Proceedings of the 5th International Conference on Civil Engineering for Sustainable Development (ICCESD 2020), 7~9 February 2020, KUET, Khulna, Bangladesh (ISBN-978-984-34-8764-3)

HISTORICAL FLOOD INUNDATION STUDIES AT SEVERAL IMPORTANT LOCATIONS OF DHAKA CITY UNDER DHAKA MASS RAPID TRANSIT DEVELOPMENT PROJECT LINE – 1

Md. Rashedul Islam*[1], M. Shahjahan Mondal[2] and Subir Biswas[3]

[1]Assistant Professor, Institute of Water and Flood Management, BUET, Dhaka, Bangladesh,
e-mail: rashed_rakib@iwfm.buet.ac.bd
[2]Professor, Institute of Water and Flood Management, BUET, Dhaka, Bangladesh,
e-mail: mshahjahanmondal@iwfm.buet.ac.bd
[3]Research Associate, Institute of Water and Flood Management, BUET, Dhaka, Bangladesh,
e-mail: subir_buet@yahoo.com

***Corresponding Author**

ABSTRACT

The capital of Bangladesh, Dhaka is located in the center of Bangladesh. The area of the present city is around 350 km^2 bounded by the Buriganga River in the south, the Demra in the east, the Tongi Khal in the north and the Turag and Buriganga rivers in the west. The metropolitan city is bounded by Gazipur in the north, Manikganj in the west, Rupganj in the east, Narayanganj in the southeast and Keraniganj in the south. Recently Government of Bangladesh has initiated the Dhaka Mass Rapid Transit Development Project to solve the extreme amount of traffic congestions that occur throughout the entire city each and every day. Among the proposed six MRT lines throughout the city, the alignment of MRT line-1 will be from Kamalapur to Hazrat Shahjalal International Airport via Malibagh, Rampura, Badda and Kuril Bishwa road. There would be 12 underground stations on its route, located in the densely populated urban areas of Dhaka City. For fixing the ground elevations of these stations, the proper understanding of flooding and drainage system surrounding each station are mandatory. Primary data and information on inundation depth, river bathymetry and land elevation were needed for this study. Under this study, primary data on inundation depth due to historical floods such as the 1988 and 1998 floods and due to heavy rainfall were collected based on local water marks and people's perception. The availability of permanent water marks, the age of the local people providing the information, the permanency of residency in the area, the level of education of the person, etc., were the prime factors to determine the reliability of the data. Land elevations were collected at those locations where flood surveys were made with reference to available benchmarks of the Survey of Bangladesh. Then, the flood level at those locations was estimated from the land elevations and flood depths. Obtained flood level data by this method was then compared with the secondary flood level data based on the frequency analysis of the gage station data located in the surrounding rivers of the Dhaka city. After this comparison and some adjustments, design flood level for these locations were estimated. Finally, a spatial map of flood inundation over each candidate site was constructed in Geographic Information System (GIS) platform. These type of maps are useful to understand the general inundation scenarios at those important locations.

Keywords: *MRT Line-1, Historical floods, People perceptions, Inundation depth, Spatial maps.*

1. INTRODUCTION

Dhaka located in the centre of Bangladesh between longitude 90°20'E and 90º30'E and latitude 23º40'N and 23º55'N, is the busiest city of Bangladesh. Although Dhaka's area is less than 1% of the country's total land area, it supports about 10% of the total population and 30% of the total urban population. (Rahman, 2008). It is the 9th largest city in the world by population which covers 360 km^2 bearing more than 15 million people. (Azam et al., 2016). The present transportation system of the city is incapable of satisfying the demand resulting in huge traffic jam every day. With the shortage of land and limited area to expand the present road network, Government of Bangladesh has initiated the Dhaka Mass Rapid Transit Development Project to introduce a new apposite mode of transportation and to utilize the underground and elevated spaces in Dhaka city. As Bangladesh is flood prone area with inundation problems in urban areas, so without proper studies on flooding and drainages can make the whole process of utilizing the underground spaces vulnerable. Previously, several researches were conducted on flooding of Dhaka city and suggested some mitigation options (Faisal et al., 1999; Mark et al., 2001; Huq et al., 2003; Khan, 2006; Dewan et al., 2008; Gain, 2015)

