



## Relations of Water-logging with Heavy Rainfall in Dhaka City (1991-2021)

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**Abstract:** The dwellers in Dhaka city have to face water-logging incidents almost every rainy season. Water-loggings have relations with various factors but heavy rainfall for climate change effects has become a major factor. This paper aims to find out the relations of water-loggings with the heavy rainfall in Dhaka city and the spatio-temporal distribution of water-logging incidents for heavy rainfall in the city. The data of water-logging incidents and the amount of rainfall caused the incidents since 1991 to 2021 were collected from at least two national daily newspapers of each day as well as daily total rainfall data (January 1991 to June 2021) and the three-hourly rainfall data (January 2003 to December 2021) were collected from Bangladesh Meteorological Department. The collected data were scrutinized and gathered as tables first and then analyzed by Microsoft Excel to represent in the paper. It is found that yearly water-logging incidents had predominance of positive correlations with annual rainfall most of the years since 1991 to 2021. It is also found that 46.67 percent water-logging incidents occurred for heavy rainfall. All of the severe and most of the major water-logging incidents occurred for heavy rainfall with previous consecutive rainfall day/days. The severity of water-logging is related with the intensity and duration of rainfall on the water-logging day and the amount of rainfall on the previous consecutive rainfall day/days. Although the water-logging incidents are distributed in many areas of the city, some areas have found highly water-logging prone than other areas. It is necessary to adapt the drainage system and the management with the heavy rainfall pattern and the distribution of water-logging incidents to reduce the effect.

**Key Words:** Water-logging, distribution, heavy rainfall, consecutive, climate change, Dhaka city.

### I. INTRODUCTION:

Water-logging has become one of the major problems in Dhaka city. The dwellers in this city have to pass some woeful days for water-logging incidents almost in every rainy season. Water-logging creates various effects on people such as difficulty to movement, traffic jams, flooding of dwelling houses and shops, hampered of economic activities, casualties, spread of diseases etc. Dhaka as the capital and prime city of Bangladesh have to perform many important dealings every day. If the water-logging hamper the activities of the city, have to face huge economic and other losses. Urban poor, who live mostly in informal housing and hazard prone areas, are affected most severely for water-logging. It is found that per house owner has to bear 14,100 Taka cost for damage of housing and per household has to bear 5,977.61 Taka cost for damaged household goods and materials by a highly impacted water-logging hazard at urban poor community in Dhaka city (Islam, 2021: e112-e113). Water-logging problem in a city is related with various reasons but all of them are not responsible equally. Subrina and Chowdhury (2018: 803-804) has identified some causes of pluvial flooding or water-logging in Dhaka city those are population growth, unplanned development and encroachment of land, disappearance of natural drainage system, shortage of drainage capacity and waste management system, disappearance of soak able green areas and topography. Heavy rainfall<sup>1</sup> due to the effects of global warming and climate change has become a major factor of water-logging with all of these reasons. Several studies have found that seasonal rainfall has become erratic and the extreme events or intensive rainfalls are increasing in Dhaka city (Alam, M. and Rabbani, 2007: 87; Murshed, Islam and Khan, 2011; Islam, Murshed, Khan and Hasan, 2014; and Khatun, Rashid, Mostafa and Mandal, 2018:35). It is necessary to know how the rainfall pattern is related with the water-logging problem in Dhaka city, which can be helpful to take necessary steps.

### II. OBJECTIVES OF THE STUDY:

The main purpose of this study is to find out the relations of water-logging with heavy rainfall in Dhaka city due to the climate change effects. The specific objectives of the study are as follows:

- To know the relations of water-logging with heavy rainfall in Dhaka city analysing the water-logging incidents and the pattern of rainfall since 1991 to 2021; and
- To identify the spatio-temporal distribution of water-logging incidents for the heavy rainfall in Dhaka city according to newspaper reports since 1991 to 2021.

<sup>1</sup> Heavy rainfall is the rate of precipitation >7.60 mm (0.30 in) per hour or between 10 mm (0.39 in) and 50 mm (2.0 in) per hour (Wikipedia, 2021)

### III. STUDY AREA:

Dhaka Metropolitan Area (DMA) is the study area of this study, which is known as Dhaka City. The city is divided into two city corporations those are Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC). Dhaka city is situated between 23°42' and 23°54' north latitudes and 90°20' and 90°28' east longitudes. As placed in the center of Bangladesh, it has a subtropical monsoon climate. There are four distinct seasons as like as the whole country from the climatic view: winter (December-February), summer or pre-monsoon (March-May), monsoon (June-September) and autumn (October-November). More than 71% of the total annual rainfall occurs in the monsoon (Khatun, Rashid, Mostofa and Mandal, 2018: 32). The average annual rainfall is 1,854 mm (73.0 in) in Dhaka city (Wikipedia, 2022). The city is surrounded by several rivers and many canals, and low-lying areas spread over around it. The elevation of the land in greater Dhaka varies from 2 to 13 meters above mean sea level (Nishat, Reazuddin, Amin, and Khan, 2000: 5). Housings and other development works have expanded to many low-lying areas with land filling due to the scarcity of high-level land for the increased population. The total population of Dhaka Metropolitan city is 8,906,039 in 315.98 sq. km area with a density of 28,185 persons per sq. km (BBS, 2014: 58). According to Dhaka Water Supply and Sewerage Authority (DWASA), there are about 380 km. of storm sewer lines and 8.75 km of box culverts making up the stormwater system of Dhaka as well as there is 882 km of sewerage lines in Dhaka (DWASA, 2016: 29-34). In addition, there are approximately 45 natural khals (canals), totaling about 142 km that are part of the drainage system. The DWASA has handed over the storm sewer lines, canals and the box culverts to DNCC and DSCC on 31 December 2020. The two city corporations also manage 2,200 km of pipe and surface drains from the previous (Alam, H. 2021b: 3).

### IV. DATA AND METHODOLOGY:

Data were collected from the secondary sources. Mainly two sources of the Data were used in this study those are the daily national newspapers and the Bangladesh Meteorological Department (BMD). At least two national daily newspapers of May to October since 1991 to 2021 had seen to collect the water-logging incidents, the amount of rainfall caused those incidents and the affected areas in Dhaka City. The Daily Ittefaq was seen for the complete duration (1991-2021). Some other newspapers were seen as the complement with it, which were: Daily Bangla (1991-September 1997); Daily Sangbad of 1997; Daily Inqilab of 1998; and Daily Prothom Alo (November 1998-2021). The newspapers were seen at the National Library of Bangladesh, National Archives of Bangladesh and web pages of the respective newspapers for the recent years. The daily total rainfall data of Dhaka station since January 1991 to June 2021 were collected from BMD. Three-hourly rainfall data available from January 2003 to December 2021 were also collected from the BMD. The collected data were compiled in tables for analysis after the scrutinizing. Microsoft Excel had used for the analysis and representation of data as the table and graph.

### V. LIMITATIONS:

The amount of daily rainfall mentioned in newspaper reports are one day earlier than the daily rainfall record of BMD in many cases. The spatio-temporal distributions of water-logging incidents according to newspaper reports do not represent the place name of all affected areas for particular water-logging incidents.

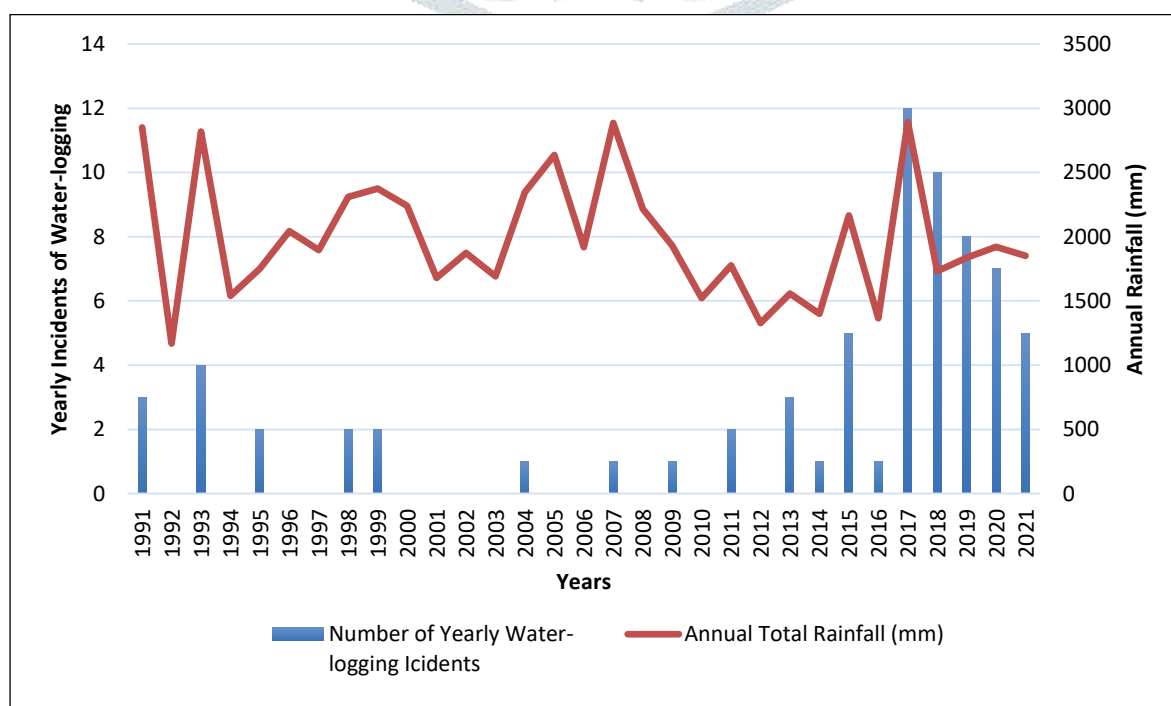
### VI. FINDINGS OF THE STUDY:

Findings of the study have given below.

