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Assessment of Water Logging and Planning of Drainage Improvement Measures using Mathematical Modelling Tools for Selected Coastal Polder of Bangladesh

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Abstract:*This research work was conducted to assess the water logging problem for a selected coastal polder namely 17/1 of district Khulna (Dumuria upazila) in the South-West region of Bangladesh. Authors evaluated the vulnerabilities of the existing situation of this polder with changing climate scenario of IPCC 2014 fifth assessment report.Also evaluated the effectiveness of different planned interventions such as re-excavation of internal khals, dredging of Peripheral Rivers, and introducing pumping system against water logging problem applying as different scenarios. Google images, river bathymetry, water level and discharge, precipitation and evaporation data were collected from different sources and incorporated in the developed Polder 17/1 drainage model.Polder 17/1 has been experiencing severe water-logging problem over the years because of high rate of sedimentation in the peripheral rivers and internal drainage khals. It severely affects the social and economic activities of the people of the study area. The drainage system of the study area includesGangril, Haria, Taltola, Bhadra and Salta Rivers along with a vast network of internal drainage khals. These entire river systems and the drainage structures have been severely silted up by the incoming silt from the sea with high tide and lost its drainage capacity severely which leads to no drainage condition through the existing structures of the polders. This investigation is made by preparing flood inundation depth maps for 3-day duration maximum water level considering 5-days cumulative rainfall by showing the area of different land classes (F0, F1, F2, F3 and F4) using model results and available Digital Elevation Model (DEM) of the study area.*

Inundationdepth of Polder 17/1 shows the significant changes due to addition of some interventions and gives the maximum flood free area increased from base condition 17.26% to 69.96% in the final option under critical climate change condition. As the internal khal systems are sedimented and gravitation drainage capacity reduced significantly, pump drainage at the low depression area can be a suitable option in future.In this research, pump drainage has beentested and got better understanding which has been described later.

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I. Introduction

Bangladesh is one of the most vulnerable countries that are facing the early impacts of climate change. The country is most vulnerable to the natural catastrophes (drainage congestion, fresh water scarcity in dry season, inundation of land at monsoon and unsteady morphological processes) which are severe at coastal region. However, natural disaster will be more severe in the near future, due to impact of climate change. The study area lies in the south-western coastal belt of Bangladesh under Khulna district, is a unique brackish water ecosystem comprising the districts of Satkhira, Khulna, Bagerhat and the southern part of Jessore. Coastal area of Bangladesh is already protected by coastal embankment called polders. There are 139 embanked polders in the coastal area (BWDB, 2012), which were constructed in the late sixties to protect the land from tidal and monsoon flooding and saline water intrusion focusing on increase the crop production. Height of all these polders varies between 3m to 7m (IWM, 2005 and Rahman et al. 2007). About 11,915 km2 in the coastal area is protected by coastal polders (MES II, 2001). IWM and CEGIS (2007) have studied that about 25 polders in the southwest region would experience severe drainage congestion due to 62 cm SLR.

Continuing process of sedimentation over the years, many of the rivers/channels/canals in the area lost its conveyance causing severe drainage congestion. Inundation problem will more severe due to heavy rainfall event and sea level rise.In this research work, numerical model has been applied to assess the impact of SLR and precipitation change due to climate change scenario with water logging problem in the selected coastal polder 17/1 and assess the effectiveness of different drainage improvement options.

II. Material And Methods

Study Area: The study area is located in the Southwest Coastal region of Bangladesh. This study mainly focuses on the drainage problem of polder 17/1. Construction of Polder-17/1 was started in1969 and completed in 1971 under Coastal Embankment Project. The Polder is located in Upazila Dumuria under Khulna District. The Polder covers the Union Parishads (U/P), namely Magurkhal, Shouna and Atlia. The polder is bounded by Salta and Taltola to the west and North, Gangrail and Bhadra River to the East and South. The study area map is shown in Figure 1.

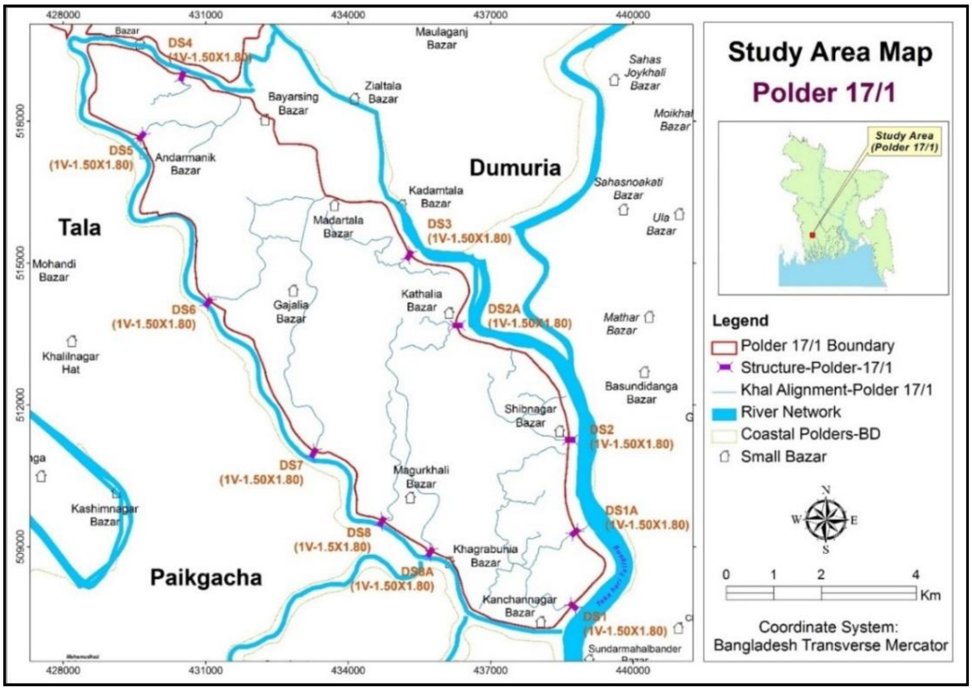

Figure 1: Study area map

Methodology and Data Collection: The existing one-dimensional hydrodynamic model (SWRM) of IWM for south-west region of Bangladesh was used in this study. Again, a dedicated one-dimensional hydrodynamic model was developed under this study focusing on Polder 17/1 to assess the existing water logging situation of this polder. River bathymetry, water level discharge and other data was collected from different secondary sources to develop and upgrade the model. Climate change projection on sea level rise, precipitation and other parameters were derived based on IPCC 5th assessment report and literature review. Different drainage improvement interventions like river and khal excavation, and introduce pump system was tested in the model to assess the effectiveness of different drainage improvement options.

