ASSESSMENT OF DRY SEASON SURFACE WATER AVAILABILITY FOR IRRIGATION IN POLDER 41/1

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SUBMITTED BY

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CERTIFICATION OF APPROVAL

The thesis titled "Assessment of dry season surface water availability for irrigation in polder 41/1" submitted by Asish Sutradhar, Student ID: 0412162061 P, Session April 2012, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of **Master of Engineering in Water Resources Engineering** on 24th March 2018.

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DECLARATION

It is hereby declared that this thesis work or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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BIWTA	Bangladesh Inland Water Transport Authority
BMD	Bangladesh Metrological Department
BWDB	Bangladesh Water Development Board
BUET	Bangladesh University of Engineering and Technology
BTM	Bangladesh Transverse Mercator
CPWF	Challenge for Water and Food
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GOB	Government of Bangladesh
IWM	Institute of Water Modelling
PWD	Public Works Datum

ABSTRACT

Dry season irrigation water scarcity is a major problem in Bangladesh. During the dry period most of the land remains fallow in the coastal area due to saline water intrusion and lack of irrigation water. For the intensification of agricultural production and protection of lives and livelihoods of the coastal communities, 139 polders were implemented in the coastal zone of Bangladesh. In the South-Eastern part of Bangladesh receives plenty of freshwater flow from the Padma and lower Meghna river through Arial Khan, Bishkhali, Buriswar and Lohalia River. As surface water irrigation is considerably less energy demanding than groundwater irrigation, Polder 41/1 has been selected as study area to assess the availability of dry season surface water for irrigation. This polder is situated in Barguna district which is in the eastern part of the southwest region of Bangladesh. Buriswar river is the main source of surface water of this polder. Salinity of this river remains below 2ds/m in all over the year. In this study, dry season irrigation assessed depending on the surface water availability in the canal system of the polder 41/1.

A mathematical model is developed in this study for assessing the water availability in the canal system inside the polder. Command area of existing canal and croplands are identified from existing Digital Elevation Model (DEM) and high-resolution satellite image (Sentinel-2 and Google earth). All the existing canal and regulators are incorporate in the hydrodynamic model of polder 41/1. Irrigation water demand and water withdrawal effects are also determined for each canal. In this study, three scenarios are developed for understanding the water availability at different condition. Scenarios are developed based on the local experience which are 1) regulator control gates are always open without water withdrawal, 2) regulator control gates are always open with water withdrawal and 3) regulator control gates are used as flushing with water withdrawal. The last scenario indicates regulators gates are open when river stage is greater than canal inside the polder and it is closed when river water level is lower than the canal water level. Pumping or water withdrawal from the canals have been considered based on irrigation water requirement for each canal. In this study, daily minimum water depth for 6-hours duration is classified into three categories (water depth 0.00 to 0.50m, 0.50 to 1.0m and water depth >1.0m). It is considered that irrigation is not possible if the water depth is less than 0.50 m.

In the Neap tide, it is observed that for scenario-2, water depth of 39.34km (57%) canal is less than 0.50m or not suitable for irrigation and 29.03km (43%) is greater than 0.50m but in Scenario-3 water depth of 22.61km (33%) canal is less than 0.50m and 46.78km (67%) is greater than 0.50m. In the Spring tide for scenario-2, 6.03km (9%) of khal is less than 0.50m and for scenario-3 water depth is always greater than 0.50m. By operating regulator properly, the depth gets below 0.5m for 1-6 days during the neap tide only. But in case of without operating regulator, 6-hour depth duration is less than 0.5m around 10days to 3 months for both spring tide and neap tide. Irrigation can be hold up to 7-10 days by keeping standing water in the field. It indicates that more irrigation water is available when the gates are properly operated. Considering the schedule for Boro rice is 120 days and days are categorized into different water depth for each canal. It is observed that around 46 days water depth is below 0.50m in Scenario-2 and only 11days in Scenario-3. It indicates that by operating regulator, farmers get more opportunity for irrigation. As water depth is made available inside the polder area, so farmers can easily understand when they have to irrigate in the field. In his regard proper gate operation during high tide will cover more crop area by water withdrawal. Scheduling of irrigation during the spring tide as well as better water management technique will increase the opportunity for irrigation in this polder.

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CHAPTER 1

INTRODUCTION

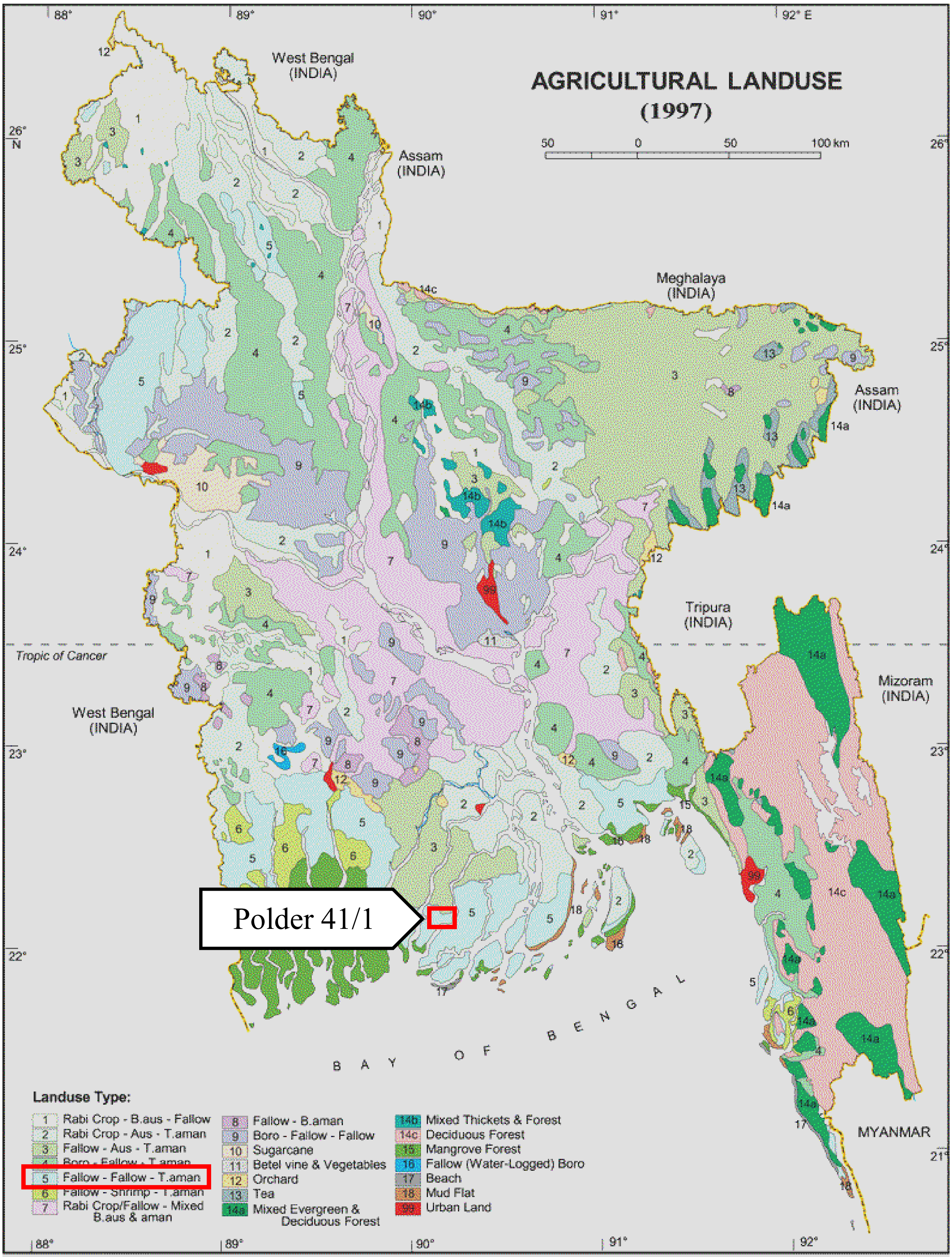
1.1 Background of the study

Agriculture sector in Bangladesh contributes about 19 percent to the country`s Gross Domestic Product (GDP) and provides employment to around 47 percent of total labour force (BBS, 2012). About 84% of the 145 million people of Bangladesh are directly or indirectly engaged in a wide range of agricultural activities (Rahman, 2004). In Bangladesh, about 1.0 million ha of land, most of which remain fallow in the dry season, are affected by varying degrees of salinity (Mondal, 2010). River systems in Bangladesh exhibits high seasonality over a year i.e. abundant of water during the monsoon and scarcity of water during the dry season from December to May. Approximately 1.7 million farming households in this area fallow their land after the monsoon, contributing to food insecurity and subsistence below the poverty line (World Bank, 2010). The availability of water for irrigation is crucial for maintaining the current and future growth in agricultural production (Ahmad et al., 2014).

For intensification of agriculture and protection of lives and livelihoods of the coastal communities, 139 polders were built in the coastal zone of Bangladesh in the late 1960s and early 1970s. A polder is a low-lying land area protected from tidal inundation and salinity intrusion by a peripheral earthen embankment. Coastal part of the south-central zone receives considerable freshwater from the Padma River and the Lower Meghna rivers (Khan et al., 2014). In Barisal area, there is plenty of fresh water throughout the dry season and that investment in irrigation will increase cropping intensity from 1 to 3 crops per year (CPWF, 2013). Water availability throughout the year creates a huge potential of this agro-based ecosystem to cultivate 3 rice crops and enhance rice production. The GoB’s emphasis on Surface water irrigation conversely stems from policy priorities to shift from subsidy- and energy-intensive Groundwater irrigation to less costly production modalities using surface water in the south (MOA and FAO, 2013). Surface Water Irrigation (SWI) is also considerably less energy demanding than groundwater extraction, with a lower carbon foot- print (Shah, 2009). The river with the level of water salinity ≤2dS/m, indicating the use for irrigation. River salinity in the Buriswar river remains low < 2dS/m throughout the year. During the Rabi period in

Barisal, Patuakhali and Barguna district gravity irrigation potentiality is very small, only possible in low areas. However, LLP can be used for irrigation as plenty of water available in the canal. In this regard, Polder-41/1 selected as case study to evaluate water availability within the polder system for the dry period.

This research will have analyzed the water available inside the Polder during the dry season after the withdrawal of water for irrigation purpose from the canal. Observed the opportunity for different regulator operation/Scenario and maximization of surface water use.



Source: *SRDI, 1997*

Figure 1.1: Agricultural Land Use of Bangladesh (Rabi-Kharif 1-Kharif 2)

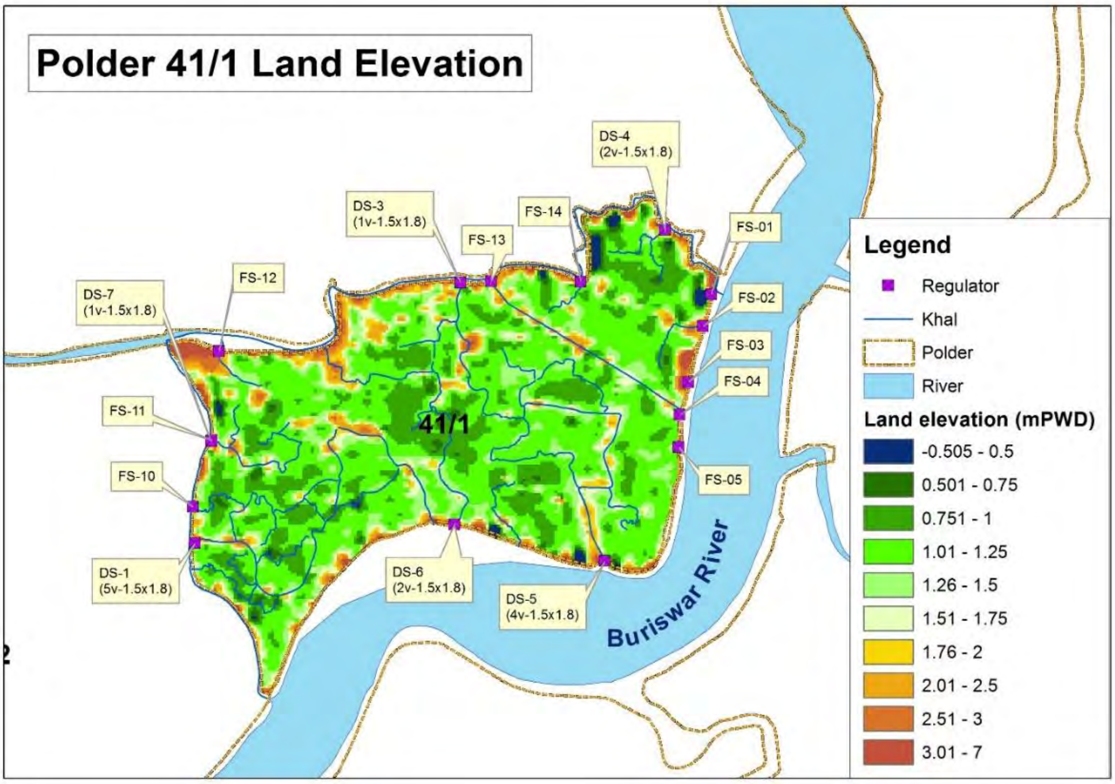


Figure 1.2: Digital Elevation Model (DEM) of Polder 41/1

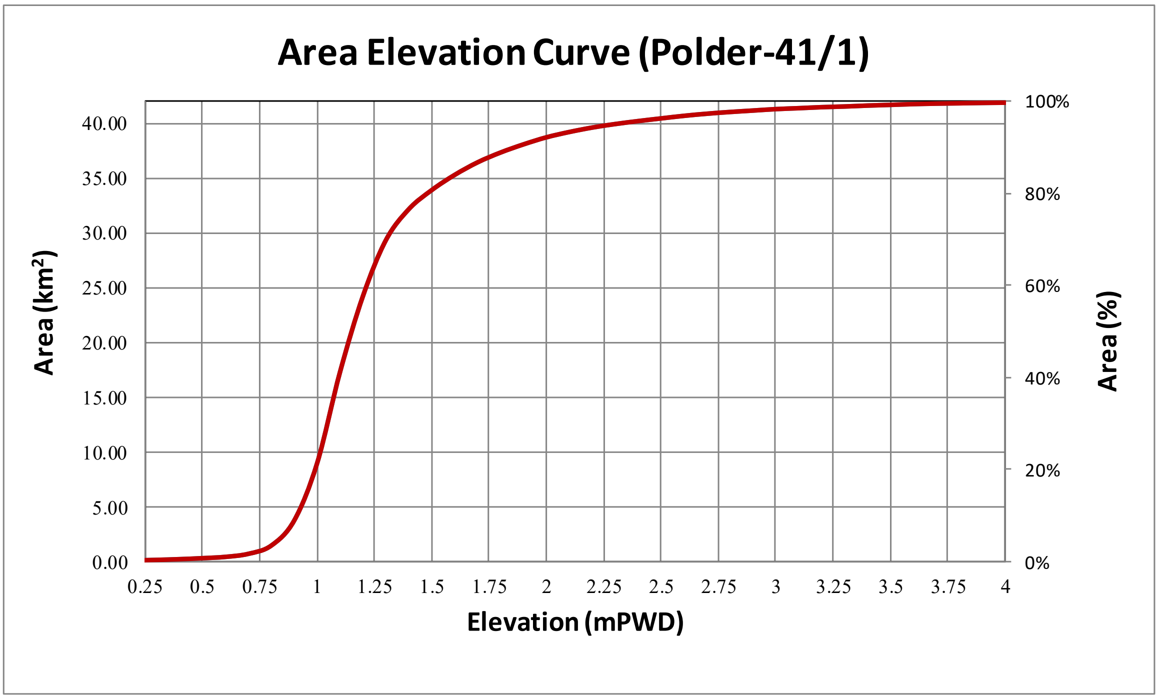


Figure 1.3: Polder 41/1 Area Elevation Curve

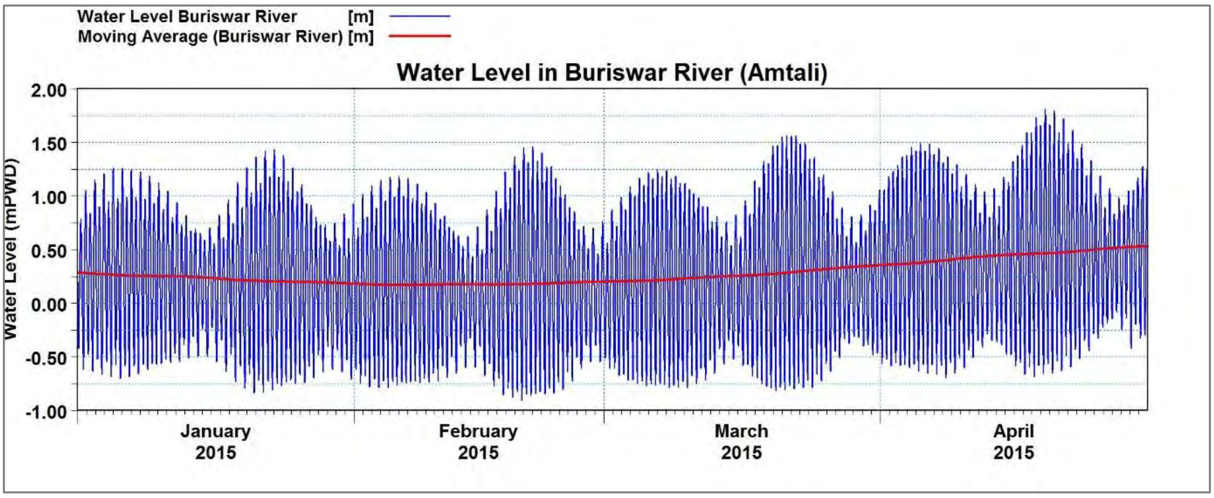


Figure 1.4: Water Level of Buriswar River

From area elevation curve of Polder 41/1, around 80% of the land varies from 0.90 to 2.00 mPWD. Water level of Buriswar river varies from -0.80 mPWD to 1.80 mPWD in four months (January to April). In January and February maximum spring tide WL 1.50 mPWD. In neap tide maximum water level in Buriswar river around 0.75 mPWD. From moving average curve of water level varies from 0.20 to 0.55 mPWD during dry period. So, it is difficult to go for gravity irrigation in all location of Polder 41/1. At present condition most of the land remain fallow (Figure 1.1) inside the polder during dry period. Satellite image (February, 2017) also show the fallow land within the study area. In the image red colour indicate vegetation or crop and white colour means fallow land. As rabi crop required very less amount of water, farmers cultivate rabi crop in the cultivable land of Polder 41/1 at present condition.

Boro rice required maximum irrigation water (around above 750 mm) during dry. Water availability for Polder 41/1 will be analyzed for the water requirement of Boro rice.

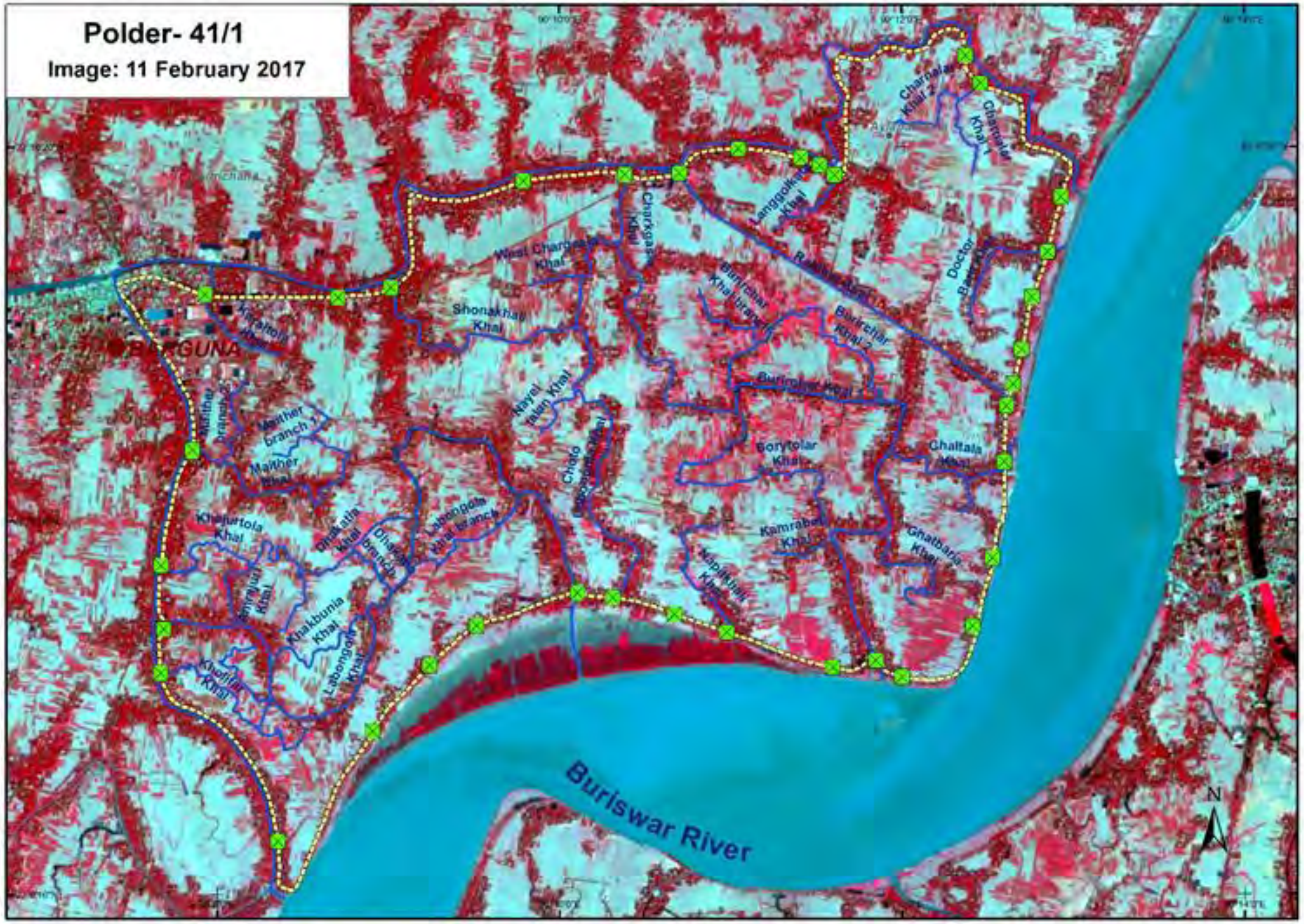


Figure 1.5: Satellite Image (Sentinel-2) Showing Fallow Land in Polder 41/

1.2 Scope of the study

Eastern part of the South East region of Bangladesh has huge opportunity for intensification of agricultural production because of low salinity in the river. This area receives huge amount of fresh water from Meghna river and salinity remains below 1 ppt all over the year. During the dry period gravity irrigation potentiality is very small in this region, only possible in low areas. However, LLP can be used for irrigation as plenty of water available in the river. The present project work is to determine the water availability inside the polder during the dry period for irrigation.

1.3 Objective of the study

The main objective of the study is to assess water availability inside the polder for irrigation in the dry season and evaluate impact of water withdrawal in the canal system using by using mathematical modelling.

The specific objectives are follows:

1. To assess water availability inside the polder for irrigation during dry period.
2. To evaluate water withdrawal impact in canal system using mathematical model.

The outputs of the study are as follows:

- Assessment of water availability in the internal canal system for irrigation during the dry period (Jan-April) at existing field condition.
- Assessment of water availability after extraction of water from the internal canal system for irrigation during the dry period (Jan-April).
- Improved gate operational rules for manage water inside the polder during the dry season.

1.4 Organization of the Thesis

Considering literature review, location of the study area, theory and methodology, mathematical modeling, data analysis, model calibration, results and discussions, the thesis has been organized under six chapters which are described below:

Chapter 1, describes the background, highlights the objectives of the study and contains organization of the thesis

Chapter 2, describes literature review

Chapter 3: describes the basic theory of hydrodynamic model

Chapter 4, describes the study area, mathematical model setup (hydrodynamic model), development of polder 41/1 dedicated model.

Chapter 5, contains the model calibration and validation for hydrodynamic modeling. Options of different simulation, water depth analysis for different scenarios.

Chapter 6: provides the overall conclusions of the study and also some recommendations for further study.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Many studies and researches were conducted independently for water resources management and agricultural aspect around the delta region in Bangladesh. In this chapter, some of the pioneering works by past researchers have been summarized in order to gain insight on the physical processes involved in surface water availability and surface water salinity, climate change impact in delta region of Bangladesh.

2.2 Crop and Agriculture Related Study

Mondal (2010), is conducted a study show that utilization of river water is a feasible technology for dry-season rice (locally known as boro rice) cultivation, but reservoir volume limits the irrigated area in the dry season. Alternatives are developed to increase the rice area and the productivity of the coastal region of Bangladesh to meet future food demand and improve farmers' livelihoods. One option is to maximize river water utilization before it becomes saline and minimize dependency on the reservoir water for boro rice cultivation. Experiments were therefore conducted in polder 30 at Batiaghata Subdistrict in Khulna District during the dry seasons of 2005/06 and 2006/07 to test the hypothesis that early crop establishment can reduce the reservoir water-use period, thereby increasing the irrigated area and productivity. The results showed that seeding on 7 November produced 4–5 t/ha rice yield by utilizing about 50% of the required water directly from the river and the remaining 50% from the reservoir. Seeding on 15 November produced a rice yield on par with that of 7 November, but more reservoir water was used for the later seeding date, which would then reduce the dry season irrigation coverage. The rice yield was reduced drastically when seeding was carried out before 7 November because of cold stress at the critical reproductive period of rice. This study determined that about 260 mm water was required from the reservoir for successful cultivation of boro rice in the coastal area and about 14% of net cultivable area (NCA) could be brought under irrigation with the existing hydraulic system of polder 30. With moderate excavation, the irrigation coverage could be increased to about 35% of NCA. Therefore, both productivity and irrigated area in the dry season could be increased by advancing the rice cultivation season to the second week of November through to the first week of April.

