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Simulation of Hydrodynamic Parameters of Dhaka Peripheral River System of Bangladesh

Rezwana Binte Hafiz, Afeefa Rahman, Dr. Anika Yunus

Abstract— Dhaka city, the capital of Bangladesh is surrounded by a peripheral river network of about 111 km which includes Turag, Buriganga, Dhaleshwari, Shitalakhya and Balu involving one major khal named as Tongi canal. The water quality in this river network is deteriorating gradually by domestic and industrial activities leading the contamination to such a devastating level that is hampering the ecological balance. Therefore the study on the detailed assessment of flow availability in the river network is of immense importance. The objective of this study is designed to assess the hydrodynamic parameters including water level, discharge and flow field along the peripheral river system of Dhaka. For assessing the hydrodynamic condition, a 1D numerical model has been developed and simulated in HEC-RAS for the year 2016. The model simulated stage hydrographs have been compared with observed stage hydrographs at station Tongi of Tongi canal and Dhaka Mill Barrack of Buriganga river to calibrate and validate the model using Manning's roughness, n as the tuning parameter. Time series plots on the hydrodynamic parameters have been generated to assess the variation along the peripheral network. Eventually, scenarios have been developed by changing the flow at the upstream boundaries to see the plausible impact of water reduction on river hydrodynamics. It is hoped that the study will be helpful to assess hydrodynamic parameters and pollution scenario of other rivers.

Keywords: Water level, Flow field, Discharge, Dhaka peripheral River Network, HEC RAS

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1 Introduction

Dhaka, a city of 19 million people, is the city with the highest population growth in the world. Higher population growth and inward migration from rural areas in the mega city Dhaka are creating unprecedented socio-economic challenges [2]. According to the study of the World Bank in 2009, the peripheral river system of Dhaka city receive 1.5 million cubic meter of waste water every day from 7,000 industrial units in the surrounding areas and another 0.5 million cubic meters from other sources. In addition, more than 5000 metric ton of solid waste is produced per day of which only 50% is collected by the service authority for proper disposal. The ultimate destination for the rest of solid waste is the 111 km river network system encompassing the city which includes Turag, Buriganga, Dhaleshwari, Shitalakhya, Balu and Tongi canal [3]. As a consequence, the water quality of the river system has deteriorated tremendously due to solid wastes, sewage from domestic and industrial activities. This contamination process has reached to such a devastating level that is hampering the ecological balance. The flow of the river system is sufficient in the monsoon season. But in the pre-monsoon and post-monsoon season, the flow is far below the requirement [3]. Though the flow is sufficient at that time, the waste disposal into the river system remains unchanged. The flow which is required to maintain or improve the health of the river, i.e. environmental flow or e-flow cannot be maintained [4]. As a result, the flow of the rivers, more specifically the flow of river Buriganga has become stagnant. The Buriganga, which once was considered the life of Dhaka, today is the drying river and the most polluted river of Bangladesh [5]. There are 343 tanneries and 627 dyeing factories are situated near this river which dispose detrimental effluent containing chromium, lead, sulphur, ammonium, epoxy, polyurethane, enamel, ductile-silvery white metal, hydrochloric acid, alkalis, lime, caustic soda, aluminum, zinc chromate, zinc phosphate, asbestos etc [6]. Previously government took several decisions for example, tannery shifting to Savar area and subsidy from the toxic industries for establishing Effluent Treatment Plant (ETP), but none of these decisions have been implemented yet [7]. In Dhaka, the demand of water is more than 0.73 km^3 per year whereas, the authority can supply only 0.51 km^3 per year and the water quality is on danger level as well [8]. Around one-quarter of total population of Dhaka live in slum [8]. This increasing environmental pollution leads towards adverse human health impacts, especially among slum dwellers, who live under the poverty line and uneducated in most of the cases [9].