Establishment of Climate change projection: Future projection is made on hydrological parameter; precipitation, evaporation and sea level rise based on IPCC 5th Assessment Report.
Projection on Precipitation: Assessment Report 5 of IPCC has provided the projections on temperature, precipitation and sea level rise for the latest fourclimate change scenarios in global and regional scale. The projection in global and regional scale is not wise to use for coastal area of Bangladesh. The present study used the projections based on statistical downscaling for the coastal area through literature review. For the current study, projections on precipitation were established based on the World Bank report (20-13). Temperature and Rainfall projections are based on downscaling of 15 GCM models at three coastal zones.

Table 1: Precipitation projection for 2050

West coastal zone Rainfall	
Month	% change
May	3.06
June	1.05
July	15.75
August	16.08
September	22.47
October	14.46

(Source: IWM, 2015)

Recommended Land Subsidence: It is very difficult to measure the land subsidence directly, butthere are several ways to do so indirectly. Three archaeological monuments have been selected in the tidal plains for assessing the rate of land subsidence, which can provide a very good indication about the range of subsidence for quite a longer period than reflecting short-term perturbations. In this thesis, 4mm/yr land subsidence has been considered to calculate the Relative Sea Level Rise (RSLR).

*Calculation on Relative Sea Level Rise:*In this study, Syvitski et al., (2009) formula is used for calculating the relative sea level rise. According to the Syvitski et al., (2009), relative mean sea is determined considering the contributions of global mean sea level, subsidence, sedimentation and tectonic movement.

$\Delta RSL = A - \Delta E - CN - CA \pm M$

Where,A = delta Aggradation Rate; ΔE = global sea level rise/ (eustatic sea-level); CN = Natural compaction (CN); CA = Accelerated compaction (CA) of deltaic deposit and M= Vertical land surface movement (plate tectonic).

If only the vertical land elevation change is considered, the equation can be simplified as, $\Delta RSL = \Delta E + C - A$

Estimation of the relative mean sea level using Syvitski's law 2009 was established for 2050 with respect to base year 2012 (Scenario: RCP 8.5).

Global sea level rise at Bay of Bengal in 2050 is 33 cm.

Land subsidence rate = 4 mm/year (Higgins et el. 2014)

Sedimentation rate = 2 mm/year (Syvitski et al, 2009)

Relative mean sea level rise = 33 cm+ (2050-2012) year * (4-2) mm/year = 40.6 cm ≈ 41 cm

The calculated relative mean sea level rise (41 cm) is used at the downstream boundary of the south-west regional model for the development of the future climate condition.

Data Collection: The Data has been collected from different sources which are listed in Table 2.

Table 2: Data type and source of collected data

Data Type	Source
Discharge (Q), Water Level (WL)	BWDB, BIWTA
Meteorological data (Temperature, Rainfall)	BMD
Topographic Information	IWM Survey
Structure Information	IWM Survey
Satellite Images	USGS
River Bathymetry	BWDB

Hydrological Analysis and Selection of Design Flood Event: Hydrological analysis on historical rainfall data in the study and surrounding areas has been carried out to identify the design flood event for the drainage study. The study area influenced by the rainfall station Dumuria, Kapilmuni, PaikgachaandNalianala. The influence of these rainfall stations has been made by generating the Theisen Polygon. According to the Theisen polygon analysis considering the four rainfall stations, Dumuria covers 57% of the study area where Kapilmuni, Keshobpur and Islamkati covers about 23%, 17% and 3% respectively. Considering the influence and availability of data a Five days (05) cumulative historical rainfall data of Dumuria, Kapilmuni, Keshobpur and Islamkati stations has been used for the analysis.About 29 years (from 1985 to 2013) rainfall data has been considered for the statistical analysis. For the statistical analysis, Gumbel, Log Normal and Log Pearson Type III distribution method have been used. As most of the study area is influenced by the Dumuria rainfall station so, the rainfall of Dumuria is considered for the final analysis. The rainfall hyetograph of Dumuria station is shown in Figure 2.

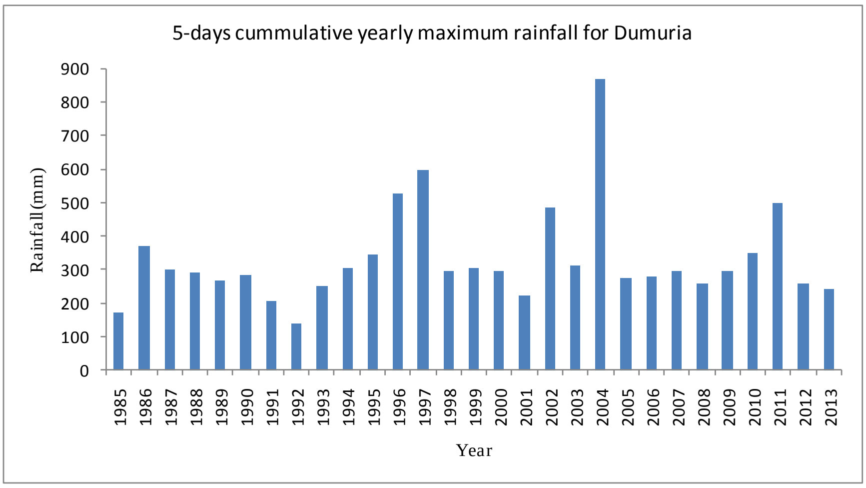

Figure 2: Annual maximum 5-day cumulative maximum rainfall at Dumuria station

Table3: Statistical distribution of 5-day cumulative rainfall for Dumuria

	Return Period [years]	Log Normal/MOM	Gumbel/MOM	Log Pearson Type 3/MOM/LOG
Estimated quantile	2.33	329	332	312
	10	496	523	507
	20	568	606	614
	25	590	632	651
	50	661	712	777
	100	731	792	921
Goodness-of-fit statistics	CHISQ	5.31	9.45	11.52
	KS	0.21	0.21	0.15

