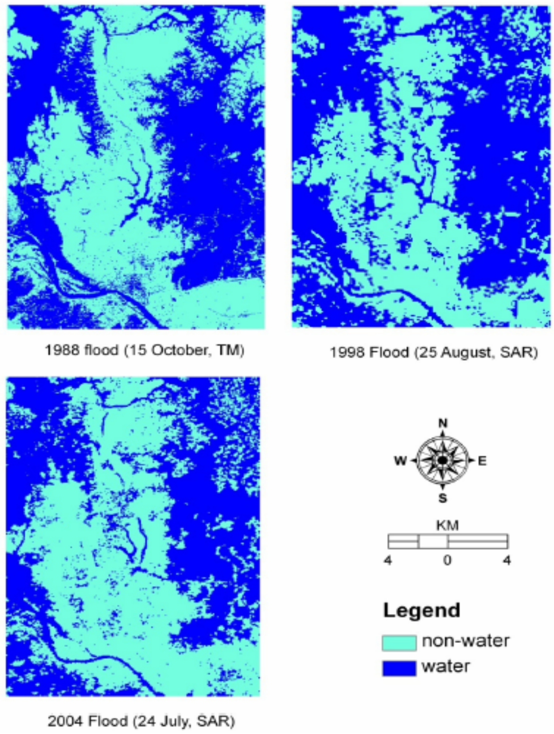


Figure 5 Water logging in the main roads during monsoons (see online version for colours)

Source: Field Study (2009)

Apart from flooding, vulnerability to earthquake is also a matter of tremendous apprehension. According to the Bangladesh National Building Code (BNBC, 1993), DMA is located within a zoning coefficient equivalent to 15% of the gravity (z = 0.15 g), which is ranked the second highest in terms of vulnerability. Experts fear that because of using poor building materials and inappropriate construction processes (Ansary, 2003); severe damage may likely occur in the event of an earthquake. Since the residents of DMA have no recent experience dealing with earthquake hazards, any tremor with a 7.0 magnitude would bring major human tragedy (Paul and Bhuiyan, 2010). One study suggests that such a tremor could cost the lives of between 45,000 and 86,000 people in DMA (depending on the time of occurrence), and human injuries could be as high as 210,000, primarily owing to structural failure (Ansary, 2004). Moreover, the construction of buildings and other urban infrastructures, which are now mainly through earth-filling on alluvial deposits, is elevating the potential of earthquake and soil liquefaction related risk (Kamal and Midorikawa, 2004). It is worth noting that the structures built on alluvial plains suffered incredible damage during the Adana-Ceyhan earthquake in Turkey in 1998 (Ulusay et al., 2002). Since 80% of the buildings in Dhaka was constructed with poor geological foundations [Rahman (2003) cited in Paul and Bhuiyan], 2010), these buildings are extremely vulnerable to earthquake. This is alongside the fact that poor building materials (i.e., masonry buildings, buildings constructed with corrugated iron (CI) sheet, bamboo, woods, mud, buildings with brick walls, etc.) used in the construction phase also represents a significant threat to an earthquake hazard (Field Study, 2009).

Other common hazards in DMA include severe local storms such as tornados and Nor'westers. Up to this point, at least four violent tornadoes have hit the city and its suburbs. These tornadoes occurred on April 7, 1888, April 12, 1902, April 14, 1969, and April 5, 1972; they killed 118, 88, 562, and 75 people, respectively (Finch and Dewan, 2004). Time series analysis of Nor'wester occurrences (1954–2000) in Bangladesh revealed that DMA is highly exposed to local damaging storms, and it had the highest incidence of such events (26–52/year) resulting in severe property damage (Dewan and Peterson, 2003; Peterson and Dewan, 2002). Since urbanisation replaces natural land with metallic and concrete infrastructures, rising temperatures, due to the heat island effect during the summer in the city, is directly responsible for the formation of severe local storms such as tornadoes (Rana, 2010). These weather-related hazards are likely to deepen in the context of global warming, which may have what may currently seem implausible impacts on the people and property of DMA.

3.3 Air pollution and public health

In Bangladesh, air pollution typically originates from the high content of lead in gasoline, the large number of polluting vehicles on the road, the use of impure fuel, improper land use, and poor traffic management (Karim et al., 1997). In addition to vehicular pollution, manufacturing industries located in and around DMA contribute considerable pollutants to the air, making DMA one of the most polluted cities in South Asia (Mahadi, 2010; Begum et al., 2010; Gurjar et al., 2010; BBS, 2005b, 2010).