The study of motion of liquids and in particular, water is known as Hydrodynamics, the branch of science that deals with the dynamics of fluids, especially incompressible fluids in motion [10]. The motion of fluids is described through the set of equations of computational hydrodynamic models, which are derived from Newton's laws of motion and describe the action of force applied to the fluid; that is, the resulting changes in flow.

Considering the importance of understanding the seasonal change of hydrodynamic characteristics of alluvial rivers, river

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courses throughout the world and major water courses of South Asia as well as Bangladesh including Ganges, Padma, Meghna, Jamuna, Surma and Gorai have drawn attention of different national and international researchers. Mondal. I (2016) estimated the hydrodynamic pattern changes and morphological parameter including bed shear stress of Ichamati River using HEC RAS model in West Bengal of India [10].Tang. G (2016) studied on Modeling and analysis of hydrodynamics and water quality for rivers in the northern cold region of China [11]. Roy. B (2015) Studied Hydro-morphological behavior of Padma river using Delft-3D.In that study hydro-morphological change pattern of Padma river is analyzed [12].Saha. P (2015) Studied different hydrodynamic characteristics and features of Surma River and performed analysis on change in peak flow due to Flash flood [13]. Khan S.K (2015) developed a hydrodynamic model of Khowai river using HECRAS which can be used to estimate the tidal volume of water flowing through the river and generation of watershed of Khowai river to estimate the runoff discharge and capacity of the Khowai river basin[14]. Rahman A. (2015) analyzed the hydrodynamic and morphological parameters of Gorai river using Delft 3D focusing the effect of dredging on the hydro-morphological parameters [15]. Several studies have been conducted to understand the hydro-morphodynamic behavior of the rivers of Bangladesh though most of the studies are based on yearly variation of river's hydrodynamic parameters, seasonal variation is least considered. A study on river hydrodynamics would help us to know the flow characteristics like rise and fall of water level, time of occurrence of the peak values of water level, velocity and discharge that would help to get an idea on the indication of flood. The specific objective of the study is to observe the seasonal variations of hydrodynamic parameters like water level, discharge and velocity in pre-monsoon, monsoon and post monsoon seasons of Balu, Shitalakhya, Turag, Buriganga and Dhaleshwari rivers those encircle the Dhaka metropolitan area. This study will represent the variation of discharge, stage & velocity of the rivers encompassing the Dhaka city. Also these hydrodynamic parameters will be highlighted for wet and dry season. The Specific Objectives of the Study are:

- ✓ To Setup a hydrodynamic model of Dhaka peripheral river system in HECRAS 1D
- ✓ To perform Calibration and Validation of the river system.
- ✓ To perform analyses on seasonal variation of flow field and water level in the river system

This paper is organized in six sections. It begins with the "Introduction" in which the background and the objectives of this study are discussed. Extent selected for the hydrodynamic model of Dhaka peripheral river network has presented in Section 2 "Study area". Data collection, model schematization, calibration and validation of the hydro dynamic model have been discussed in the section 3 "Methodology". Section 4 "Result and discussion" focused on the seasonal variation of stage and discharge at Dhaka peripheral rivers. Velocity distribution profiles for maximum flow and minimum flow at Dhaka peripheral rivers have also included. This section ends with a table representing the maximum & minimum values of the hydro-dynamic parameters of Dhaka peripheral rivers and observations from the result. In section 5 "Conclusion and recommendation", the significance of this study has been discussed and recommendation for prospective study has made as well in which the findings of this study could be used.

2 Study Area

The study area covers about 111 km length of river system encompassing the Dhaka city. In this work mid to lower reach of Balu river , Shitalakhya river , Turag river and Dhaleshwari river and full reach of Buriganga river and Tongi Khal creating the Dhaka river peripheral river system have been selected as the study area as shown in Figure 1. Intermediate locations named as Dhaka mil Barrack (SW 42) in Buriganga river and Tongi (SW 299) of Tongi khal have been selected for calibration and validation purpose. Figure 1 shows the map of the study area.