Saha (2010), states that the cropping intensity and productivity of the coastal zone of Bangladesh is much lower than that of the country as a whole. In the coastal zone, most farmers grow a single, low yielding, late maturity aman variety during the rainy season, and much of the land is fallow for much of the time during the dry season. There is a general perception that during the dry season, the river water is saline throughout the coastal zone; however, most of the rivers in Barisal Division remain non-saline and suitable for rice irrigation throughout most or all of the year. Furthermore, there is a perception that modern, high yielding and early maturity aman varieties cannot be grown in the coastal zone due to water stagnation. However, with separation of lands of different elevation using small levees, and by draining excess water from the fields at low tide, modern aman varieties can be successfully grown. Given this, and the recent availability of the first high yielding, short duration aus variety for Bangladesh, it should be possible to intensify to two and three high yielding crops per year in much of Barisal Division. Furthermore, increasing productivity of the coastal zone is now a high priority of the Government of Bangladesh. Studies were therefore conducted in Patuakhali District to determine the feasibility of growing three rice crops per year, and to evaluate planting date and aman variety options. The experiment was conducted for two years (2012- 14) with 3 aus sowing dates (10 April, 25 April, 1 May), 4 aman varieties (BRRI dhan33, BRRI dhan49, BRRI dhan52, BRRI dhan53), and 5 boro sowing dates (15, 20, 30 November and 05, 15 December) in 12 aus-aman-boro cropping system combinations. Total in-field duration of the systems ranged from 277 to 312 d, showing the feasibility of growing three rice crops per year. Total system productivity ranged from 13.4 to 17.2 t/ha/yr, 2 to 4 times that of current farmer practice. The results show that cultivation of three rice crops per year in the low salinity coastal zone is a feasible technology for greatly increasing productivity of the coastal zone and contributing to the future food security of Bangladesh.

2.3 Mathematical Model on Agriculture

Khan (2015), states that the problem of river salinity is most severe in the southwest zone. The water resource system of the southwest zone has degraded considerably over time, primarily because of the reduction in freshwater inflows from the Ganges due to withdrawal of fresh water at Farakka. of special relevance are the problems that arise at the bifurcation between Ganges and Gorai River. During the dry period the Gorai inflow is severely decreased, creating problems of downstream freshwater availability. Salinity intrusion reduces the freshwater area that results in decrease of agricultural production in many parts of the coastal zone, especially the Khulna region and the extreme south of the Patuakhali region, and locally in the Noakhali and Chittagong regions. Increase of salinity is damaging the freshwater fish habitat and has adverse impact on the Sundarban ecosystems. Although the Ganges Coastal Zone is besieged with multiple problems and constraints it has tremendous potential to create innumerable opportunities for agricultural and aqua cultural production through improved use of available water resources. River salinity in the Tentulia, Bishkhali, Buriswar and upstream stretch of Baleswar rivers (i.e., most of Barisal Division) was found to be very low throughout the year. The availability of water (high river flows) is high; simulation results show that the minimum flow in the Payra River (the peripheral river of polder 43/2F) during the dry season is 5400m3 /s (Khan et al., 2015). Irrigation can also be practiced during the dry season by filling the canals at high tide using gravity, storing the water in the canal systems and pumping from the canal systems using low lift pumps.

Mondal (2001), States that, in the coastal region of Bangladesh, considerable amounts of salt accumulate on the soil surface by evaporation, particularly in presence of a shallow saline water table during the dry period from February to May when the land remains fallow. If the fallow period is long, severe salinity may be developed. Soil salinity is therefore a major, and the most persistent, threat to irrigated agriculture in that area. The study however developed multiple linear and non-linear regression models to predict topsoil salinity of the fallow land for both moderately saline and saline soils by using daily rainfall and evaporation as independent variables. A linear model may be used to predict topsoil salinity of the coastal rice lands of Bangladesh. The salt dynamics is mainly governed by the evaporation process and rainfall. Groundwater at shallow depths also contributes to salt build-up in the soil through the evaporation process. To describe the complex interaction between the abovementioned parameters, they are collected and analyzed. Soil salinity is more hazardous in the southwestern part than in any other part of the coastal region. Most rice lands of this part fall under the categories of moderately saline (ECe=4±8 dS m-1) and saline (ECe = 8±16 dS m-1) soils. However, selected sites are situated in Barodanga village and another in Mirzapur village, both in Dumuria thana of Khulna district to respectively represent the saline and moderately saline soil categories. The two sites are located at an altitude of 4 m above mean sea level between 22.470 and 22.490N latitude, and 89.240 and 89.340E longitude. At each site, the experimental field was divided into 25 plots (5 blocks X 5 replications). Soil samples from 0±15 cm depth were collected at the middle of each plot to determine EC and SAR of the surface soils. Groundwater level and salinity are also collected at both research sites for 7-days and 15-days intervals respectively. Rainfall and evaporation data for the study period were also collected from the Khulna meteorological station. According to authors that linear salinity prediction models is suitable for study area, as it is gives the opportunity to predict the salinity in easiest way. It is the suggestion of that author's dry season cropping may be a cheapest mechanism to lower the topsoil salinity.

Khan (2015), conducted study in two scales: regional level for the coastal regions of Bangladesh and at local level for the selected polders (Polder 3, Polder 30 and Polder 43/2f). Regional models [South West regional model (SWRM) and Bay of Bengal (BOB) model] were used to simulate salinity intrusion and cyclonic storm surge, while on the other hand, dedicated local level models were used for drainage modeling to investigate the water logging and irrigation opportunity at present and climate change condition. From, extensive analysis it has been discovered that, the quantity of freshwater is likely to decrease due to changes in a number of external drivers (sea level rise and trans-boundary flow). The study also found that, drainage congestion and polder level water management is major problem at local level. The research covers a wide range of analysis, and still scope for a future study, like detailed polder level water management, ground water use efficiency and working with arsenic contamination at south-west and south-central coastal zone. Therefore, researchers proposed to improvement the capacity of canal system, renovate sluices and embankments and establish operation rules for sluices.

Pervez (2014), The study focuses on to evaluate sensitivities and patterns in freshwater availability due to projected climate and land use changes in the Brahmaputra basin by using the Soil and Water Assessment Tool. The daily observed discharge at Bahadurabad station in Bangladesh was used to calibrate and validate the model and analyze uncertainties with a sequential uncertainty fitting algorithm. The sensitivities and impacts of projected climate and land use changes on basin hydrological components were simulated for the A1B and A2 scenarios and analyzed relative to a baseline scenario of 1988–2004. Present research shows that the stream flow patterns during FMA suggested that the impacts of spring snowmelt on the stream flow could diminish by 2030. The long-term patterns in the groundwater recharge showed a significant decreasing trend for the early monsoon period (MJJ) and a significant increasing trend for the later monsoon period. SWAT model has been used in this study. To simulate this model weather data (daily precipitation, maximum/minimum air temperature, solar radiation, wind speed, and relative humidity) stream flow data (discharge data at Bahadurabad gauge station) and land use data has been collected from different organizations. ArcSWAT (Winchell et al., 2010) – was used to parameterize the model for the Brahmaputra basin. The annual total water yield was predicted to increase by 2% and 5% in response to a 1.5× and 2× increase in CO2 concentration, respectively. The average annual precipitation in the Brahmaputra basin was predicted to increase from 1849 mm to 2013 mm and 2029 mm, a 9% and 10% increase com-pared to baseline precipitation and groundwater recharge was predicted to increase by 47% and 49% annually under the A1Band A2 scenarios. The stream flow patterns during FMA suggested that the impacts of spring snowmelt on the stream flow could diminish by 2030. The long-term patterns in the ground water recharge showed a significant decreasing trend for the early monsoon period (MJJ) and a significant increasing trend for the later monsoon period. The study combined analyses of sensitivity of hydrological components to climate change and long-term impacts of future climate and land use change on freshwater availability can offer much needed inputs for resource but it should be evaluated at the sub basin level to provide a more complete picture to make decisions. There are some uncertainties in this study. These are model is calibrated against flow, therefore, predicted estimates of those components that were not calibrated were more uncertain Also future climate change projections, GCM predictors and model down scaling was not accurately predicted.

2.4 Agriculture based economy

Ali (2007), Sustainable agricultural growth is the key to rural system changes that include changes in rural bio-physical environment, economic infrastructure and social conditions. The study examined 18 selected indicators of rural systems in Bangladesh during the period 1975–2000. The influences of demographic, market forces, environmental, institutional and technological factors inducing and mediating different changes were explored in the research. Significant increase in agricultural intensity, cropping patterns, land productivity and farm income; decline in labor and technological productivities and major improvement in rural housing, economic and social conditions during this period were observed in the analysis of 64 district level census data. The study measures the agricultural growth as an average of percent change in cropping intensity, land, labor, technological productivity and per capita farm income derived from 21 field crops and fisheries during 1975–2000. The cropping intensity (%) of a district was computed by dividing the total cropped area (TCA) by the Net Cropped Area (NCA) and multiplying the result by 100. The study aims to construct an index to measure the degree of rural systems change, and to examine the effects of population growth, market price incentives, environmental constraints, technology, political economy and institutional forces on such changes. It has been observed that the intensification process has been hindered by severe environmental and social constraints. Labour and technological productivities have declined over the period. The efficiency of chemical fertilizers and irrigation under severe flooding and drought has been declined. The study results demonstrate that both population pressure and market incentives have been the key driving forces inducing agricultural intensification and rural system changes. Adoption of more sustainable farming practices and genetically improved high yielding crops, continuous soil quality monitoring, urban land use planning and zoning, controlling market prices of both consumption and commodity crops are found necessary; so that increased farm production and high economic return can save farmlands from loss and over-cultivation under increased demands. Expansion of flood control and irrigation projects can be the key to accelerate both agricultural growth and rural development. Although, the present study examines the nature and determinants of rural system changes in Bangladesh, it does not explore the nature and causes of rural system changes.

CPWF (2013), The brackish-water coastal zone of the Ganges is fertile flood plain delta, yet home of most food insecure, and most vulnerable people. The goal of Research for Development Program for Ganges Basin Development Challenges (BDC) is set up with a goal to reduce poverty, improve food security, and strengthen livelihood resilience in coastal areas through improved water governance and management, and more productive and diversified farm systems. The project seeks to take advantage of community managed water infrastructure to develop and disseminate agriculture technologies and cropping systems for the saline influenced areas of the coastal Ganges basin. The project carries out researches that results in improvements in income, resilience and nutritional outcomes for poor households. The project mainly focused on improvements in agriculture and aquaculture systems that raise cropping intensity, diversity and productivity. However, the researchers proposed to explore for two or three crops per year in less saline area. Where, in areas with medium salinity levels, integrated rice-aquaculture systems are likely are suggested. In areas with higher salinity levels, it was recommended to focus on, risk management in aquaculture. It was also proposed by study to use, higher yields, are short-maturing salt tolerant crops in coastal area, as numerous salt-tolerant and submergence-tolerant varieties of rice are now available to prove their adaptation and suitability to replace the low-yielding rice. It is evident from the study, achievement of crop diversification is suggested by the introduction of non-rice upland crops such as short-duration mung bean, maize, or sunflower, with enhanced tolerance to submergence and salinity. Project findings indicates, that there is tremendous scope for increasing the productivity, profitability and resilience of agricultural and aqua-cultural production systems in the Ganges coastal zone, through adoption of improved germplasm and management, cropping system intensification and diversification. However, achieving this will require improved water management, and in particular drainage management. Changing current water management practices requires a change in mindsets to treat each polder as an integrated water management unit, with a single entity responsible for coordination. It will also require significant investment in polder infrastructure, within the polders as well as around the perimeters, zonation and synchronization of production systems.

2.5 Summary

Several studies have been carried out on agriculture in coastal region of Bangladesh. The research mentions difficulties of agriculture and opportunity of agriculture in coastal region, ensuring the food securities and contribution in Bangladesh economy. South central zone of Bangladesh does not affect by salinity and have huge potential for irrigation during the dry period. Polder 41/1 selected to evaluate water availability inside the polder during the dry period to unlock the opportunity.

CHAPTER 3

THEORY AND METHODOLOGY

3.1 General

Mathematical models are an effective tool to characterize and predict the movement and quality of water. A 1-dimensional hydrodynamic model used to assess the water availability. A dedicated model of Polder 41/1 developed for this study. The theories that are used in the model have been discussed in this chapter. A numerical 1-dimensional model named MIKE11 developed by DHI Water and Environment has been used for simulation in this study. Rainfall Runoff Model (NAM) and Hydrodynamic Model (HD) modules of MIKE 11 used in this study. The governing equations for these modules have been described in this chapter.

3.2 Basic Theory of Hydrodynamics

Numerical techniques have been applied in this study to simulate the hydrodynamic model. Hydrodynamic model has been simulated to calculate water level and water depth in river and khals. The mathematical calculation has been done based on some basic equations which are described below separately.

3.2.1 Governing Equation for Hydrodynamics

The hydrodynamic module (HD) uses an implicit, finite difference scheme for the computation of unsteady flows in rivers and estuaries. The module can describe sub-critical as well as super critical flow conditions through a numerical scheme which adapts according to the local flow conditions (in time and space). Advanced computational modules are included for description of flow over hydraulic structures, including possibilities to describe structure operation. The formulations can be applied to looped networks and quasi two-dimensional flow simulation on flood plains. The computational scheme is applicable for vertically homogeneous flow conditions extending from steep river flows to tidal influenced estuaries.

(i) Basic Hydrodynamic Equations

The basic governing equations for incompressible fluid flow are time independent and two dimensional. Equations in Cartesian coordinates (x,y) are as follows:

Continuity Equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (3.1)$$

Momentum Equation:

$$p\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial P}{\partial x}\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \qquad (3.2)$$

$$p\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial P}{\partial y}\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \qquad (3.3)$$

Where,
u,v = velocity field in X and Y direction
ρ = Density

V= (u,v) is the velocity field. The first term on the RHS in Equations (3.2) & (3.3) refers to pressure forces, ∇. P. The rest of the RHS describe viscous forces, $\mu\nabla^2$v. The LHS is the momentum change that any element experiences as it moves between regions of different velocity in the flow field. This has the dimensions of a force, and is referred to as the inertia force, ρv . ∇v.

(ii) Hydrodynamic Equations (MIKE 11)

The equations which are solved for the flow simulations are called Saint Venant equation. These are derived from the Navier Stokes equation. Saint Venant equations are:

$$\frac{\delta q}{\delta x}+\frac{\delta A_{fl}}{\delta t}=q_{in} \qquad (3.4)$$

$$\frac{\delta q}{\delta t}+\frac{\delta\left(\alpha\frac{q^2}{A_{fl}}\right)}{\delta x}+gA_{fl}\frac{\delta h}{\delta x}+gA_{fl}I_f=\frac{f}{\rho_w} \tag{3.5}$$

Where,

q	Discharge
A_{fl}	Flow area
q_{in}	lateral inflow
h	water level
α	momentum distribution coefficent
I_f	Flow resistance
f	Momentum forcing
ρ_w	Density of Water

Equation (3.4) is called the mass equation or continuity equation and expresses conservation of mass. Equation (3.5) is called the momentum equation and expresses conservation of momentum.

3.2.2 Rainfall Runoff Model (NAM)

The NAM (Nedbør-Afstrømnings-Model) hydrological model simulates the rainfall-runoff processes occurring at the catchment scale. NAM forms part of the rainfall-runoff (RR) module of the 1D river modelling system. The rainfall-runoff module can either be applied independently or used to represent one or more contributing catchments that generate lateral inflows to a river network. In this manner it is possible to treat a single catchment or a large river basin containing numerous catchments and a complex network of rivers and channels within the same modelling framework. NAM is the abbreviation of the Danish "Nedbør-Afstrømnings-Model", meaning precipitation-runoff-model, also named RDII in English standing for Rainfall Dependent Inflow and Infiltration model. A mathematical hydrological model like NAM is a set of linked mathematical statements describing, in a simplified quantitative form, the behavior of the land phase of the hydrological cycle. NAM represents various components of the rainfall-runoff process by continuously accounting for the water content in four different and mutually interrelated storages. Each storage represents different physical elements of the catchment. NAM can be used either for continuous hydrological modelling over a range of flows or for simulating single events. The NAM model can be characterized as a deterministic, lumped, conceptual model with moderate input data requirements.

3.2.2.1 Basic modelling component

The implemented conceptualization of the physical processes treated by NAM model is illustrated in Figure 3.1 and exposed below in full detail.

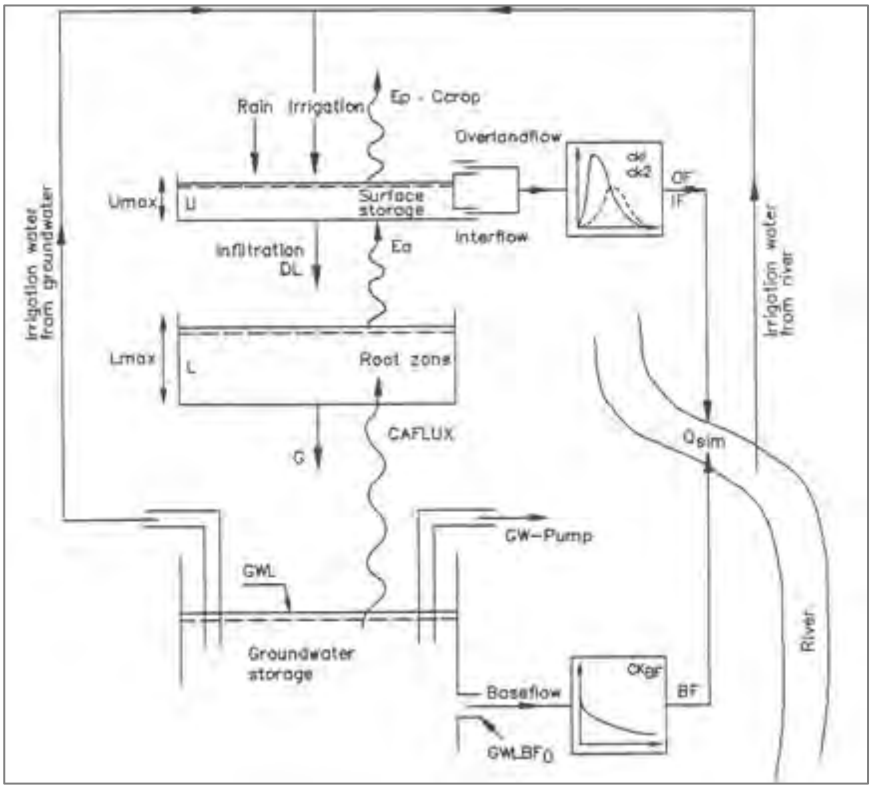


Figure 3.1: Physical process in rainfall runoff (NAM) model (Source: MIKE 11 Manual)

Surface storage

Moisture intercepted on the vegetation as well as water trapped in depressions and in the uppermost, cultivated part of the ground is represented as surface storage. U_{max} denotes the upper limit of the amount of water in the surface storage. The amount of water, U, in the surface storage is continuously diminished by evaporative consumption as well as by horizontal leakage (interflow). When the surface storage spills, i.e. when $U > U_{max}$, some of the excess water, P_N, will enter the streams as overland flow, whereas the remainder is diverted as infiltration into the lower zone and groundwater storage.

Lower zone or root zone storage

The soil moisture in the root zone, a soil layer below the surface from which the vegetation can draw water for transpiration, is represented as lower zone storage. L_{max} denotes the upper limit of the amount of water in this storage. Moisture in the lower zone storage is subject to consumptive loss from transpiration. The moisture content controls the amount of water that enters the groundwater storage as recharge and the interflow and overland flow components.

Evapotranspiration

Evapotranspiration demands are initially met at the potential rate from the surface storage. If the moisture content U in the surface storage is less than these requirements ($U< E_p$), the remaining fraction is assumed to be withdrawn by root activity from the lower zone storage at an actual rate E_a. E_a is proportional to the potential evapotranspiration and varies linearly with the relative soil moisture content, L/L_{max}, of the lower zone storage

$$E_a = (E_p - U)\frac{L}{L_{max}} \tag{3.6}$$

Where,

E_a = Actual evaporation in mm

E_p = Potential evaporation in mm

L = Water content in the lower or root zone in mm

L_{max} = Maximum water content in the lower or root zone (mm)

U = Moisture content

Overland flow

When the surface storage spills, i.e. when $U> U_{max}$, the excess water P_N gives rise to overland flow as well as to infiltration. QOF denotes the part of P_N that contributes to overland flow. It is assumed to be proportional to P_N and to vary linearly with the relative soil moisture content, L/L_{max}, of the lower zone storage

$$QOF = \begin{cases} CQOF\frac{L/L_{max}-TOF}{1-TOF}P_N & for\ L/L_{max} > TOF \\ 0 & for\ L/L_{max} \leq TOF \end{cases} \tag{3.7}$$

Where,

CQOF	Overland flow runoff coefficient (0 ≤CQOF ≤1)
TOF	Threshold value for overland flow (0 ≤TOF ≤1)

The proportion of the excess water P_N that does not run off as overland flow infiltrates into the lower zone storage. A portion, ΔL, of the water available for infiltration, (P_N-QOF), is assumed to increase the moisture content Lin the lower zone storage. The remaining amount of infiltrating moisture, G, is assumed to percolate deeper and recharge the groundwater storage.

Interflow

The interflow contribution, QIF, is assumed to be proportional to U and to vary linearly with the relative moisture content of the lower zone storage.

$$QIF = \begin{cases} (CKIF)^{-1}\frac{L/L_{max}-TIF}{1-TIF}U & for\ L/L_{max} > TIF \\ 0 & for\ L/L_{max} \leq TIF \end{cases} \tag{3.8}$$

Where:

CKIF	Time constant for interflow
TIF	Root zone threshold value for interflow (0 ≤ TIF ≤1)

Interflow and overland flow routing

The interflow is routed through two linear reservoirs in series with the same time constant CK12. The overland flow routing is also based on the linear reservoir concept but with a variable time constant

$$CK = \begin{cases} CK_{12} & for\ OF < OF_{min} \\ CK_{12}\left(\frac{OF}{OF_{min}}\right)^{-\beta} & for\ OF \geq OF_{min} \end{cases} \tag{3.9}$$

Where:

OF = Overland flow intensity (mm/hour)

OF_{min} = Upper limit for linear routing (= 0.4 mm/hour),

β = 0.4

The constant β= 0.4 corresponds to using the Manning formula for modelling the overland flow**.** This ensures in practice that the routing of real surface flow is kinematic, while subsurface flow being interpreted by NAM as overland flow (in catchments with no real surface flow component) is routed as a linear reservoir. The reservoir time constants CK_1 and CK_2 taken equal to CKOF in both reservoirs.

Groundwater recharge

The proportion of net excess rainfall, P_n, that does not run off as over land flow infiltrates into the lower zone storage representing the root zone. A portion, ΔL, of the amount of infiltration, (P_n-OF), is assumed to increase the moisture content, L, in the lower zone storage. The remaining amount of infiltrating water, G, is assumed to percolate deeper and recharge the groundwater storage. The G and ΔL are calculated from:

$$G = \begin{cases} (P_N - QOF)\frac{L/L_{max} - TG}{1 - TG} & for\ L/L_{Max} > TG \\ 0 & for\ L/L_{Max} \leq TG \end{cases} \tag{3.10}$$

And

$$\Delta L = P_N - QOF - G \tag{3.11}$$

Where:

TG = Root zone threshold value for groundwater recharge ($0 \leq TG \leq 1$)

Baseflow

The baseflow BF from the groundwater storage is calculated as the outflow from a linear reservoir with time constant CK_{BF}.

3.2.3 1D Hydrodynamic Model (MIKE11-HD)

3.2.3.1 General Description

The MIKE 11 hydrodynamic module (HD) uses an implicit, finite difference scheme for the computation of unsteady flows in rivers and estuaries. The module can describe sub-critical as well as super critical flow conditions through a numerical scheme which adapts according to the local flow conditions (in time and space). Advanced computational modules are included for description of flow over hydraulic structures, including possibilities to describe structure operation. The formulations can be applied to looped networks and quasi two-dimensional flow simulation on flood plains. The computational scheme is applicable for vertically homogeneous flow conditions extending from steep river flows to tidal influenced estuaries.

Governing equations:

MIKE 11 applied with the fully dynamic descriptions solves the vertically integrated equations of conservation of volume and momentum (the 'Saint Venant' equations), which are derived on the basis of the following assumptions:

- The water is incompressible and homogeneous, i.e. without significant variations in density
- The bottom slope is small
- The wave lengths are large compared to the water-depth. This ensures that the flow everywhere can be regarded as having a direction parallel to the bottom, i.e. vertical acceleration can be neglected and a hydrostatic pressure variation along the vertical can be assumed
- The flow is sub-critical

For a rectangular cross-section with a horizontal bottom and a constant width, the conservation of mass and momentum can be expressed as follows (in the first instance neglecting friction and lateral inflows):

Conservation of mass:

$$\frac{\partial(\rho H b)}{\partial t} = \frac{\partial(\rho H b \bar{u})}{\partial x} \tag{3.12}$$

Conservation of momentum:

$$\frac{\partial(\rho Hb\bar{u})}{\partial t}=-\frac{\partial(\alpha'\rho Hb\bar{u}^2+\frac{1}{2}\rho gbH^2)}{\partial x} \tag{3.13}$$

Where, ρ is the density, H the depth, b the width, u the average velocity along the vertical and α’ the vertical velocity distribution coefficient.

Introducing the bottom slope, I_b and allowing for the channel width to vary will give rise to two more terms in the momentum equation. These terms describe the projections in the flow direction of the reactions of the bottom and side-walls to the hydrostatic pressure.

The momentum equation now becomes:

$$\frac{\partial(\rho Hb\bar{u})}{\partial t}=-\frac{\partial\left(\alpha'\rho Hb\bar{u}^2+\frac{1}{2}\rho gbH^2\right)}{\partial x}+\frac{\partial b}{\partial x}\frac{\rho gH^2}{2}-\rho gHbI_b$$

$$=-\frac{\partial(\alpha'\rho Hb\bar{u}^2)}{\partial x}-b\frac{\partial\left(\frac{1}{2}\rho gH^2\right)}{\partial x}-\rho gHbI_b \tag{3.14}$$

When the water level, h, is introduced into the relationship instead of water depth:

$$\frac{\partial h}{\partial x}=I_b+\frac{\partial H}{\partial x} \tag{3.15}$$

and the equations are divided by ρ, the conservation laws of mass and momentum become:

$$\frac{\partial(Hb)}{\partial t}=-\frac{\partial(Hb\bar{u})}{\partial x} \tag{3.16}$$

$$\frac{\partial(Hb\bar{u})}{\partial t}=-\frac{\partial(\alpha'\rho Hb\bar{u}^2)}{\partial x}-Hbg\frac{\partial h}{\partial x} \tag{3.17}$$

These equations can be integrated to describe the flow through cross-sections of any shape when divided up into a series of rectangular cross sections as shown in Figure 3.2.