It is seen that Chi-Square values is smaller in Log Normal distribution than the other methods for all rainfall station data analysis. Lower standard deviation is also found for the Log Normal distribution method. So, Log Normal distribution has been selected for the further statistical analysis.

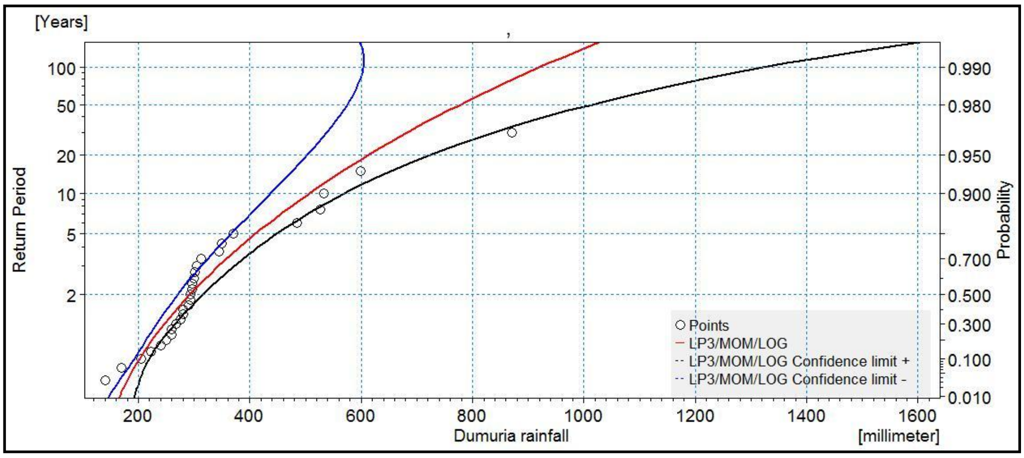

Figure 3: Frequency analysis for Dumuria rainfall station by Log Normal Distribution

Ten (10) years return period has been selected to observe the drainage condition of the selected polder area.

Table4: Statistical Analysis result and selected simulation year

Polder ID	Rainfall Station	Method of Analysis	Rainfall in mm	Coincident Year
			1 in 10 Yr	1 in 10 Yr
Polder 17/1	Dumuria	Log Normal	496	2011 (498)
		Gumbel Method	523	
		Log Pearson Type-III	507	
	Kapilmuni	Log Normal	440	2011(425)
		Gumbel Method	475	
		Log Pearson Type-III	451	
	Keshabpur	Log Normal	324	2006 (324)

		Gumbel Method	330	
		Log Pearson Type-III	329	

Frequency analysis shows 10-year return period rainfall is about 496 mm of Dumuria station in Log-Normal distribution. It is also found that year 2011 has the value of 498 mm for Dumuria station. Based on frequency analysis result of 5 rainfall stations in this area the hydrological year 2011 has been selected as design flood event and the Rainfall-Runoff model and polder drainage model has been simulated for the year 2011 for assessing the drainage performance of the study area and effectiveness of the potential improvement options.

III. Mathematical Model Setup

Hydrological (Rainfall-Runoff) model: Rainfall Runoff Model is applied to estimate the runoff generated from rainfall occurring in the catchment. The model takes into consideration the basin characteristics including specific yield, initial soil moisture contents and initial ground water level and irrigation/abstraction from the surface or ground water sources. The catchments of the rainfall runoff model are delineated according to the topographic barriers/water shed boundaries, roads and river networks. According to the findings of the hydrological analysis rainfall-runoff model has been carried out for the year 2011(1in 10 year) for extreme flood event study. Finally, this model result has been used in the Hydrodynamic model as an input file for generating the runoff according to catchment-wise.

Drainage Model: The existing calibrated and validated One-Dimensional hydrodynamic model (South West Regional Model) of IWM has been used for drainage study which covers the entire area lying to the south of the Ganges and west of the Meghna estuary. Further, a dedicated drainage model has been developed focusing on polder 17/1 in order to investigate the adequacy and performance of the existing structures and drainage systems and potential drainage improvement interventions. The south-west regional model has been simulated for different hydrological year to generate the boundary conditions for the dedicated drainage model.

The dedicated Drainage model has been simulated by taking the peripheral river network, drainage canal system, catchment area for each of the drainage channels and drainage sluices of Polder no. 17/1. At upstream of the model, water flow boundary and at downstream, water level has been applied as boundary. The schematic diagram of the dedicated drainage model is given in the Figure 4.