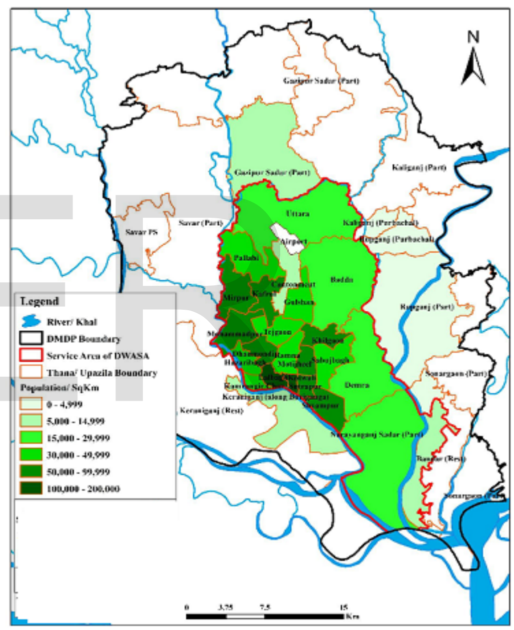

Figure 1: Map of the study area

3 Methodology

3.1 Data Collection

Data on Bathymetry, discharge and stage of Dhaka peripheral river network from the year 2014 to 2016 have been collected from Bangladesh Water Development Board (BWDB) and previous studies as shown in Table 1.

Table 1: List of Location where data have been collected

River	Station
Turag	Kaliakoir, Mirpur
Buriganga	Dhaka mill barrack, Hariharpara
Dhaleshwari	Jagir Dhaleshwari, Kalatia, Rekabi bazaar, Kalagachia
Shitalakhya	Ghorashal, Demra, Fatulla

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Balu	Pubali, Demra
Tongi canal	Tongi

3.2 Model Schematization

The x and y coordinate of the collected bathymetry data were plotted in Arc-GIS to determine downstream reach lengths for the pre-processing of the bathymetric setup. A 1D numerical model for Dhaka peripheral river network was developed in HEC-RAS with the help of Hydrological Station Network map from BWDB. The intersecting points between two rivers were defined as junctions. Manning's n value, Main channel bank stations, contraction and expansion coefficients were specified for the simulation. Flow hydrograph in four upstream stations named as Kaliakoir in Turag, Jagir in Dhaleshwari, Pubail in Balu and Ghorashal in Shitakhaya and stage hydrograph in one downstream station named as Kalagachia in Dhaleshwari river were introduced as the boundary conditions. Initial conditions were specified in the upstream of each reach for unsteady flow simulation as well. Figure 2 shows the schematic plot of the bathymetry of the river network shown in HECRAS.

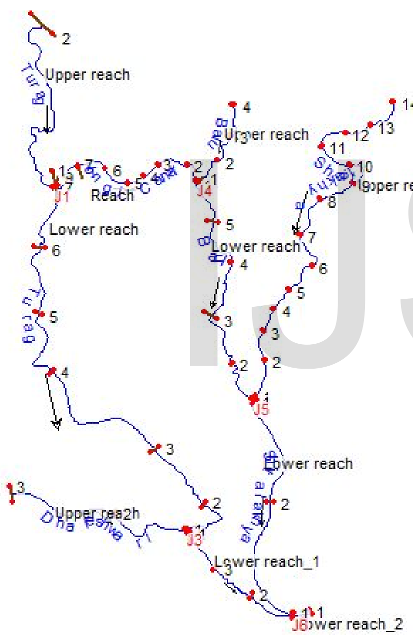

Figure 2 : Schematic plot of bathymetry of the river network in HECRAS

3.3 Calibration and Validation

Calibration shows the matching of simulated water level obtained as model output with the observed water level data by measurement from a gauge confirming similar data is produced by the model as existing in real life. After complete model simulation, simulated results shows water level data for different observation points and in this case we had 2 observation stations namely Dhaka Mil barrack in Buriganga river and Tongi in Tongi khal. Graphs are generated showing comparison between the observed and simulated data. To calibrate the model simulated stage hydrographs were compared with observed stage hydrographs at station Tongi and Dhaka Mill Barrack for the month of June in 2016 and to validate the values were compared for the month of July, 2016 using Manning's n value as tuning parameter. After several trial of the manning's roughness coefficient during calibration, the model showed good match with observed data for an average value of n=0.025.Validation results show good agreement with the calibration results as well. Figure 3 shows the calibration hydrograph at Dhaka Mill Barrack in Buriganga river.