#### 6.1 Relations of Water-logging Incidents with Heavy Rainfall:

##### 6.1.1 Relations of Yearly Water-logging Incidents and Annual Rainfall:

Figure-1 shows a total of 70 incidents of water-logging which occurred in different years and the annual rainfall of every year since 1991 to 2021. According to the figure, three incidents of water-logging occurred in 1991 when the annual rainfall was 2,850 mm. The annual rainfall decreased drastically to the lowest 1,169 mm in 1992 and no water-logging incident occurred on that year but the annual rainfall increased sharply to 2,819 mm in 1993 and the incidents of water-logging raised to four.



Source: Daily Ittefaq (1991-2021), Daily Bangla (1991-September 1997), Daily Sangbad of 1997, Daily Inqilab of 1998, Daily Prothom Alo (November 1998-2021); and Bangladesh Meteorological Department

### Figure-1: Relations of Yearly Water-logging Incidents and Annual Rainfall in Dhaka City (1991-2021)

Again, the annual rainfall decreased to 1,540 mm in 1994 and increased to 2,374 mm in 1999 with some up and down (Figure-1). In this time, the incidents of water-logging were two in each of 1995, 1998 and 1999. Then, the annual rainfall decreased from 2,241 mm in 2000 to 1,693 mm in 2003 but no water-logging incident occurred. The annual rainfall increased again from 2,347 mm in 2004 to 2,885 mm in 2007 with some up and down but the incidents of water-logging happened one in 2004 and another one in 2007. The rainfall decreased from 2,217 mm in 2008 to 1,329 mm in 2012 with some up and down and the incidents of water-logging occurred only one in 2009 and two in 2011. Again, the rainfall decreased from 1,556 mm in 2013 to 1,365 mm in 2016 with some up and down, simultaneously the water-logging incidents also raised and felled with a correlation with the annual rainfall, which were three in 2013, one in 2014, five in 2015 and one in 2016. The highest amount of rainfall since 1991 to 2021 occurred in 2017 that was 2,892 mm when the highest 12 incidents of water-logging also occurred. Then, the rainfall decreased with some up and down to 1,852 mm in 2021 but the incidents of water-logging decreased steadily from 10 in 2018 to 5 in 2021. In the last nine years (2013-2021), the incidents of water-logging were higher than any other period of the total 31 years since 1991 to 2021.

The Figure-1 illustrates that the yearly incidents of water-logging and annual rainfall in Dhaka city had predominance of positive correlations since 1991 to 1999 and 2013 to 2021 but the predominance of negative correlation had since 2000 to 2012.

#### 6.1.2 Relations of Water-logging with Amount of Heavy Rainfalls and the Durations:

Table-1 depicts the sixty incidents of water-logging and the amount of rainfalls with the durations related with the incidents since 1991 to 2021 in Dhaka city. Among them, 46.67 percent incidents of water-logging (28 incidents) occurred for heavy rainfall. The remaining 53.33 percent incidents of water-logging (32 incidents) occurred for light to moderate rainfall<sup>2</sup>. It is found that long duration<sup>3</sup> heavy rainfall caused four water-logging incidents in which two were severe incidents. The highest 341 mm of heavy rainfall in 24 hours caused the most severe water-logging incident on 13 September 2004 when the per hour rainfall was 14.21 mm. Then, the second highest 333 mm of heavy rainfall in 9 hours caused another severe water-logging incident on 28 July 2009 when the per hour rainfall was 37 mm. Two more incidents of water-logging have found for long-duration heavy rainfall i.e. 121 mm heavy rainfall in 12 hours (10.08 mm rainfall per hour) caused a major water-logging incident on 17 August 1998 which worsened the flood situation on that time and 96 mm heavy rainfall on 11 July 1999 in 12 hours (8 mm rainfall per hour) created a medium water-logging incident.

According to the Table-1, medium duration heavy rainfall (>3 hour to <6 hours) caused ten minor to major water-logging incidents but seven of them were medium incident i.e. a minor water-logging incident on 9 Sept. 1991 for 97 mm heavy rainfall in 6 hours (16.17 mm rainfall per hour); a major water-logging on 15 Sept. 1991 for 120 mm heavy rainfall in 6 hours (20 mm rainfall per hour); a medium water-logging on 13 Aug. 1998 for 71 mm heavy rainfall in 6 hours (11.83 mm rainfall per hour); a medium water-logging on 24 Aug. 2007 for 118 mm heavy rainfall in 6 hours (19.67 mm rainfall per hour); a medium water-logging on 26 July 2017 for 56 mm heavy rainfall in 6 hours (9.33 mm rainfall per hour); a medium water-logging on 11 Sept. 2017 for 78 mm heavy rainfall in 6 hours (13 mm rainfall per hour); a medium water-logging on 23 May 2018 for 52 mm heavy rainfall in 6 hours (8.67 mm rainfall per hour); a medium water-logging incident on 23 June 2018 for 54 mm heavy rainfall in 6 hours (9 mm rainfall per hour); a medium water-logging on 8 Aug. 2019 for 49 mm heavy rainfall in 6 hours (8.17 mm rainfall per hour) and a major water-logging on 1 Oct. 2019 for 47 mm heavy rainfall in 6 hours (7.83 mm rainfall per hour).

On the other hand, fourteen short durations heavy rainfall caused water-logging incidents. Six of them were major incidents, four medium incidents and another four minor incidents such as maximum 50 mm of heavy rainfall in one hour only caused a medium water-logging on 29 April 2018; 41 mm heavy rainfall per hour in 3 hours caused a major water-logging on 3 August 2017; 39.23 mm heavy rainfall per hour in 1.3 hour caused a minor water-logging on 12 June 2018; 28.33 mm heavy rainfall per hour in three hour caused a major water-logging on 1 June 2021; 28 mm heavy rainfall per hour in two hours caused a major water-logging on 23 May 2013; 28 mm heavy rainfall per hour in 1.5 hour caused a major water-logging on 1 Sept. 2015; 23 mm heavy rainfall in one hour caused a minor water-logging incident on 14 October 2020; and 22.79 mm heavy rainfall per hour in 2.15 hour caused a major water-logging incident on 12 July 2019 (Table-1).

In contrast, eight water-logging incidents occurred for short to medium duration light and moderate rainfall among the 32 water-logging incidents for light to moderate rainfall. Five incidents of the eight water-logging incidents for short to medium duration light and moderate rainfall were minor incidents i.e. the lowest 10 mm of rainfall in three hours (3.33 mm rainfall per hour) caused a minor water-logging incident on 23 July 2016; 17 mm rainfall in 3.30 hours (5.15 mm rainfall per hour) caused a medium water-logging on 29 Sept. 2019; 18 mm rainfall in 6 hours (3 mm rainfall per hour) caused a minor water-logging on 25 May 2018; 30 mm rainfall in 6 hours (5 mm rainfall per hour) caused a medium water-logging on 25 June 2018; 33 mm rainfall in 6 hours (5.50 mm rainfall per hour) caused a minor water-logging on 5 April 2017; 34 mm rainfall in 6 hours (5.67 mm rainfall per hour) caused a minor incident on 19 June 2020; 38 mm rainfall in 6 hours (6.33 mm rainfall per hour) caused a minor water-logging on 8 Jul. 2019 and 45 mm rainfall in 6 hours (7.50 mm rainfall per hour) caused a medium water-logging on 16 May 2013 (Table-1). On the other hand, long duration light to moderate rainfall caused 24 minor to major water-logging incidents in which thirteen were medium incidents such as 233 mm of rainfall in 36 hours (6.47 mm rainfall per hour) caused a major water-logging incident on 20 and 21 October 2017; 133 mm rainfall in 24 hours (5.54 mm rainfall per hour) caused a medium water-logging on 12 June 2017; 111 mm rainfall in 24 hours (4.63 mm rainfall per hour) caused a medium water-logging on 5 June 2021; 108 mm rainfall in 24 hours (4.50 mm rainfall per hour) caused a medium water-logging on 29 Sep. 2017; and 88 mm rainfall in 21 hours (4.19 mm rainfall per hour) caused a major water-logging on 20 and 21 Aug. 2015.