Vehicular (e.g., busses, trucks, three-wheelers, etc.) emissions currently account for major pollution in DMA's air (Table 2). While motor cars, busses, and trucks contribute the largest percentage of the total emission, the contribution from motorcycles and auto-rickshaws (e.g., three-wheelers) is not negligible (DITS, 1994). Although the latest statistics are not available, it is widely believed by urban planners, environmentalists, and decision makers of the city that the air quality is worsening with the dramatic increase in the number of automotive vehicles (Personal Communication, 2009). For example, the number of two-stroke vehicles, believed to emit 30 times more pollutants than a car, rose from 2.2% in 1982 and 83 to 35.3% in 2005 (BRTA, 2005). The contribution of particulate matter (PM_{10}) and hydrocarbon (HC) by two-stroke engines is estimated to about 40% and 50%, respectively, while busses and trucks combined contribute about 44% PM_{10} to the city's air (UNEP, 2001). The air quality of DMA is also being worsened by the fact that most of the automobiles are aging, overloaded, and poorly maintained. Studies indicate that 90% of the vehicles now travelling Dhaka's street are defective, and emit black smoke through their tailpipes – far exceeding the allowable limit (DOE, 1990). Report also shows that the number of defective vehicles on the road has increased sharply due to poor maintenance, over fuelling, and overuse (UNEP, 2006).

Table 2 Vehicular emission inventory of DMA (tons/year)

Type of vehicle	*CO*	*NO_2*	*SO_2*	*HC*	*PM10*
Motor car	47,752	2,865	153	7,640	191
Three-wheelers	2,728	819	0	1,091	16
Bus	5,870	9,978	470	2,348	939
Trucks	4,228	7,188	338	1,691	677
Taxi	2,040	612	0	816	12
Motorcycles	6,369	382	25	5,095	127

Source: BBS (2010)

In DMA, the per day emission of sulfur dioxide (SO_2) and nitrous oxide (NO_2) were estimated to be about 72 and 70 tons, respectively, of which the major release comes from vehicles (Azad and Kitada, 1998). Estimates show that the annual increase of NO_x, HC, carbon monoxide (CO), PM, and SO_x in DMA's air has been approximately 6.5%, 5.8%, 5.9%, 5.6%, and 6%, respectively since 1996 (Karim, 1999).

The level of other pollutants, such as airborne lead (Pb), is also a matter of serious concern in the study area. The lead concentration in the air is still extremely high in comparison to that of other developing cities such as Mexico City and Mumbai, India. The estimated lead density in the air of DMA is 463 ng/m^3 (Mahadi, 2010; Rahman et al., 1999), particularly during the dry season, while for the cities of Mexico and Mumbai, the figure represents 383 ng/m^3 and 360 ng/m^3, respectively. Automobile exhaust is the primary source of the higher lead concentration in DMA (Ahmed et al., 2005; 2007). However, a contrasting finding suggests that airborne lead has been reduced noticeably in response to the introduction (by the government) of lead-free gasoline in early 2000 [Biswas et al. (2003) cited in UNEP, 2006]. Nonetheless, the legislation for actual banning is yet to come (Bowman et al., 2005; Salam et al., 2003). Of additional note, the concentration of toluene (a known carcinogen) was found to be 50–100 times higher than the standard limit when samples were tested from an auto-rickshaw stand (Hussam et al., 2002).

Industrial emission is another source of air pollution. Leather, food, pulp and paper, textile industries, and brickfields around the city significantly contribute SO_2, NO_2, CO, PM and volatile organic compounds (VOCs) to the air. For example, the estimated emission of SO_2 to the atmosphere by the brick kilns and manufacturing industries is 28.8% and 10%, respectively. In the vicinity of the Tejgaon industrial belt, the maximum concentration of suspended particulate matter (SPM) was 1849 $\mu gm/m^3$, as opposed to the allowable limit of 500 $\mu gm/m^3$ specified by the Department of Environment (DOE) (UNEP, 2001). It is of interest that the emission rate of SPM was 4 ton/day in 1985, which has increased to 7 ton/day in 1999 (DOE, 1999). In addition, carbon dioxide (CO_2) and Methane (CH_4), which is produced by the tanneries, both pollute the air considerably (Khatun and Houqe, 1994).

In addition to outdoor air pollution, burning discarded tires for cooking indoors, and the household-use of kerosene, wood, and biomass are all sources of severe indoor pollution. To estimate the status of indoor pollution in the slums in DMA, a number of air quality parameters (e.g., VOCs, CO, CO_2, NO_2, and dust particles) were tested by taking samples from both biomass and fossil fuel users. The results showed that CO was considerably higher with the biomass users, while NO_2 and VOCs were markedly higher with the fossil fuel users (Khalequzzaman et al., 2007).

The previous results indicate that the air quality of DMA has already reached an alarming state, which has serious implications for public health. A recent study by Gurjar et al. (2010) suggests that megacities such as New York and Tokyo have very low cases of total mortality from pollutants such as SO_2, NO_2, and total suspended particles (TSP), while Karachi ranks the highest (15,000 per year) followed by Dhaka (7,000 per year) and Beijing (5,500 per year). Another study showed that blood lead concentration levels (Bpb) among children in Dhaka were 7–16 times higher than the normal of $\geq$ 10 µg/dL (Khan, 2000). An analysis of 779 school students revealed that 87.4% of the students had a higher elevated Bpb than the standard limit specified by the centres for disease control (CDC) and prevention. This high Bpb concentration could have serious health effects for the children since a higher concentration of Bpb can affect development and learning ability in children (Kaiser et al., 2001). The study concluded that combustion of leaded gasoline is the main source of lead exposure in DMA.