In Bangladesh, depth of inundation over the floodplain is not systematically monitored and recorded by any organization. We know only the flood level at the gage stations, which are located on the rivers. While these rivers are responsible for the strategic location and the fertile soils of the region, they also carry with them the threat of destructive flooding for the city, all of which lies at relatively low elevation (Hafiz, 2011). But, a high-water level in a river may not necessarily correspond to a high-water level in a locality. A number of factors including flood characteristics, distance of the locality from the river, vegetation and physical obstructions influence the local inundation depth. An assessment of the local inundation depth, based on local people's experience on past floods and their depths in the area is necessary to understand the overall inundation scenario in that certain area. In order to fix the ground elevations of the underground stations, same approach was taken for the proper understanding of flooding and drainage system surrounding each station.

2. METHODOLOGY

MRT Line-1 will have 12 underground stations, 7 elevated stations, 1 transition section (heading to Purbachal) and 1 depot area. In this study, we will focus on the 12 underground stations that are located in the central part of Dhaka city. These stations are Kamalapur, Rajarbagh, Malibagh, Rampura, Hatir Jheel, Badda, Uttar Badda, Notun Bazar, Future Park, Khilkhet, Airport Terminal 3 and Airport Area. For further discussion, Kamalapur is considered as station 1 and this way Airport is considered as station 12. Figure 1 illustrates the layout plan of MRT Line-1 where green circles denote the underground stations.

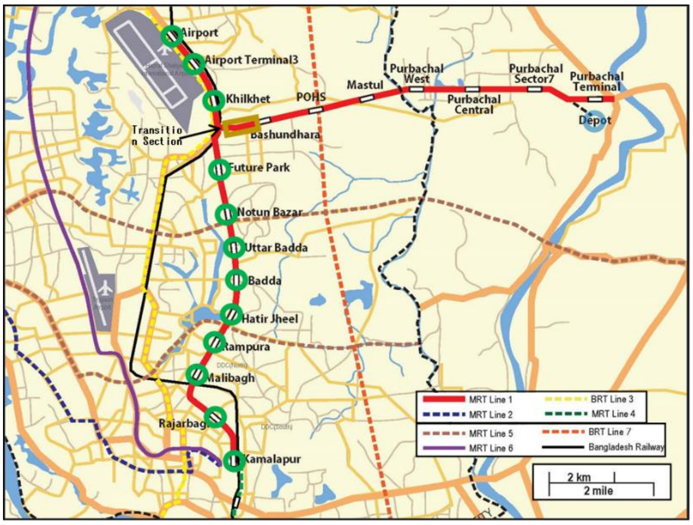

Figure 1: Layout plan of MRT Line-1

For each station, flood depths were collected at 20 points near the location with a radius of 500m surrounding the station. The initial task was to collect relevant flood and drainage information from these locations. Intensive interactions were made with the local people regarding this. The local people were specifically asked about the history of floods in the area, the highest flood year, the last flood year, known flood marks on houses, trees, etc., and the difference between the highest and recent flood levels. While collecting such information, a handheld GPS was carried to record coordinates.

2.1 Incorporation of Flood depth with Ground Level Data

A professional survey team was engaged to estimate the land levels at the locations where flood surveys were made. Ground level information were measured exactly at the same points where flood depths were collected with high accuracy. By combining the ground level data and flood depth data for certain point, flood level of that particular point was calculated (in m, PWD format) by adding these two.

2.2 Data Reliability Checking

The data for all these points were not equally reliable. So, screening out of the unreliable data was needed. The first level of screening was done by making a box plot of the collected flood level data at each station and noting the outliers and extremes in the data set. Outliers are values which are more than 3 box-lengths from the upper or lower edge of the box, and extremes are values with more than 1.5 box-lengths. These identified outliers and extremes were dropped from further analyses.

The second level of reliability checking was done by making a station-wise plot of all the data and then noting the overall regional pattern in the data. The data in which there was a large deviation from the regional pattern was considered to be unreliable and dropped.