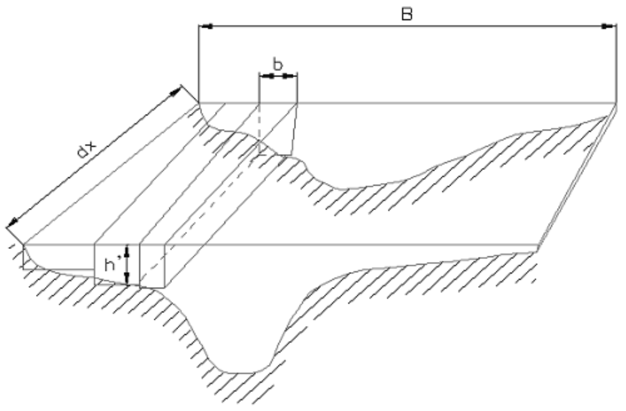


Figure 3.2: Cross-section divided into a series of rectangular channels in MIKE11 (Source: MIKE11 Manual)

According to the previous assumptions, δh/δx is constant across the channel and no exchange of momentum occurs between the sub channels. If the integrated cross-sectional area is called A and the integrated discharge Q, and B is the full width of the channel, then:

$$A = \int_0^B Hdb \tag{3.18}$$

$$Q = \int_0^B H\bar{u}db = \overline{uA} \tag{3.19}$$

Integrating the mass and momentum conservation equations and introducing in above equations yields:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \tag{3.20}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial(\alpha\frac{Q^2}{A})}{\partial x} + gA\frac{\partial h}{\partial x} = 0 \tag{3.21}$$

Including the hydraulic resistance, e.g. using the Chezy description and the lateral inflow; q into these equations leads to the basic equations used in MIKE 11:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \tag{3.22}$$

$$\frac{\partial Q}{\partial t}+\frac{\partial(\alpha\frac{Q^2}{A})}{\partial x}+gA\frac{\partial h}{\partial x}+\frac{gQ|Q|}{C^2AR}=0 \tag{3.23}$$

Solution Scheme:

The solution to the combined system of equations at each time step is performed according to the procedure outlined below. The solution method is the same for each model level (kinematic, diffusive, and dynamic). The transformation of Saint Venant Equations, to a set of implicit finite difference equations is performed in a computational grid consisting of alternating Q- and h-points, i.e. points where the discharge, Q and water level h, respectively, are computed at each time step, see Figure 3.3. The computational grid is generated automatically by the model on the basis of the user requirements. Q-points are always placed midway between neighboring h points, while the distance between h-points may differ. The discharge will, as a rule, be defined as positive in the positive x-direction (increasing chainage).

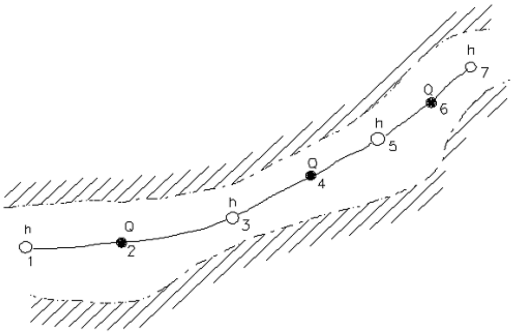


Figure 3.3: Channel section with computational grid in MIKE11

Continuity equation

In the continuity equation the storage width, b_s, is introduced as:

$$\frac{\partial A}{\partial t}=b_s\frac{\partial h}{\partial t} \tag{3.24}$$

giving:

$$\frac{\partial Q}{\partial x}+b_s\frac{\partial h}{\partial t}=q \tag{3.25}$$

As only Q has a derivative with respect to x, the equation can easily be centred at an h-point, see Figure 3.4.

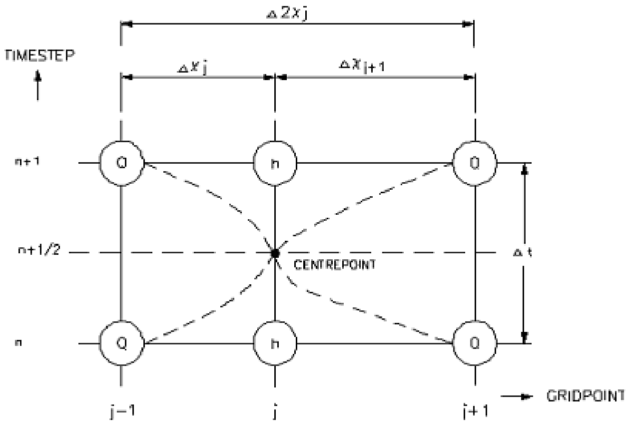


Figure 3.4: Centering of continuity equation in 6-point Abbott scheme (Source: MIKE11 Manual)

The derivatives in Saint Venant equations are expressed at the time level, n+½, as follows:

$$\frac{\partial Q}{\partial x} \approx \frac{\frac{(Q_{j+1}^{n+1} + Q_{j+1}^{n})}{2} - \frac{(Q_{j-1}^{n+1} + Q_{j-1}^{n})}{2}}{\Delta 2x_j}$$

$$\frac{\partial h}{\partial t} \approx \frac{(h_j^{n+1} - h_j^{n})}{\Delta \mathrm{t}}$$

b_s is approximated by:

$$b_s = \frac{A_{0,j} + A_{0,j+1}}{\Delta 2x_j} \tag{3.26}$$

where:

$A_{o,j}$ is the surface area between grid point j-1 and j

$A_{o,j+1}$ is the surface area between grid point jand j+1

$\Delta 2x_j$ is the distance between point j-1 and j+1

Substituting for the derivatives gives a formulation of the following form:

$$\alpha_j Q_{j-1}^{n+1} + \beta_j h_j^{n+1} + \gamma_j Q_{j+1}^{n+1} = \delta_j \tag{3.27}$$

where, α, β and γ are functions of band δ and, moreover, depend on Q and h at time level n and Q on time level n+½.

Momentum equation

The momentum equation is centred at Q-points as illustrated in Figure 3.5.

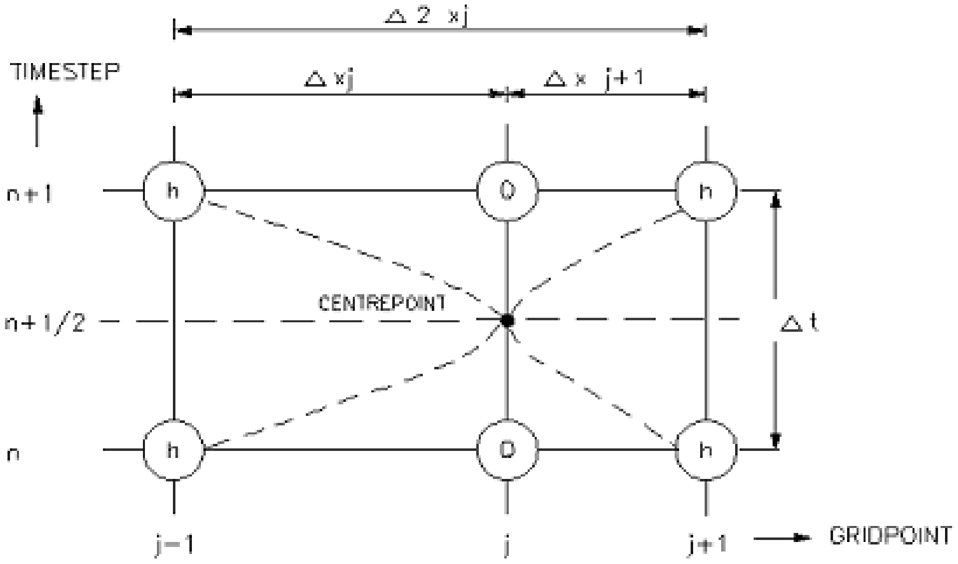


Figure 3.5: Centering of momentum equation in 6-point Abbott scheme

The derivatives of Saint Venant Equations, are expressed in the following way:

$$\frac{\partial Q}{\partial t} \approx \frac{Q_j^{n+1} - Q_j^{n}}{\Delta t} \tag{3.28}$$

$$\frac{\partial(\alpha\frac{Q^2}{A})}{\partial x} \approx \frac{[\alpha\frac{Q^2}{A}]_{j+1}^{n+1/2} - [\alpha\frac{Q^2}{A}]_{j-1}^{n+1/2}}{\Delta 2x_j}$$

$$\frac{\partial h}{\partial x} \approx \frac{\frac{(h_{j+1}^{n+1} + h_{j+1}^{n})}{2} - \frac{(h_{j-1}^{n+1} + h_{j-1}^{n})}{2}}{\Delta 2x_j} \tag{3.29}$$

For the quadratic term, a special formulation is used to ensure the correct sign for this term when the flow direction is changing during a time step:

$$Q^2 \approx \theta Q_j^{n+1} Q_j^n - (\theta - 1) Q_j^n Q_j^n \tag{3.30}$$

where, θ can be specified by the user (THETA coefficient under the Default values in the HD parameter editor) and by default is set to 1.0. With all the derivatives substituted, the momentum equation can be written in the following form:

$$\alpha_j h_{j-1}^{n+1} + \beta_j Q_j^{n+1} + \gamma_j h_{j+1}^{n+1} = \delta_j \tag{3.31}$$

where,

$\alpha_j = f(A)$

$\beta_j = f(Q_j^n, \Delta t, \Delta x, C, A, R)$

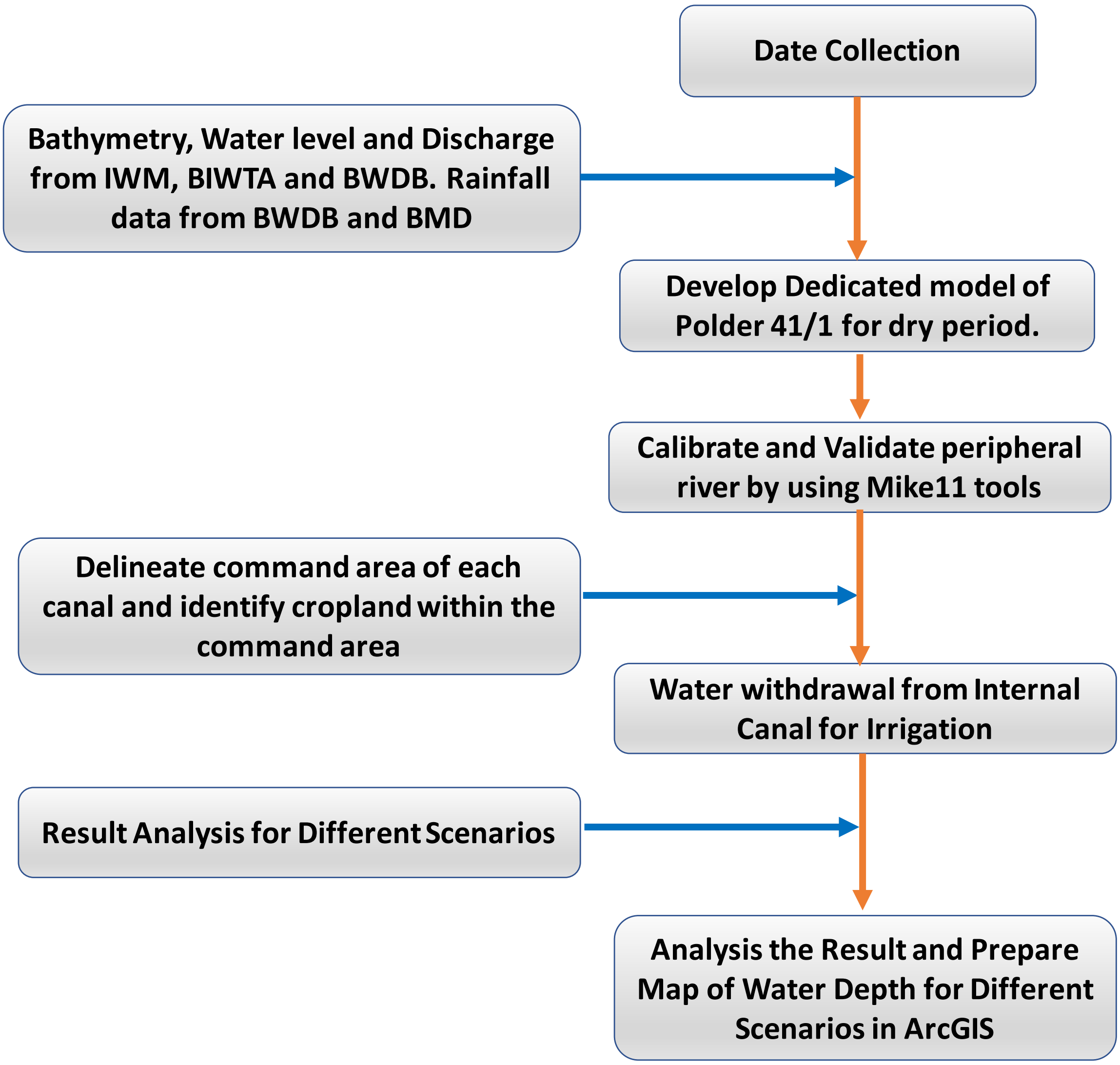
$\gamma_j = f(A)$

$\delta_j = f(A, \Delta t, \Delta x, \alpha, q, v, \theta, h_{j-1}^n, Q_{j-1}^{n+1/2}, Q_j^n, h_{j+1}^n, Q_{j+1}^{n+1/2})$

To obtain a fully centred description of Aj+1, these terms should be valid at time level n+½ which can only be fulfilled by using an iteration. For this reason, the equations are solved by default two times at every time step, the first iteration starting from the results of the previous time step, and the second iteration using the centred values from this calculation. The number of iterations can be changed using the NoITER coefficient.

3.3 Methodology

Mathematical models are an effective tool to characterize and predict the movement and quality of water. These models provide a means of moving beyond point-based measurements to develop a continuous and comprehensive picture of hydrologic and hydrodynamic conditions. Schematic diagram of Model Development is giver below:



Schematic diagram of Model Development

Figure 3.6: Schematic diagram of Model Development and Outputs Results

3.3.1 Data Collection and Compilation

Primary and secondary data have been collected in order to find the prevailing conditions; establish the water availability and develop dedicated 1D Hydrodynamic model for Polder 41/1. Water level, discharge, rainfall, evaporation and latest bathymetric data were collected from different sources for this study. The list of data and their respective sources are presented in Table-3.1.

Table 3.1: List of data collected from different source for model update, calibration and validation

Data type	Period	Frequency	Source
Rainfall	2014-2015	Daily	BWDB
Evaporation	2014-2015	Daily	BWDB, BMD
Tidal Water Level	2014-2015	Half hourly	BIWTA, IWM
Tidal Water flow	2015	Full tidal cycle: Spring and Neap	IWM
River bathymetry and Khals cross section	Most recent surveyed		IWM
Structural information	Most recent surveyed		IWM
Surface water salinity	2013-2016	High and Low tide-alternate day	IWM

3.3.2 Identify existing canal network and sluicegate

Existing canal alignment, cross sections and regulator information required to develop the dedicated model of Polder 41/1. Alignment of internal canals and information of regulators have been collected from IWM.

3.3.3 Identify cropland and irrigation water requirement of each canal

Cropland within the polder need to identify by using high resolution satellite image (Sentinel-2 and google earth). Command area will be delineated by using existing land elevation, road network and homestead area. Amount of irrigation water required to determine for water withdrawal from the canals inside the polder according to irrigation requirement.

3.4 Scenario selection and simulation

Different scenarios selected to evaluate the water availability inside the polder for irrigation. The scenarios considered different operation of regulators and water withdrawal from the canal. Three scenarios considered for this study. The description of selected scenarios are given below:

3.4.1 Scenario-1: Polder system considering regulator always open without water withdrawal

Scenario-1 considers that controlling gate of regulator is always open. River tide can enter into the polder through the regulator and tidal characteristic observed in internal canals. No water withdrawal is considered for this scenario.

3.4.2 Scenario-2: Polder system considering regulator always open with water withdrawal

Scenario-2 considers that regulator gate is always open. River tide can enter into the polder through the regulator and tidal characteristic observed in internal canals. Water withdrawal from the canal is considered for this scenario according to irrigation water demand.

3.4.3 Scenario-3: Polder system considering sluicegate operation with water withdrawal

Scenario-3 considers that regulator gate is operate as flushing condition. Regulator operate to utilize maximum river water during high tide. By operating regulator as flushing condition, water can only enter in to the polder when the water level of peripheral river is higher than the canal water inside the polder. Regulator will be close when the river water level is lower than internal canal. Water withdrawal from the canal is considered for this scenario according to irrigation water demand.

CHAPTER 4

STUDY AREA AND MODEL SETUP

4.1 General

The southwest costal region is characterised with high poverty, food insecurity, vulnerable to multi hazards and limited livelihood opportunities. River salinity and poor water management are main constraints that restrict the intensification of agricultural production. Fresh water availability is likely to decrease in times of climate change. However, all agricultural lands are not exposed to high river salinity. River salinity in the Tentulia, Bishkhali, Buriswar and upstream stretch of Baleswar rivers is low throughout the year. There is huge potential for intensification of agricultural production by improving water management, bringing the fallow lands under agricultural production and introducing new cropping system.

South Central Zone, which was chosen as the most active hydrological zone in which surface water irrigation has potential. Tentulia, Burisware and Bishkhali rivers are contain a huge amount of fresh water during dry period. Salinity remains <1 ppt in Buriswar river at Amtali all over the year. So, adjacent area of Buriswar river can be brought under irrigation. In downstream the river meets with Baleswar and Bishkhali river after that these three rivers meets the sea. Most of the land adjacent to Buriswar area are polder area. In Patuakhali, Barguna and Barisal district huge amount of agricultural land remains fallow during the dry period. Polder-41/1 is situated at the right bank of Buriswar river and salinity remains less than 1ppt all over the year. Considering low salinity in the dry period and scarcity of irrigation water, Polder 41/1 of Barguna district has been chosen to assess the water availability inside the polder for the dry period. At present condition Khasari-T.Aus-T.Aman and Mug bean-T.Aus-T.Aman these two type of cropping pattern observed in Barguna district (FAO, 2012). In our study area (Polder 41/1) mostly lands remain fallow during the dry period. Rabi crop cultivates in some area and Boro rice cultivate in very little scale. Crop production of Barguna District is shown in Table 4.1.

Table 4.1 Estimates of Dry season crop for Barguna District, 2013-14 to 2014-15

Zila/ Division	**Crop**	**2013-2014**					**2014-2015**				
		Area		Yield per		Production (M.Ton)	Area		Yield per		Production (M.Ton)
		Acres	Hectares	Acre (Maund)	Hectare (M.Ton)		Acres	Hectares	Acre (Maund)	Hectare (M.Ton)	
Barguna	Lentil (Masur)	230	152	35	296	220	65	230	152	35	296
	Green gram (Mug)	2183	189	413	2315	217	502	2183	189	413	2315
	Kheshari	12785	256	3273	7610	153	1161	12785	256	3273	7610
	pulses (Rabi & Kharif)	93	204	19	62	323	20	93	204	19	62
	Sesame (Till) (Rabi & kharif)	187	246	46	193	316	61	187	246	46	193
	Local Boro	140	57	20.66	1.906	108	-	-	-	-	-
	HYV Boro	937	379	33.43	3.084	1169	726	294	31.4	2.896	851
	Hybrid Boro	-	-	-	-	-	-	-	-	-	-
	Local+HYV+ Hybrid	1077	436	31.77	2.93	1277	726	294	31.4	2.896	851

Source: Year book 2015

4.2 Study area

The Polder 41/1 situated in Barguna Sadar Upazilla under Barguna District at South central region of Bangladesh. The polder covers two Union Parishads (U/P), namely Burir-Char and Aila Patakata. It is surrounded by Bashbunia Khal in west, Buriswar rivers to the East and South, Khakdon river at north side of the polder. The total polder area is 42.05 Square KM. Map of the study area is shown in Figure-4.1. River salinity of the peripheral river is less than 1 ppt. Measured salinity of Buriswar river at Amtali is shown in Figure 4.2.

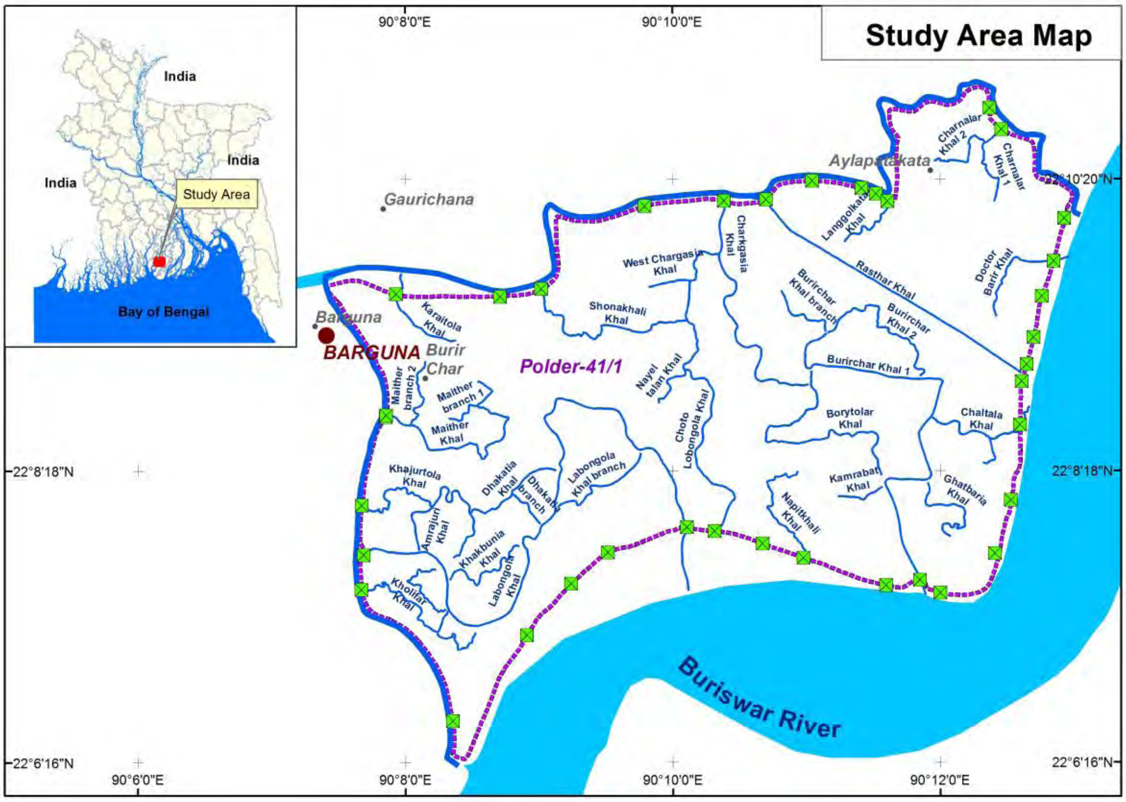


Figure 4.1: Provide map of Polder-41/1 showing internal canals and existing regulator

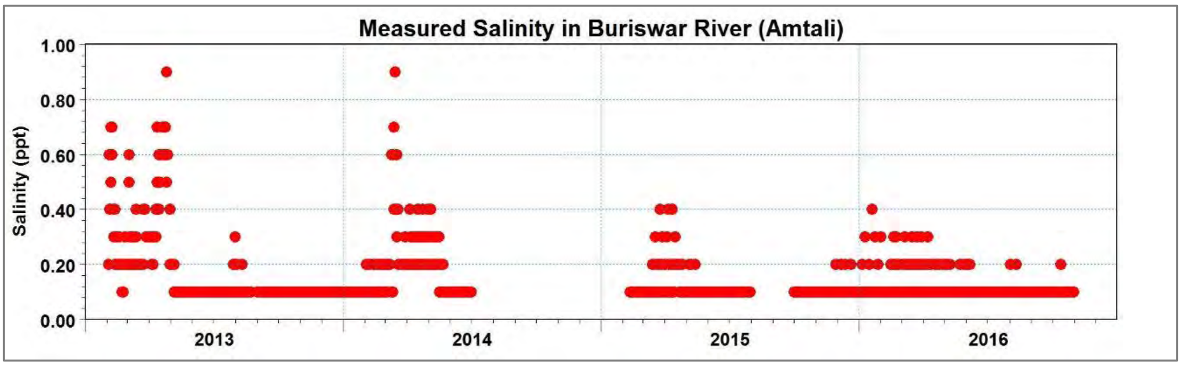


Figure 4.2: Measured Salinity in Amtali from 2013 to 2016

4.3 Identify existing canal network and sluicegate

Existing canal network inside the polder and regulators information collected from the survey data done by IWM and verify by using satellite image (Sentinel-2 and Google earth). There are 37 regulators situated in polder 41/1. Drainage regulators are functioning but required repairing. Most of the flushing regulator are not functioning properly. Only flushing regulator connecting with canal are in function. Existing canal and regulator of polder 41/1 are shown in Figure 4.3

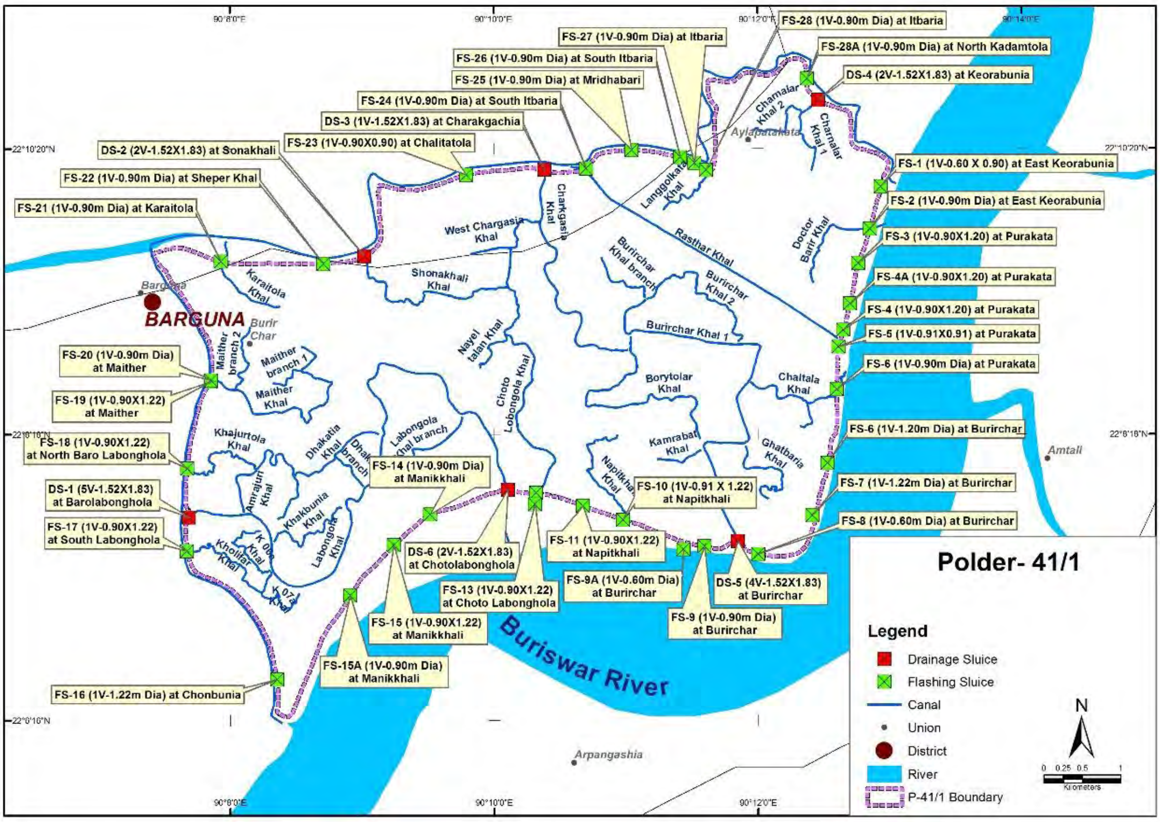


Figure 4.3: Showing Map of Polder 41/1 including existing canal and regulators

4.4 Available Cropland Area in Polder 41/1

Existing cropland of polder 41/1 identified by using latest satellite high resolution image (Sentinel-2 and Google earth). To identify maximum cropland within the polder, fallow land is also considered as cropland area. Around 26 square km of cropland identified in Polder 41/1. Identified cropland shown in Figure-4.4.