The population of DMA also has a high incidence of bronchitis and other respiratory diseases, which is evidently due to the exposure to polluted air (UNDP, 1987). Samples from Dhaka Child Hospital (DCH) showed that acute respiratory infection (ARI) and the number of wheezing patients increased from 138 in 1996 to 191 in 1998. According to the 1999 Nutritional Surveillance Report, 14.3% of children <5 years of age in DMA had symptoms of acute respiratory infection (Hellen Keller International, 2001). It is imperative to note that, every year, the deaths of nearly 120,000 children in Bangladesh are directly attributed to acute respiratory infection (Dana, 2002). Where chronic obstructive pulmonary disease (COPD) morbidity is concerned, DMA ranks on the top with Karachi, having about 2,100 per year excess cases, demonstrating higher level NO_2 concentration in the air. Conversely, Osaka has the lowest number of excess cases, i.e., 60 per year (Gurjar et al., 2010). Indoor air pollution is also causing a number of health problems. As found by Khalequzzaman et al. (2007), due to burning biomass for cooking, the slum children in DMA are typically affected by redness of eyes, itching of skin, nasal discharge, cough, shortness of breath, chest tightness and wheezing.

3.4 Water pollution

Historically, DMA has been endowed with an abundance of water resources. As the population increased since the independence of Bangladesh in 1971, DMA's significant amount of wetlands and water bodies have been simultaneously filled-up (Table 1). Because of increasing anthropogenic activities, the quality of surface water has also been continuously deteriorating in the peripheral rivers and lakes. As DMA hosts more than 40% of the industries in the country, industrial effluents directly discharged into the rivers are found to be the primary cause of water pollution (Field Study, 2009) (Figure 6). Water quality parameters, such as dissolved oxygen (DO), are found to be completely depleted in the Buriganga River during the dry season while biological oxygen demand (BOD) increases concurrently (Sohel et al., 2003), indicating the existence of substantial amounts of inorganic and non-biodegradable components in the river (BBS, 2010; Karn and Harada, 2001; Kamal et al., 1999). The annual increase of BOD in the Buriganga River is estimated to be about 1.03 μg/l (microgram per litre) while the decrease of DO is 0.276 μg/l (DWASA, 1998). A similar trend is observed in the Balu and Turag rivers (Table 3), where the presence of DO is zero in the dry season due to the release of untreated effluents from the fertiliser and dyeing industries. Among other pollutants, the chromium concentration (Cr) in the Buriganga River was found to be extremely high (19.4 μg/l), significantly higher than the Bangladesh standard (0.05 μg/l), more than 90% of which come from the Hazaribagh area, which houses approximately 160 tanneries (Karn and Harada, 2001). A representative example of the pollution loads of different industries is presented in Table 4. It shows that the pollution loads in terms of chemical oxygen demand (COD) and total dissolve solids (TDS) are much higher than that of the Bangladesh standard. For instance, the highest COD load of a garment industry was found to be 1,152 μg/l (opposed to the Bangladesh standard of 200 μg/l). Likewise, the allowable TDS load for an industry is 2,100 μg/l, but Table 4 shows that 7 out of 12 industries exceeded the acceptable limit (Table 4). Estimation of per capita pollution load discharge for three South Asian urban rivers revealed that the Bagmati River in Nepal ranks at the top with 31 gBOD/capita/day whereas the Buriganga ranks second (25 gBOD/capita/day) and the Yamuna River in Delhi stands third (19 gBOD/capita/day) (Karn and Harada, 2001). Researchers asserted that if these non-biodegradable organic components persist in the water systems for long, they could eventually enter into the food chain, and that could prove damaging for human physiology (Ahmed and Reazuddin, 2000).

In addition to industrial wastes, pollution from domestic wastes, agrochemicals, and restaurants commonly built on or near the water bodies are also responsible for the contamination of surface water systems (BBS, 2010; UNDP, 1987). In 1999, sewage treatment facilities (Kamal et al., 1999) served less than 25% of the people in DMA. Currently, those who do not have access to sanitary latrines rely on open or hanging latrines, usually constructed on the roadside or over water bodies. As observed during field visits (2009), slum dwellers typically build open-latrines on the roadside or construct hanging latrines on the water bodies. When natural runoff drains and transports human wastes to the surrounding water bodies, this could result in severe water pollution. Consequently, all manner of water related diseases (e.g., water borne, water washed, water-based, and water related) are widespread in DMA (Hasan and Mulamottil, 1994). According to a government report, disease cases and the number of deaths due to diarrhea in Bangladesh have increased in recent years (DOE, 2008). Typhoid is another water-borne disease, which increased substantially in recent times, largely affecting the infant population, aged between 0 and 4 (Ongee, 2011).