The third level of screening was done based on the information while collecting the field data. If water mark was shown by a local respondent, the data was considered to be reliable. Also, if the respondent were an aged person, lived in the area during the said flood, is educated and has knowledge on local flooding pattern, the information provided by the respondent was considered to be reliable.

The fourth and final level of checking was made with the secondary data collected from BWDB. Considering all the stations, about 61% of the data was retained after these four levels of rigorous checking. The above four levels of checking provided reliable flood information at each station based on local people’s perception. It is to be noted that, since this approach is based on local people’s experience and information, it is likely to be fairly good. Figure 2 shows the view of the flood marks shown by the local people.

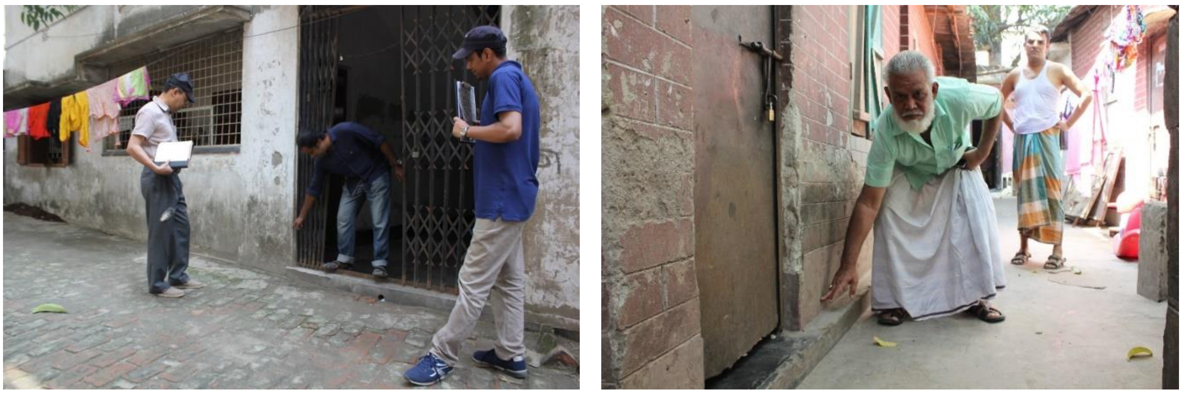

Figure 2: Flood marks shown by the local people

2.3 Comparison of Measured Flood Level Data with the Secondary Data

There are a number of gage stations maintained by the Bangladesh Water Development Board (BWDB) on the rivers surrounding Dhaka City. Figure 3 shows the locations of these stations. Frequency analysis was carried out with the annual maximum water level data using a number of probability distribution functions. The gage stations are located at different distances from the MRT Line 1 stations. Thus, using the U.S. National Weather Service Method, the water levels at the different MRT stations were estimated. Then these estimated flood level data were compared to the flood level data obtained from the primary survey data.