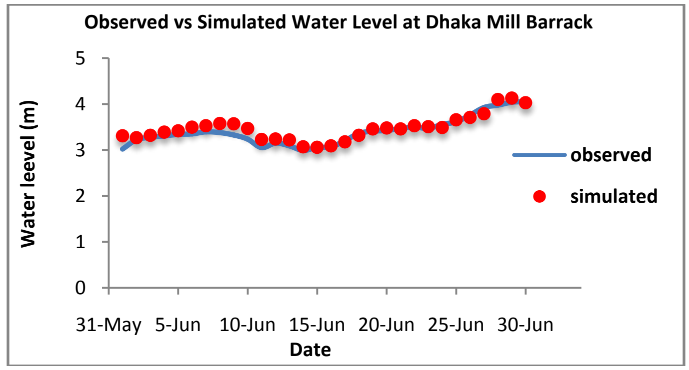

Figure 3: Calibration hydrograph at Dhaka Mill Barrack in Buriganga river

3 Results and Discussions

According to the climate of the world, wet season and dry season has been considered from 1st June to 31th October and from 1st November to 28th February respectively. Here the stage and discharge of year 2016 of four major rivers encompassing the Dhaka city i.e. Turag, Buriganga, Shitalakhya and Balu have been presented. The velocity distribution profile for maximum flow and minimum flow for these four rivers are presented as well to highlight the time of peak flow.

3.1 Variation of stage and discharge

The time series plot of stages and discharges at different specified location of the Dhaka peripheral river network have been prepared to analyze the spatial and temporal variation of the parameters. The time series plot of stage and discharge at different locations of Turag river have been shown in Figure 4 (a) and (b). In Turag, the average water level varies from 3.30 m to 5.26 m in wet period and the maximum water level is observed in the first week of August. In dry period, it varies from 1.72 m to 2.63 m and the minimum water level is observed in the first week of January. From similar time series plot of stage of Buriganga river it has been found that the average water level varies from 3.41 m to 5.12 m and from 1.72 m to 2.63 m in wet and dry period respectively. In wet period, the average water level varies from 3.30 m to 5.32 m and in dry period, the average water level varies from 1.82 m to 3.02 m for Shitalakhya. In case of Balu river, the average water level varies from 3.53 m to 5.25 m in wet and in dry period it varied from 1.78 m to 3.25 m. The maximum and minimum water level are observed in the first week of August and in the first week of January respectively for each river. The average discharge of Turag varies from 324.74 m^3/s to 693.77 m^3/s in wet period and the maximum discharge is observed in the first week of August. In dry period, it varies from 12.85 m^3/s to 150.59 m^3/s and the minimum discharge is observed in the first week of January. For Buriganga, the average discharge varies from 543.22 m^3/s to 1790.55 m^3/s and from 30.99 m^3/s to 305.15 m^3/s in wet period and dry period respectively. Figure 4(b) represents the time series plot of discharge at different locations of Turag river. In wet period, the average discharge varies from 440.62 m^3/s to 1787.81 m^3/s and in dry period, the average discharge varies from 67.87 m^3/s to 361.66 m^3/s for Shitalakhya. In Balu, the average discharge varies from 107.31 m^3/s to 239.69 m^3/s in wet period and in dry period it varies from 9.66 m^3/s to 81.16 m^3/s. The maximum discharge and the minimum discharge are observed in the first week of August and in the first week of January respectively for each river.