Figure 6 Discharge of industrial effluents on the Buriganga River (see online version for colours)

Source: Field Study (2009)

Table 3 Water quality characteristics of four major rivers in DMA between 2005 and 2010

Year	*Buriganga at Sadarghat*				*Balu at Bengali Indico*			
	Dry season		*Wet season*		*Dry season*		*Wet season*	
	DO	*BOD*	*DO*	*BOD*	*DO*	*BOD*	*DO*	*BOD*
2005	2	14	6.8	3.3	3	16.5	4.8	2.2
2006	2	12.8	5	2.4	1	14	4.9	1.6
2007	0	33	2.2	16.4	0	26	6.4	3
2008	0	20	6	2.9	0	24	4	18
2009	0.	26	6.	2.9	0	34	5.9	16
2010	0	26	5	2.6	0	38	5.1	2.4

Note: DO and BOD unit is in µg/l.

Source: Department of Environment (2010)

Table 3 Water quality characteristics of four major rivers in DMA between 2005 and 2010 (continued)

Year	*Lakhya at ACI*				*Dry season*			
	Dry season		*Wet season*		*Dry season*		*Wet season*	
	DO	*BOD*	*DO*	*BOD*	*DO*	*BOD*	*DO*	*BOD*
2005	5.4	2.6	6.8	3.2	-	-	-	-
2006	4.7	2.8	5.	2.8	6.2	3	6.2	3
2007	4.8	10	6.6	3.2	2.6	12	2.6	12
2008	1.4	14	5	3	0	26	0	26
2009	1.8	22	5.2	3.2	0	34	0	34
2010	2	18	6	3	0	32	0	32

Note: DO and BOD unit is in µg/l.

Source: Department of Environment (2010)

Table 4 Pollution loads of selected industries

Name of the industry		*pH*	*DO (µg/l)*	*BOD (µg/l)*	*COD (µg/l)*	*TDS (µg/l)*
1	Santa Washing Ltd.	7.91	1.2	160	260	2,210
2	Inter Staff Apparels Ltd.	7.99	1.2	210	630	3,320
3	Nasha Tipey Textile Mills	7.45	0.1	2006	475	1,245
4	Anower Knit Composite	10.2	4.0	76	-	5,700
5	Karna Para Thread Industries	6.84	4.6	44	93	-
6	Shasa Denims Ltd.	11.81	0.0	282	825	8,160
7	MBM Garments Ltd.	7.22	1.0	430	1,152	1,250
8	Baily Yearn Dying	6.09	7.2	184	294	3,610
9	Hatim Industries Ltd. Tongi	6.1	3.7	190	640	2,440
10	Popular Pharmaceuticals	7.75	1.1	52	113	930
11	Aboni Textiles Ltd.	7.3	3.8	540	1142	2,573
12	Land Mark Group, Ashulia	6.49	5.2	70	182	1,820
Bangladesh standard		6.0–9.0	4.5–8.0	150.0	200.0	2,100.0

Source: Department of Environment (2008)

Groundwater provides 95% of the water supply in Dhaka (Morris et al., 2003). Increasing water abstraction has been severely affecting the availability of groundwater, particularly in the dry season. The groundwater table in Dhaka is declining between 0.75 and 1.5 m/year due to over abstraction (Morris et al., 2003). In addition, aquifer contamination is already evident in the city where the Buriganga River allows direct recharge to the aquifer (Ahmed et al., 2005). Apart from quantity, the quality of drinking water is also questionable. For example, the zinc concentration in the piped water supply in Dhaka is much higher (54–3,800 ppb) than the admissible limit (50 ppb), which can strongly affect human growth and may decrease the liver catalase (Maroof et al., 1986). Groundwater quality can be even further deteriorated when industrial wastes infiltrate the soil. In the southern part of the city, where leather industries discharge untreated effluents to open waters, aquifer recharge from rivers may result in severe contamination. For example, the Cr concentration (4,120–26,100 mg/kg) in the topsoil (at a depth of 1.5 m) of the same area is found to be significantly higher than a typical concentration of 53 mg/kg (Zahid et al., 2006).