<sup>2</sup> Light rainfall is <2.5 mm (0.098 in) rainfall per hour and moderate rainfall is between 2.5 mm (0.098 in) to 7.6 mm (0.30 in) or 10 mm (0.39 in) rainfall per hour (Wikipedia, 2021).

<sup>3</sup> Rainfall events can be generally divided into long-duration (more than 6 hours) and short-duration (1-3 hours) events (Kang, Peng, Wang, Dong, Shang, & Zhao, 2020).

The mean total rainfall of the sixty incidents is 70.69 mm, mean duration of rainfall is 10.85 hours and mean per hour rainfall is 11.47 mm (Table-1). The standard deviation of the total rainfall is 63.69 mm, standard deviation of rainfall duration is 8.59 hours and standard deviation of per hour rainfall is 11.15 mm.

**Table-1: Amount of Rainfalls and their Durations Caused the Water-logging Incidents (1991-2021)**

Date of Water-logging Incidents*	Total Amount of Rainfall (mm)	Duration of Rainfall (Hour)	Per Hour Rainfall (mm)	Types of Incidents	Source of Data
9-Sep-1991	97	6	16.17	Minor	Daily Ittefaq, 1991a: 1.
15-Sep-1991	120	6	20.00	Major	Daily Ittefaq, 1991b: 1.
26-Sep-1991	53	12	4.42	Minor	Daily Bangla, 1991b: 1.
23-Aug-1993	78	12	6.50	Major	Daily Bangla, 1993a: 1; Daily Ittefaq, 1993: 1.
24-Aug-1993	56	12	4.67	Major	Daily Bangla, 1993b: 1.
2-Sep-1993	55	12	4.58	Medium	Daily Bangla, 1993c: 1.
13-Aug-1998	71	6	11.83	Medium	Daily Ittefaq, 1998a: 1.
17-Aug-1998	121	12	10.08	Major	Daily Ittefaq, 1998b: 1.
11-Jul-1999	96	12	8.00	Medium	Daily Ittefaq, 1999: 1.
22-Sep-1999	155	24	6.46	Medium	Daily Prothom Alo, 1999: 1.
13-Sep-2004	341	24	14.21	Severe	Daily Prothom Alo, 2004a: 1
24-Aug-2007	118	6	19.67	Medium	Daily Prothom Alo, 2007: 1.
28-Jul-2009	333	9	37.00	Severe	Daily Prothom Alo, 2009a: 1; Daily Ittefaq, 2009: 1.
9-Aug-2011	56	12	4.67	Medium	Daily Prothom Alo, 2011a: 1-2.
10-Aug-2011	20	12	1.67	Medium	Daily Prothom Alo, 2011b: 1-19.
16-May-2013	45	6	7.50	Medium	Daily Prothom Alo, 2013b: 7.
23-May-2013	56	2	28.00	Major	Mahmud, I. 2013: 1.
9-Jul-2015	40	24	1.67	Medium	Daily Ittefaq, 2015: 20.
10-Jul-2015	38	12	3.17	Medium	Daily Prothom Alo, 2015a: 8.
15-Jul-2015	63	9	7.00	Medium	Daily Prothom Alo, 2015b: 8.
20 & 21 Aug-2015	88	21	4.19	Major	Daily Prothom Alo, 2015c: 8.
1-Sep-2015	42	1.5	28.00	Major	Daily Prothom Alo, 2015d: 1.
22-Jul-2016	26	15	1.73	Minor	Daily Prothom Alo, 2016: 8.
23-Jul-2016	10	3	3.33	Minor	Daily Prothom Alo, 2016: 8.
5-Apr-2017	33	6	5.50	Minor	Daily Prothom Alo, 2017a: 9.
12-Jun-2017	133	24	5.54	Medium	Daily Prothom Alo, 2017b: 1
26-Jul-2017	56	6	9.33	Medium	Daily Prothom Alo, 2017c: 1-8; Daily Samakal, 2017.
2-Aug-2017	23.6	3	7.87	Medium	Daily Ittefaq, 2017: 20.
3-Aug-2017	123	3	41.00	Major	Daily Prothom Alo, 2017d: 1; Sarkar and Kaysar, 2017: 1.
11-Sep-2017	78	6	13.00	Medium	Daily Prothom Alo, 2017e: 1-8.
29-Sep-2017	108	24	4.50	Medium	Daily Prothom Alo, 2017f: 8.
20 & 21 Oct-2017	233	36	6.47	Major	Daily Prothom Alo, 2017g: 1.
29-Apr-2018	50	1	50.00	Medium	Daily Prothom Alo, 2018a: 1-4.
30-Apr-2018	32	12	2.67	Minor	Daily Prothom Alo, 2018b: 7.
13-May-2018	42	24	1.75	Minor	Daily Prothom Alo, 2018c: 6.
23-May-2018	52	6	8.67	Medium	Daily New Age, 2018.
25-May-2018	18	6	3.00	Minor	Daily Prothom Alo, 2018d: 6.
31-May-2018	81	3	27.00	Medium	Daily Prothom Alo, 2018e: 6.
12-Jun-2018	51	1.30	39.23	Minor	Daily Prothom Alo, 2018f: 6.
23-Jun-2018	54	6	9.00	Medium	Daily Prothom Alo, 2018g: 6.
25-Jun-2018	30	6	5.00	Medium	Daily Prothom Alo, 2018h: 6.
23-Jul-2018	35	2	17.50	Minor	Daily Prothom Alo, 2018i: 6.
30-Jun-2019	18	24	0.75	Minor	Daily Prothom Alo, 2019a: 6.
8-Jul-2019	38	6	6.33	Minor	Daily Prothom Alo, 2019b: 6.
12-Jul-2019	49	2.15	22.79	Major	Daily Ittefaq, 2019: 20.
8-Aug-2019	49	6	8.17	Medium	Daily Prothom Alo, 2019c: 7.
29-Sep-2019	17	3.30	5.15	Medium	Daily Prothom Alo, 2019d: 7.
1-Oct-2019	47	6	7.83	Major	Daily Prothom Alo, 2019e: 1.
26-Apr-2020	40	2	20.00	Medium	Daily Prothom Alo, 2020a: 4.
19-Jun-2020	34	6	5.67	Minor	Daily Prothom Alo, 2020b: 16.
20-Jul-2020	63	3	21.00	Major	Daily Prothom Alo, 2020c: 1-4; Mamun, 2020.
21-Jul-2020	64	24	2.67	Major	Hossain and Mostafa, 2020: 1-4.
12-Oct-2020	57	24	2.38	Medium	Daily Prothom Alo, 2020d: 1-2.
14-Oct-2020	23	1	23.00	Minor	Daily Prothom Alo, 2020e: 1-2.
23-Oct-2020	28	24	1.17	Minor	Daily Ittefaq, 2020a: 1-11.
18-May-2021	43	2	21.50	Minor	Daily Prothom Alo, 2021a: 6.
1-Jun-2021	85	3	28.33	Major	Daily Prothom Alo, 2021b: 1; Alam, H. 2021a.
5-Jun-2021	111	24	4.63	Medium	Daily Prothom Alo, 2021c: 1-4.
9-Jun-2021	23	24	0.96	Medium	Daily Prothom Alo, 2021d: 6.
4-Jul-2021	42	12	3.50	Medium	Daily Prothom Alo, 2021e: 6.
<b>Mean</b>	<b>70.69</b>	<b>10.85</b>	<b>11.47</b>		
<b>STDEV</b>	<b>63.69</b>	<b>8.59</b>	<b>11.15</b>		

\*Incidents have found with amount of rainfalls and the duration

Not only the rainfall on the day of water-logging incident is responsible for the water-logging in Dhaka city but also the consecutive day/days of rainfall before the water-logging day have relations with the incidents. The rainfall in previous consecutive day/days increases the wetness of the environment and water deposition in the drainage and low-lying areas. The Table-2 shows that 44 water-logging incidents (73.33%) out of the 60 incidents occurred with the previous consecutive rainfall day/days. The remaining 16 water-logging incidents (26.67%) occurred without previous consecutive rainfall day/days. The previous consecutive rainfall day/days range from one to ten days.

It is found that both of two severe water-logging incidents occurred with large amount of rainfall on the previous consecutive rainfall day/days. The amount of rainfall had occurred 3 mm to 156 mm during the 5 days of consecutive rainfall before the most

severe water-logging incident occurred on 13 September 2004 for 341 mm heavy rainfall in 24 hours; and the amount of rainfall had occurred 89 mm in one day consecutive rainfall before another severe water-logging incident occurred on 28 July 2009 for 333 mm heavy rainfall in 9 hours (see Table-1 and Table-2).