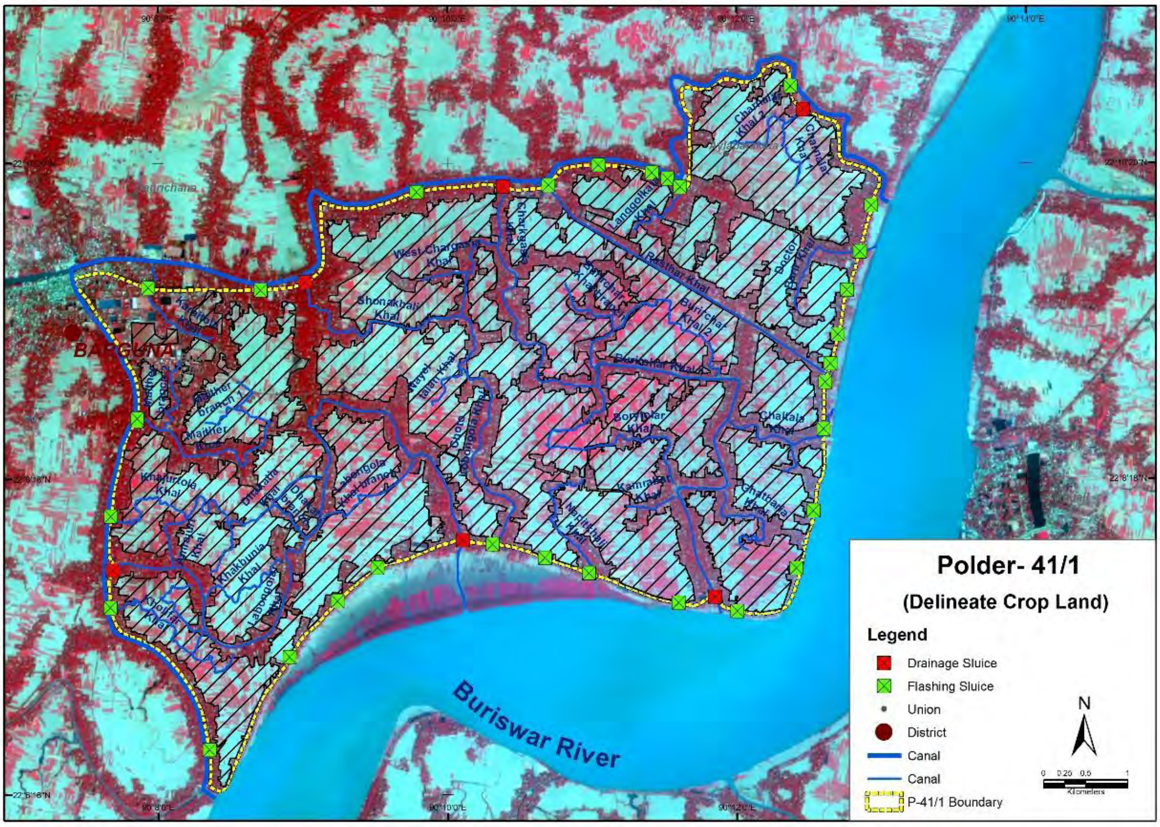


Figure 4.4: Cropland inside Polder 41/1

4.5 Delineate command area and Identify Cropland

Delineation of command area and the cropland within the command area is essential to know the irrigation water demand from each canal. Command area delineated for each canal considering existing land level, road network and satellite image (Sentinel-2 and Google earth image). Required irrigation water estimate for each canal after the identification of command area. Identified command area shown in Figure 4.5 to 4.6. Area of command area and available cropland for each canal are shown in Table 4.2.

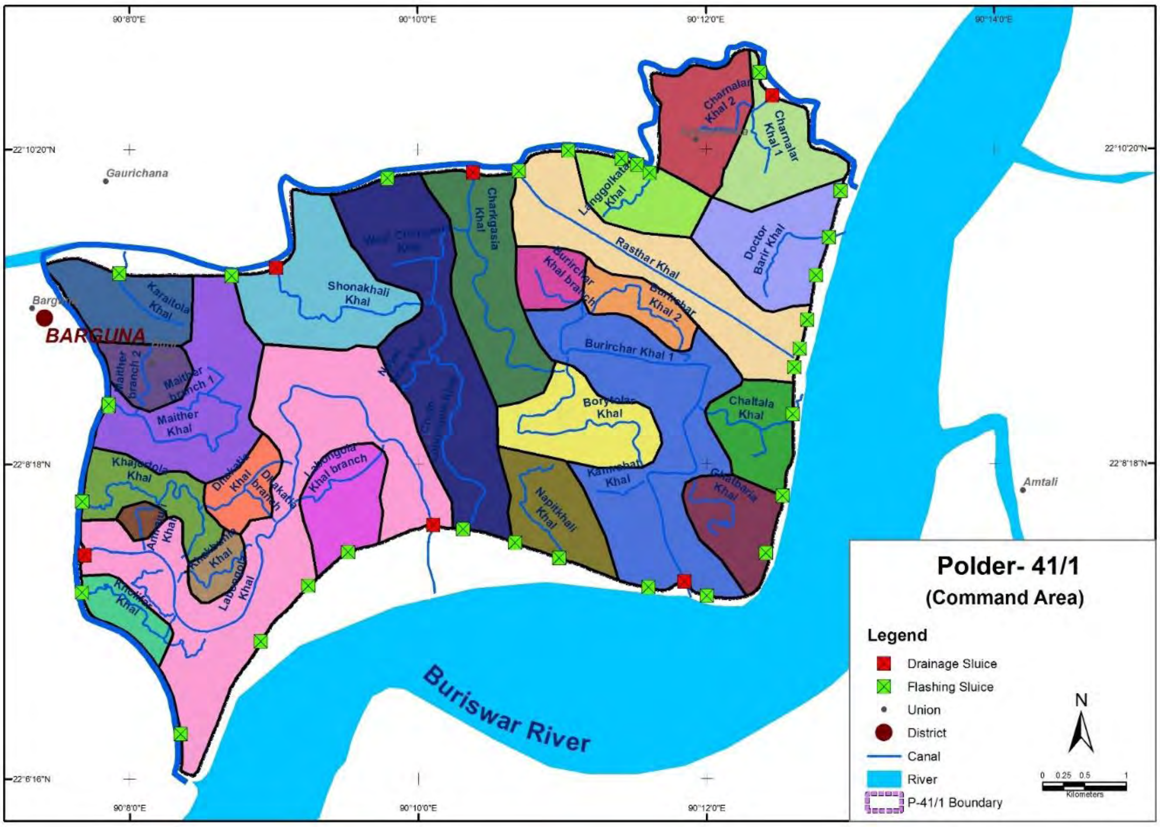


Figure 4.5: Delineate command area for existing canal

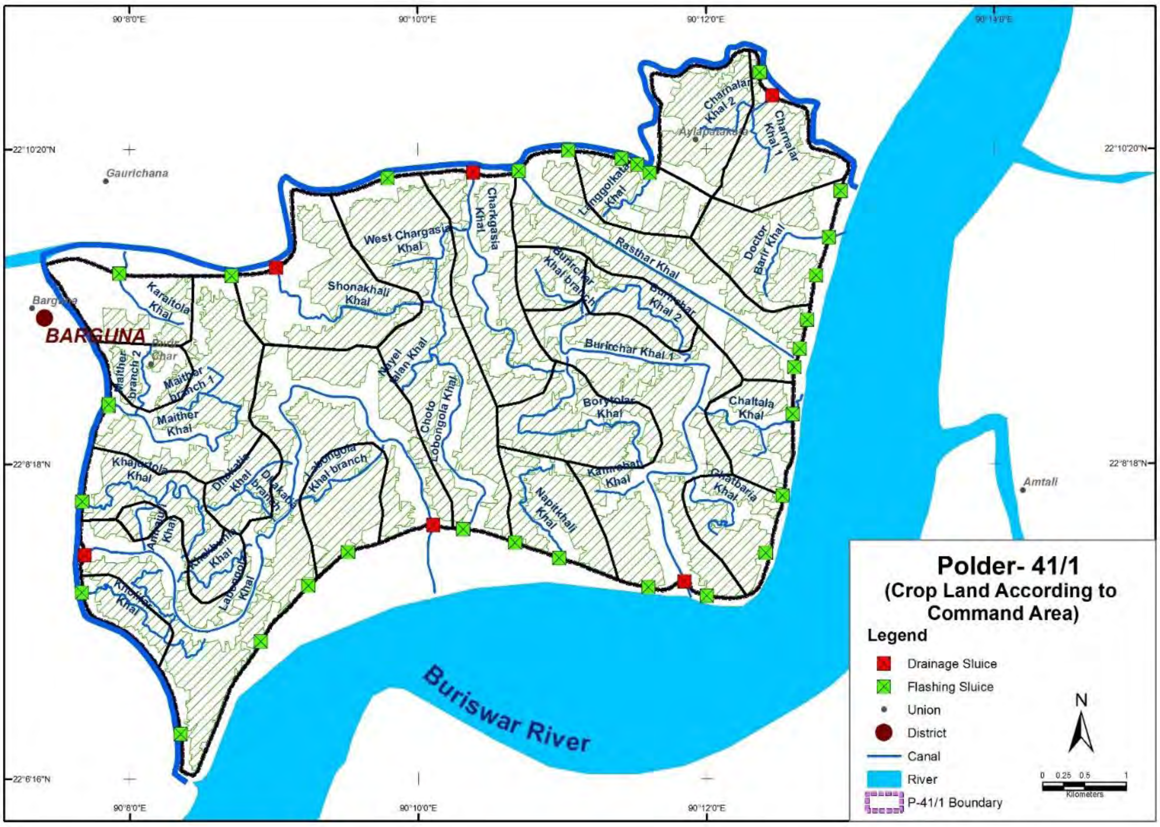


Figure 4.6: Delineated command area for each canal inside the Polder

Table 4.2: Table showing Polder 41/1 Canal, Canal Length, Command area and Cropland within the command area

Canal Name	**Length (km)**	**Command area (sq. km)**	**Crop land area (sq. km)**
Amrajuri Khal	0.77	0.179	0.104
Borytolar Khal	3.58	1.543	1.168
Burirchar Khal 1	5.90	4.265	2.677
Burirchar Khal 2	2.27	0.701	0.589
Burirchar Khal branch	0.97	0.571	0.414
Chaltala Khal	1.83	1.041	0.659
Charkgasia Khal	3.60	2.201	1.299
Charnalar Khal 1	1.28	1.328	1.053
Charnalar Khal 2	1.02	1.389	1.043
Choto Lobongola Khal	4.76	3.891	2.560
Dhakatia Khal	1.39	0.621	0.520
Doctor Barir Khal	1.60	1.688	1.086
Ghatbaria Khal	1.69	1.064	0.717
Karaitola Khal	1.38	1.247	0.305
Khajurtola Khal	3.39	1.053	0.871
Khakbunia Khal	1.47	0.380	0.380
Kholifar Khal	1.86	0.546	0.390
Labongola Khal	9.54	6.502	3.784
Labongola Khal branch	1.48	1.129	1.005
Langgolkata Khal	1.02	1.053	0.565
Maither branch 2	1.04	0.668	0.277
Maither Khal	3.37	2.517	1.653
Napitkhali Khal	1.81	1.241	0.916
Rasthar Khal	4.22	2.935	1.780
Shonakhali Khal	2.67	2.300	1.295

4.6 Irrigation water requirement for water withdrawal

Crop water requirement estimated from the Evaporation data of Bangladesh Meteorological Department (BMD) of Barisal Station. As there is no evaporation station near polder 41/1 for that reason evaporation data of Barisal used in to calculate crop water requirement. To estimate crop water requirement daily evaporation data collected from BMD and estimate required crop water from evaporation data considering percolation rate of soil. 10 percent irrigation loss considered to estimate irrigation water requirement as the farmers use pipe. Farmers can irrigate into their plot directly. Less irrigation loss observed in this process. To understand the water withdrawal impact in canal system, irrigation water requirement estimated for each canal according to their command area.

Estimated water extracted from each canal in the hydrodynamic model to observe the impact after extraction. Identified cropland for each canal shown in Figure 4.7. Estimated required water are presented in Table 4.4.

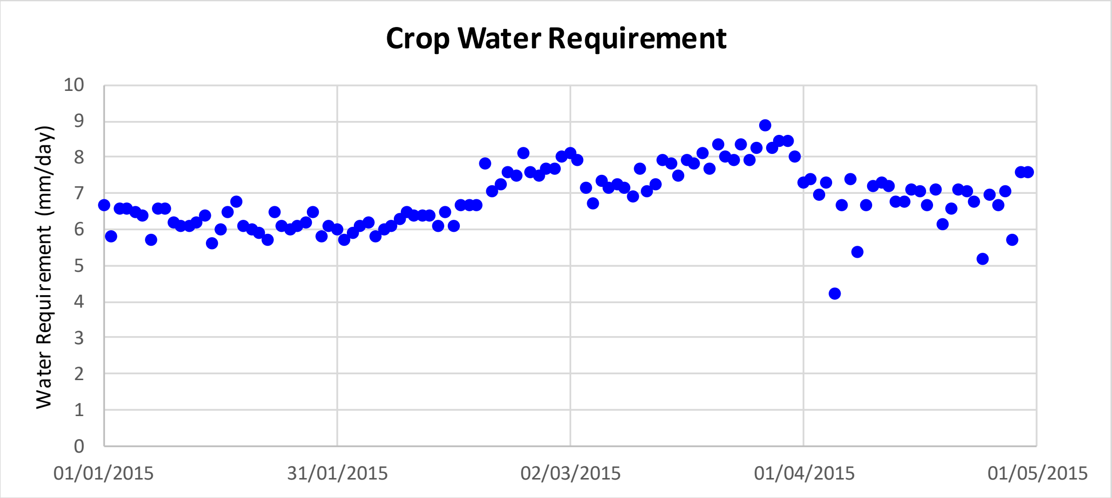


Figure 4.7: Crop Water Requirement for Boro Rice

Table 4.3: Growth stage, duration and KC select for MDIP for Boro rice (IWM 1999)

Growth stages	**Boro rice**	
	K_C	**Days**
Initial stage	1.10	20
Development stage	1.10	30
Mid-season	1.25	40
Late season	1.00	30
Total duration		120

$$ET_0 = Kp * E_{Pan} \quad (4.1)$$

ETo = *Reference evapotranspiration [mm/day]*
Kp = *Pan coefficient*
Epan = *Pan evaporation [mm/day].*

$$ET_C = K_C * ET_0 \quad (4.2)$$

ET_C = *Crop evapotranspiration (mm/day)*
ET_0 = *Reference Evapotranspiration (mm/day)*
K_C = *Crop Coefficient*

Table 4.4: Estimate required water for Boro rice from Evaporation data of Barisal, BMD Station

Date	**Daily Evaporation E_{Pan} (mm)**	**ET_0 = $Kp*E_{Pan}$ (mm/day)**	**Kc**	**$ET_C = K_C*ET_0$ (mm/day)**	**E_{TC} + Percolation (2.8 mm)**	**Consider 10 Percent Irrigation Loss (mm/day)**
01/01/2015	3.70	2.96	1.10	3.26	6.06	6.66
02/01/2015	2.80	2.24	1.10	2.46	5.26	5.79
03/01/2015	3.60	2.88	1.10	3.17	5.97	6.56
04/01/2015	3.60	2.88	1.10	3.17	5.97	6.56
05/01/2015	3.50	2.80	1.10	3.08	5.88	6.47
06/01/2015	3.40	2.72	1.10	2.99	5.79	6.37
07/01/2015	2.70	2.16	1.10	2.38	5.18	5.69
08/01/2015	3.60	2.88	1.10	3.17	5.97	6.56
09/01/2015	3.60	2.88	1.10	3.17	5.97	6.56
10/01/2015	3.20	2.56	1.10	2.82	5.62	6.18
11/01/2015	3.10	2.48	1.10	2.73	5.53	6.08
12/01/2015	3.10	2.48	1.10	2.73	5.53	6.08
13/01/2015	3.20	2.56	1.10	2.82	5.62	6.18
14/01/2015	3.40	2.72	1.10	2.99	5.79	6.37
15/01/2015	2.60	2.08	1.10	2.29	5.09	5.60
16/01/2015	3.00	2.40	1.10	2.64	5.44	5.98
17/01/2015	3.50	2.80	1.10	3.08	5.88	6.47
18/01/2015	3.80	3.04	1.10	3.34	6.14	6.76
19/01/2015	3.10	2.48	1.10	2.73	5.53	6.08
20/01/2015	3.00	2.40	1.10	2.64	5.44	5.98
21/01/2015	2.90	2.32	1.10	2.55	5.35	5.89
22/01/2015	2.70	2.16	1.10	2.38	5.18	5.69
23/01/2015	3.50	2.80	1.10	3.08	5.88	6.47
24/01/2015	3.10	2.48	1.10	2.73	5.53	6.08
25/01/2015	3.00	2.40	1.10	2.64	5.44	5.98
26/01/2015	3.10	2.48	1.10	2.73	5.53	6.08
27/01/2015	3.20	2.56	1.10	2.82	5.62	6.18
28/01/2015	3.50	2.80	1.10	3.08	5.88	6.47
29/01/2015	2.80	2.24	1.10	2.46	5.26	5.79
30/01/2015	3.10	2.48	1.10	2.73	5.53	6.08
31/01/2015	3.00	2.40	1.10	2.64	5.44	5.98
01/02/2015	2.70	2.16	1.10	2.38	5.18	5.69
02/02/2015	2.90	2.32	1.10	2.55	5.35	5.89
03/02/2015	3.10	2.48	1.10	2.73	5.53	6.08
04/02/2015	3.20	2.56	1.10	2.82	5.62	6.18
05/02/2015	2.80	2.24	1.10	2.46	5.26	5.79
06/02/2015	3.00	2.40	1.10	2.64	5.44	5.98
07/02/2015	3.10	2.48	1.10	2.73	5.53	6.08
08/02/2015	3.30	2.64	1.10	2.90	5.70	6.27

Date	**Daily Evaporation E_{Pan} (mm)**	**ET_0 = K_p*E_{Pan} (mm/day)**	**Kc**	**$ET_C = K_C*ET_0$ (mm/day)**	**E_{TC} + Percolation (2.8 mm)**	**Consider 10 Percent Irrigation Loss (mm/day)**
09/02/2015	3.50	2.80	1.10	3.08	5.88	6.47
10/02/2015	3.40	2.72	1.10	2.99	5.79	6.37
11/02/2015	3.40	2.72	1.10	2.99	5.79	6.37
12/02/2015	3.40	2.72	1.10	2.99	5.79	6.37
13/02/2015	3.10	2.48	1.10	2.73	5.53	6.08
14/02/2015	3.50	2.80	1.10	3.08	5.88	6.47
15/02/2015	3.10	2.48	1.10	2.73	5.53	6.08
16/02/2015	3.70	2.96	1.10	3.26	6.06	6.66
17/02/2015	3.70	2.96	1.10	3.26	6.06	6.66
18/02/2015	3.70	2.96	1.10	3.26	6.06	6.66
19/02/2015	4.90	3.92	1.10	4.31	7.11	7.82
20/02/2015	4.10	3.28	1.10	3.61	6.41	7.05
21/02/2015	3.80	3.04	1.25	3.80	6.60	7.26
22/02/2015	4.10	3.28	1.25	4.10	6.90	7.59
23/02/2015	4.00	3.20	1.25	4.00	6.80	7.48
24/02/2015	4.60	3.68	1.25	4.60	7.40	8.14
25/02/2015	4.10	3.28	1.25	4.10	6.90	7.59
26/02/2015	4.00	3.20	1.25	4.00	6.80	7.48
27/02/2015	4.20	3.36	1.25	4.20	7.00	7.70
28/02/2015	4.20	3.36	1.25	4.20	7.00	7.70
01/03/2015	4.50	3.60	1.25	4.50	7.30	8.03
02/03/2015	4.60	3.68	1.25	4.60	7.40	8.14
03/03/2015	4.40	3.52	1.25	4.40	7.20	7.92
04/03/2015	3.70	2.96	1.25	3.70	6.50	7.15
05/03/2015	3.30	2.64	1.25	3.30	6.10	6.71
06/03/2015	3.90	3.12	1.25	3.90	6.70	7.37
07/03/2015	3.70	2.96	1.25	3.70	6.50	7.15
08/03/2015	3.80	3.04	1.25	3.80	6.60	7.26
09/03/2015	3.70	2.96	1.25	3.70	6.50	7.15
10/03/2015	3.50	2.80	1.25	3.50	6.30	6.93
11/03/2015	4.20	3.36	1.25	4.20	7.00	7.70
12/03/2015	3.60	2.88	1.25	3.60	6.40	7.04
13/03/2015	3.80	3.04	1.25	3.80	6.60	7.26
14/03/2015	4.40	3.52	1.25	4.40	7.20	7.92
15/03/2015	4.30	3.44	1.25	4.30	7.10	7.81
16/03/2015	4.00	3.20	1.25	4.00	6.80	7.48
17/03/2015	4.40	3.52	1.25	4.40	7.20	7.92
18/03/2015	4.30	3.44	1.25	4.30	7.10	7.81
19/03/2015	4.60	3.68	1.25	4.60	7.40	8.14
20/03/2015	4.20	3.36	1.25	4.20	7.00	7.70
21/03/2015	4.80	3.84	1.25	4.80	7.60	8.36

Date	Daily Evaporation E_{Pan} (mm)	$ET_0 = Kp*E_{Pan}$ (mm/day)	Kc	$ET_C = K_C*ET_0$ (mm/day)	E_{TC} + Percolation (2.8 mm)	Consider 10 Percent Irrigation Loss (mm/day)
22/03/2015	4.50	3.60	1.25	4.50	7.30	8.03
23/03/2015	4.40	3.52	1.25	4.40	7.20	7.92
24/03/2015	4.80	3.84	1.25	4.80	7.60	8.36
25/03/2015	4.40	3.52	1.25	4.40	7.20	7.92
26/03/2015	4.70	3.76	1.25	4.70	7.50	8.25
27/03/2015	5.30	4.24	1.25	5.30	8.10	8.91
28/03/2015	4.70	3.76	1.25	4.70	7.50	8.25
29/03/2015	4.90	3.92	1.25	4.90	7.70	8.47
30/03/2015	4.90	3.92	1.25	4.90	7.70	8.47
31/03/2015	4.50	3.60	1.25	4.50	7.30	8.03
01/04/2015	4.80	3.84	1.00	3.84	6.64	7.30
02/04/2015	4.90	3.92	1.00	3.92	6.72	7.39
03/04/2015	4.40	3.52	1.00	3.52	6.32	6.95
04/04/2015	4.80	3.84	1.00	3.84	6.64	7.30
05/04/2015	1.30	1.04	1.00	1.04	3.84	4.22
06/04/2015	4.10	3.28	1.00	3.28	6.08	6.69
07/04/2015	4.90	3.92	1.00	3.92	6.72	7.39
08/04/2015	2.60	2.08	1.00	2.08	4.88	5.37
09/04/2015	4.10	3.28	1.00	3.28	6.08	6.69
10/04/2015	4.70	3.76	1.00	3.76	6.56	7.22
11/04/2015	4.80	3.84	1.00	3.84	6.64	7.30
12/04/2015	4.70	3.76	1.00	3.76	6.56	7.22
13/04/2015	4.20	3.36	1.00	3.36	6.16	6.78
14/04/2015	4.20	3.36	1.00	3.36	6.16	6.78
15/04/2015	4.60	3.68	1.00	3.68	6.48	7.13
16/04/2015	4.50	3.60	1.00	3.60	6.40	7.04
17/04/2015	4.10	3.28	1.00	3.28	6.08	6.69
18/04/2015	4.60	3.68	1.00	3.68	6.48	7.13
19/04/2015	3.50	2.80	1.00	2.80	5.60	6.16
20/04/2015	4.00	3.20	1.00	3.20	6.00	6.60
21/04/2015	4.60	3.68	1.00	3.68	6.48	7.13
22/04/2015	4.50	3.60	1.00	3.60	6.40	7.04
23/04/2015	4.20	3.36	1.00	3.36	6.16	6.78
24/04/2015	2.40	1.92	1.00	1.92	4.72	5.19
25/04/2015	4.40	3.52	1.00	3.52	6.32	6.95
26/04/2015	4.10	3.28	1.00	3.28	6.08	6.69
27/04/2015	4.50	3.60	1.00	3.60	6.40	7.04
28/04/2015	3.00	2.40	1.00	2.40	5.20	5.72
29/04/2015	5.10	4.08	1.00	4.08	6.88	7.57
30/04/2015	5.10	4.08	1.00	4.08	6.88	7.57
Total	**458.50**	**366.80**		**413.32**	**749.32**	**824.25**

4.7 Develop Water Flow Model

Mathematical models are an effective tool to characterize and predict the movement and quality of water. A dedicated model developed for Polder 41/1. All the boundary for the dedicated model generated from South West Regional Model (SWRM), Developed by IWM. Calibration done in the source peripheral river of the Polder 41/1. All the canal and sluice gate are included in this dedicated model.

4.7.1 Water Flow Models

The one-dimensional hydrodynamic model consists of two different modules: rainfall runoff (NAM) and hydrodynamic (HD). The rainfall-runoff (NAM) model is applied to estimate the runoff generated from rainfall occurring in the catchments of the model area. The model considers the basin characteristics including specific yield, initial soil moisture contents and irrigation/water extraction from the surface or ground water sources in the catchments. Rainfall and evaporation data have been incorporated into the model. The model computes evaporation, percolation and other losses and gives the catchment runoff as outputs.