Table 5 Estimated solid waste generation in DMA

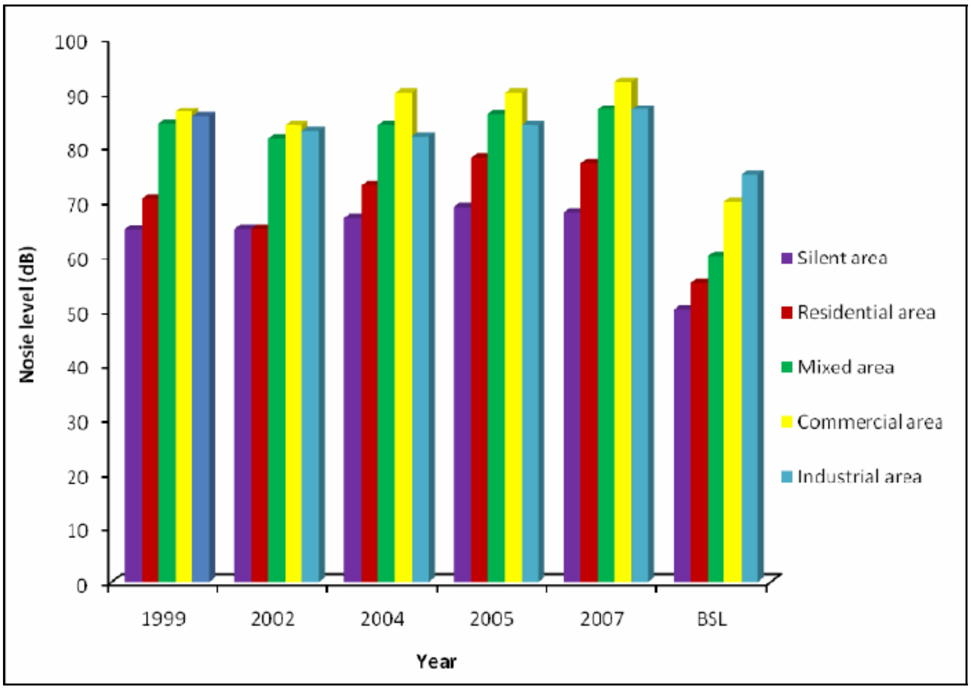
Data source	*Assumed collection by DCC (%)*	*Solid waste generation (ton/day)*	*Quantity disposed at dump sites (ton/day)*
BKH (1985–1986)	50	1,040	520
DCC (1985)	50	1,776	888
LBI (1990)	50	2,500	1,250
Bhide (1990)	50	2,210	1,105
MMI (1991)	45	1,300	683
PCI (1991)	50	1540	770
PAS (1997)	50	3,000–5,000	-
RSWC (1998)	75–80	1,200–1,600	600–800
BCAS (1998)	50	2,398	1,199
Bhuiyan (1999)	50	3,500	1,800
JICA (2005)	52	3,200	-

Source: BUET (2000)

3.5 Noise pollution

In recent years, the noise pollution of the city has been seen as a matter of concern, posing a considerable threat to public health (Dey et al., 2002). Noise measurement at thirty-seven roadside points in DMA revealed that the average level (e.g., 79.4dB for the residential area at Mirpur) of noise excelled the allowable limit (e.g., Bangladesh standard for residential area is 55dB and 45dB during day and night-time, respectively) by 20% at all locations. For example, the noise level measured according to different land uses in DMA indicated that all the land use categories exceed the allowable limits (Figure 7). At sensitive locations, such as near hospitals, schools, and parks, the figure was much higher (Alam et al., 2000). Similar to residential land use, sensitive land use zones (such as with hospitals) also represent elevated noise levels (65 dB in 1999 and 68 dB in 2007) as opposed to the Bangladesh Standard (50 dB). Similar to DMA, noise pollution is found to be 5–10 dB higher at sensitive locations in Visakhapatnam City, India, than the allowable limit (Sagar and Rao, 2006). Figure 7 again confirms that the highest noise level measured in the commercial land use zone (92 dB in 2007 compared to its allowable limit of 70 dB). Because of improper maintenance, the frequent use of horns, and the use of high-pitched horns, motor vehicles are found to be the major cause of noise pollution (Field Study, 2009). The use of microphones at public meetings also causes significant noise pollution. In addition, *Waz* (sermons) and *kawali* (devotional songs), common during the winter months, go on throughout the night and further contribute to the serious level of noise pollution in DMA (Hasan and Mulamottil, 1994).

Figure 7 Trend of noise pollution in DMA according to land use (see online version for colours)



Note: BSL denotes Bangladesh standard.

3.6 Solid waste management

Three primary sources of municipal solid waste (MSW) in DMA are residential, commercial, and street sweeping. Solid waste discharge, which amounted to 1,040 tons/day in 1985, rose to 3,200 tons/day in 2004 (JICA, 2005), demonstrates a 300% growth since 1985. High moisture content and low calorific value characterise the solid waste properties of DMA. One study shows that the percentage of the organic portion is decreasing in domestic waste, whereas the percentage for paper and plastic waste is increasing (Yousuf and Rahman, 2007). However, the same study reported no proportional change in business and commercial wastes. Although medical waste contributes a small portion (one percent) of the total solid waste, its management remains somewhat unexplored (Hasan et al., 2006). Estimates are that approximately 10% to 25% of medical wastes are hazardous, and hence present a potential threat to public health (Ahmed, 2000).

Similar to Bangkok, the capital city of Thailand (Chiemchairsi et al., 2007), the waste disposal method practiced in DMA is open dumping, which takes place in the low-lying areas both within and on the outskirts of the city, causing land, and water pollution within DMA (Field Study, 2009; UNEP, 2006). Sanitary landfill or incineration is not yet available, but some small scale composting and recycling have been initiated in recent years. Paper and plastic recycling have contributed to a significant reduction of waste in the city. Although organic waste constitutes a major part of the total waste, composting has not yet become a popular option (Sufian and Bala, 2007). As a large proportion of those domestic wastes remain uncollected and become part of the surface runoff, both surface and groundwater become contaminated, posing an unknown but potentially hazardous problem. Further growth of DMA in the coming years is likely to increase the generation of hazardous, toxic, and medical wastes, which may have considerable implications to public health.