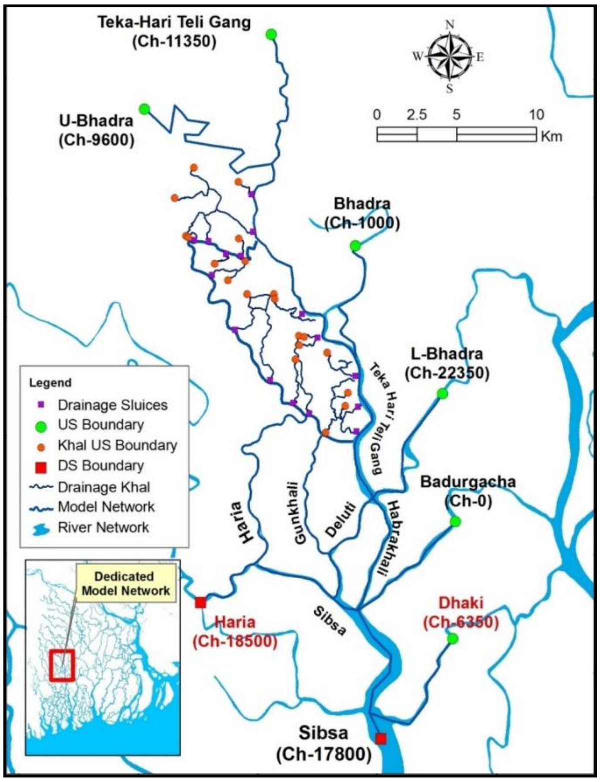

Figure 4: The schematic diagram of Drainage model for Polder 17/1

Boundary Conditions of Drainage Model: Year2012 has been selected as Base year and 2011 has been selected as hydrological design year. At first South-West, regional model has been simulated for generating the boundary for 2012. After calibration and validation, the base model set-up has been simulated for the design year 2011. Then the boundary condition of the newly developed dedicated drainage model has been extracted from the simulation of south west regional model for hydrological design year 2011.

Climate change projection has been applied into the downstream water level time series data, upstream rated time series data. About 41 cm sea level has been added into the downstream water level data and increase of flow of Ganges with 16% -28%, Brahmaputra with 8.5 % to 18.5% and Upper Meghna with 8% to 11% during May to November also been added into upstream discharge time series data.The drainage model of Polder 17/1 contains total 8 boundaries, of which 6 are upstream and 2 are downstream boundaries. After simulation of south-west regional model, time series water and discharge data has been extracted from south-west regional model result for generating the boundary data for the dedicated polder model.

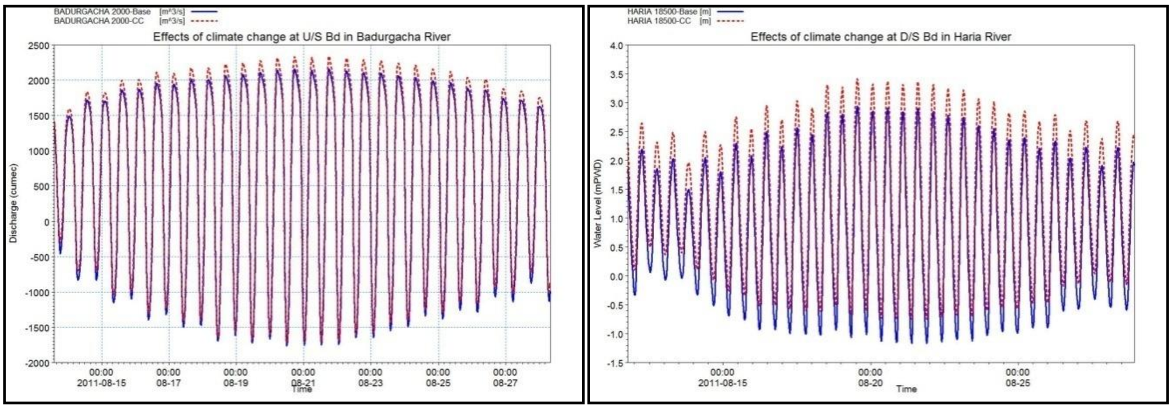

Figure 5: Climate change effects at the upstream discharge data in BadurgachaRiver (left) and downstream water level data in HariaRiver (right)

In the process of catchment delineation single or multiple channels are grouped together to form a single hydrological unit which drained through a single structure. Delineation of catchments area has been done on the basis of Land level data of the polder, alignment of existing khals, hydraulic structures, and other topographical features including road networks and Satellite Images.

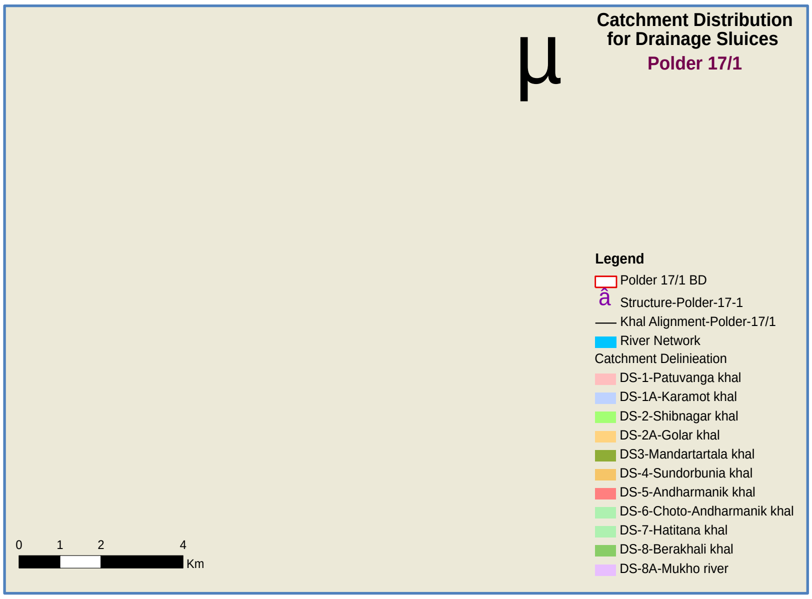

Figure 6: Delineated catchment of poldere 17/1

Calibration of the Dedicated Water-Flow Model: Channel roughness (Manning's M is the inverse of Manning's n) is the controlling calibration parameter of water-flow model. The calibration of the Polder Drainage Model is done by comparing the simulated water level and discharge with observed values of Upper-

Bhadra and Haria River. Calibration location of the water level and discharge is shown in the Figure 7. The calibration plot for water level and the calibration plot for discharge is presented in Figure 8. From the above listed figures, it is revealed that the simulated result matched well with the observed values for both water level and discharge.The dedicated water-flow model is also validated with the measured water level and discharge. Validation of the drainage model is done for the year 2009, only changing the upstream and downstream boundary and remaining the same modelling parameter. The water level and discharge validation in Teka Hari Teli Gang is presented in Figure9.