The 1-D hydrodynamic model calculates water flow and water level using the runoff generated from the catchments (output of rainfall runoff Model) as well as taking input of flow from the upstream rivers. It incorporates water flow data at upstream boundaries and water level data at downstream boundaries.

The 1-D hydrodynamic developed using MIKE11 HD module. In this research for the study area the 1-D South-West Regional Model (SWRM) and Bay of Bengal model available in IWM has been updated, calibrated and validated. A dedicated model developed from SWRM of IWM and include Polder 41/1 in the dedicated model.

4.7.1.1 Rainfall Runoff Model (NAM)

NAM model for Polder 41/1dedicated model

The South West Region rainfall runoff model (NAM) contains 4 catchments. These catchments are named as SC-11, SC-12, SC-14 and SC-15. Figure- 4.8 showing the map of catchments with BWDB rainfall stations.

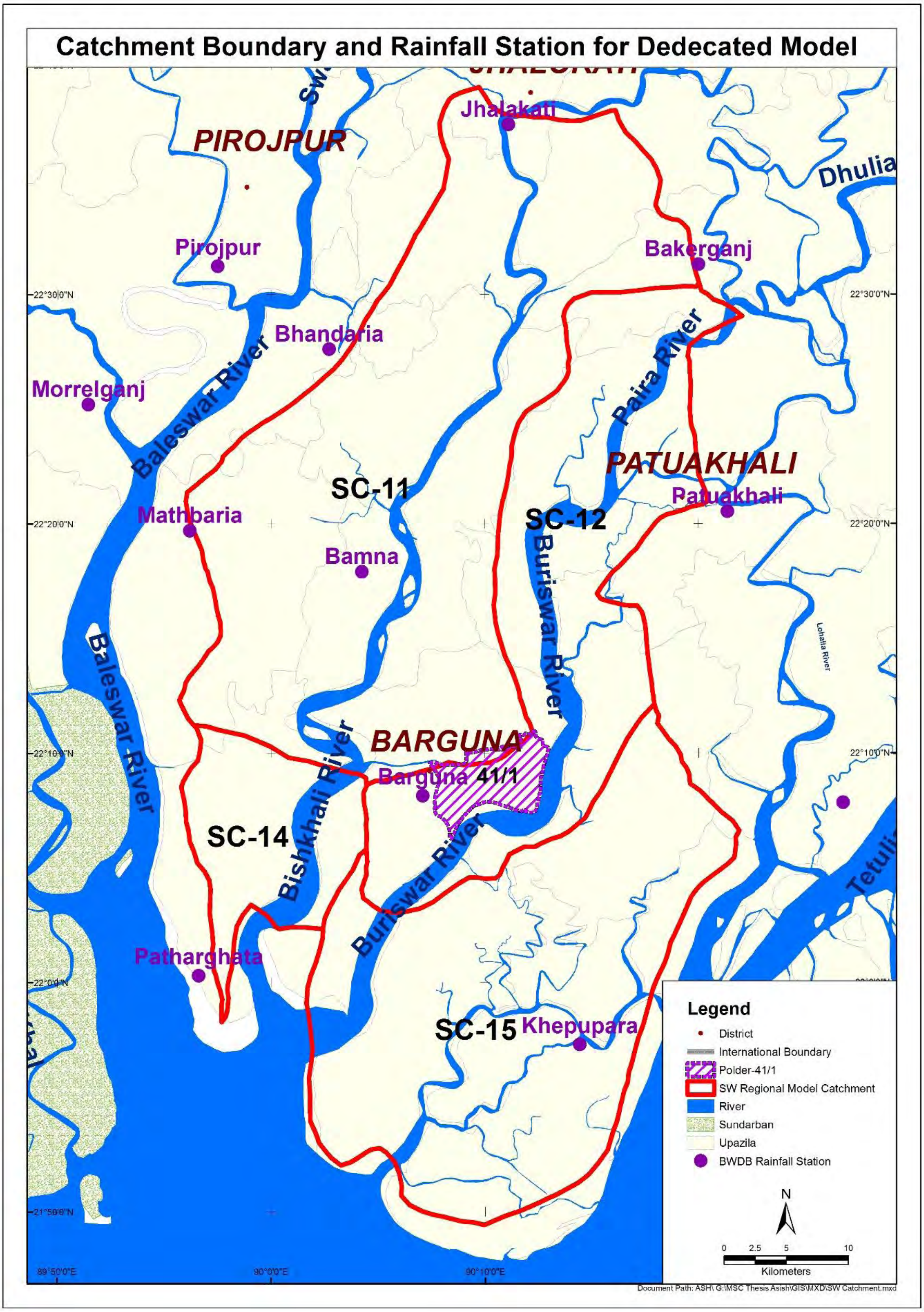


Figure 4.8: Catchments and rainfall stations of dedicated model.

4.7.1.2 1D Dedicated Hydrodynamic Model for Polder 41/1

A dedicated 1D hydrodynamic model developed for Polder 41/1 to analysis the study. Inputs for a water flow model include the cross-sectional river/khal data, rainfall runoff estimates from the rainfall-runoff model, water flow data at the upstream end of the river/khal system (upstream boundary), water level data at the downstream end of the river/khal system (downstream boundary). There are three boundaries in this dedicated model. The boundary condition for upstream and downstream extracted from calibrated South West Region Model (SWRM) develop by IWM. Existing structure also include in the model and operate structure for different scenarios. Developed dedicated model of Polder 41/1 shown in Figure-4.9.

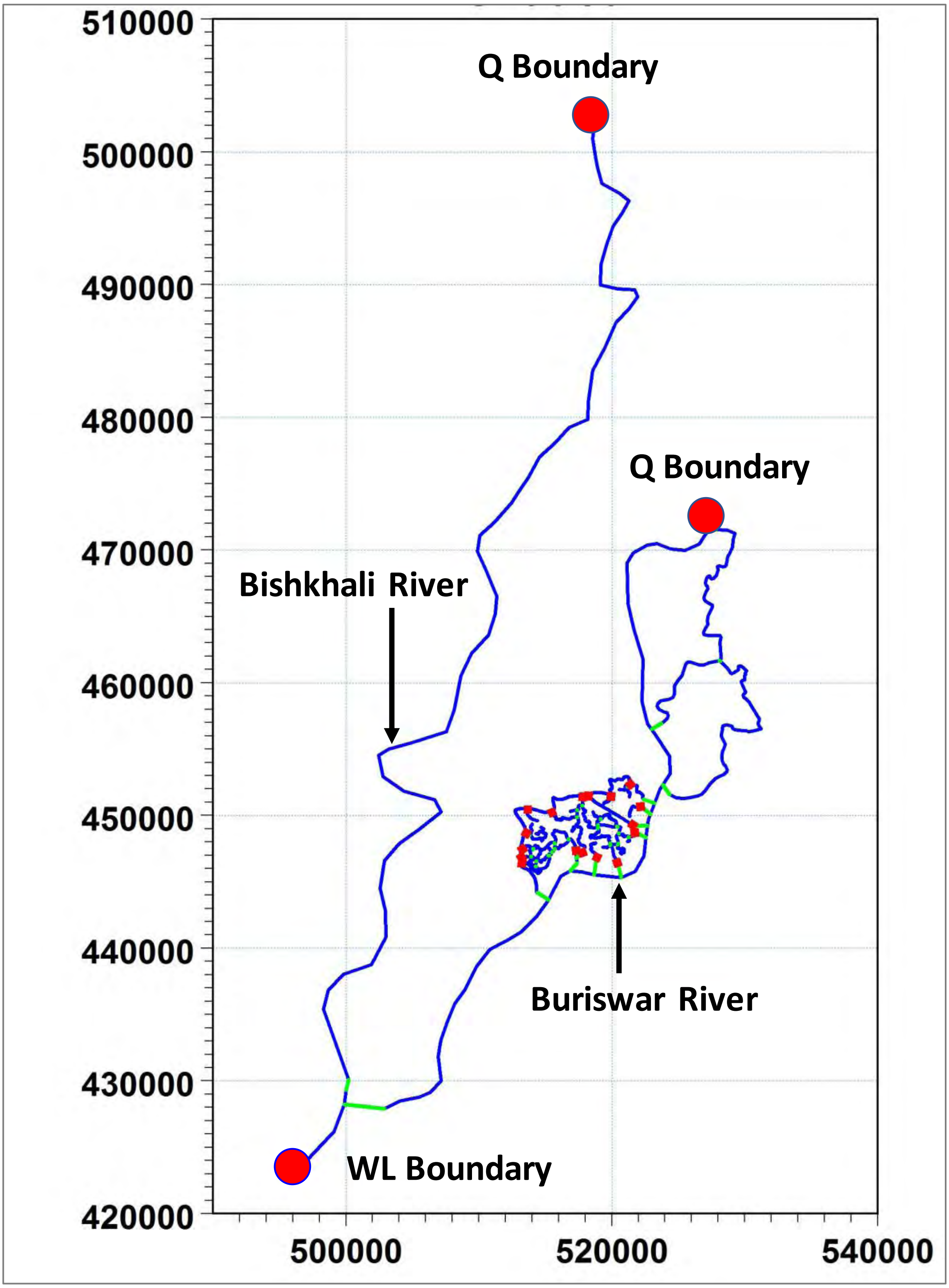


Figure 4.9: River network system and important upstream and downstream boundaries with controlling structure in 1D P-41/1 dedicated model

CHAPTER 5

RESULTS AND DISCUSSION

5.1 General

A dedicated Polder-41/1 model has been developed including Baleswar river, Bishkhali river, Kakdon river, Keorabunia khal, Bashbunia khal, internal canal of Polder 41/1 and existing regulator of Polder 41/1. Calibrated of model has been done for both water level and discharge. After the calibration of the model, selected scenarios simulated and analysis for this study.

5.2 Model Calibration and Validation

5.2.1 Model Calibration

Model calibration demonstrates the capability of the model to produce accurate predictions. Water level and discharge has been calibrated in Buriswar river (Amtali) for Polder 41/1 model. Map of Calibration locations shown in Figure 5.1. Water level and discharge calibration plot of Buriswar river (Amtali) are shown in Figure 5.2 and Figure 5.3.

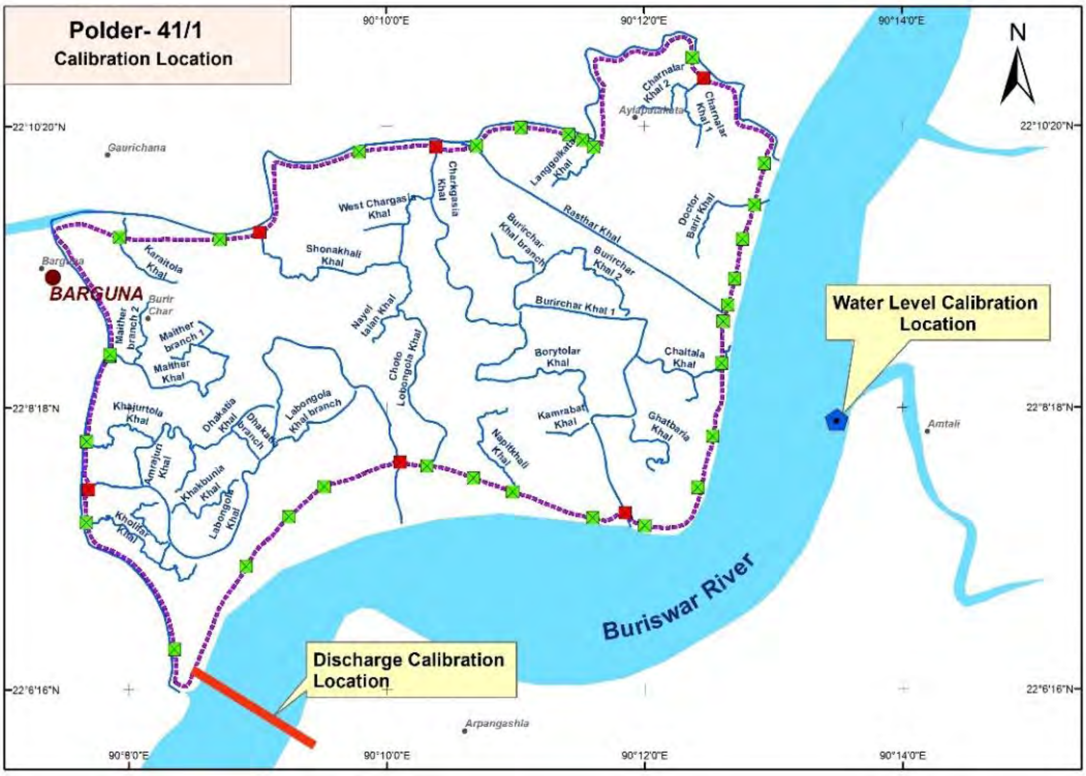


Figure 5.1: Water and discharge calibration locations

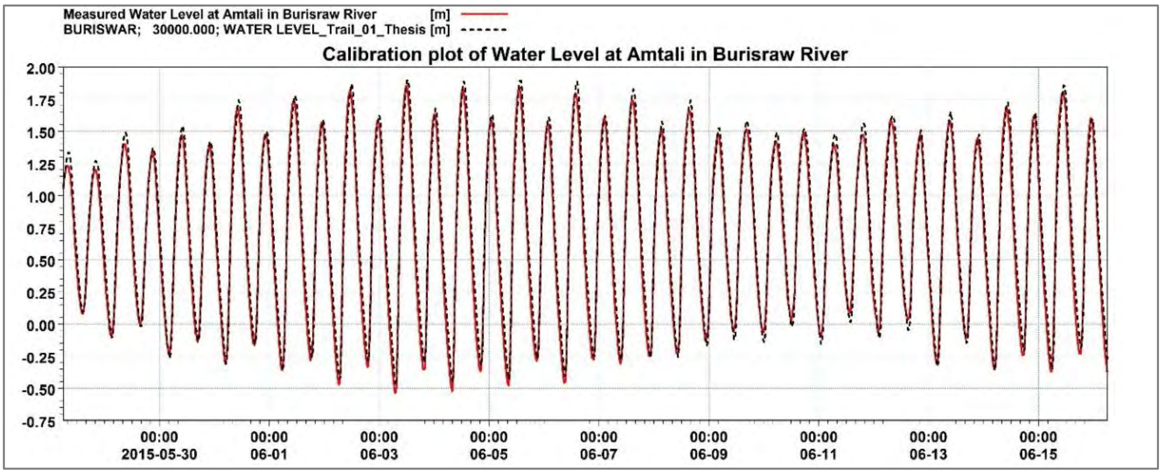


Figure 5.2: Water Level Calibration in Buriswar River (Amtali)

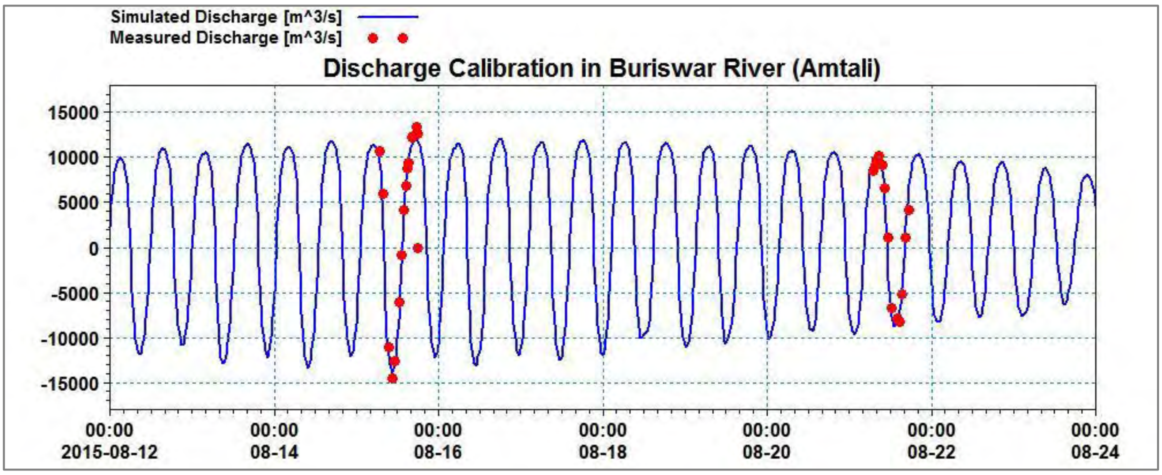


Figure 5.3: Discharge Calibration in Buriswar River (Amtali)

5.3 Result analysis

Water level inside the polder depends on the water level of peripheral river, condition of internal canal and regulators operation. Polder 41/1 surrounded by Buriswar river and Kakdon river. These two rivers are the main source of surface water of this polder. As rainfall is very limited in the dry season. Water level insides the polder depends on these two peripheral rivers.

5.3.1 Water Availability in Present Condition

At present condition Khasari-T.Aus-T.Aman and Mug bean-T.Aus-T.Aman these two type of cropping pattern observed in Barguna district (FAO,2012). In Polder 41/1 most of the cropland remains fallow, in some are farmers cultivate Rabi crop, pulses and boro rice in very little area during the dry period. Pulses required very less irrigation water around 200 mm (CSIRO,2014). Most of the regulators kept close because of low irrigation demand during the dry period.

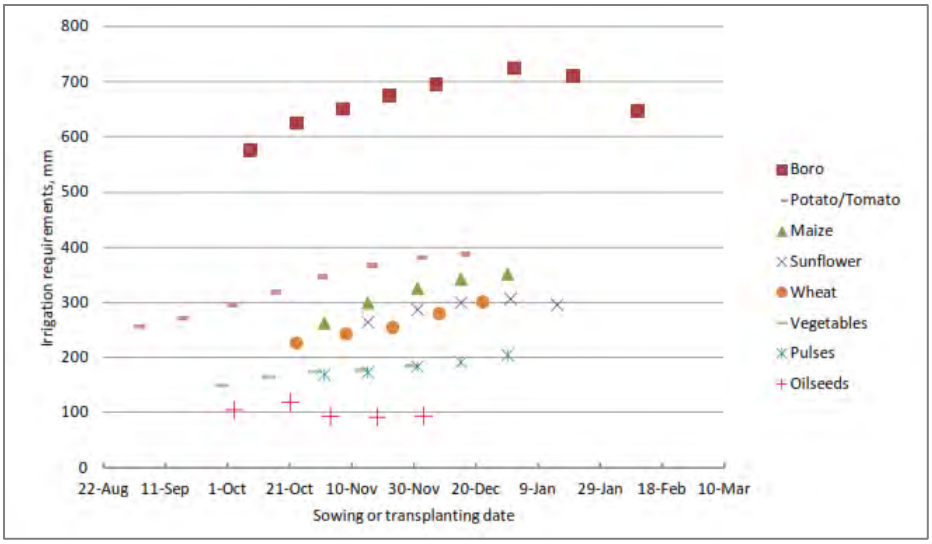


Figure 5.4: Variation in irrigation requirements of Rabi season crops due to the variation in planting or sowing date, (CSIRO,2014)

Buriswar and Kakdon rivers are the main source of water of polder 41/1 during dry period. Water level hydrograph of Buriswar river and Kakdon river shown in Figure 5.5 and Figure 5.6

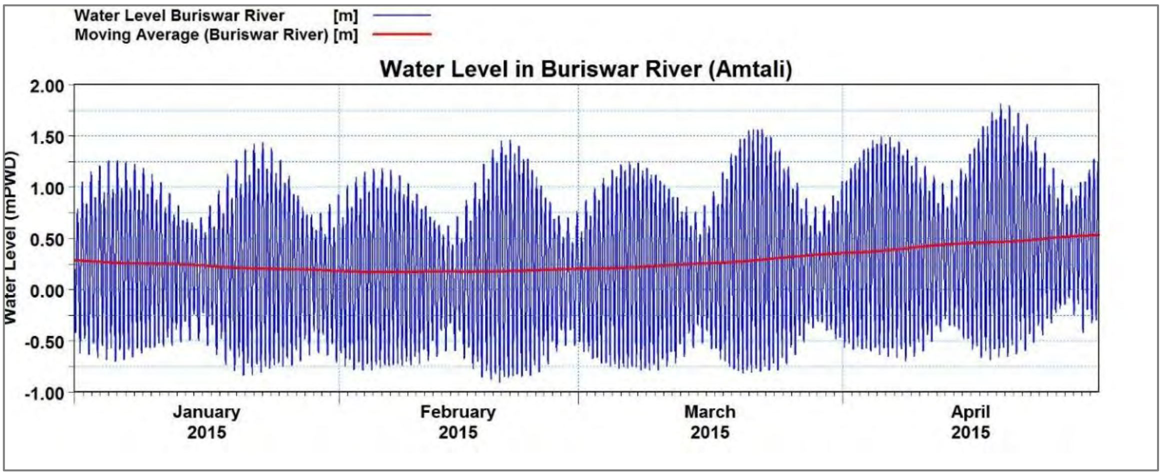


Figure 5.5: Water level of Buriswar river

Water level of Buriswar river varies from -0.70 mPWD to 1.8 mPWD. Water level of Kakdon river varies from 0.20 to 1.70 mPWD.

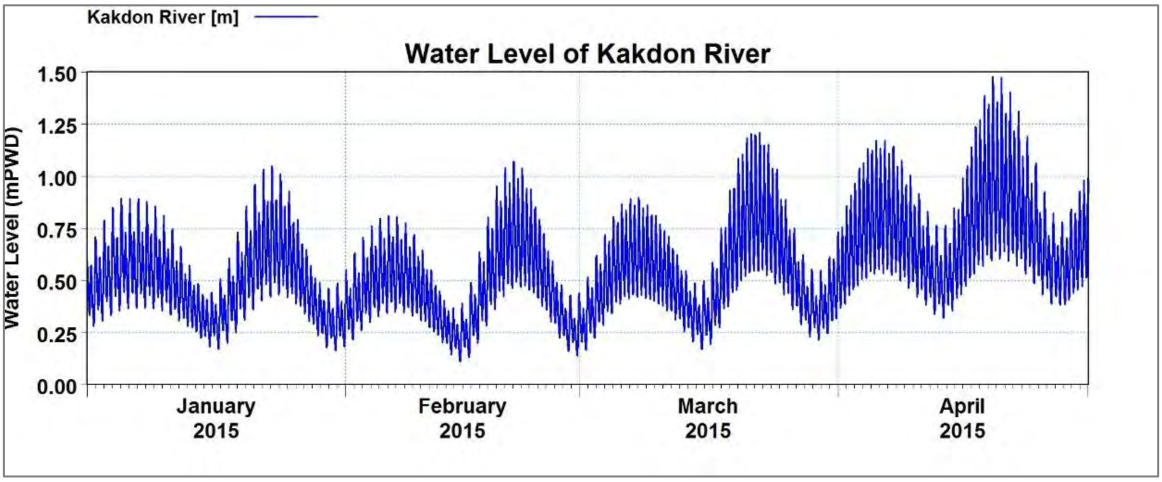


Figure 5.6: Water level of Kakdon river

Tidal range of Buriswar river is around 1.25 m to 2.35 m and tidal range of Kakdon river varies from 0.25 to 0.70 m during the dry period. The tidal range of Kakdon river is very low compared to Buriswar river.

5.3.2 Water level of Peripheral River for different scenarios

Buriswar River

Buriswar river gets huge flow from Meghna river. The maximum tidal range of Buriswar river is around 2.00 to 2.35 meter. Tidal range varies from 1.25 to 2.35m during neap tide and spring tide. It is observed that water level in Buriswar river have not change due to water withdrawal inside the polder 41/1. There is no water withdrawal impact in Buriswar river. Water level of Buriswar river for three scenarios shown in Figure5.7.

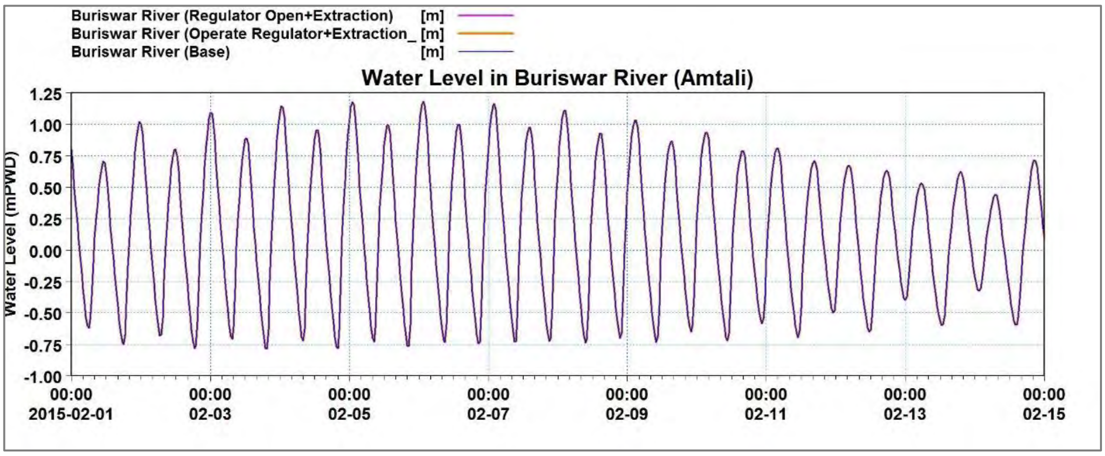


Figure 5.7: Water level compare between canal adjacent to Buriswar river after water withdrawal with regulator operate and without regulator operate

Kakdon River

Kakdon river situated at north side of Polder 41/1. The range of this river is around 0.70 m spring tide and 0.25 m in neap tide during the dry period. Change of water level observed in Kakdon river after water withdrawal from polder 41/1. Water level of Kakdon river reduced after extraction. Figure 5.8 Shows the change of water level within polder for different scenarios.