3.7 The growth of slums and squatters

The relationship between poverty and environmental degradation can be best illustrated in DMA, where the growth of slums and squatters is distinctive and pervasive (Table 6). Given that it is the capital city, it provides better job opportunities, wages, infrastructure, and other public services, which encourages people to migrate. Since the growth of DMA is not commensurate with its economic development, the large influx from rural-urban migration, particularly by marginalised rural people (e.g., landless rural people), has caused a rapid increase in the number of slum dwellers. Table 6 shows that the slum population in DMA has more than doubled within the last decade, reaching 3.4 million in 2005. The number of slum clusters (nearly 5,000 at present) increased about 70% during the same period [Centre for Urban Studies, National Institute of Population, Research and Training (NIPORT) and Measure Evaluation, 2006]. This tremendous growth might be attributed to the blooming of ready-made garment industries in the area since the 1980s (Islam, 1996). The contribution of these people to the growth of Dhaka's economy is significant since they provide cheap labour to the manufacturing, service, and other sectors as well (World Bank, 2007). However, the slums, where most of these people live, are under-serviced or with no service at all, and therefore the living conditions are extremely poor (Chowdhury and Amin, 2006; Mahmud, 2003). Ninety percent of the members of the slum population are extremely poor with an average income of Tk 3,000/month/household ($1 US = 76 Taka), which is significantly below the national poverty line. Currently, the density of the slum population is 891/acre [Centre for Urban Studies, National Institute of Population, Research and Training (NIPORT) and Measure Evaluation, 2006], which exerts tremendous pressure on the existing resources, particularly on water and energy, with important implications for urban governance (Siddiqui et al., 2000). A similar fact is observed in other parts of the world such as Hyderabad, in India, where a typical 6.4 km^2 can host 140,000 slum dwellers (Kit et al., 2012).

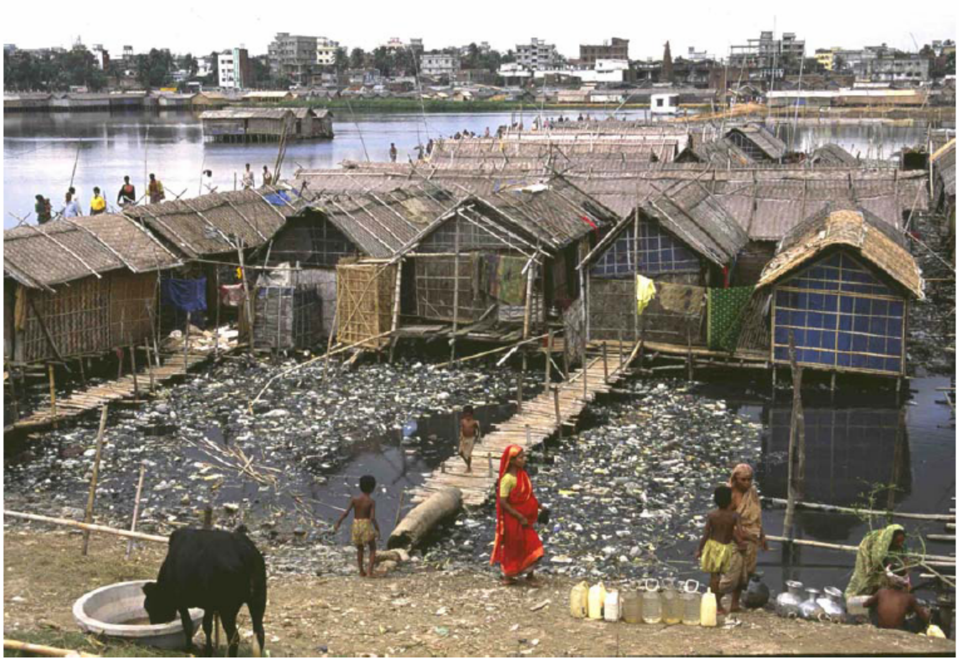
Table 6 Slum clusters and slum population in DMA from 1974 to 2005

	Year			
	1974	*1991*	*1996*	*2005*
No. of slum clusters	500	2156	3007	4966
Total slum population (m)	0.27	0.7	1.5	3.4
Proportion of total population (%)	10	20	22	37.4

Source: Centre for Urban Studies, National Institute of Population, Research and Training (NIPORT) and Measure Evaluation (2006), Islam (1991, 1996, 2005) and Islam and Mahbub (1988)

The physical environments of the slum settlements are tremendously unhygienic (Figure 8) since they are often located in both unconventional and undesirable places – such as near solid waste dumps, open drains and sewers, on low lands, on embankments, and along railway tracts (UN-Habitat, 2003). As a result, the people living in slums are extremely vulnerable to natural calamities, such as flooding (Rashid et al., 2007; Rashid, 2000). Additionally, they suffer from an acute shortage of potable water (Akbar et al., 2007), and it is estimated that over 70% of slum dwellers do not have access to safe sanitation [Centre for Urban Studies, National Institute of Population, Research and Training (NIPORT) and Measure Evaluation, 2006]. As most of the slum dwellers heavily rely on burning biomass for cooking, environmental pollution in the slum areas is also widespread (Field Study, 2009). Solid wastes produced by these slum and squatter dwellers remain mostly uncollected by the authority (e.g., Dhaka City Corporation, DCC). Ultimately, these wastes are disposed into low-lying areas, such as water bodies, or on the streets, canals, and open spaces, causing a number of environmental problems, such as blockage of the drainage system.