Thirteen major water-logging incidents out of fourteen major incidents occurred with previous consecutive rainfall day/days. Although most of them (nine incidents) occurred for heavy rainfall on water-logging day with previous consecutive rainfall day/days, some of them occurred even for moderate rainfall on the water-logging day with the large amount of rainfall on the previous consecutive rainfall day/days e.g. the amount of rainfall had occurred 10 mm to 87 mm during the four days of consecutive rainfall before a major water-logging incident on 21 July 2020 in which the per hour rainfall was 2.67 mm; and the amount of rainfall had occurred 01 mm to 115 mm during the 8 days of consecutive rainfall before another major water-logging incident on 24 Aug. 1993 in which the per hour rainfall was 4.67 mm (see Table-1 and Table-2).

**Table-2: Consecutive Day/Days and Amount of Rainfall Before the Water-logging Incident Day (1991-2021)**

Pre-Consecutive Day/ Days and Amount of Rainfall (mm)	Date of Water-logging Incidents	Pre-Consecutive Day/ Days and Amount of Rainfall (mm)	Date of Water-logging Incidents
10 Days (6-69)	9-Sep-1991	1 Day (5)	29-Sep-2017
3 Days (5-47)	15-Sep-1991	1 Day (50)	20 & 21 Oct-2017
2 Days (19-33)	26-Sep-1991	Not Consecutive	29-Apr-2018
7 Days (1-35)	23-Aug-1993	1 Day (77)	30-Apr-2018
8 Days (1-115)	24-Aug-1993	Not Consecutive	13-May-2018
6 Days (1-54)	2-Sep-1993	5 Days (12-35)	23-May-2018
3 Days (1-91)	13-Aug-1998	7 Days (1-52)	25-May-2018
1 Day (8)	17-Aug-1998	Not Consecutive	31-May-2018
2 Days (48-69)	11-Jul-1999	Not Consecutive	12-Jun-2018
4 Days (1-41)	22-Sep-1999	Not Consecutive	23-Jun-2018
5 Days (3-156)	13-Sep-2004	Not Consecutive	25-Jun-2018
Not Consecutive	24-Aug-2007	3 Days (3-23)	23-Jul-2018
1 Day (89)	28-Jul-2009	Not Consecutive	30-Jun-2019
6 Days (2-26)	9-Aug-2011	3 Days (1-15)	8-Jul-2019
7 Days (2-79)	10-Aug-2011	2 Days (1-33)	12-Jul-2019
1 Day (3)	16-May-2013	3 Days (1-31)	8-Aug-2019
3 Days (1-30)	23-May-2013	1 Day (10)	29-Sep-2019
2 Days (29-36)	9-Jul-2015	Not Consecutive	1-Oct-2019
3 Days (29-40)	10-Jul-2015	Not Consecutive	26-Apr-2020
1 Day (13)	15-Jul-2015	3 Days (4-24)	19-Jun-2020
4 Days (4-38)	20 & 21 Aug-2015	3 Days (10-20)	20-Jul-2020
5 Days (2-38)	1-Sep-2015	4 Days (10-87)	21-Jul-2020
7 Days (1-22)	22-Jul-2016	Not Consecutive	12-Oct-2020
8 Days (1-35)	23-Jul-2016	Not Consecutive	14-Oct-2020
Not Consecutive	5-Apr-2017	3 Days (9-46)	23-Oct-2020
2 Days (1-30)	12-Jun-2017	Not Consecutive	18-May-2021
10 Days (1-64)	26-Jul-2017	5 Days (1-25)	1-Jun-2021
4 Days (1-17)	2-Aug-2017	Not Consecutive	5-Jun-2021
5 Days (1-24)	3-Aug-2017	1 Day (10)	9-Jun-2021
1 Day (55)	11-Sep-2017	Not Consecutive	4-Jul-2021

Source: Daily Ittefaq (1991-2021), Daily Bangla (1991-September 1997), Daily Sangbad of 1997, Daily Inqilab of 1998, Daily Prothom Alo (November 1998-2021); and Bangladesh Meteorological Department

Among the 28 of medium water-logging incidents, 19 incidents occurred with previous consecutive rainfall day/days. Seven incidents occurred for heavy rainfall and 12 incidents occurred for light to moderate rainfall among the 19 medium water-logging incidents with previous consecutive rainfall day/days. Some medium water-logging incidents occurred even for very light rainfall on water-logging day with previous consecutive rainfall day/days e.g. the amount of rainfall had occurred 10 mm during the one-day consecutive rainfall before a medium water-logging incident on 9 June 2021 in which the per hour rainfall was 0.96 mm only; the amount of rainfall had occurred 2 mm to 79 mm during the 7 days of consecutive rainfall before a medium water-logging incident on 10 Aug. 2011 in which the per hour rainfall was 1.67 mm; and the amount of rainfall had occurred 29 mm to 36 mm during the two days of consecutive rainfall before another medium water-logging incident on 9 July 2015 in which the per hour rainfall was 1.67 mm (see Table-1 and Table-2).

Ten minor water-logging incidents occurred with previous consecutive rainfall day/days out of 16 minor incidents. Among the 10 minor water-logging incidents with previous consecutive rainfall day/days, two incidents occurred for heavy rainfall and eight incidents occurred for light to moderate rainfall. Some minor water-logging incidents occurred even for the small amount of total rainfall and light to moderate per hour rainfall on the water-logging day with previous consecutive rainfall day/days e.g. the amount of rainfall had occurred 01 mm to 35 mm during the 8 days of consecutive rainfall before a minor water-logging incident on 23 July 2016 in which the total rainfall was 10 mm in 3 hours (3.33 mm rainfall per hour); the amount of rainfall had occurred 01 mm to 52 mm during the 7 days of consecutive rainfall before a minor water-logging incident on 25 May 2018 in which the total rainfall was 18 mm in 6 hours (3 mm rainfall per hour); and the amount rainfall had occurred 9 mm to 46 mm during the 3 days of consecutive rainfall before another minor water-logging incident on 23 Oct. 2020 in which the total rainfall was 28 mm in 24 hours (1.17 mm rainfall per hour) (see Table-1 and Table-2).

In contrast, three minor water-logging incidents occurred for small amount of total rainfall and light to moderate per hour rainfall on the water-logging day without the previous consecutive rainfall day/days i.e. a minor water-logging incident occurred for 18 mm rainfall in 24 hours (0.75 mm rainfall per hour) on 30 June 2019 without any previous consecutive rainfall day/days; a minor water-logging incident occurred for 33 mm rainfall in 6 hours (5.50 mm rainfall per hour) on 5 April 2017 without any previous consecutive rainfall day/days; and another minor water-logging incident occurred for 42 mm rainfall in 24 hours (1.75 mm rainfall per hour) on 13 May 2018 without any previous consecutive rainfall day/days (see Table-1 and Table-2).

The above pattern of the rainfall on the water-logging day and the consecutive rainfall day/days before the water-logging day represents that the severity of water-logging incidents is related with the intensity and the duration of rainfall on the water-logging day, and the amount of rainfall on the consecutive rainfall day/days before the water-logging incident day. It should be mentioned here that water-logging incidents are also related with lacking of drainage, their management and other reasons, which are not measured in this study.

### 6.2 Spatio-temporal Distribution of Water-logging Incidents:

Spatio-temporal distribution of two severe and some major water-logging incidents caused by heavy rainfall since 1991 to 2021 as follows:

On 15 Sept. 1991, 120 mm heavy rainfall in 6 hours caused a major water-logging incident at Gopibagh, Doyagonj, Brahmonchiron, Basabo, Shahjahanpur, Khilgaon, Malibagh, Rampura and Goran (Figure-3). Many houses, home stead and roads were water-logged at Rayerbazar, Mohammadpur, Kollyanpur, Agargaon and Adabor Areas on that day. Shantinagar, Nimtoli, Elephant Road, Motijheel C/A, Kamlapur, Inner Circular Road, DIT Extension Road, New Market Area, Jhigatola, Modhubazar at West of Dhanmondi, Rayerbazar Staff Quarter, Sangkor, Lalmatia, Mirpur, Monipur and more areas were also waterlogged by knee to chest deep water (Daily Ittefaq, 1991b:1; and Daily Bangla, 1991a: 1).