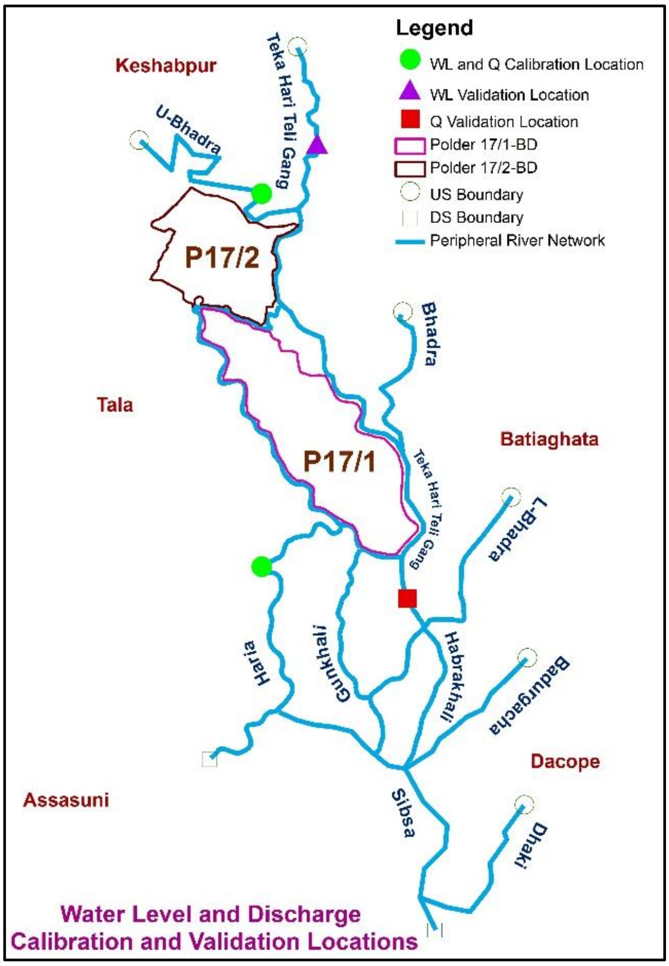

Figure 7: Water Level and Discharge calibration locations

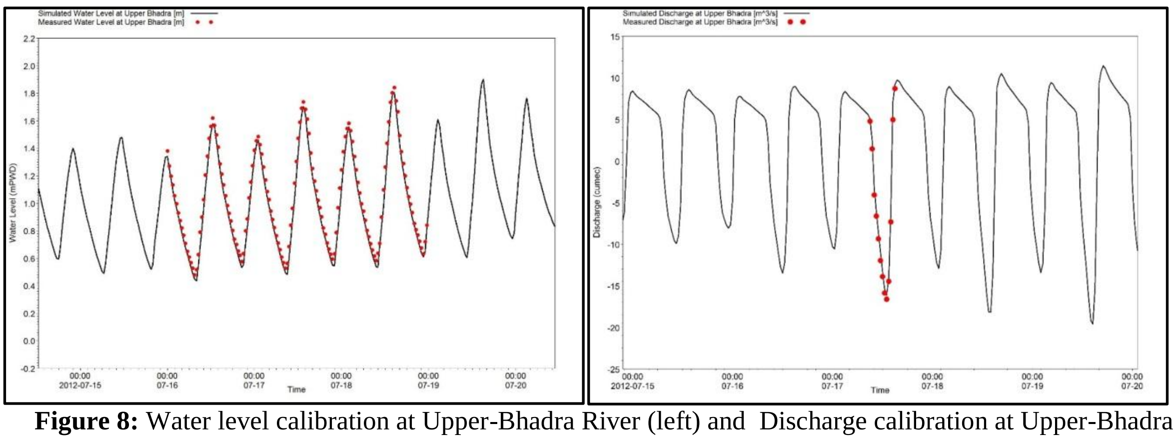

Figure 8: Water level calibration at Upper-Bhadra River (left) and Discharge calibration at Upper-Bhadra River (right)

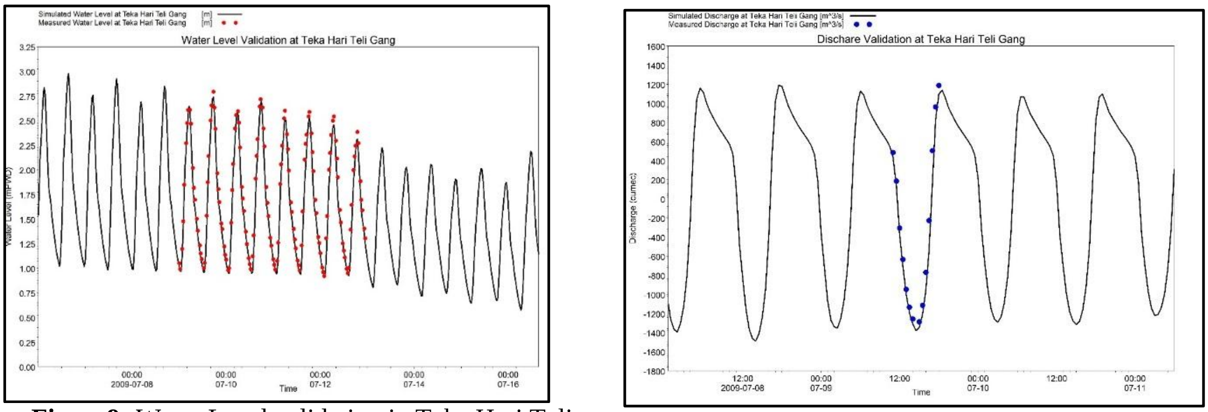

Figure9: Water Level validation in Teka Hari Teli Gang River and Water flow validation in Teka Hari Teli Gang River

IV. Results AndDiscussions

Inundation depth for the existing condition of polder drainage system is developed for assessing water logging condition considering the future climate condition. Then projected scenarios have been developed for removing the present condition and build climate resilient polder system. The drainage performance/effectiveness of each option is evaluated in terms of 1.)Decrease of flood, 2.) Decrease inundation area and 3.) Decrease of water depth of the polder area (land classification) compared to the existing condition. This investigation is made by preparing flood inundation depth maps for 3-day duration maximum water level.