Figure 8 Living conditions of a slum in DMA (see online version for colours)



Source: Field Study (2009)

4 Discussions

In response to rapid population growth, mainly triggered by rural to urban migration, the land use/cover of DMA has undergone dramatic changes since the 1960s. A significant increase in built-up and other impervious surfaces resulted in the reduction of expensive natural lands including wetlands, vegetation, and agricultural lands. It is interesting to note that the pace of urbanisation in DMA is almost double compared to the rate of urban growth in India, Nepal, and Pakistan (World Bank, 2006). With the increasing population, the development of high quality agricultural areas may have considerable impacts on future agricultural production. Since DMA's recent urban expansion is taking place mostly on low-lying lands, the vulnerability to natural hazards is also exacerbated. As these areas formerly served as reservoirs and/or retention ponds, the conversion of low-lying lands and wetlands to the built-up category apparently has a detrimental impact on both the surface and groundwater of the city, particularly on flooding (Dewan et al., 2004, 2006; Hasan and Mulamoottil, 1994). Earthquake related risks have also been amplified because of DMA's location, its socio-economic condition, and the construction of buildings on alluvial plains with poor building materials. A study by Davidson et al. (1998) suggests that Dhaka and Tehran both have a heightened earthquake disaster risk. While Tehran's vulnerability is primarily attributed to its large exposure, a number of factors, including high population density, rapid development, low income, and limited recovery and response capabilities, all influence Dhaka's vulnerability.

The quality of air, noise, and water are all found to be severely degraded in the study area. As far as air pollution is concerned, air quality parameters such as PM_{10} SPM, lead concentration in the air, have already crossed the standard levels and thus pose serious health hazards. For instance, the lead concentration in the air is the highest in the world compared to other cities such as Mexico City (Mahadi, 2010). A similar statistic holds true for PM concentration (Begum et al., 2010). The relationship between air pollution and human health clearly shows a lower probability of survival rate for certain age groups in the most polluted communities in comparison to the cleaner ones. Pope et al. (1995) estimated that at least 3% of all deaths in the USA are caused by air pollution. The situation is also critical for Bangladesh, particularly in DMA. The World Bank estimated that public exposure to air pollution in DMA causes nearly 15,000 premature deaths and 6.5 million cases of illness per year (Hossen, 2002). Khatun (1997) estimated that premature deaths and morbidity costs range from 1.6% to 4.5% of GDP. Using the dose-response method, Brandon (1997) pointed out that maintaining Bangladesh's air quality standards could save many lives.

Apart from air pollution, contamination of both surface and groundwater of Dhaka appears to be seriously deteriorated due to a number of reasons including industrial effluents and unplanned urbanisation; it is also responsible for the generation of water related diseases in the study area. The water quality is further aggravated by flooding since tube wells are contaminated with organisms during monsoonal inundation (Luby et al., 2006). Hence, water-related diseases have become widespread both during and after monsoon. In addition to human health, surface water contamination is also tremendously impacting the aquatic diversity of floral and faunal species. Due to the increasing concentration of chromium, lead, and zinc in the peripheral rivers, eutrophication has been a common phenomenon, threatening the ecological processes of rivers (Kamal et al., 1999). Groundwater quality and quantity are also likely to be dilapidated in the coming years in response to over abstraction. Consistent with air and water pollution, the noise quality of DMA remains another potential threat to public health as the pollution level continues to get worse with time. Although regulations have been devised to control environmental pollution, most of them are merely on paper (Personal communication, 2009). Hence, strict enforcement of the laws is required to achieve a sound urban environment.

Although the influx from rural-urban migration, coupled with the natural population growth in DMA, has tremendously accelerated the amount of solid waste generation, its management is very poor and unhygienic. The fact that the concerned authority (e.g., DCC) does not have adequate resources with which to deal with its increase further aggravates the management of solid waste. Since most of the households in the city dispose of their wastes in roadside containers, this type of practice causes environmental problems such as water and soil pollution, foul odours, flies, etc. While the generation of solid waste in DMA is obviously increasing with time, an opportunity exists to exploit its usage for the generation of electricity and other forms of energy. Alam and Bole (2001) suggest that Dhaka could produce 71-MW of electricity from municipal waste, but except for producing composts from the wastes, no significant attempt has ever been made in this regard.