Most of the roads and stations of Dhaka city were flooded by knee to waist deep water on 13 Sept. 2004 (Figure-2) due to 341 mm of record heavy rainfall in a day (24 hours) caused from the low-pressure in the Bay of Bengal (Daily Prothom Alo, 2004a: 1). Ground floor of numerous houses, shops and offices were also water-logged. Almost areas of old Dhaka were water-logged by knee deep water (Figure-3). Basabo, Madartek, Sipahibagh, Khilgaon, Manda were affected worse due to be lower than other areas (Daily Prothom Alo, 2004b: 1; and Aldin, 2004: 1). Many areas in Mirpur, Mohammadpur, Hazaribagh and Lalbagh were water-logged until one day later of the record heavy rainfall. People at the low-lying areas of Mirpur Section-1, embankment area, North Bishil, Jheelpar slum of Mirpur Section-6, Ta-Block, W-Block, Dha-Block and Kalapani of Section-12 in Mirpur were in severe situation for deposited water until one day later. Monsurabad area of Mohammadpur, Awal's slum near to Nobodoy Housing, Jabbar's slum behind Mohammedi Housing, Katasur of Mohammadpur, Sultanganj, Rayerbazar, Hazaribagh, and Shmashanghat of Lalbagh were also water-logged until one day later (Daily Prothom Alo, 2004a: 1). Shajahanpur intersection to Malibagh crossing, Shantinagar intersection to Malibagh crossing, Baily Road, Kakrail crossing etc. roads were water-logged even two days later of the record heavy rainfall. In addition, the low-lying areas of Eastern part of Dhaka including Basabo, Madartek, Nandipara were also water-logged even two days later (Daily Prothom Alo, 2004c: 1).



Figure-2: Water-logging at Dhanmondi-27 Crossing on 13 Sept. 2004 (Photo: Author)

A large part of the roads and houses of Dhaka city were water-logged on 28 July 2009 for 333 mm heavy rainfall within 9 hours only (Figure-3). In front of Prime Minister's office, Shapla Chattar of Motijheel, Dilkusha, Dainik Bangla crossing, secretariat, Tupkhana road to Naya Paltan, Bijoy Nagar, Baily road, Ramna Park, roads in front of Motsya Bhaban, Eskaton Garden, in front of Vikarunnesa Noon School and its playground, Siddeshwari area, Mouchak to Malibagh rail gate, Mouchak crossing to Shajahanpur, Kamlapur to Notre Dame College, Green Road, Kathalbagan Bazar, Ahmed Publishing House of Kathalbagan Dal were water-logged. Slums at Rupnagar and extended Pallabi, Pallabi Bus Station, Dewantek and Damalkut slum of Kafrul, Konapara of Demra, Tikkapara, Nobodoy Housing and Lalmatia of Mohammadpur, Asad gate, in front of Rapa Plaza, Malibagh rail gate to Abul Hotel, some roads of Khilgaon Chowdhurypara were also water-logged (Daily Prothom Alo, 2009a: 1).

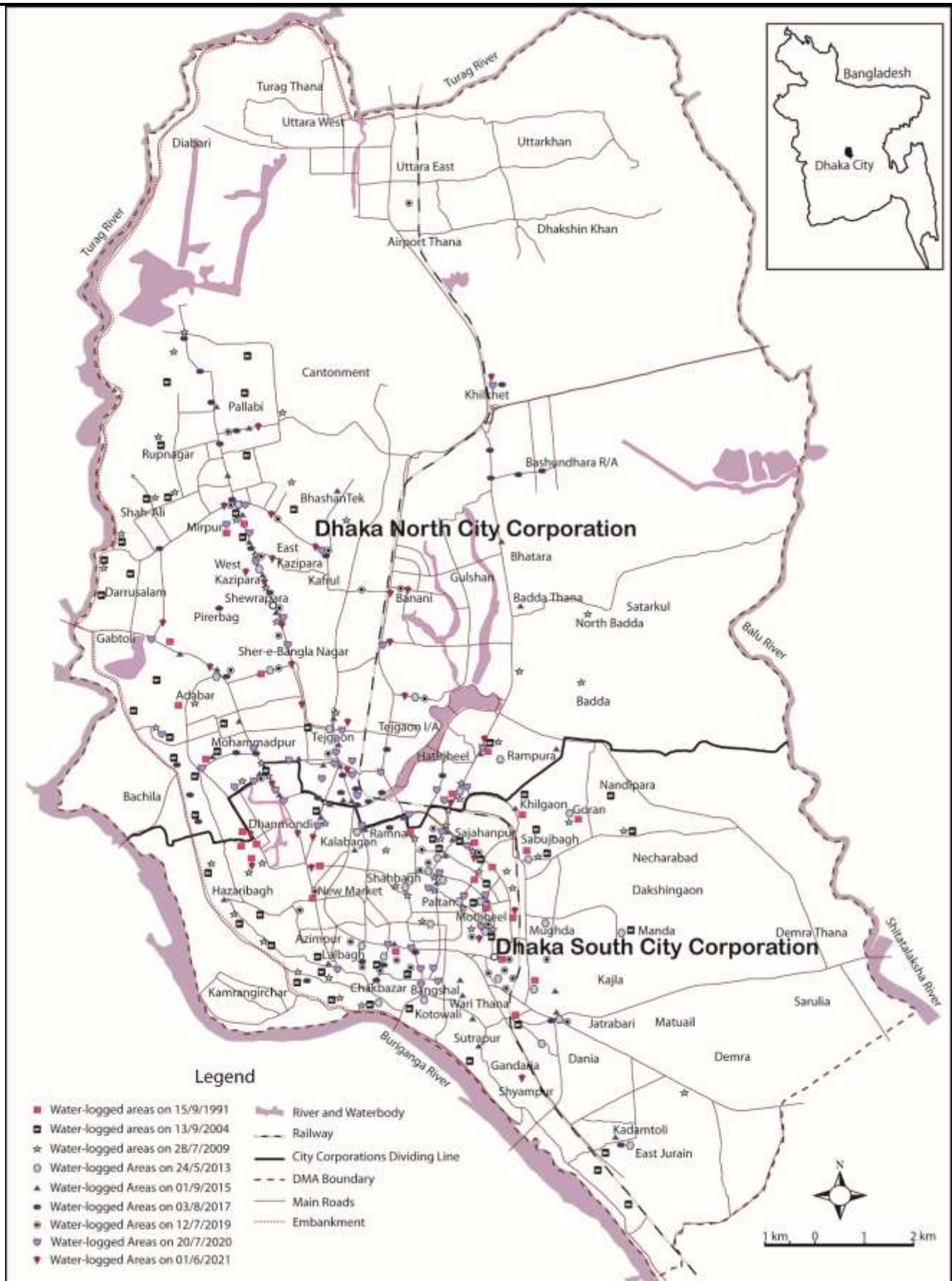


Figure-3: Spatio-temporal Distribution of Major Water-logging Incidents in Dhaka City (1991-2021)

Different areas of the capital including Mirpur, Senpara Parbata, Kazipara, Shewrapara, Taltola, Rampura, North-Badda, Jigatola, Moneshwar Road, Rayerbazar, Sultanganj were water-logged until one day later of the heavy rainfall on 28 July 2009 (Daily Prothom Alo, 2009b: 1 and Daily Ittefaq, 2009: 1). Shahidnagar, Islambagh, Kamalbagh and Boubazar of Lalbagh; and some areas of Badda, Goran and Basabo were water-logged until two days later (Daily Prothom Alo, 2009c: 1-20).

Roads and lanes were water-logged on 23 May 2013 for 56 mm heavy rainfall in 2 hours at many areas including Motijheel, Shantinagar, Arambagh, Ramkrishna Mission Road, K. M. Das Lane, Mirpur-10 to Kazipara, Shewrapara, Rokeya Sarani, Sher-e-Bangla Nagar, Shamoly, Monipuripara and Bijoy Sarani, Tejgaon Link Road and surrounding areas, Rampura, Malibagh, Basabo, Goran, Mugdapara, Manda, Maniknagar, Fakirapol, Nayapaltan, Kakrail, Motsya Bhaban area, Bangla Motor Area, Jurain,

Jatrabari, Dolairpar, Bangshal, Boxibazar, Nazimuddin Road and different areas of old Dhaka (Mahmud, 2013: 1; and Daily Prothom Alo, 2013a: 21).

Road in front of Prime Minister's Office, Manikmia Avenue, Dhanmindi-27, Kalshi of Mirpur, Mirpur-10 to Shewrapara, Rokeya Sarani, Nayapaltan, Shantinagar, Mouchak, Malibagh, Moghbazar, Chankharpul, Green Road, Indira Road, Sukrabad, Paribagh, Bangla Motor, Kawran Bazar, Panthpath, Roads Behind the Basundhara City, Mohammadpur, College Gate, Shyamoli, Kollyanpur, Pallabi, Khilgaon, Arambagh, Bhashantek, Badda, Bhatara, Rampura, Farmgate, Tejgaon, Jatrabari, Kodomtoli, Banogram of old Dhaka, Shasimohon Basak Lane, North Moishandi, Lalbagh, Sutrapur, Dhalpur, and Hazaribagh were water-logged on 1 Sept. 2015 for 42 mm heavy rainfall in 1.50 hours (Taleb and Rahman, 2015: 1; and Daily Prothom Alo, 2015d: 1). Many houses, shops and markets were also water-logged.