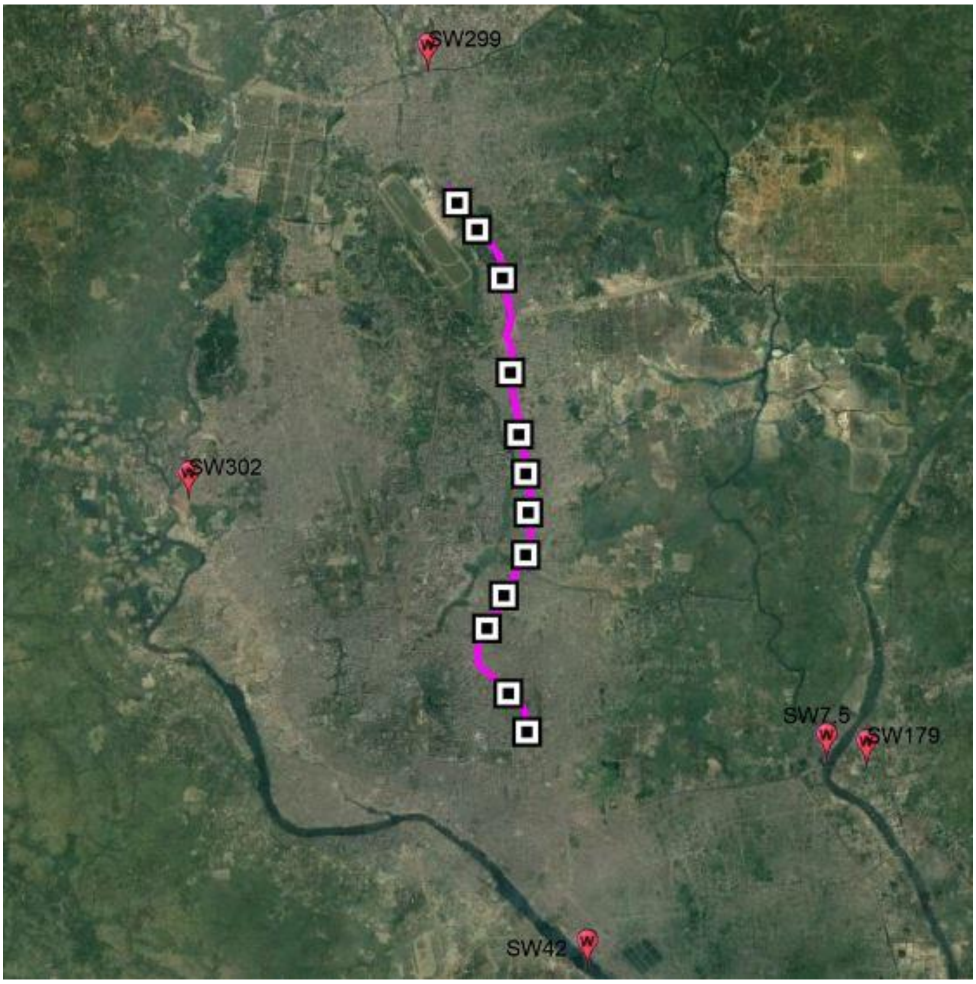

Figure 3: Locations of the gage stations surrounding Dhaka City (Source: Google Earth)

2.4 Preparation of Spatial Maps for Each Station

With ground level data provided by the survey team for each station, at first, ground level (GL) maps were prepared in Geographic Information System (GIS) platform to understand the land topography and identity high, medium and low lands. After incorporating collected flood depth data with the ground level, flood level map for all the stations were also done. The ground level maps and flood level maps are then used for fixing the ground elevation of those underground stations.

3. RESULTS AND DISCUSSIONS

3.1 Data Reliability Analyses

As mentioned in the methodology part, first level of reliability check was done by dropping out outliers and extreme values in the flood level data set. Figure 3 shows a box plot of the flood level data from the Rajarbagh Area (station 2 of MRT Line-1) as an example. The plot shows that there are three outliers in the data. Hence, these three outliers were dropped from further analysis. It is to be noted that the process of identification of outliers and extremes, dropping them from the data, and making the box plot again was repeated until the plot showed no outlier or extreme in the data set.