Since one-sixth of the global population is currently living in shantytowns, these are the places where social problems such as crime, alcoholism, and drug smuggling are very common (Whitehouse, 2005), creating 'unrest' condition in developing countries. In the future, rapid unplanned urbanisation, coupled with growing poverty and income inequality, will undoubtedly initiate more slums and squatter settlements. This will not only put a heavy burden on the environment of the city, but it will also potentially expose even more people to unhealthy and degraded environmental conditions.

5 Conclusions and recommendations

This paper was an attempt to highlight the impacts of urbanisation on the environment through a comprehensive review of the published literature, secondary data, field visits, and the authors' long-term research experience in the area. The DMA is used as a case study. The analyses reveal that increasing population, triggered by rural-urban migration, is imposing enormous pressure on the meagre resource bases (especially on the existing land resources) of the city. Both the sustainable development of the city and the natural environment are in jeopardy by the combined rapid urban growth and economic development. While drawing examples from other developing countries, the results presented here appear extremely distressing; nonetheless, it is envisaged that the situation is likely to dwindle gradually with increasing per capita resource consumption.

In order to ease the negative impacts of urbanisation, to improve the quality of life, and attain urban sustainability, a holistic approach should be considered for the management of the urban area and its environment. Considering the existing state of DMA's environment and anticipated circumstances, some recommendations are put forward for the mitigation and management of urban growth and the associated environmental impacts:

a Rapid urbanisation driven by population growth and economic development are the primary causes of environmental degradation in DMA. The current practice of urban expansion seems to be unrealistic and destructive for the environment. Therefore, it is imperative to develop a few satellite towns as growth poles away from DMA with infrastructure and services to the present one, so that they would be able to attract rural people to work and live there. This could lessen the increasing pressure on DMA. Furthermore, urban expansion should be restrained on wetlands, vegetation cover, expensive floodplains, and/or on cultivated lands. This could save productive fertile soils from urbanisation, and eventually contribute to the constitution of essential ecological processes.

b Urban growth should be delimited only toward elevated areas, i.e., to further north, northwest, and north-east, which could ensure minimum flood damage during monsoon. Although this will save low-lying lands, it is also important to save biodiversity and conserve natural resources. Since Dhaka is in a high earthquake risk zone, land use restrictions should be enforced. A detailed and up-to-date seismic risk evaluation for the area should be undertaken.

c In order to keep air pollution at the lowest level possible, vehicular emissions should be controlled by eliminating old vehicles from the street. Catalyst converters and other emission-control devices should be required. Leaded gasoline from the city needs to be gradually phased out and unleaded fuel should be simultaneously encouraged.

d It is found that most of the industries located around the study area are not equipped with effluent treatment systems. Depending on industry type, treatment facilities should be required. To curb unplanned and illegal establishment of industry near riverbanks, industrial townships should be constructed. Wherever possible, granting concessions and imposing restrictions should be developed. In addition, a 'polluter pays' principle, green tax can be introduced to save human health and aquatic diversity in the study area.

e To keep the city noise pollution free, tree plantations on road sides have to be encouraged since trees can absorb a good deal of sound. Noise generated from the hydraulic horns of the vehicles has to be strictly controlled. Furthermore, environmental awareness among the inhabitants could be of immense help in minimising noise pollution in DMA.

f A number of environmental laws and regulations are available to save DMA's environment; however, very little is being done to implement these policies. Strict implementation of environmental and traffic laws could significantly offset the problem associated with rapid urban development. Strengthening the Department of Environment (DOE) and related organisations are believed to play an important role in this respect.

g Solid waste management systems need to be improved by bringing slums and squatters under the service. It has been noticed that the community-based solid water management system has become a very effective tool, which needs to be supported for better management of solid waste. A sanitary landfill should be introduced and the capacity of the relevant authorities should be simultaneously increased.

h Effective coordination among development organisations must be ensured. At least thirteen organisations are involved in the planning and management of DMA. The lack of coordination among them is a tremendous hurdle to ensuring a sustainable urban environment. Therefore, a good governance approach among service providers and development authorities is strongly suggested to achieve sustainability.

i Awareness must be raised by providing education and training to the people. As noticed in DMA, many civic organisations (e.g., Bangladesh Environmental Movement, Green Bangladesh) are presently working for a sustainable environment. This civic organisation should be supported and all types of logistics should be provided so that mass awareness can be developed in mitigating and controlling the adverse effects of urbanisation.

j The shortage of timely, consistent, and publicly available data is a significant DMA problem. A number of new systems must be introduced, including those for access to data and information, environmental monitoring, measuring the infrastructure, conducting natural resource inventories based on geographic information systems, remote sensing, and relational database technology. There is also a need for a full environmental pollution research laboratory, to include up-to-date equipment and instrumentation.

k Regional and local land use policy needs to be revised, and an integrated multidisciplinary research team from all required disciplines should be initiated so that sustainable urban environmental strategies can be formulated.

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Notes

1 A megacity is generally regarded as a metropolitan area with at least ten million inhabitants.

2 The landfill category is defined as exposed soils, landfill sites, and areas of active excavation.