Water-logging occurred on 3 August 2017 for 123 mm heavy rainfall only in 3 hours at Nazimuddin Road, Alauddin Road, Chakbazar Road, Umesh Datta Road of old Dhaka; Jatrabari Crossing, Jurain, Shahidnagar, Modhubagh, Kazi Nazrul Islam Avenue, Kawran Bazar, Garden Road, BFDC to Petro-Bangla Road, in front of Sonargaon Hotel, Eskaton, Shewrapara to Mirpur-12 Crossing, Pirebagh, Mirpur-1, Kochukshet, Kalshi, Shyamoli, Town Hall to Asadgate, areas behind the embankment at Mohammadpur, Basundhara R/A to Natun Bazar, Khilkshet, Begunbari, Panthpath and Kuril by knee to waist deep water (Daily Prothom Alo, 2017h: 8; and Sarkar and Kaysar, 2017: 1).

Water-logging occurred on 12 July 2019 for 81 mm rainfall in 12 hours (of which 49 mm heavy rainfall in 2.15 hours) at Dhanmondi-27, in front of Dhaka College and Gausia Market, Ramkrishna Mission Road, Avoy Das Lane, Hatkhola Road, Gopibag, Swamibag, K. M. Das Lane, Dilkusha, Motijheel, Kakrail, Rajarbagh, Circuit House Road, Baily Road, Siddesari; Boxibazar, Nazimuddin Road, Azimpur Graveyard area, Agamasi Road, Agasadiq Road and Chakbazar of old Dhaka; Mirpur 10 to 13 and 14, Kazipara, Shewrapara, Taltola, Sher-e-Bangla Nagar, Shyamoli, Monipuripara, Tejgaon Link Road, Kalshi; and Road No. 2 of Section-4 at Uttara, Rampura, Banani-11, Jatrabari and Cantonment area (Daily Prothom Alo, 2019f: 6 and Daily Ittefaq, 2019: 20).

A vast areas of Mirpur road, Dhanmondi-27, Parliament area, Airport Road, Mirpur, Lalmatia, Asad Gate, Nobodoy Housing area, Darussalam Road, Tejgaon, Kawran Bazar, North gate of Rajarbagh Police Line, Nayapaltan, Mohakhali, Rampura, Khilkshet, Noyatola, Sonalibagh, Moghbazar, Malibagh, Mouchak, Bangla Motor, Green Road, Farmgate, Rajabazar, Sukrabad, Bijoy Nagar, Rokeya Sarani, Mirpur-10 to 14, Senpara, Kazipara, Shewrapara, Tejkunipara, Tejturibazar, Satrasta crossing, Mohammadpur, Motijheel, Fakirapul and Arambag were water logged on 20 July 2020 for 63 mm heavy rainfall in 3 hours. Different areas of old Dhaka including Banga Bazar area, Nazimuddin Road, Siddiq Bazar, Bangshal, Alauddin Road, Najirabazar, and Lalbagh were also water-logged by knee deep water (Daily Prothom Alo, 2020c: 1-4 and Daily Ittefaq, 2020b: 15).



Figure-4: Water-logging for Overflowing an upstream of Kollyanpur Canal between West Shewrapara and South Pirebagh on 11 Sept. 2017 (Photo: Author)

Banani, Kalshi Road, Mirpur-10 to Agargaon and Mirpur-14 roads, East and West Kazipara, Shewrapara, Rokeya Sarani, Darrussalam Road, Shyamoli, Dhanmondi-27, Mirpur Road, Green Road, Nakhhalpara, roads behind the Bangabhaban, Ganderia DIT plot, in front of Gabtola Mosque at Jigatola, Satmosjid Road, Tejturibazar, Mohakhali and Malibagh were water-logged on 01 June 2021 for 85 mm heavy rainfall in 3 hours (Daily Prothom Alo, 2021b: 1 and Alam, H. 2021a). New Elephant Road, Kamlapur, Rajarbagh, Rampura, Khilkshet, Kakli and Gulshan Link road were also water logged by knee to waist deep water.

The Figure-3 illustrate that some areas are highly water-logging prone than other areas. Begum Rokeya Sarani (Mirpur-10 to Sher-e-Bangla Nagar) is highly water-logging prone. Then, Dhanmondi-27 crossing, some areas in Mohammadpur and Tejgaon are water-logging prone. Some areas in Rampura, Khilgaon, Shajahanpur, Paltan and Motijheel are also water-logging prone. Old Dhaka including Lalbagh, Chalkbazar and Bangshal are very water-logging prone.



**VII. DISCUSSION:**

The yearly incidents of water-logging and annual rainfall in Dhaka city had predominance of positive correlation since 1991 to 1999 and 2013 to 2021 but the predominance of negative correlation had since 2000 to 2012. In 2017, the total rainfall increased to the highest 2892 mm when the water-logging also raised to the highest 12 incidents. Among all water-logging incidents since 1991 to 2021, 46.67 percent incidents occurred for heavy rainfall and the remaining 53.33 percent incidents occurred for light to moderate rainfall. The mean total rainfall is 70.69 mm, mean duration of rainfall is 10.85 hours and mean per hour rainfall is 11.47 mm of the sixty water-logging incidents related rainfall events, which indicate the central tendency of water-logging related total rainfall, duration and per hour rainfall respectively. In general, 73.33 percent water-logging incidents occurred with the previous consecutive rainfall day/days. All of the severe and most of the major water-logging incidents occurred for heavy rainfall with previous consecutive rainfall day/days. This study reveals that severity of water-logging in Dhaka city is related with rainfall intensity and the duration of rainfall on the water-logging day, and the amount of rainfall on the previous consecutive rainfall day/days. Islam, Murshed, Khan and Hasan, (2014: 54) have found that short duration high intensity rainfall and extreme events are increasing in Bangladesh including the Dhaka city. The average monsoon rainfall is increasing in Dhaka region as a rate of 0.24 mm per year (Khatun, Rashid, Mostafa and Mandal, 2018:35). The relations of the severity of water-logging incidents with rainfall intensity, the duration of rainfall, extreme rainfall events and the increased annual rainfall of some years in this study shows some similarity with their findings. Although the water-logging incidents were distributed many areas in the city since 1991 to 2021, some areas were more water-logging prone than other areas. Areas such as Mirpur-10 to Sher-e-Bangla Nagar; Dhanmondi-27 crossing, Mohammadpur and Tejgaon area; Rampura, Khilgaon, Shajahanpur and Motijheel area; and Lalbagh, Chalkbazar and Bangshal of old Dhaka are found highly water-logging prone. It is evident that water-loggings have relations with the heavy rainfall in Dhaka city but other causes such as population growth, unplanned development and encroachment of land, disappearance of natural drainage system, shortage of drainage capacity and waste management system, disappearance of soak able green areas and topography has also relations with water-loggings those are identified by Subrina and Chowdhury (2018: 803-804). So, it is necessary to improve the drainage system and their management otherwise the situation of water-logging may become more severe with the increasing trend of heavy rainfall due to climate change effects.

**VIII. CONCLUSION:**

Water-logging incidents have correlations with annual rainfall in Dhaka city. The positive correlations of water-logging incidents with annual rainfall had predominance most of the years since 1991 to 2021. The incidents of water-logging were higher in the last nine years (2013-2021) than any other periods. It is also found that 46.67 percent water-logging incidents occurred for heavy rainfall and the 53.33 percent incidents occurred for light to moderate rainfall. The central tendency of the water-logging related total rainfall is 70.69 mm, duration of rainfall is 10.85 hours and per hour rainfall is 11.47 mm. Long duration heavy rainfall with large amount of rainfall on the previous consecutive rainfall day/days caused the most severe water-logging incident on 13 September 2004 and another severe incident on 28 July 2009. Most of the major water-logging incidents also occurred for heavy rainfall with previous consecutive rainfall day/days. In general, 73.33 percent water-logging incidents occurred with the previous consecutive rainfall day/days. The study reveals that the severity of water-logging in Dhaka city is related with intensity and duration of the rainfall on the water-logging day, and the amount of rainfall on the previous consecutive rainfall day/days. The spatio-temporal distribution of water-logging spreads over many areas in the city but some areas were most water-logging prone than other areas. Highly water-logging prone areas were Mirpur-10 to Sher-e-Bangla Nagar; Dhanmondi-27 crossing, Mohammadpur and Tejgaon area; Rampura, Khilgaon, Shajahanpur and Motijheel area; and Lalbagh, Chalkbazar and Bangshal of old Dhaka. Although the water-loggings have relations with heavy rainfall in Dhaka city due to climate change effects, it is necessary to adjust other causes of water-logging to improve the situation which are the alternatives to be controlled. Because, the rainfall may be more intensive or erratic and the extreme events can increase with the increasing trend of global warming and climate change effects. Drainage system should be adapted with the pattern of heavy rainfall and the distribution of water-logging incidents. Water containing space and flow of storm water towards pumping stations or rivers should be increased. Above all, a comprehensive strategy should be taken to reduce the water-logging in Dhaka city.