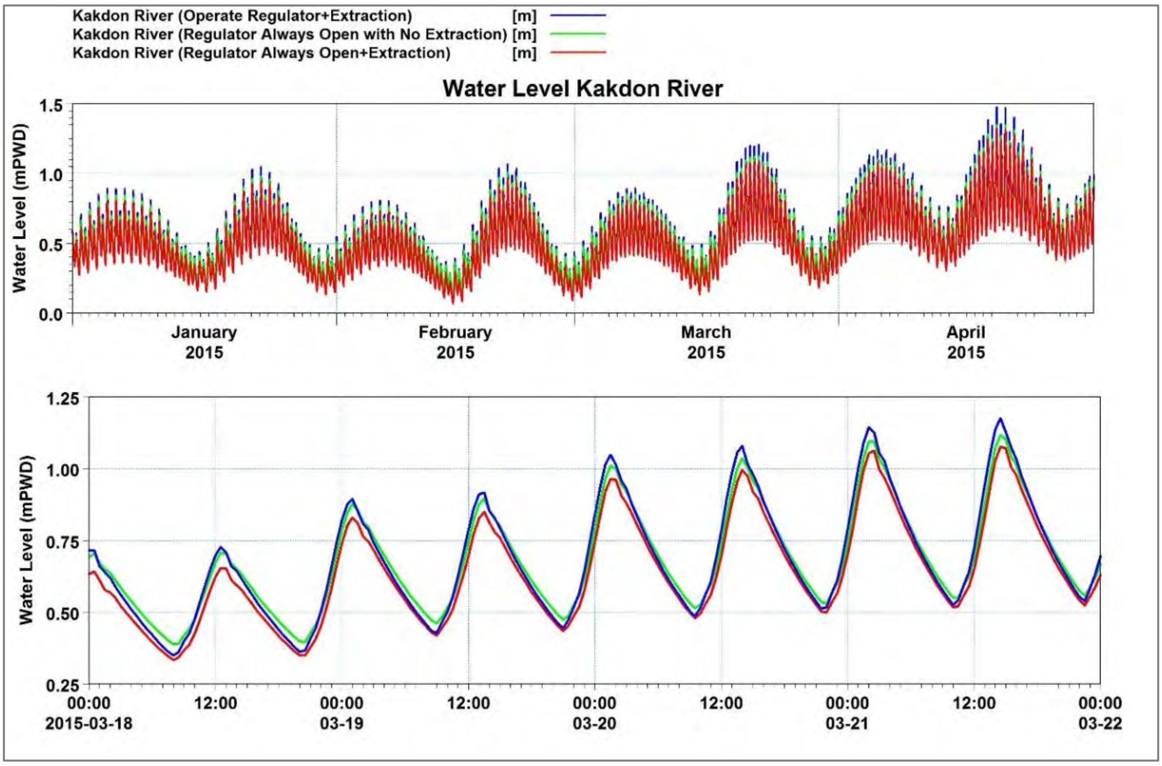


Figure 5.8: Water level compare between canal adjacent to Kakdon river after water withdrawal with regulator operate, Water withdrawal with regulator always open and no water withdrawal with regulator always open

5.3.3 Available Water Level and Water Depth Inside the Canal

Water level compared in selected locations to evaluate water withdrawal impact for different scenarios~~.~~ After operating regulator as flushing condition water level increase quickly during flood tide and in low tide no water can drain out from the polder. Water level reduced due to water withdrawal from the canal. At neap tide tidal range of peripheral river is lower than spring tide. Tidal range of peripheral river also decreased. At neap tide water depth inside the canal is lower than spring tide. Hydrograph of water level and water depth of different canal comparing with different scenarios are shown in below. Water level and water depth compare locations are shown in Figure 5.9

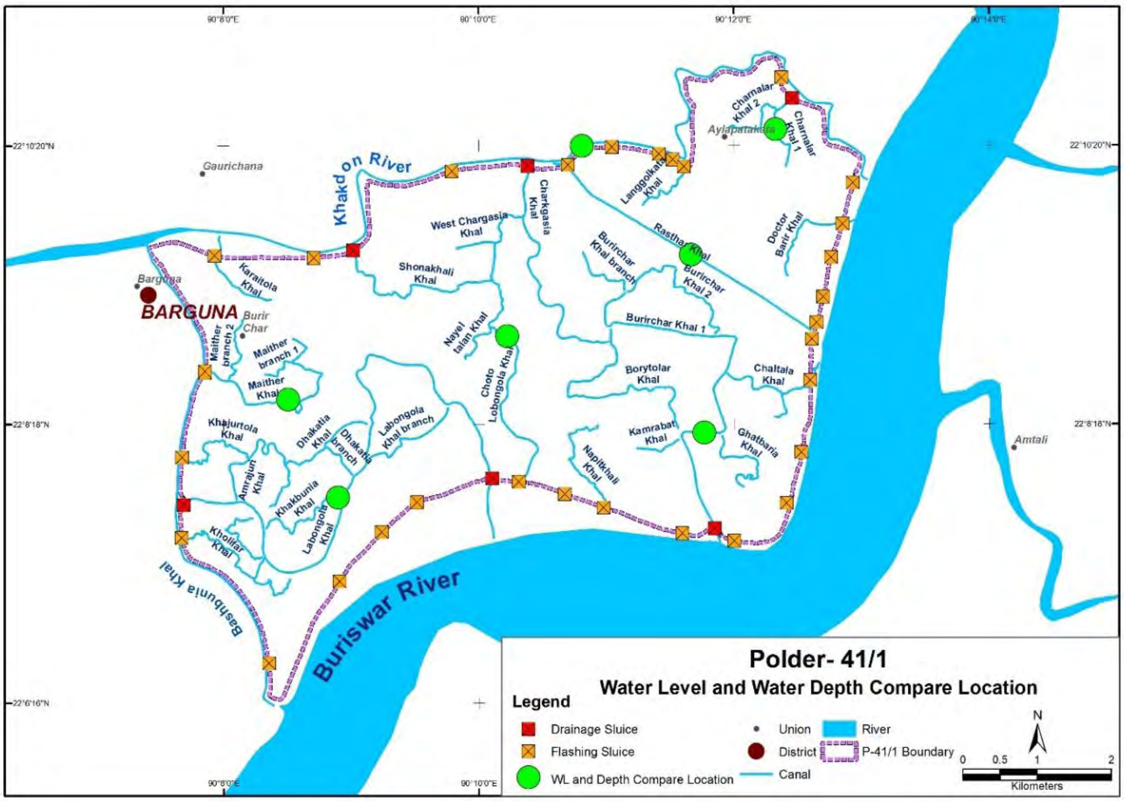


Figure 5.9: Location of Water Level and Water Depth for Different Scenarios

Burirchar Khal

Burirchar khal connected with Buriswar River. If the regulator always open, phase lag observed around 30 min from the just up of the sluicegate to upstream of khal. If regulator operate as flushing condition, maximum water entered into the polder and water level in higher than sluicegate always open. Water level for different scenarios and phase lag upstream and downstream of the canal shows in Figure 5.10 and Figure 5.11. Water depth of Burirchar Khal presented in Figure 5.12.

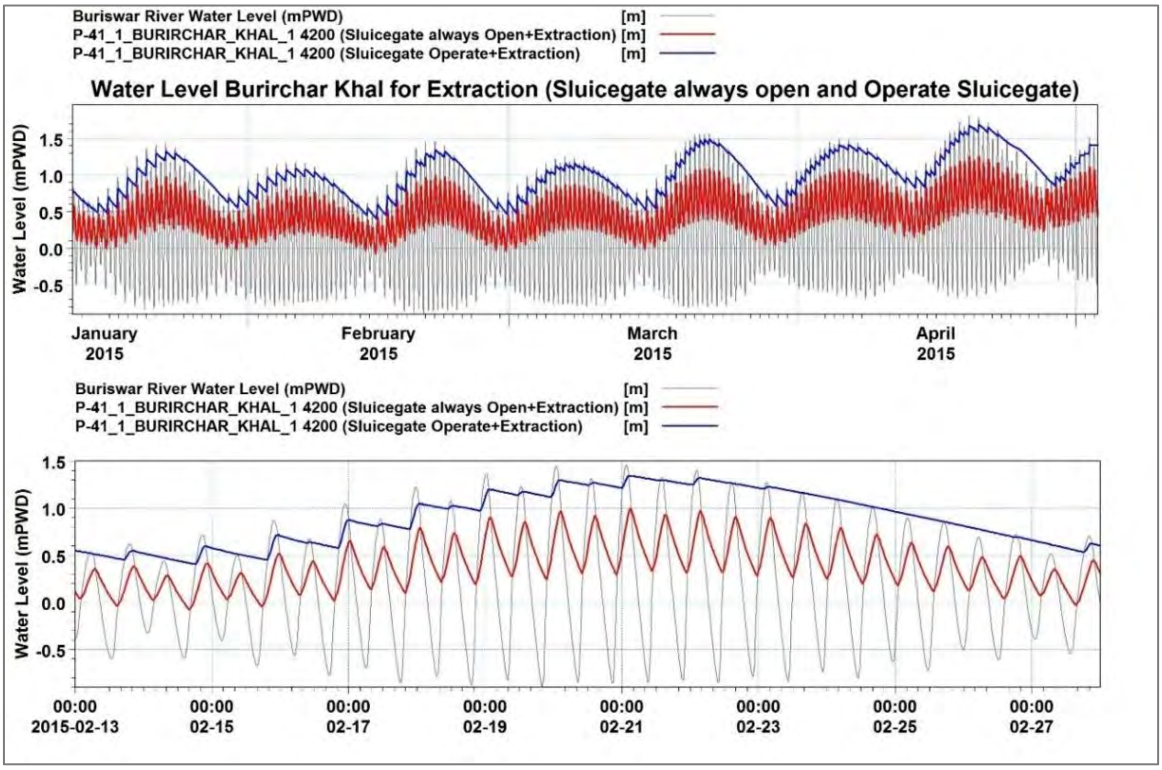


Figure 5.10: Compare water level in Burichar khal for different scanarios

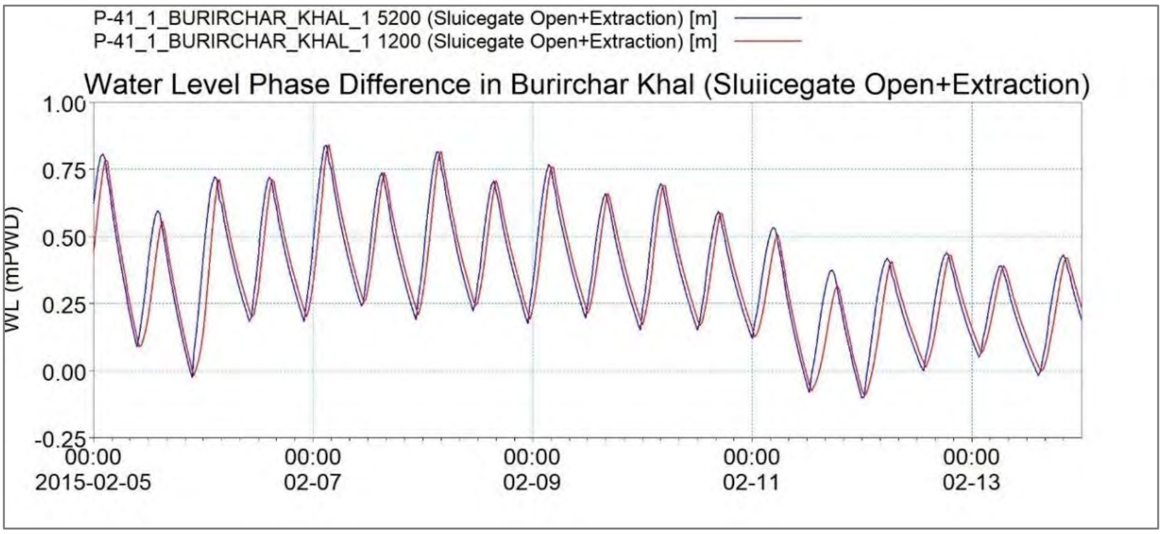


Figure 5.11: Observed the phase lag upstream and downstream of Burichar khal

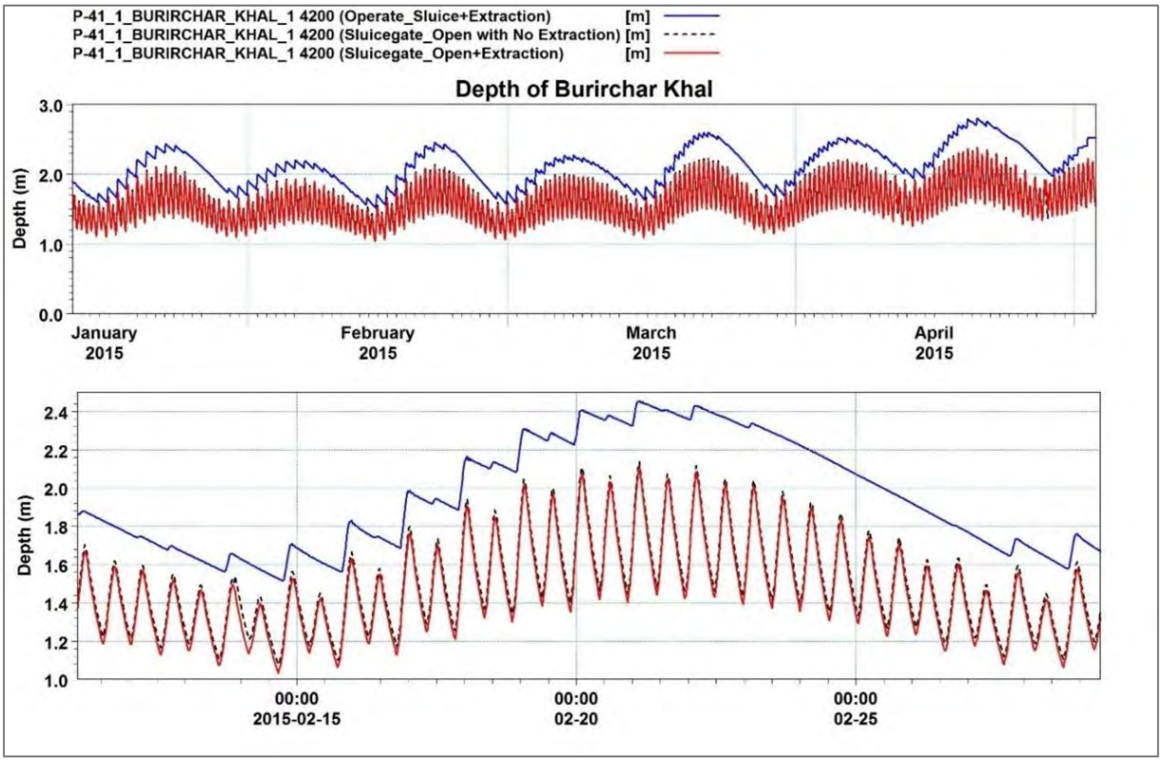


Figure 5.12: Water depth of Burichar khal under different scenarios

Labongola Khal

Labongola khal also behave as Burirchar Khal. Water level and water depth hydrograph are presented in Figure 5.13 and Figure 5.14:

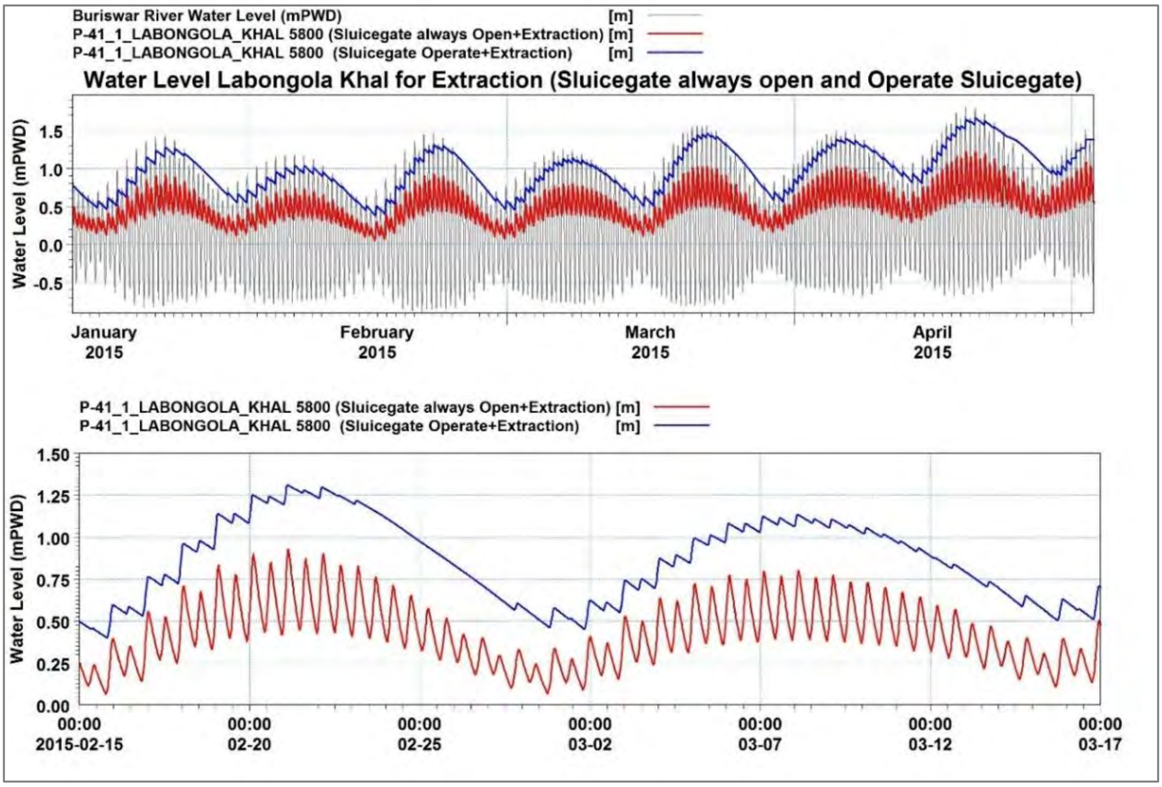


Figure 5.13: Observed water level of Labongola Khal

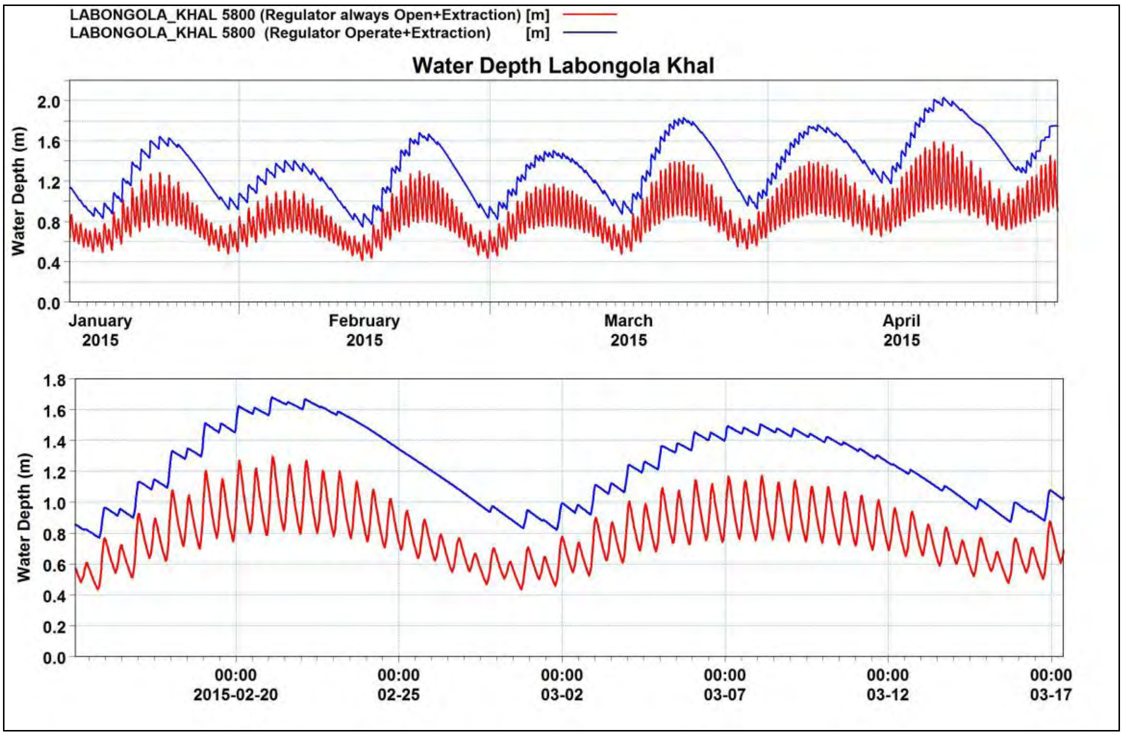


Figure 5.14: Water depth of Labongola khal for different scenarios

Charnalar Khal

In Charnalar Khal a huge tidal influence observed after regulator always open. In this canal regulator operation with flushing condition shows better water availability. Water level hydrograph of Chalnar at different scenarios shown in Figure 5.15.

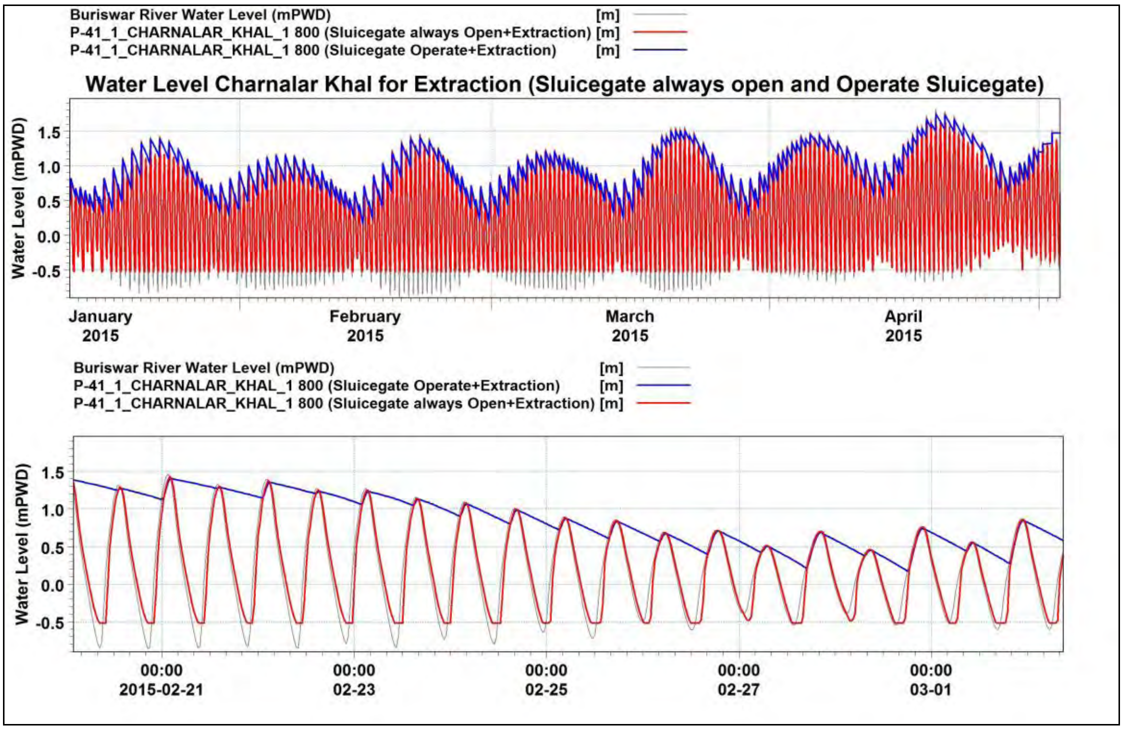


Figure 5.15: Water level of Chalnar Khal for different Scenario

Choto Labongola Khal

Water level and water depth of Choto Lonongola khal for different scenarios are presented in Figure 5.16 and Figure 5.17.

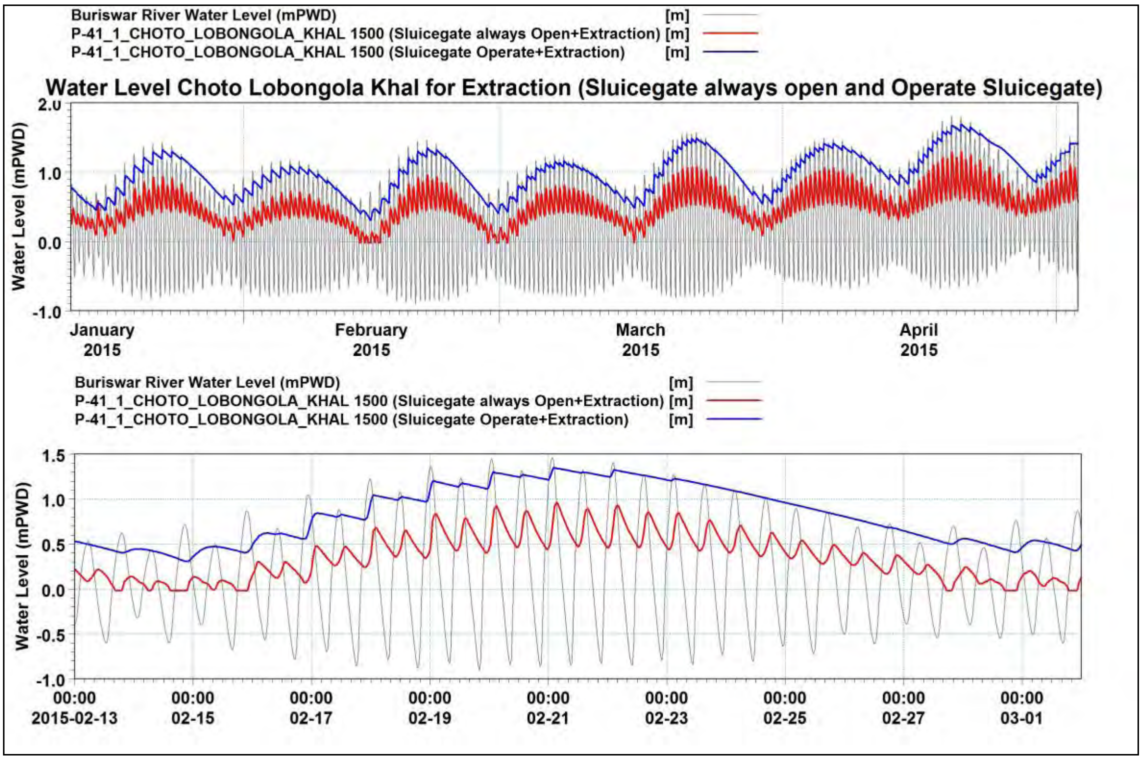


Figure 5.16 Water level of Choto Labongola Khal for different Scenario

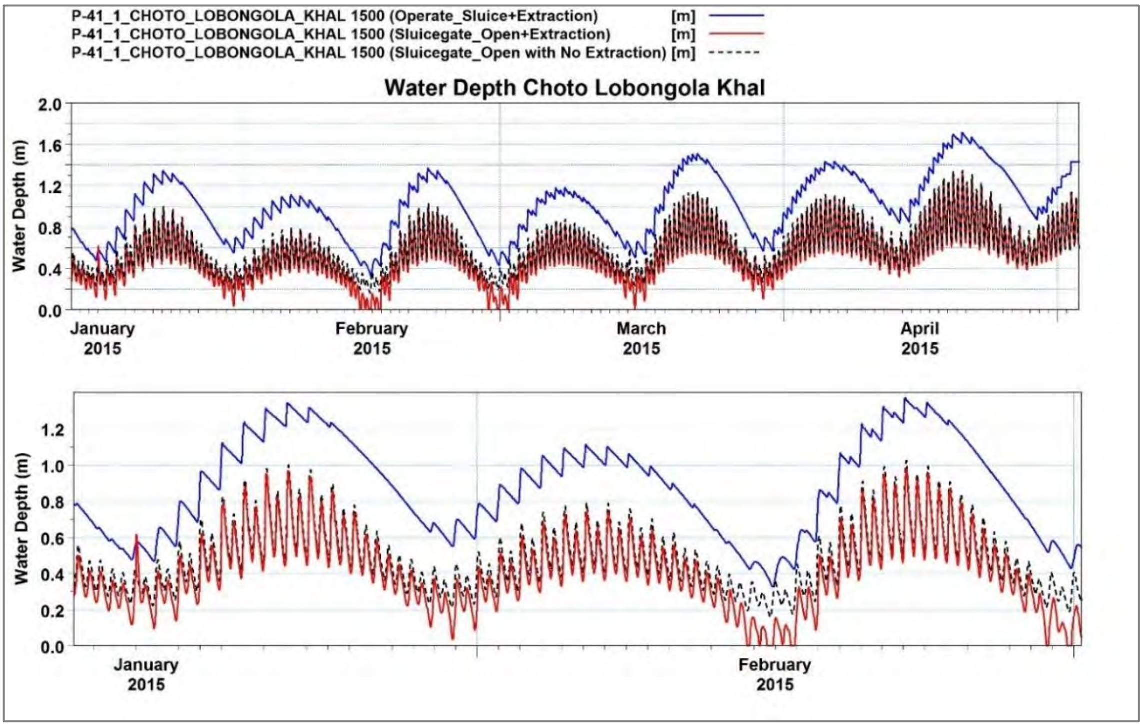


Figure 5.17 Water depth data of Choto Labongola Khal for different Scenario

5.3.4 Availability of water inside the polder

The daily 6-hour depth duration is defined as the specific depth of water is available in the specific location for 6 hours in a day. The final results are presented in a map showing whether the water depth in the khals is dry or not and how many day pumping is possible from the canal. In this map, khal is assumed to be dry if its water depth falls below 0.5 m because in that case it cannot be pumped into the boro fields. In each scenario, such maps have been generated for khal water depths, for 6 hour duration. The six-hour depth duration maps show the khals from which water can be pumped for six hour durations respectively during each tidal cycle (1 tidal cycle equals 12 hours 25 minutes for a semi-diurnal tide as in coastal area of Bangladesh).