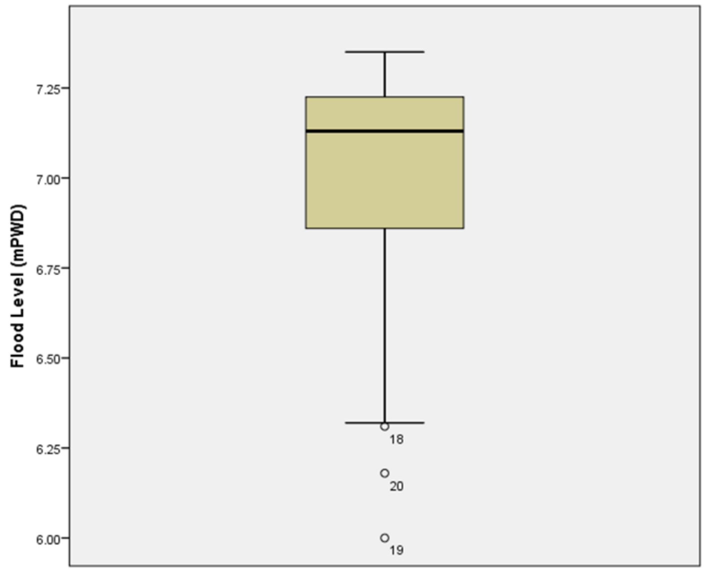

Figure 3: Box plot of the flood level data collected for the Malibagh Area

During second level of reliability check, for a data with large deviation from the regional pattern was considered to be unreliable and dropped from further analysis. Figure 4 shows such a plot. It is seen from the figure that the flood levels at the first four stations and at station 7 are more or less the same. The stations around Hatirjheel area (stations 5 and 6) show slightly higher flood level. The northern stations (stations 8-12) have the highest flood levels among the stations as they are close to the Tongi Khal in the north. Among the surveyed stations, station 9 provides the most reliable results. As seen in the figure, there are a few stations, such as stations 5, 6 and 11, which have long tails in the data. The lower long tail may lead to an under-estimation in flood level and upper long tail may lead to an over-estimation. To reduce the tail length, the reliability of the large and small data were checked further with the actual field information.

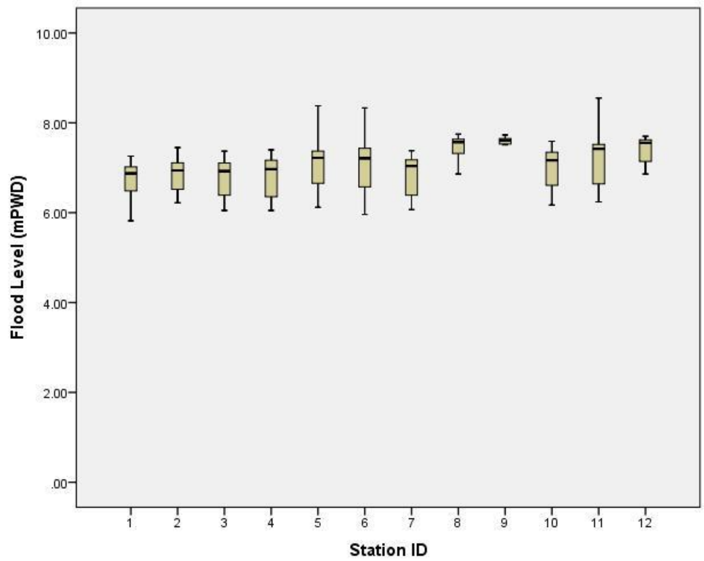

Figure 4: Station-wise Box plot of the flood levels after second level of reliability check

The third level of reliability was based on the level of people's perception regarding the flood depth. If water mark was shown by an aged local respondent, the data was considered to be reliable. In figure 5, as an example of the third level of screening, the field information revealed that the data for 6 points at the station 4 may not be very reliable though there was no outlier or extreme in this data set. So, the data from these 6 points were treated as 'doubtful' and ultimately dropped.

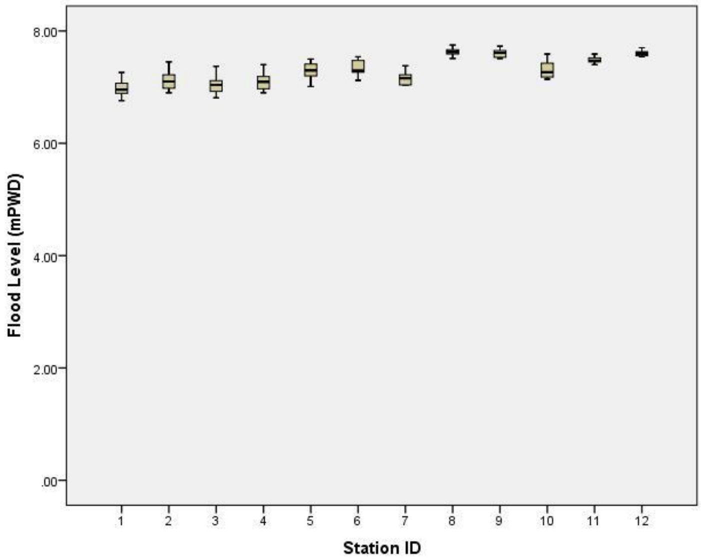

Figure 5: Station-wise Box plot of the screened flood levels

The fourth and final level of checking was made by comparing with the secondary data collected from Bangladesh Water Development Board. The highest flood level of the Balu at Demra was about 7.09 m PWD in 1988 and that of the Tongi Khal at Tongi was 7.84 m PWD. The highest flood levels from the survey data varied between 7.26 m and 7.75 m PWD at the MRT Line-1 stations. Thus, the filtered surveyed flood levels appear to be reasonable.