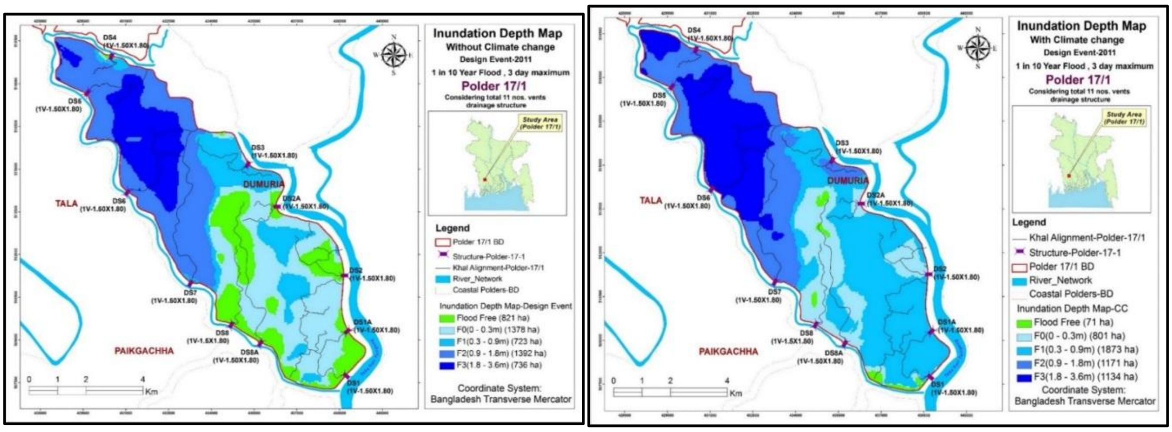

Figure 9: Inundation depth map of polder 17/1 for 3-days duration and land class during designyear considering without climate change (left) and with climate change condition (right)

Table 5: Inundated area for existing drainage condition for with and without climate change

Condition	%Inundated Area of Polder 17/1							
	Flood Free	F0 (inundation upto 0.30m)	F1 (inundation 0.3m to 0.9m)	F2 (inundation 0.9m to 1.8m)	F3 (inundation 1.8m to 3.6m)	F4 (inundation >3.6m)	Total (%) (FF and F0)	Total (%) (FF, F0 & F1)
Inundation for existing condition without climate change	16.26%	27.28%	14.32%	27.57%	14.58%	0.00%	43.54%	57.86%
Inundationfor existing condition with climate change	1.40%	15.86%	37.09%	23.19%	22.46%	0.00%	17.26%	54.35%

Improved options: The present condition of the selected polder is vulnerable. Many of the hydraulic structures are fully or partially damaged and are non-functioning due to which internal drainage congestion is prevalent. The other structures, though functional, are in an extremely bad condition. The gates are corroded by saline water and concrete surface of the structures are in a very deplorable condition. There are some places where there are existing khals but no drainage structures are present. The internal drainage channels have become silted up due to lack of maintenance for a long time and the bed level of the peripheral rivers has raised due to lack of fresh water from upland and upward movement of sediment from the sea during the flood tide. Considering the drainage problems, climate change issue, water-logging risk reduction an improvement option has been devised in this study. The devised improved options have been selected as below:

*Sill Level Fixation***:** The invert level/Sill level of the Sluices have been ascertained in the proposed improvement options based on the following criteria;

(i) Average minimum water level of the monsoon period,
(ii) Average ground level of the drainage basin;
(iii) Re-excavated long profile of the drainage channel; and
(iv) Existing sill level.

*Dredging/ Re-excavation of Peripheral Rivers/Khals***:** The overall peripheral river network of the study area has been silted up due to reduction of fresh water flow from upstream and upward movement of tidal water during flood tide, raise the bed level of the surrounding rivers. The critical silted up stretches of Bhadra, Upper Bhadra, Teka Hari Teli Gang, Haria, Gunkhali and peripheral khal of the selected polders need to be excavated to increase the drainage capacity. Drainage improvement measures by re-excavation of internal drainage khals, increase number of vents of the existing drainage structures will not be effective unless the outfall Rivers are made smoothly functional by dredging or excavation.

*Re-excavation of Internal Drainage khals***:** About 33 numbers of internal drainage channels have been excavated by 1m in order to accelerate smooth drainage of the polder area. The channels are excavated by adjusting the invert level of the drainage sluices. Most of the khals have been silted up due to lack of re-excavation works under periodic maintenance. So, all the major and minor internal khals have been proposed for re-excavation to increase drainage and storage facility. The water level condition at the upstream of Andharmanikkhal in polder 17/1 during the dredging condition is shown later.