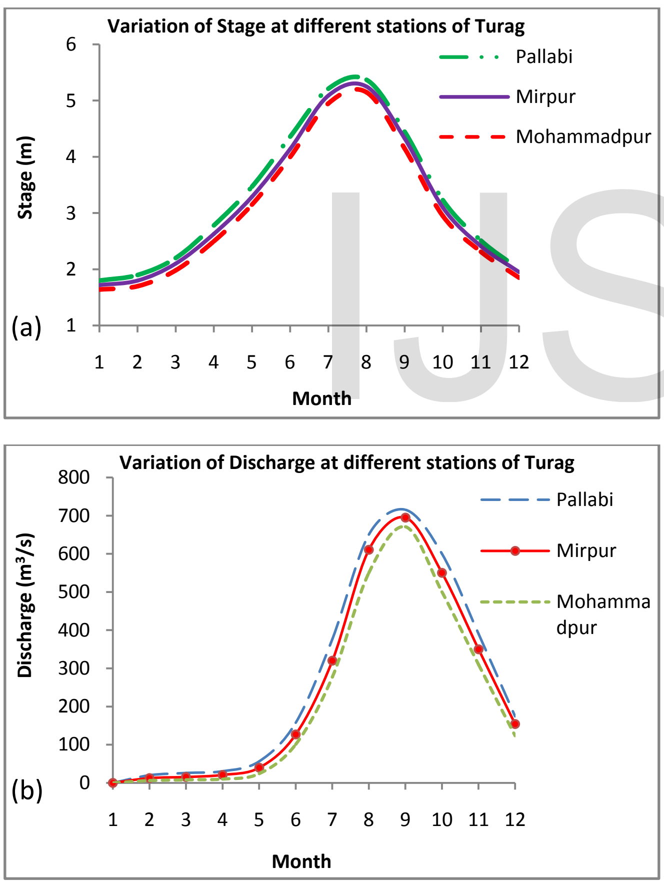

Figure 4: (a) Variation of stage in Turag River (b) Discharge in Turag River

3.2 Variation of Velocity

Cross-sectional velocity distribution for maximum flow in Dhaka peripheral river network have been exported form the HECRAS model domain to analyze the existing flow field. Figure 5(a) and Figure 5(b) represent the cross-sectional velocity distribution for maximum flow in Turag and Buriganga. The average velocity in wet period for Turag varies from 0.48 m/s to 0.89 m/s, 0.21 m/s to 0.85 m/s for Buriganga, 0.40 m/s to 1.62 m/s for Shitalakhya and 0.10 m/s to 0.61 m/s for Balu. Velocity of flow decreases downstream as river slope generally decreases in a downstream direction [16]. Analysis on spatial variation of velocity showed good agreement with the statement stated above. Temporal analysis on velocity throughout the year showed that in dry period, the average velocity become almost 0 m/s for Turag, Buriganga, Shitalakhya and Balu.