**REFERENCES:**

- Alam, H. 2021a. "85 mm rain drowns Dhaka". *The Daily Star*, 02 June. Retrieved on 12 Oct. 2021 from <https://www.thedailystar.net/city/news/85mm-rain-drowns-dhaka-2103329>
- Alam, H. 2021b. "Two City Corporations Chalk Out Priorities". *The Daily Star*, 12 March: 3.
- Alam, M. and Rabbani, M. G. 2007. "Vulnerabilities and responses to climate change for Dhaka". *Environment and Urbanization*, Vol. 19 (1): 81-97.
- Aldin, A. 2004. "Panite Bhasche Dhaka (Dhaka is Floating on Water)". *Daily Ittefaq*, 14 September: 1.
- BBS. 2014. *Bangladesh Population and Housing Census 2011, Volume-3, Urban Area Report*. Bangladesh Bureau of Statistics (BBS), Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka.
- Daily Bangla. 1991a. "Ektana Borshone Dhaka Mahanagori Saylab: Jonjibon Biporjosto (Dhaka Metropolitan Inundated by Continuous Rainfall: Public Life Disrupted)". 16 September: 1.
- Daily Bangla. 1991b. "Rajdhanite Probol Borshon: Barighore Pani (Heavy Rainfall in the Capital: Water in Houses and Homestead)". 27 September: 1.
- Daily Bangla. 1993a. "Nogorite Obiram Bristi: Jonojibon Onchal (Unrest Rain in the City: Motionless Public Life)". 24 August: 1.
- Daily Bangla. 1993b. "Borshone Nagorir Pathghat Nimojjito: Durbhogh (Rain Inundated Roads-Stations in the City: Sufferings)". 25 August: 1.
- Daily Bangla. 1993c. "Saradeshe Bristi: Dhakay Jibonjatra Byahot (Rainfall in Whole Country: Disrupted Livelihood in Dhaka)". 3 September: 1.
- Daily Ittefaq. 1991a. "Abiram Borshone Jibonjatra Biporjosta (Livelihoods Disrupted by Continuous Rainfall)". 10 September: 1
- Daily Ittefaq. 1991b. "Rajdhanite Jibonjatra Biporjosto (Disrupted Livelihoods in the Capital)". 16, September: 1.

- Daily Ittefaq. 1993. "Panch Ghontar Obiram Borshone Rajdhanir Jonojibon Biporjosto (Livelihood Disrupted by Five Hours Continuous Rainfall in the Capital)". 24 August: 1.
- Daily Ittefaq. 1998a. "Probol Borshone Dhakar Ninmanchaler Rastaghat Barighor Dhokanpate Hatu Pani (Roads, Shops, Houses Under Knee Deep Water at Low-lying Areas in Dhaka for Heavy Rainfall)". 14 August: 1.
- Daily Ittefaq. 1998b. "Probol Borshone Rajdhanir Rastaghat Plabito (Heavy Rainfall Flooded Roads and Stations in the Capital)". 18 August: 1.
- Daily Ittefaq. 1999. "Obiram Borshone Rajdhani Sthabir (Slotted Capital for Unrest Rainfall)". 12 July: 1.
- Daily Ittefaq. 2009. "Rajdhanir Ninmanchale Lakho Manush Ekhono Pani Bandhi (Hundreds of Thousand People in the Low-lying Areas in the Capital yet Water-logged)". 30 July: 1.
- Daily Ittefaq. 2015. "Jaljote Biporjosto Rajdhani Nakal Nagarjibon (Disrupted Capital for Water-logging, Urban Life Discomfited)". 11 July: 20.
- Daily Ittefaq. 2017. "Ek Ghantar Bristite Rajdhanite Fer Jalabodhdota (Water-logging Again for One Hour Rain)". 3 August: 20.
- Daily Ittefaq. 2019. "Bhari Bristite Panir Niche Rajdhanir Rasta-ghat (Roads and Stations under Water for Heavy Rainfall)". 13 July: 20.
- Daily Ittefaq. 2020a. "Bhari Borshone Desh Jure Durbhog (Trouble All Over the Country for Heavy Rainfall)". 24 October: 1-11.
- Daily Ittefaq. 2020b. "Bristite Dublo Rajdhani (Capital Inundated by Rainfall)". 21 July: 15.
- Daily New Age. 2018. "Water-logging triggered by heavy rains hampers Dhaka life". 24 May, Retrieved on 13 September 2021 from <http://www.newagebd.net/article/41956/water-logging-triggered-by-heavy-rains-hampers-city-life>.
- Daily Prothom Alo. 1999. "Dhakasoho Bibinno Jelay Ninmanchal Dube Gheche (Low-Lying Areas of Different Districts including Dhaka Gone under Water)". 23 September: 1.
- Daily Prothom Alo. 2004a. "Ekanno Bachorer Modhey Dhakay Sorbocho Bristipat (Highest Rainfall in Dhaka within 51 Years)". 15 September: 1.
- Daily Prothom Alo. 2004b. "Abiram Borshone Achal Rajdhani (Motionless Capital for Continuous Rainfall)". 14 September: 1.
- Daily Prothom Alo. 2004c. "Ninmochaper Bipad Kateni (The Calamity of Low Pressure not Overcome)". 16 September: 1.
- Daily Prothom Alo. 2007. "Bari Borshone Dhakar Rastay Hatu Pani (Roads Under Knee Deep Water in Dhaka for Heavy Rainfall)". 25 August: 1.
- Daily Prothom Alo. 2009a. "Ratbhor Bristi Dinbhor Durbhogh (Whole Night Rain Sufferings for Whole Day)". 29 July: 1.
- Daily Prothom Alo. 2009b. "Paristhiti Kichuta Swabhabik Tobe Anek Alakay Pani Nameni (Situation Normal in some extent but Water not receded from many areas)". 30 July: 1.
- Daily Prothom Alo. 2009c. "Pani Komte Shuru Korleo Lalbagher Koyek Hazar Manush Chorom Durbhoge (Water Receding but Several Thousand People of Lalbagh are Suffering yet)". 31 July: 1-20.
- Daily Prothom Alo. 2011a. "Srabondharay Amone Sasthi Jibone Kosto (Downpour in Srabon Fortune for Amon Crop Suffering in Livelihood)". 10 August: 1-2.
- Daily Prothom Alo. 2011b. "Bristite Biporjosto Jibon (Disrupted Livelihood for Rain)". 11 August: 1-19.
- Daily Prothom Alo. 2013a. "Ashwabhabik Bristite Rajdhanir Anek Elakay Jalabodhdota (Many Areas of the Capital Water-logged for Abnormal Rainfall)". 24 May: 21.
- Daily Prothom Alo. 2013b. "Bristi-Jalabodhdotay Nakal Nagarbasi (Urban Dwellers Discomfited for Rain and Water-logging)". 17 May: 7.
- Daily Prothom Alo. 2015a. "Bristi Jalabodhdota Janjote Bhoganti (Rain Water-logging Trouble of Traffic Jams)". 11 July: 8.
- Daily Prothom Alo. 2015b. "Rajdhanite Dinbhor Bristi Bhoganti (Daylong Rain in the Capital Sufferings)". 16 July: 8.
- Daily Prothom Alo. 2015c. "Rajdhani Jure Byapok Jalabodhdota (Water-logging in Vast Area of the Capital)". 22 August: 8.
- Daily Prothom Alo. 2015d. "Rajpath Thoi Thoi, Nakal Manush (People in Weary for Water-logged Public Road)". 2 September: 1.
- Daily Prothom Alo. 2016. "Bristi Ar Joljote Purano Bhoganti (Old Trouble of Rain and Water-logging)". 24 July: 8.
- Daily Prothom Alo. 2017a. "Bristi Joljot Janjote Nakal Rajdhanibasi (Dwellers of the Capital Discomfited by Rain, Water-logging and Traffic Jams)". 6 April: 9.
- Daily Prothom Alo. 2017b. "Dhakay Bristite Jalabodhdota Janjote Durbhog (Water-logging for Rain Sufferings for Traffic Jams in Dhaka)". 13 June: 1.
- Daily Prothom Alo. 2017c. "Dubonto Dhakake Banchabe Ke? (Who Will Save Drowning Dhaka?)". 27 July: 1-8.
- Daily Prothom Alo. 2017d. "Megh Bisforene Bristi (Rainfall for Cloud Blast)". 4 August: 1.
- Daily Prothom Alo. 2017e. "Jalaboddo Dhakay Osahay Manush (People Are Helpless in Water-logged Dhaka)". 12 September: 1-8.
- Daily Prothom Alo. 2017f. "Swastir Bristite Asistikor Jalabodhdota (Comfortable Rain but Discomfortable Water-logging)". 30 September: 8.
- Daily Prothom Alo. 2017g. "Surjahin Duidin Jalamogno Dhaka (Two Days Without Sunshine Water-logged Dhaka)". 22 October: 1.
- Daily Prothom Alo. 2017h. "Jalabodhdota, Janjote Nakal Nagarbasi (Dwellers in the City Discomfited for Water-logging, Traffic Jams)". 4 August: 8.
- Daily Prothom Alo. 2018a. "Borsha Shurur Agei Bhogantir Sangket (Sign of Suffering Before Monsoon)". 30 April: 1-4.
- Daily Prothom Alo. 2018b. "Bristi Holei Jalabodhdota Bhoganti (Water-logging and Suffering When Rain)". 01 May: 7.
- Daily Prothom Alo. 2018c. "Jaljote Dinbhor Nakal (Discomfited Whole Day for Water-logging)". 14 May: 6.
- Daily Prothom Alo. 2018d. "Jhum Bristite Durbhoger Bikel (Suffered Afternoon for Jingling Rain)". 26 May: 6.
- Daily Prothom Alo. 2018e. "Swastir Bristite Aswastir Jaljot (Comfort for Rain but Water-logging of Discomfort)". 01 June: 6.
- Daily Prothom Alo. 2018f. "Der Ghantar Bristite Jaljot Janjot Durbhog (Water-logging, Traffic Jams and Trouble for One and Half an Hour Rain)". 13 June: 6.
- Daily Prothom Alo. 2018g. "WASAr Karzyaloyer Samneo Jalabodhdota (Water-logging also in front of DWASA Office)". 24 June: 6.
- Daily Prothom Alo. 2018h. "Tris mm Bristitei Jalabodhdota (Water-logging for Only 30 mm Rain)". 26 June: 6.
- Daily Prothom Alo. 2018i. "Choytris mm Bristitei Jalabodhdota (Water-logging for Only 36 mm Rain)". 24 July: 6.