Development of Improvement Option

<table>
<tr><th>Existing</th><th>Improved Option-1</th><th>Improved Option-2</th><th>Improved Option-3</th></tr>
<tr><td>DS-1(1V-1.50X1.80)</td><td rowspan="11">only sill level modified</td><td>additional 1 no. vent</td><td>additional 1 no. vent</td></tr>
<tr><td>DS-1A(1V-1.5X1.8)</td><td rowspan="3">only sill level modified</td><td rowspan="3">only sill level modified</td></tr>
<tr><td>DS-2(1V-1.5X1.8)</td></tr>
<tr><td>DS-2A(1V-1.5X1.8)</td></tr>
<tr><td>DS-3(1V-1.5X1.8)</td><td>additional 1 no. vent</td><td>additional 1 no. vent</td></tr>
<tr><td>DS-4(1V-1.5X1.8)</td><td>only sill level modified</td><td>additional Pump</td></tr>
<tr><td>DS-5(1V-1.5X1.8)</td><td rowspan="3">additional 1 no. vent</td><td rowspan="3">additional 1 no. vent and pump</td></tr>
<tr><td>DS-6(1V-1.5X1.8)</td></tr>
<tr><td>DS-7(1V-1.5X1.8)</td></tr>
<tr><td>DS-8(1V-1.5X1.8)</td><td>only sill level modified</td><td>only sill level modified</td></tr>
<tr><td>DS-8A(1V-1.5X1.8)</td><td>additional 1 no. vent</td><td>additional 1 no. vent</td></tr>
<tr><td>Internal Drainage Khal Cross Section</td><td>Excavation is made considering the invert level and slope of the khal.</td><td>Excavation is made considering the invert level and slope of the khal.</td><td>Excavation is made considering the invert level and slope of the khal.</td></tr>
<tr><td>Peripheral River Cross Section</td><td>Excavation/Dredging is made considering the longitudinal slope of the river and sedimentation.</td><td>Excavation/Dredging is made considering the longitudinal slope of the river and sedimentation.</td><td>Excavation/Dredging is made considering the longitudinal slope of the river and sedimentation.</td></tr>
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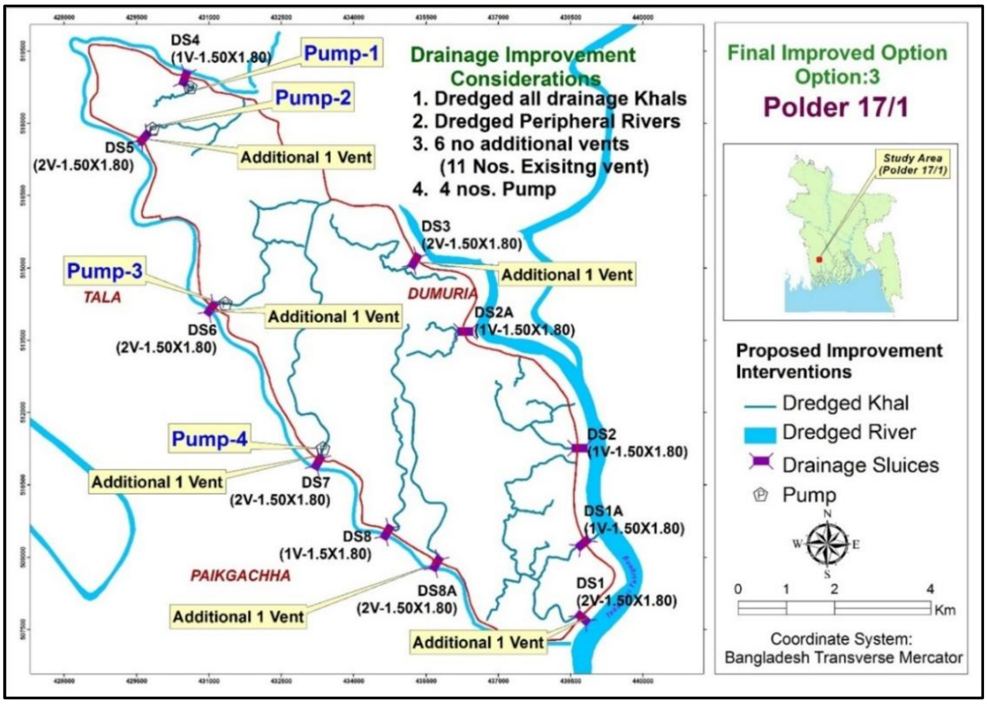