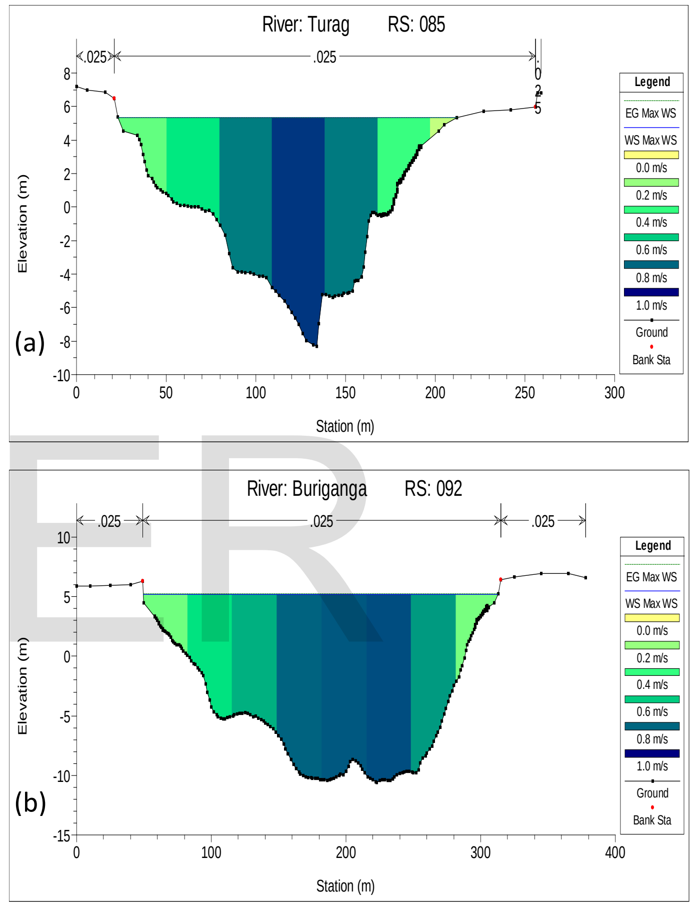

Figure 5: Velocity distribution profile for maximum flow in (a) Turag River (b) Buriganga River

3.3 Comparison on Stage, Velocity and Discharge in Dry and Wet Season for Existing and Hypothetical Flow Scenario

The 1D hydrodynamic model has been analyzed for existing flow condition, 15% and 30% decrement of flow and the resultant maximum and minimum values of the hydrodynamic parameters of Dhaka peripheral rivers are shown in Table 2, Table 3 and Table 4. To compare the maximum and minimum values of the hydrodynamic parameters of the present flow with the 15% and 30% decremented flow, column charts have been plotted. Figure 6(a) represents that, the water level in the peripheral rivers decrease by 15% and 30% when the flow is decreased by 15%

and 30% respectively. Figure 6(b) and (c) represent the decrement of discharge and velocity for almost 15% and 30% for the flow decrement of 15% and 30%.

Table 2: Maximum and minimum values of the hydrodynamic parameters of Dhaka peripheral rivers

Name of River		Stage (m)	Discharge (m^3/s)	Velocity (m/s)
Turag	max	5.37	715.37	0.89
	min	1.64	5.85	0
Buriganga	max	5.27	1948.82	0.85
	min	1.68	8.19	0
Shitalakhya	max	5.6	2019.24	1.62
	min	1.8	48.46	0.02
Balu	max	5.46	247.2	0.61
	min	1.7	5.43	0.02

Table 3: Maximum and minimum values of the hydrodynamic parameters of Dhaka peripheral rivers for 15% decrement of upstream flow

Name of River		Stage (m)	Discharge (m^3/s)	Velocity (m/s)
Turag	max	4.56	608.06	0.77
	min	1.39	4.97	0
Buriganga	max	4.48	1656.50	0.72
	min	1.43	6.96	0
Shitalakhya	max	4.76	1716.35	1.45
	min	1.53	41.19	0.01
Balu	max	4.64	210.12	0.53
	min	1.45	4.62	0.01

Table 4: Maximum and minimum values of the hydrodynamic parameters of Dhaka peripheral rivers for 30% decrement of upstream flow

Name of River		Stage (m)	Discharge (m^3/s)	Velocity (m/s)
Turag	max	3.76	500.759	0.63
	min	1.15	4.095	0
Buriganga	max	3.69	1364.174	0.59
	min	1.18	5.733	0
Shitalakhya	max	3.92	1413.468	1.25
	min	1.26	33.922	0.01
Balu	max	3.82	173.04	0.44
	min	1.19	3.801	0.02