3.2 Flood Level from Secondary Data

As mentioned in the article 2.3, highest water level at the gage stations maintained by BWDB on the rivers surrounding Dhaka City were collected. Table 2 shows the highest flood level and its year of occurrence for each gage station. It is seen from the table that the highest flood level occurred in the year of 1988, except for Demra on the Shitalakhya. However, the difference between the 1988 water level at Demra on the Balu and the 1998 water level at Demra on the Shitalakhya is only 2 cm.

Table 1: Available hydrologic gage stations surrounding Dhaka City

River Name	Gage Station Name	Station ID	Type of Station	Available Period of Record	Observed Highest Flood Level (mPWD)
Turag	Mirpur	SW302	Tidal	1981-2018	8.35 (1988)*
Tongi Khal	Tongi	SW299	Tidal	1985-2018	7.84 (1988)*
Balu	Demra	SW7.5	Tidal	1985-2018	7.09 (1988)*
Buriganga	Mill Barrack	SW42	Tidal	1985-2018	7.58 (1988)*
Shitalakhya	Demra	SW179	Tidal	1985-2018	7.11 (1998)*

* The value within parentheses indicates the year of occurrence of the highest flood.

Then, frequency analysis was carried out for these rivers with the annual maximum water level data using a number of probability distribution functions, such as Two Parameter Log Normal (LN2), Three Parameter Log Normal (LN3), Pearson Type III (P3), Log Pearson Type III (LP3) and Gumbel's Extreme Value Type 1 (EV1). As, the gage stations are located at various distances from the MRT stations, in order to find the high flood level and different return period flood levels for each of these locations, U.S. National Weather Service Method (equation 1) was used in which the inverse of squared distance of a gage station is used as weightage.

$$X = \sum_{i=1}^{n} W_i X_i \quad (1)$$

where, W_i is the weight for station i, X_i is the water level at station i and n is the number of stations.

The maximum flood levels at different stations thus estimated are given in Table 2. It is seen from the table that the highest flood level varies from 7.55 m PWD at Kamalapur to 7.89 m at Future Park.

Table 2: Maximum and different return period flood levels obtained from secondary data at different MRT stations

Station No./Id.	Station Name	Highest Flood Level (mPWD)	2.33-Year Flood Level (mPWD)	5-Year Flood Level (mPWD)	10-Year Flood Level (mPWD)	20-Year Flood Level (mPWD)	50-Year Flood Level (mPWD)	100-Year Flood Level (mPWD)
1	Kamalapur	7.55	5.68	6.14	6.54	6.98	7.51	7.90
2	Rajarbagh	7.61	5.72	6.19	6.59	7.05	7.59	7.99
3	Malibagh	7.72	5.79	6.26	6.67	7.17	7.74	8.17
4	Rampura	7.72	5.80	6.26	6.67	7.18	7.74	8.16
5	Hatir Jheel	7.77	5.93	6.38	6.79	7.29	7.83	8.23
6	Badda	7.81	5.93	6.39	6.80	7.31	7.85	8.26
7	Uttar Badda	7.84	5.94	6.41	6.82	7.33	7.88	8.30
8	Notun Bazar	7.87	5.94	6.41	6.83	7.34	7.90	8.33
9	Future Park	7.89	5.94	6.42	6.84	7.34	7.90	8.32
10	Khilkhet	7.88	5.94	6.42	6.84	7.30	7.83	8.24
11	Airport T-3	7.87	5.93	6.42	6.84	7.27	7.80	8.20
12	Airport	7.86	5.93	6.42	6.84	7.26	7.78	8.17

3.3 Summary of Probable Flood Level

Based on inundation survey and secondary data analysis, a summary of probable flood levels at different stations of MRT Line 1 was prepared and is given in Table 3. From this Table, it is seen that, highest flood level from inundation survey varies from 7.26 to 7.59 mPWD whereas from secondary data analysis varies from 7.55 to 7.89 mPWD.