Figure 10: Proposed improvement interventions map for polder 17/1

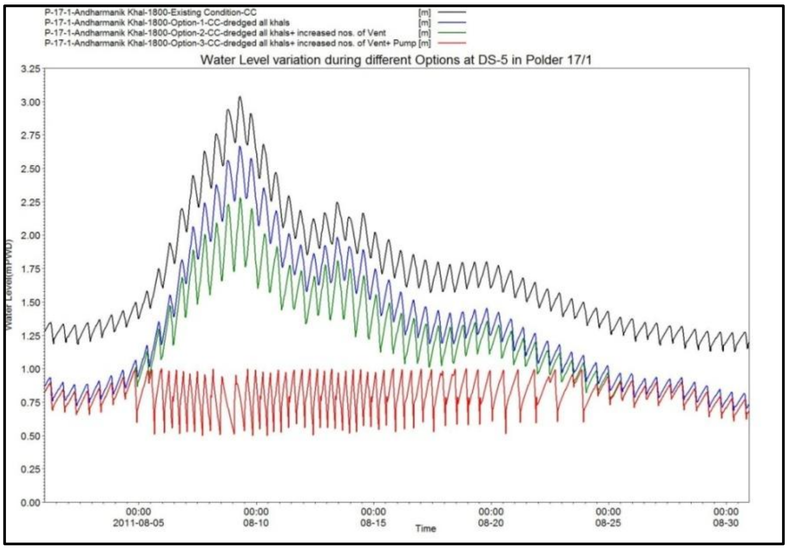

Figure 11: Water level condition at Andharmanik khal in polder-17/1

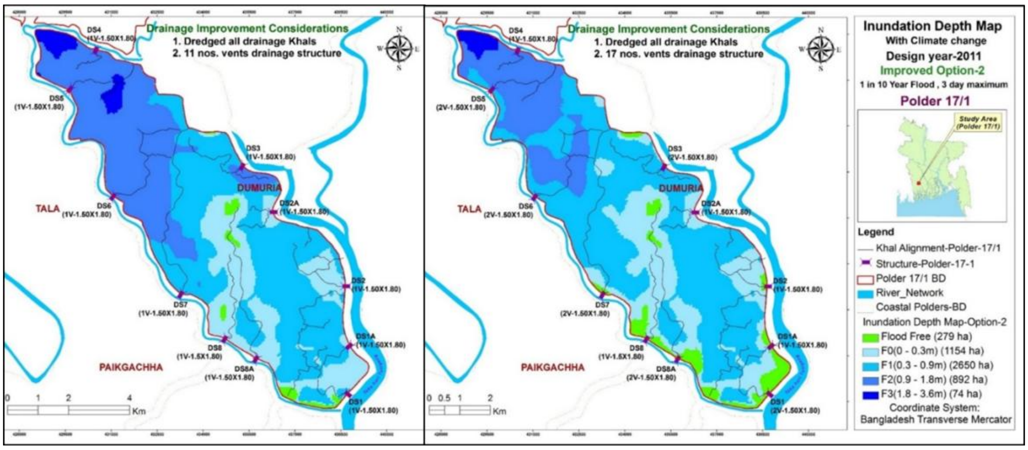

Figure 12: Inundation depth map for polder 17/1 under improved option-1 and 2

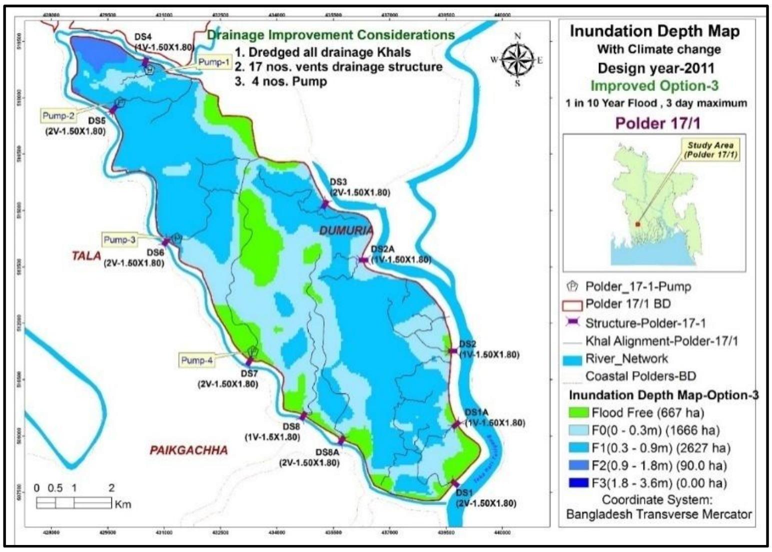

Figure 13: Inundation depth map for polder 17/1 under proposed improved option-3

Table 6: Percentage (%) of inundation under the proposed final improved option of polder 17/1

Existing Condition and Potential Improved Options under climate change condition	% Inundated Area of Polder 17/1							
	Flood Free	F_0 (inundation up to 0.3m)	F_1 (inundation 0.3m to 0.9m)	F_2 (inundation 0.9m to 1.8m)	F_3 (inundation 1.8m to 3.6m)	F_4 (inundation >3.6 m)	Total (%) (FF and F0)	Total (%) (FF, F0 & F1)
Existing Condition and Potential Improved Options under climate change condition	1.40%	15.86%	37.09%	23.19%	22.46%	0.00%	17.26%	54.35%
Option -1	1.61%	20.89%	43.27%	31.44%	2.79%	0.00%	22.50%	65.77%
Option -2	5.53%	22.85%	52.49%	17.67%	1.47%	0.00%	28.37%	80.86%
Option-3	13.21%	32.98%	52.03%	1.77%	0.00%	0.00%	46.20%	98.23%

In this research, sill level fixation, additional vent and additional pumps have been considered. The bed level of the peripheral rivers becomes high due to sedimentation management problem in the study area. Gravitational flow throughout the regulators from the remote place to peripheral River is not possible due to high deposition rate. Therefore, pumping system is added in the polder drainage model for pumping the additional amount of water during the extreme condition. Pumping idea has been devised in this research for removing the additional water level where gravitation flow is not possible. In this research, pumping is applied water level up to 1.0 mPWD and lowest at 0.50 mPWD for getting the highest benefit at extreme climate change condition.

Improved option showing the following results in inundation area percentage in polder 17/1, about 46.20% (option-3) area remains flood free (i.e., flood free and F0 land class). The percentage of Inundation area (inundation depth 0.30m to 0.90m) increases from 37.09% (existing condition) to 43.27% (option-1), 52.49% (option-2) and 52.03% (option-3) In the improved option it is seen that about 98.23% land becomes productive for people movement, agricultural production and fish culture. About 46.20% land area is suitable for people movement and agricultural production.

V. Conclusion And Recommendation

The main task of this study is to assess the drainage problem in the Polder 17/1 and find out the sustainable solutions. Climate change scenario have been considered to analyze the drainage problem and devise the drainage improvement measures. The study area is experiencing severe water logging problem in the existing situation. At present 56.46% of the area is facing severe water logging problem.It is evident that theeffect of climate change will deteriorate the existing drainage situation.Due to impact of climate change the inundation area will be increased by 26.28%.

In near future,thegravity drainage will not be sufficient enough and the alternative option will be application of pumps, which has been devised in this study. Option-1 & option-2 comprised of river/khal re-excavation and modification/redesign of existing drainage structures. Option-3 considered pump drainage in addition to other interventions of option-2.

In option-1 & Option-2 flood free area will be 22.50% & 28.37% for climate change scenario. In option-3 the flood free area increased to 46.20%. Finally, it can be concluded that all of the interventions can be selected for polder management in the South-West Region to mitigate the climate change impact.

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