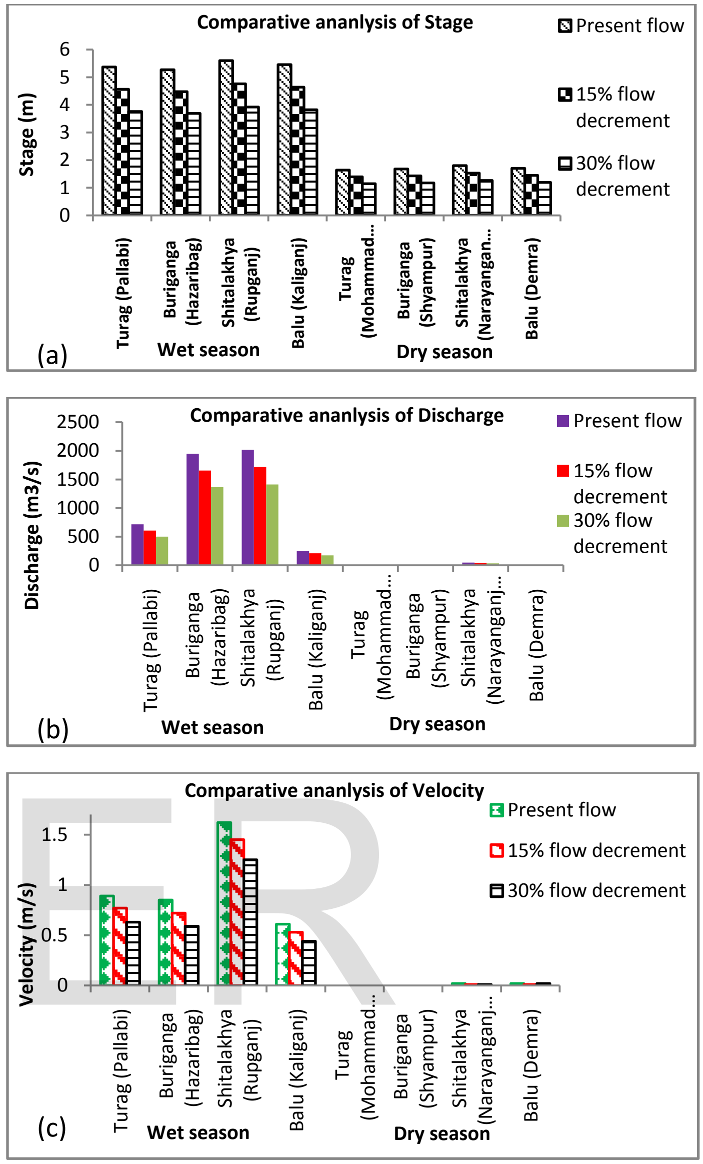

Figure 6: Comparative analysis on hydrodynamic parameters (a) Stage (b) Discharge (c) Velocity

Overall findings of the study on hydrodynamic parameters of Dhaka peripheral river network can be summarized as follows-

- From the Stage Hydrographs it can be observed that, in each river, the maximum stage occur in August and the minimum stage occur in January.
- From the Flow Hydrographs it can be observed that, in each river, the maximum discharge occur in August and the minimum discharge occur in January.
- From the velocity distribution profile it can be observed that, the maximum velocities vary from 0.60 m/s to 0.90 m/s for Turag, Buriganga and Balu. The maximum velocity of Shitalakhya is 1.62 m/s. The minimum velocity is almost 0 for all rivers in January.
- Shitalakhya have the highest stage, discharge & velocity due to the lateral inflow from Balu at Demra station.

4 Conclusion and Recommendation

In this study, unsteady flow analysis has been done to show the variation of stage, discharge and velocity of the rivers surrounded the Dhaka city for wet and dry season. Several studies have been done to understand the yearly variation of hydro-morphodynamic behavior of the rivers of Bangladesh. An overall idea about the maximum and minimum flow and also the month in which it occur has been highlighted. The time of occurrence of the maximum flow helps to get the idea about inundation whereas, the time of occurrence of the minimum flow helps to get the idea about draught. From the velocity distribution it can be seen that, though the velocity of the rivers in the wet season is satisfactory to maintain the ecological balance, but in dry season it become 0. Thus the health of the river is deteriorating day by day in a devastating manner. Future studies to augment the flow of Dhaka peripheral system to maintain the ecological balance can be done base on the finding of this study.

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