Table 3: Probable flood levels at different stations of MRT Line 1

Station No./Id.	Station Name	Flood Level from Inundation Survey (mPWD)	Flood Level from Secondary Data (mPWD) (Table 2)	Recommended Highest Flood Level (mPWD)
1	Kamalapur	7.26	7.55	7.29
2	Rajarbagh	7.12	7.61	7.35
3	Malibagh	7.18	7.72	7.45
4	Rampura	7.40	7.72	7.45
5	Hatir Jheel	7.50	7.77	7.50
6	Badda	7.49	7.81	7.54
7	Uttar Badda	7.38	7.84	7.54
8	Notun Bazar	7.57	7.87	7.59
9	Future Park	7.59	7.89	7.59
10	Khilkhet	7.59	7.88	7.59
11	Airport T-3	7.59	7.87	7.59
12	Airport	7.56	7.86	7.59

Table 3 shows that the survey flood level is lower than the secondary data driven flood level. This could be due to the fact that the MRT Line 1 stations are on floodplains, whereas the BWDB gage stations are on the rivers. During flood time, the river water level is usually higher than the corresponding floodplain level during a rising flood phase when the water flow is from the river towards the floodplain. To take this factor into account, the secondary flood level needed to be adjusted. The adjustment was made by looking at the relation between the two data sets and divided these MRT stations into two groups. For the first group, there is a general increasing trend in flood level from station 1 to station 7. This trend was also maintained in the adjusted highest flood level shown in the last column of Table 3. Stations 8 to 12 in the second group have almost the same flood level and the highest surveyed flood level was 7.59 m PWD. This level was maintained for the adjusted highest flood level in the last column.

3.4 Survey Results into Spatial Maps

Spatial maps are produced for each station location with a radius of 500m taking the station as a centre. Ground level maps were prepared based on the survey data provided by the surveyor. For flood level maps, at first, flood depths were added to respective ground level data to measure the flood levels. Then after four levels of reliability check with the flood level data, finally flood level maps were created. For generating both the ground level maps and the flood level maps, Geographic Information System (GIS) tool was used. Figure 6 shows the existing ground level map and flood level map for the Khilkhet area (station 10). Although, there are 20 measured points in the ground level map, after the reliability check, the number of reliable flood level data are 12 for this site.