It is observed that in scenario-3 overall farmers cannot irrigate for 11 days within total crop period 120 days for 6-hour duration. On the other hand, if community do not operate regulator, the available 6-hours water depth is <0.50 m for 43 days. Greater than 1m for 6-hour depth duration increased 35 days to 78 days by operating regulator at flushing condition. which implies that there are plenty of water for operating LLP for boro crop during the spring tide. Figure 5.18 to figure 5.22 shows that the daily 6-hour depth duration in different depth range which is available in canal after water withdrawal of different scenarios for four months (January-April).

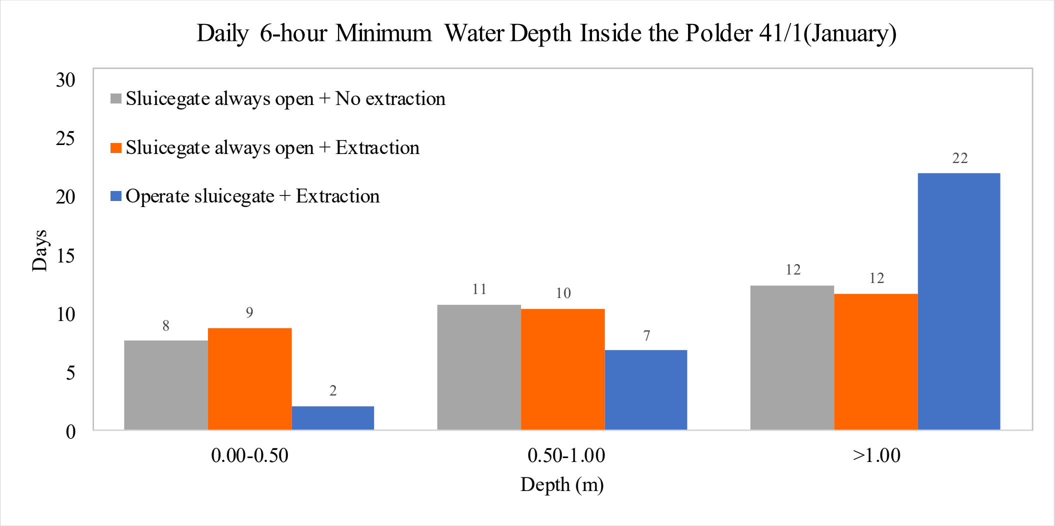


Figure 5.18 Daily 6-hour depth duration for January

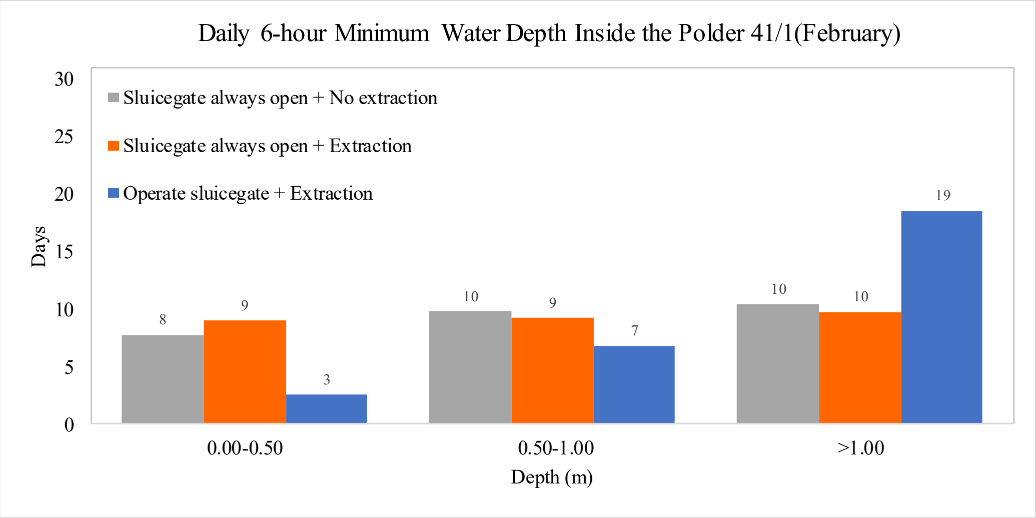


Figure 5.19 Daily 6-hour depth duration for February

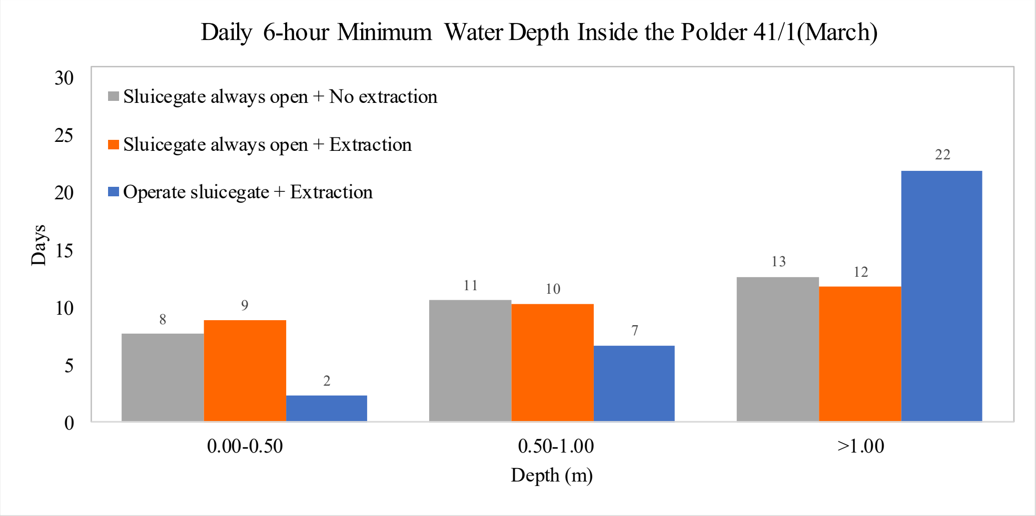


Figure 5.20 Daily 6-hour depth duration for March

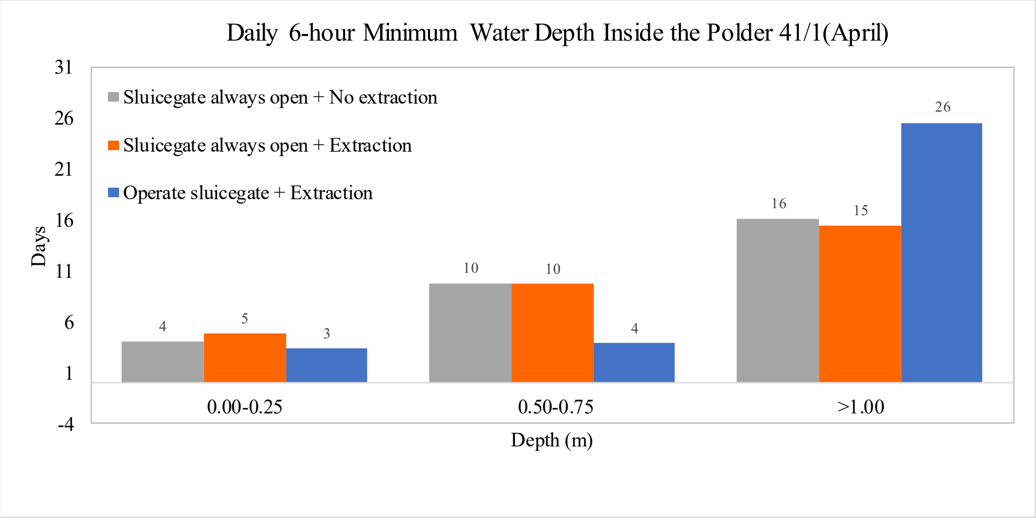


Figure 5.21 Daily 6-hour depth duration for April

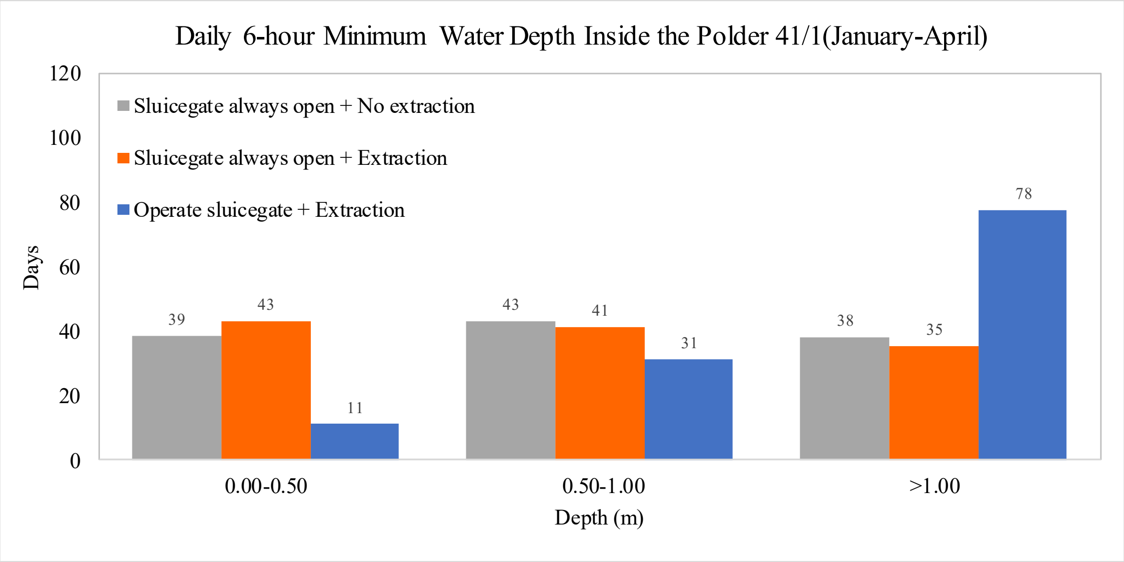


Figure 5.22 Daily 6-hour depth duration for (January-April)

Table 5.1: 6-hour water depth duration in the canal inside Polder 41/1

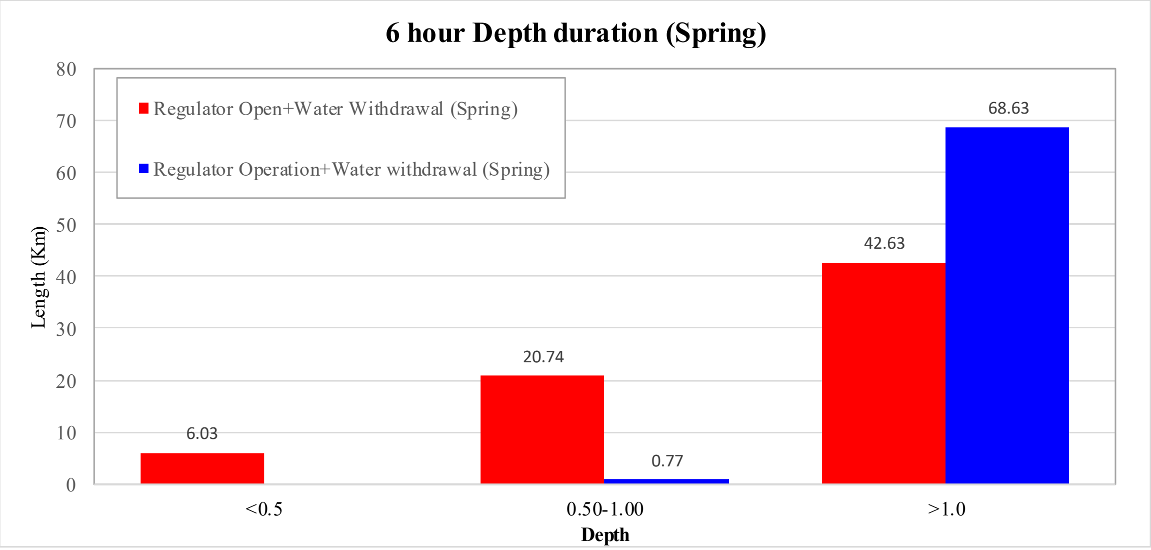
Canal Name	**Sluicegate always open + No extraction**			**Sluicegate always open + Extraction**			**Operate sluicegate + Extraction**		
	0.00-0.50 (m)	**0.50-1.00 (m)**	**>1.00 (m)**	**0.00-0.50 (m)**	**0.50-1.00 (m)**	**>1.00 (m)**	**0.00-0.50 (m)**	**0.50-1.00 (m)**	**>1.00 (m)**
Amrajuri khal	46	70	4	54	64	3	4	43	73
Borytolar khal	2	36	83	3	35	81	0	7	113
Burirchar khal 1	0	3	117	0	3	117	0	0	120
Burirchar khal 2	0	58	62	0	62	58	0	5	115
Burirchar khal branch	38	10	72	38	16	66	7	24	89
Chaltala khal	24	82	13	28	81	11	5	34	81
Chaltala khal branch	33	83	5	41	77	3	1	41	79
Charkgasia khal	8	47	66	10	48	62	1	14	106
Charnalar khal 1	25	37	57	29	36	56	6	14	100
Charnalar khal 2	61	40	19	59	43	18	1	30	89
Choto lobongola khal	51	58	11	61	50	10	8	47	65
Dhakatia branch	0	34	87	0	42	79	0	4	117
Dhakatia khal	10	69	41	14	75	31	1	22	97
Doctor barir khal	39	41	40	48	39	33	7	40	73
Ghatbaria khal	6	54	61	8	54	57	0	12	109
K 06e khal	80	41	0	83	38	0	28	50	42
K07a khal	53	66	1	58	62	0	11	57	53
Kamrabat khal	5	98	18	10	94	17	0	18	103

Canal Name	Sluicegate always open + No extraction			Sluicegate always open + Extraction			Operate sluicegate + Extraction		
	0.00-0.50 (m)	0.50-1.00 (m)	>1.00 (m)	0.00-0.50 (m)	0.50-1.00 (m)	>1.00 (m)	0.00-0.50 (m)	0.50-1.00 (m)	>1.00 (m)
Karaitola khal	28	52	41	35	48	36	16	51	53
Khajurtola khal	25	70	25	30	69	21	1	35	85
Khakbunia khal	95	26	0	102	17	0	35	61	25
Kholifar khal	83	18	19	86	16	19	23	47	51
Labongola khal	0	34	87	0	38	82	0	3	117
Labongola khal branch	41	21	58	42	23	55	18	24	78
Langgolkata khal	38	23	59	46	19	57	42	15	64
Maither branch 1	118	3	0	121	0	0	49	64	8
Maither branch 2	2	36	82	7	32	82	0	11	109
Maither khal	28	55	37	50	36	34	2	38	81
Napitkhali khal	103	18	0	111	9	0	42	49	31
Nayel talan khal	109	12	0	112	9	0	29	70	23
Rasthar khal	44	56	20	48	57	16	27	38	55
Shonakhali khal	4	40	76	6	44	70	0	8	112
West chargasia khal	78	43	0	90	31	0	10	68	43
Grand Total	39	44	**38**	44	41	**35**	11	31	**78**

5.3.5 Water availability in the different tidal condition

6h-depth duration map has been prepared for all of the khal of the Polder 41/1. It indicates the minimum depth of water which is available in the different segment of the khal. Analysis has been carried out for both Spring tide and Neap tide to understand the water availability in the khals of the Polder. Depth duration map presents the three types of different depth of water i) 0.0 m to 0.50m depth of water ii) 0.50m to 1.0m depth of water and iii) >1.0 m depth of water. Analysis is done for two conditions i) Regular operation of sluice gates with water withdrawal and ii) Gates are always open with water withdrawal.

The following figure presents the 6-hour depth duration map for all of thr khals of the polder for the spring tide. It is observed that 6-hour minimum water depth of all khals is greater than 0.50m when regulators are always operated with continuous water withdrawal. About 6.03km length of khal has less than 0.50m depth of water or completely dry when the gates are always open. Significant figure has found when gates are operated. It is found that about 68.63km lentgh of water has the minimum depth of water greater than 1.0m.



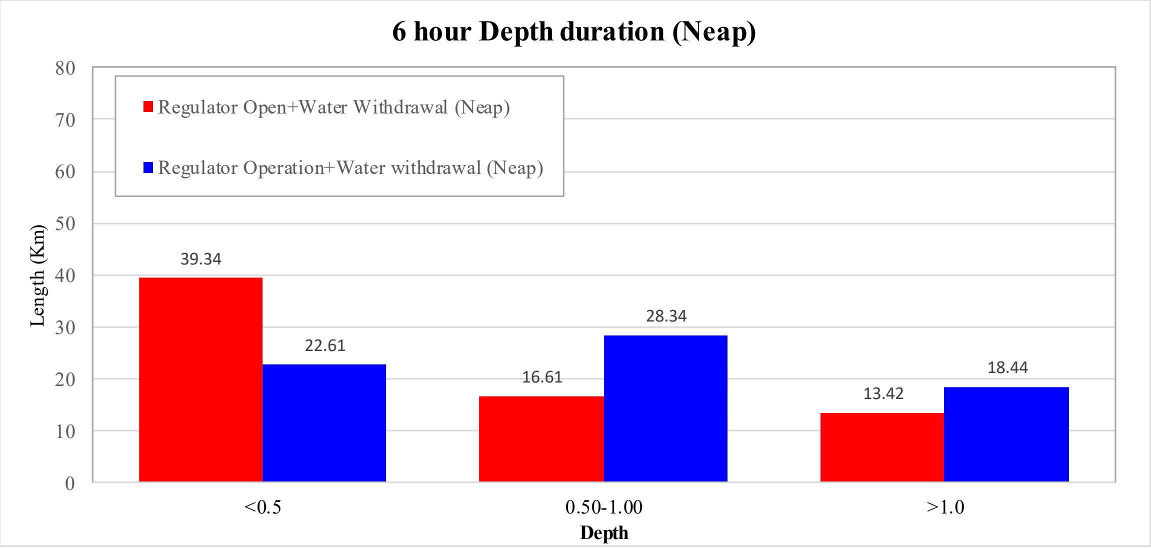


Figure 5.23: 6-hour depth duration for total canal (spring tide and neap tide)

In the Neap tide, it is observed that water depth of 22.61km length of khal is less than 0.50m when gates are always operated with continuous water withdrawal and about 39.34km length of khal is completely dry or less than 0.50m depth when the gates are always open with water withdrawal. About 46.78km length of khal has the water depth greater than 0.50m when gates are properly operated whereas only 30km length of khal has similar depth of water when gates are always open with water withdrawal. It indicates that more irrigation water is available when gates are properly operated.

Table 5.2: Regulator always open with water withdrawal

Water Depth (m)	Spring Tide		Neap Tide	
	Khal Length (km)	Percentage	Khal Length (km)	Percentage
h<0.5	6.03	9%	39.34	57%
0.5<h<1	20.74	30%	16.61	24%
h>1	42.63	61%	13.42	19%
Total Khal Length = 69.4 km				

Table 5.3: Regulator always operation with water withdrawal

Water Depth (m)	Spring Tide		Neap Tide	
	Khal Length (km)	Percentage	Khal Length (km)	Percentage
h<0.5	0	0%	22.61	33%
0.5<h<1	0.77	1%	28.34	41%
h>1	68.63	99%	18.44	27%
Total Khal Length = 69.4 km				

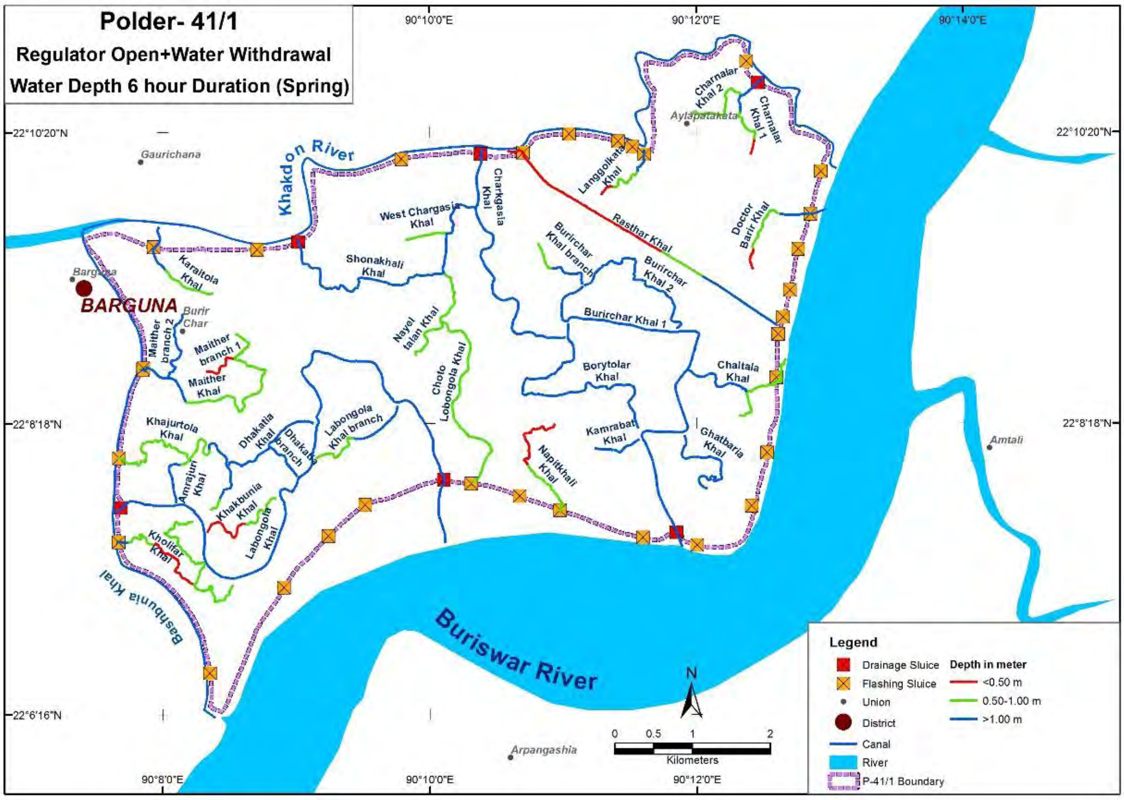


Figure 5.24: Secnario-2, 6-hour depth duration map (Spring tide)

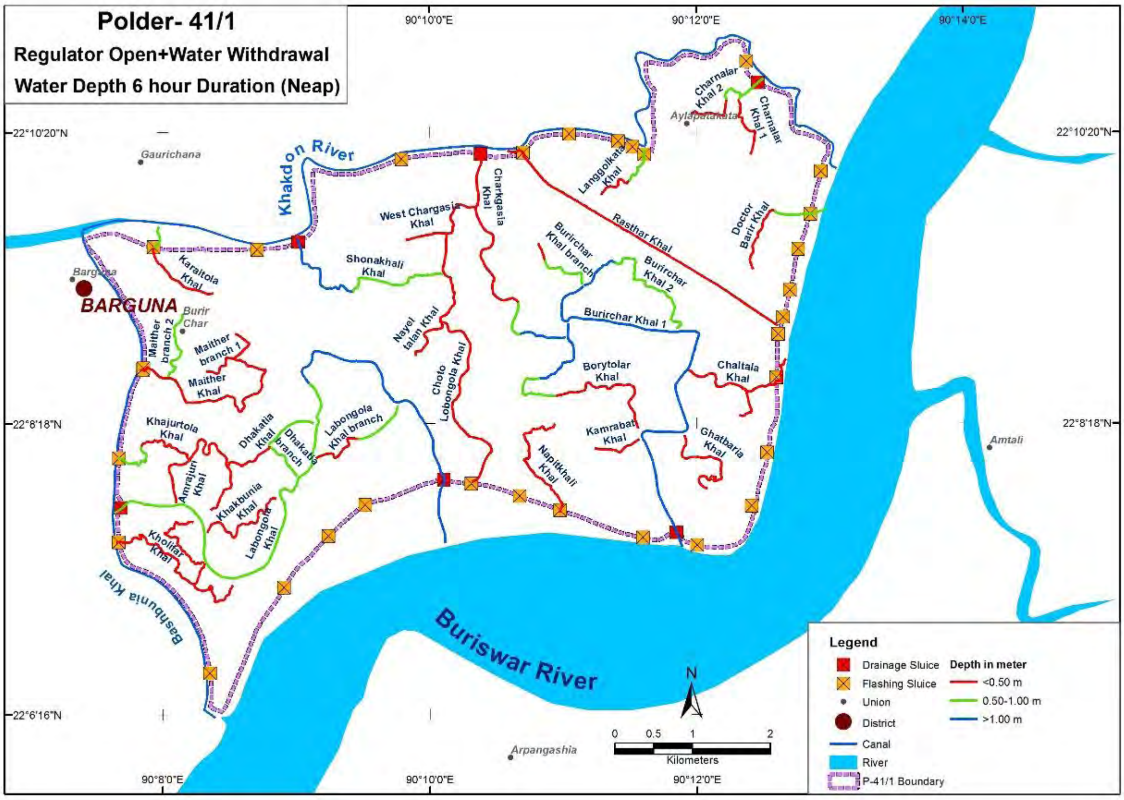


Figure 5.25: Secnario-2, 6-hour depth duration map (Neap tide)