- Daily Prothom Alo. 2019a. "Bristi Holei Saroke Pani (Water-logged Road if Rain)" 01 July: 6.
- Daily Prothom Alo. 2019b. "Bristi Jalabodhdhota Janjot Durbhoge Nagarbasi (Urban Dwellers in Trouble for Rain, Water-logging and Traffic Jams)". 9 July: 6.
- Daily Prothom Alo. 2019c. "Bristite Joljot Janjot (Water-logging and Traffic Jams by Rain)". 9 August: 7.
- Daily Prothom Alo. 2019d. "Bristi Jalabodhdhotay Bhoganti (Trouble for Rain and Water-logging)". 30 September: 7.
- Daily Prothom Alo. 2019e. "Shoya Ghantar Bristite Dublo Dhaka (Dhaka Inundated by 1.15 Hours Rain)". 02 October: 1.
- Daily Prothom Alo. 2019f. "Saradin Bristi, Shahor Jalomogno (Whole Day Rain, Water-logged City)". 13 July: 6.
- Daily Prothom Alo. 2020a. "Rajdhanisoh Dhakshin Anchole Ajo Bristi Hote Pare (Rain May also be Today in Southern Region including the Capital)". 27 April: 4.
- Daily Prothom Alo. 2020b. "Tindin Dhore Bristi Hote Pare, Pahar Dhoser Shanka (Rain May be Three Consecutive Day, Fear of Hill Collapse)". 20 June: 16.
- Daily Prothom Alo. 2020c. "Mukher Buli Ar Takar Shraddho (Word of Mouth and Bury of Money)". 21 July: 1-4.
- Daily Prothom Alo. 2020d. "Ninmochaper Provabe Bristi, Thakbe Koyekdin (Rain by Depression, Remain Several Days)". 13 October: 1-2.
- Daily Prothom Alo. 2020e. "Dupurer Bristite Joljot, Sandhar Poro Janjot, (Water-clogging by Rain at Noon, Traffic Jams Even after Evening)". 15 October: 1-2.
- Daily Prothom Alo. 2021a. "Bochorer Dwitio Sorbochcho Bristi, Nakal Rajdhanibasi (Second Highest Rain in the Year, Dwellers in the Capital Discomfited)". 19 May: 6
- Daily Prothom Alo. 2021b. "Bhora Borshar Agei Dhakay Joljot (Water-logging in Dhaka before full monsoon)". 02 June: 1.
- Daily Prothom Alo. 2021c. "Bhari Bristi Holei Joljote Vinno Chaharay Rajdhani (Different Appearance of the Capital for Water-logging if Heavy Rain)". 6 June: 1-4.
- Daily Prothom Alo. 2021d. "Teish mm Bristitei Basabarite Pani (Water at Home for Only 23 mm Rain)". 10 June: 6.
- Daily Prothom Alo. 2021e. "156 Jaygay Jalabodhdhota (Water-logging in 156 Places)". 05 July: 6.
- Daily Samakal. 2017. "Choy Ghantay Chappano Milimiter Bristi Rajdhanite Durbhog (56 mm Rain in Six Hours Sufferings in the Capital)". 26 July, Retrieved on 03 Oct. 2021 from <https://samakal.com/capital/article/1707311447>.
- DWASA. 2016. Master Plan Report (Updating / Preparation of the Stormwater Drainage Master Plan). Dhaka Water Supply and Sewerage Authority (DWASA), Retrieved on 18 September 2021 from [https://dwasa.portal.gov.bd/sites/default/files/files/dwasa.portal.gov.bd/page/071726be\\_2cac\\_41f0\\_9412\\_be8936c47d2c/Drainage%20master%20Plan.pdf](https://dwasa.portal.gov.bd/sites/default/files/files/dwasa.portal.gov.bd/page/071726be_2cac_41f0_9412_be8936c47d2c/Drainage%20master%20Plan.pdf).
- Hossain, S. and Mostafa, M. 2020. "Kaj Angshik, Bhoganti Dhirgho (Incomplete Work, Long Sufferings)". *Daily Prothom Alo*, 22 July: 1-4.
- Islam, A.K.M.S., Murshed, S. B., Khan, M. S. A. and Hasan, M. A. 2014. Impact of Climate Change on Heavy Rainfall in Bangladesh, Final Report. Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, Dhaka. Retrieved on 12 September 2021 from <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.727.8506&rep=rep1&type=pdf>.
- Islam, M. N. 2021. *Impacts of Environmental Hazards and Disasters on Urban Poor Community in Dhaka City (1991-2017)*, JETIR, Vol. 8, Issue 6: e107-e116, Retrieved on 24 June 2021 from <https://www.jetir.org/papers/JETIR2106570.pdf>.
- Kang, Y., Peng, X., Wang, S., Dong, C., Shang, K., & Zhao, Y. 2020. Statistical characteristics and synoptic situations of long-duration heavy rainfall events over North China. *Earth and Space Science*, 7, e2019EA000923. <https://doi.org/10.1029/2019EA000923>
- Khatun, K., Rashid, B. M., Mostafa, F. B., and Mandal, H. S. M. 2018. *Monsoon Rainfall Trend over Bangladesh and Teleconnection with Southern Oscillation Index (SOI) and Indian Ocean Dipole (IOD)*, DEW-DROP: A Scientific Journal of Meteorology and Geo-Physics, Bangladesh Meteorological Department, Vol. 5. No. 1: 32-38.
- Mahmud, I. 2013. "Borshar Agei Borshar Bristi (Rain of Rainy Season Before Monsoon)." *Daily Prothom Alo*, 24 May: 1.
- Mamun, S. 2020. "Dhaka Brought to Standstill by Water-logging, Traffic". *Dhaka Tribune*, 20 July, Retrieved on 13 Sept. 2021 from <https://www.dhakatribune.com/bangladesh/dhaka/2020/07/20/overnight-rains-lead-to-waterlogging-in-dhaka>.
- Murshed, S. B., Islam, A. K. M. S., and Khan, M. S. A. 2011. Impact of Climate Change on Rainfall Intensity in Bangladesh. 3<sup>rd</sup> International Conference on Water and Flood Management (ICWFM-2011), Retrieved on 14 Nov. 2021 from <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.716.8645&rep=rep1&type=pdf>.
- Nishat, A., Reazuddin, M., Amin, R. and Khan, A. R. (eds.). 2000. *The 1998 Flood: Impact on Environment*; Department of Environment and IUCN Bangladesh, Dhaka, Bangladesh.
- Sarkar, S. and Kaysar, B. 2017. "Bristite Bhaslo Dhaka (Dhaka Inundated by Rain)". *Daily Ittefaq*, 4 August: 1.
- Subrina, S. and Chowdhury, F. K. 2018. "Urban Dynamics: An undervalued issue for water logging disaster risk management in case of Dhaka city, Bangladesh". *Procedia Engineering* 212 (2018): 801-808, Retrieved on 22 August 2021 from <https://www.sciencedirect.com/science/article/pii/S1877705818301267>.
- Taleb, M. A. and Rahman, S. 2015. "Stobdha Rajdhani (Immoveable Capital)". *Daily Ittefaq*, 02 September: 1.
- Wikipedia, 2022. *Climate of Dhaka*, Retrieved on 12 January 2022 from [https://en.wikipedia.org/wiki/Climate\\_of\\_Dhaka](https://en.wikipedia.org/wiki/Climate_of_Dhaka).
- Wikipedia. 2021. *Rain*, Retrieved on 20 December 2021 from <https://en.wikipedia.org/wiki/Rain>.