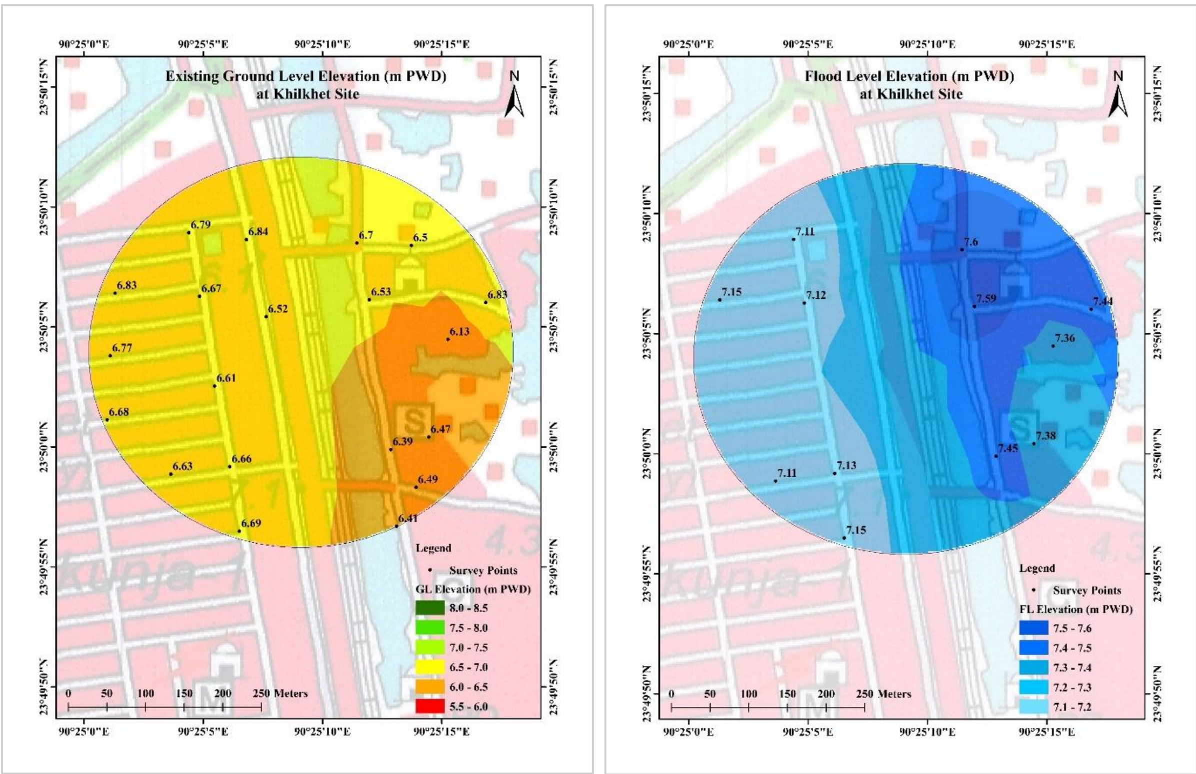

Figure 6: Ground level map and flood level map for the Khilkhet area (station 10)

4. CONCLUSIONS

This study estimates the design flood levels at different locations of MRT Line-1 after comparing the surveyed inundation data and secondary data. For this, primary field data on flood level from 12 underground stations were gathered. Secondary water levels at different available gage stations were collected from BWDB for making comparisons with the flood level obtained from field survey. Primary survey of flood depths at 20 points of each station was done on the basis of local water marks and people's perception. Then land levels at these 20 locations of each station were obtained by a professional survey team. These together provided flood information for each station. A number of reliability checking was done with the collected data. The surveyed flood level included both riverine and rainfall floods. The highest flood level varied between 7.26 m PWD at station 1 to 7.59 m PWD at station 11 and was comparable with the flood level from the secondary data. As MRT stations are located at the floodplain whereas secondary flood level data were obtained based on the frequency analysis of the gage stations located in the surrounding rivers, relatively higher values were obtained by this method compared to the primary surveyed data. By considering all of these and after making some adjustments, highest flood levels for these important locations were proposed. Finally, prepared spatial maps of flood level at different station locations can be used for understanding the common flooding scenario in these places.

ACKNOWLEDGEMENTS

As this study is based on primary field survey, the authors are grateful to the local residents of the locations studied. Their cooperation and valuable information regarding the flood inundation make this study successful.

REFERENCES

Azam, F., Islam, M. S., & Shahin, H. M. (2016). Study on Tunneling for Underground Metro Rail System in Dhaka City. *International Journal of GEOMATE*, *11*(20), 1776-1783.

Dewan, A. M., & Yamaguchi, Y. (2008). Effect of land cover changes on flooding: example from Greater Dhaka of Bangladesh. *International Journal of Geoinformatics*, *4*(1), 11-20.

Faisal, I. M., Kabir, M. R., & Nishat, A. (1999). Non-structural flood mitigation measures for Dhaka City. *Urban Water*, *1*(2), 145-153.

Gain, A. K., Mojtahed, V., Biscaro, C., Balbi, S., & Giupponi, C. (2015). An integrated approach of flood risk assessment in the eastern part of Dhaka City. *Natural Hazards*, *79*(3), 1499-1530.

Hafiz, R. (2011). Urban Hazards in Dhaka. In 400 Years of Capital Dhaka and Beyond: Urbanization and Development. *Dhaka: Asiatic Society of Bangladesh*, 3.

Huq, S., & Alam, M. (2003). Flood management and vulnerability of Dhaka City. *Building Safer Cities*, *121*.

Khan, M.S.A. (2006). Stormwater flooding in Dhaka city: causes and management. *Journal of Hydrology and Meteorology*, *3*(1), 77-85.

Mark, O., Apirumanekul, C., Kamal, M. M., & Praydal, G. (2001). Modelling of urban flooding in Dhaka City. In *Urban Drainage Modeling* (pp. 333-343).

Rahman, M. (2008). Future mass rapid transit in Dhaka city: Options, issues and realities. *Jahangirnagar Planning Review*, *6*, 69-81.