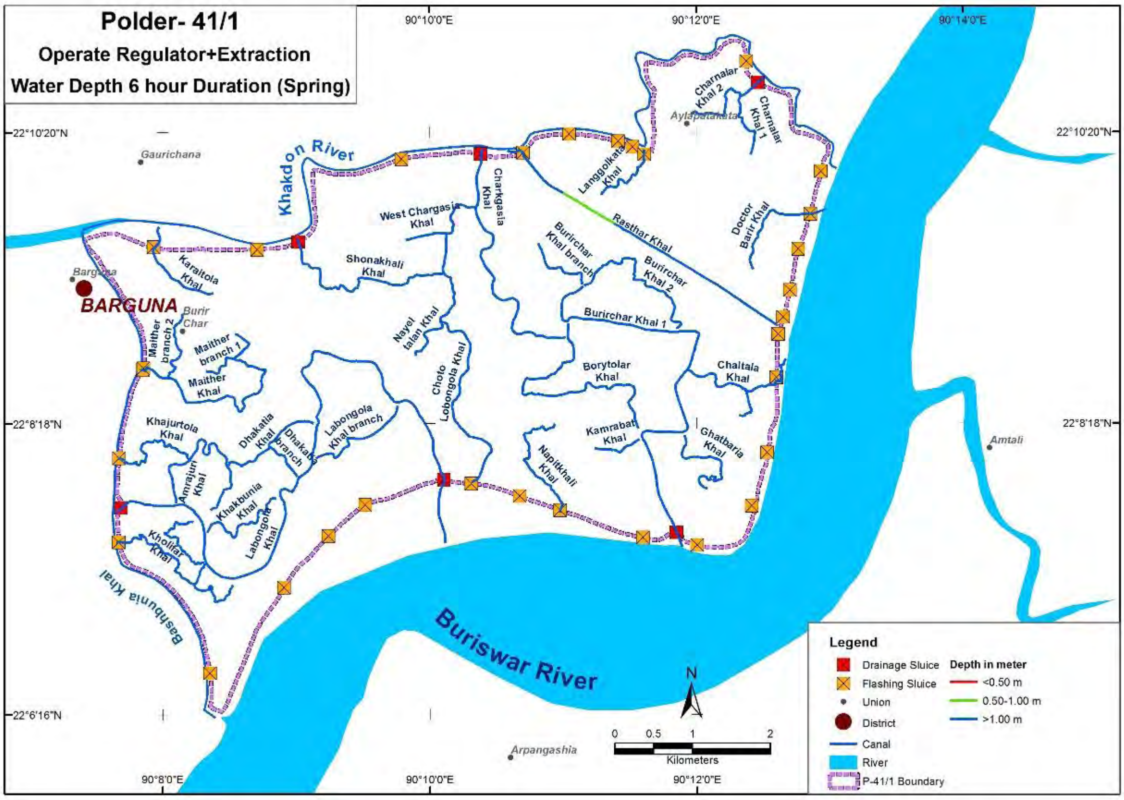


Figure 5.26: Secnario-3, 6-hour depth duration map (Spring tide)

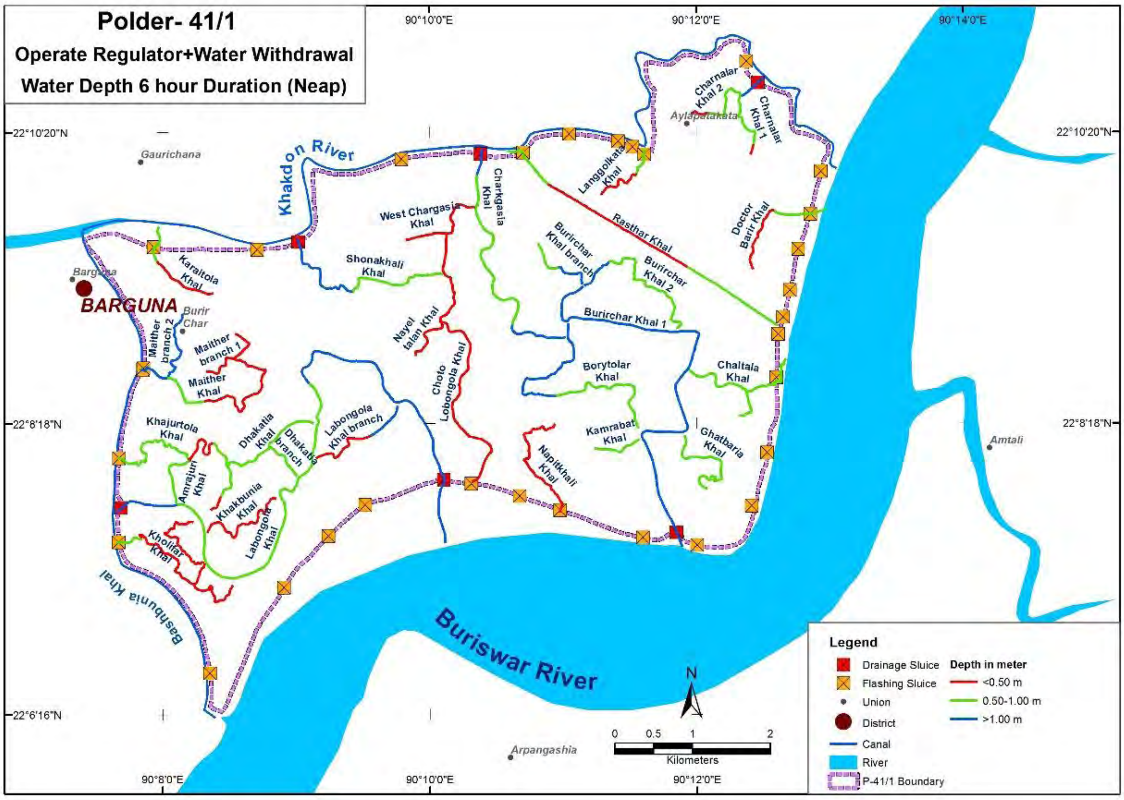


Figure 5.27: Secnario-3, 6-hour depth duration map (Neap tide)

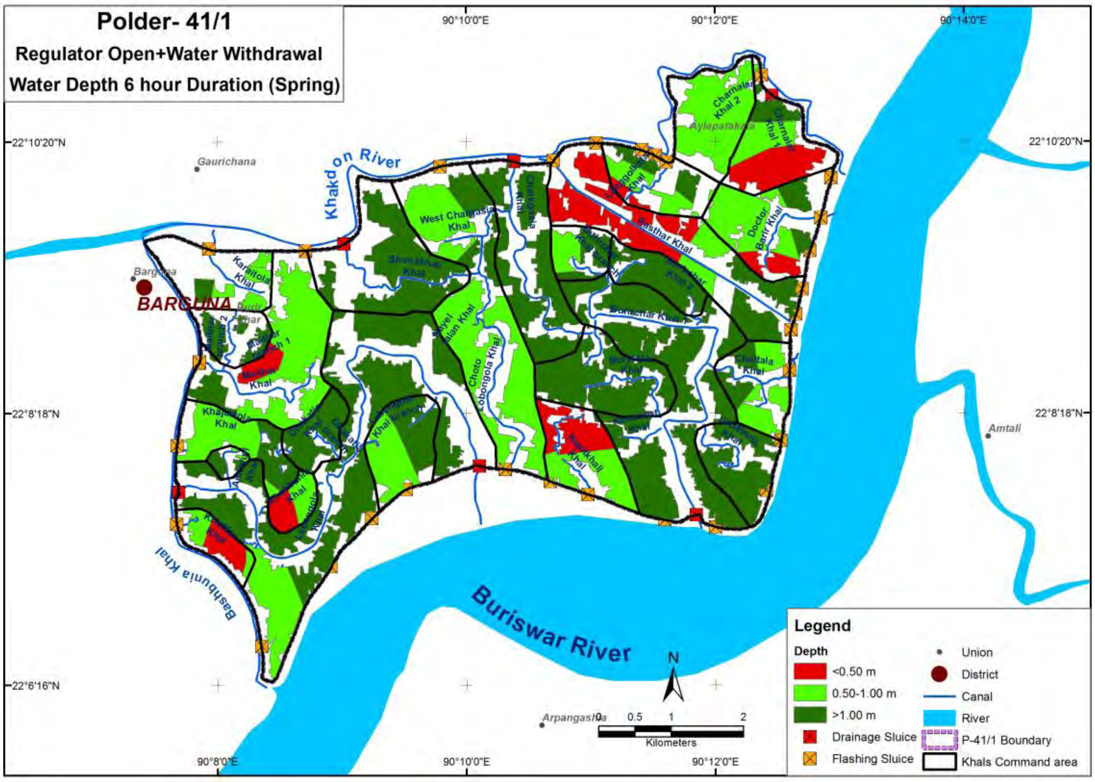


Figure 5.28: Irrigation area coverage for Secnario-2, 6-hour depth duration map (Spring tide)

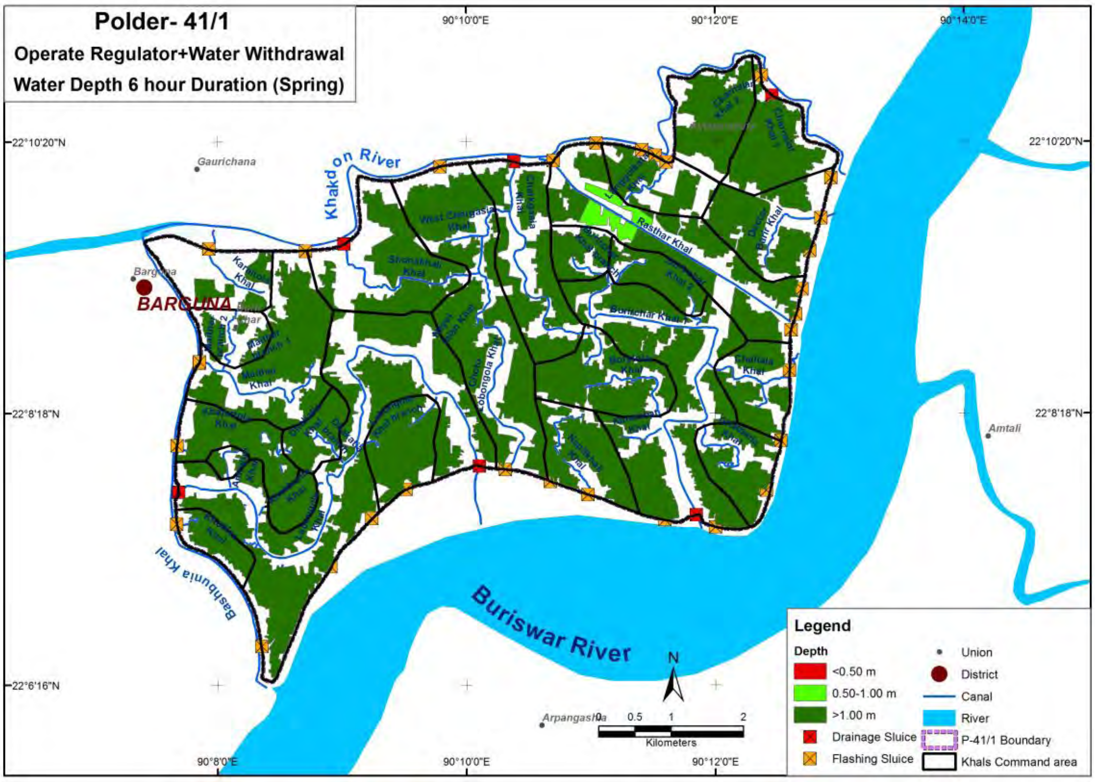


Figure 5.29: Irrigation area coverage for Secnario-3, 6-hour depth duration map (Spring tide)

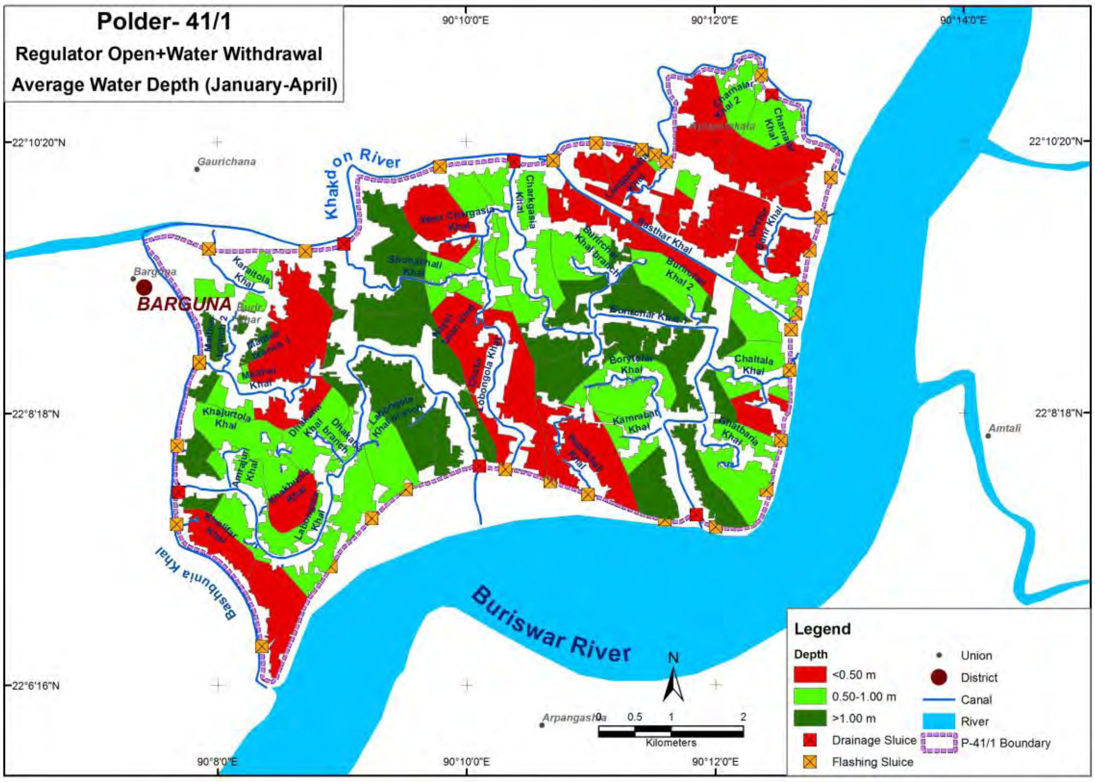


Figure 5.30: Irrigation area coverage for Secnario-2, Average water depth (January-April)

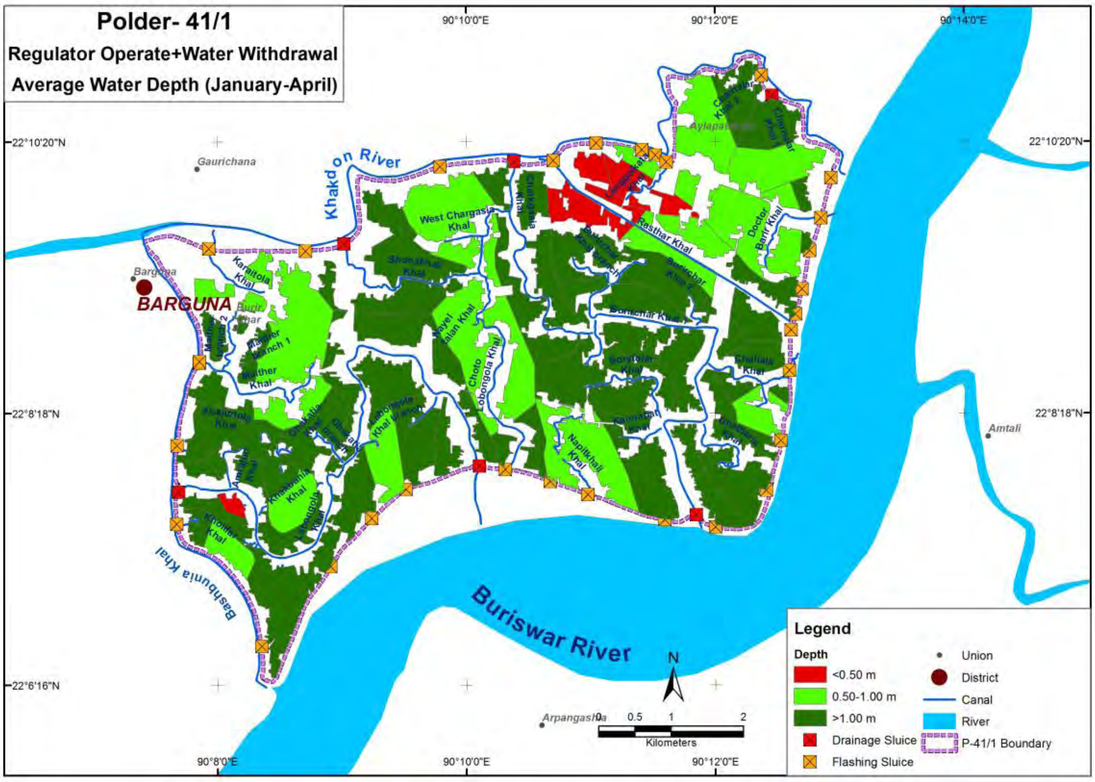


Figure 5.31: Irrigation area coverage for Secnario-3, Average water depth (January-April)

Irrigation coverage area at spring tide and average water depth (January to April) Presented in Table 5.4

Table 5.4: Irrigation coverage area comparison in different condition

Water Depth (m)	Irrigation Coverage (Km^2) (Spring Tide)		Irrigation Coverage (Km^2) (Neap Tide)		Irrigation Coverage (Km^2) (Average Water Depth from January-April)	
	Scenario-2	Scenario-3	Scenario-2	Scenario-3	Scenario-2	Scenario-3
h<0.5	2.75	0	16.67	10.89	10.09	1.02
0.5<h<1	9.54	0.306	5.43	10.41	9.90	9.25
h>1	14.82	26.80	5.02	5.82	7.06	16.78

5.3.6 6-hours Depth duration profile for different khals

Depth duration time series of water depth profile for different khals are plotted to understand the variation of the three scenarios. Figure shows that there is no significant change when the gates always open without water withdrawal and gates are open with water withdrawal. It has been observed that significant water depth increased after gates operation. It is found from time series profile for Burir char khal, Charnalar khal and choto Lobongola khal etc khals are represents the similar result.

Burirchar Khal 6-hour depth duration

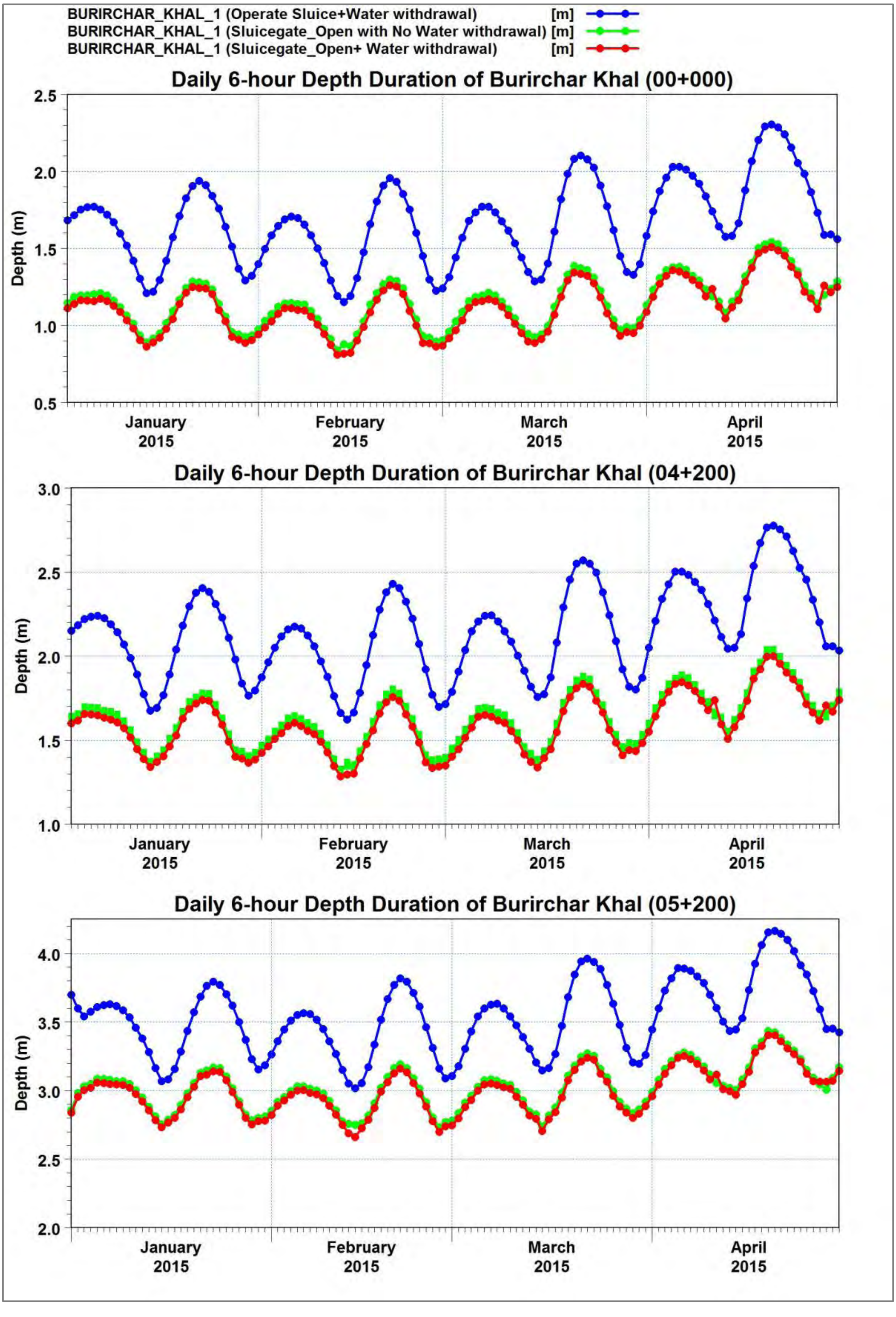


Figure 5.32: Burirchar Khal 6-hour depth duration

Charnalar Khal 6-hour depth duration

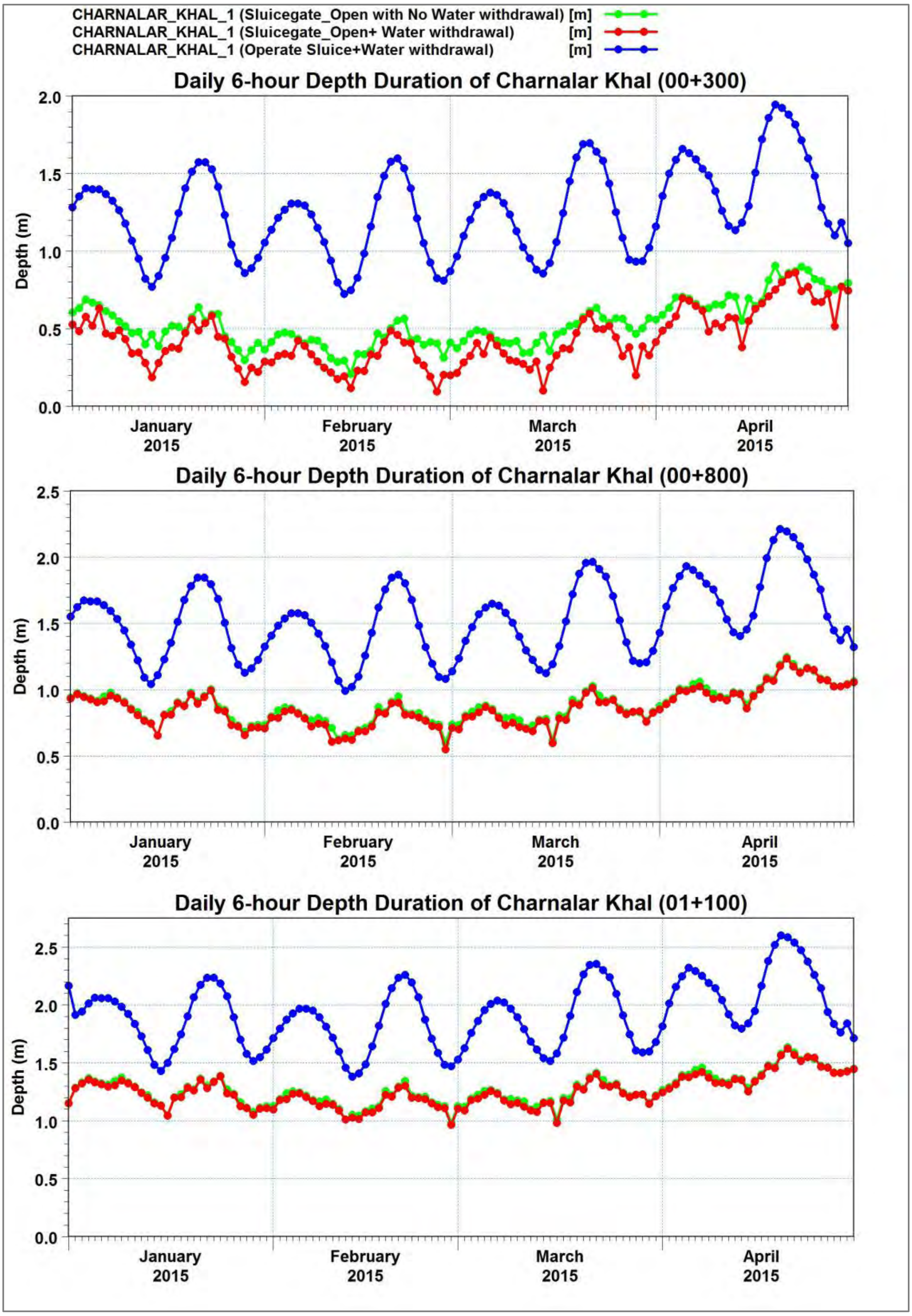


Figure 5.33: Charnalar Khal 6-hour depth duration

Choto Labongola Khal 6-hour depth duration

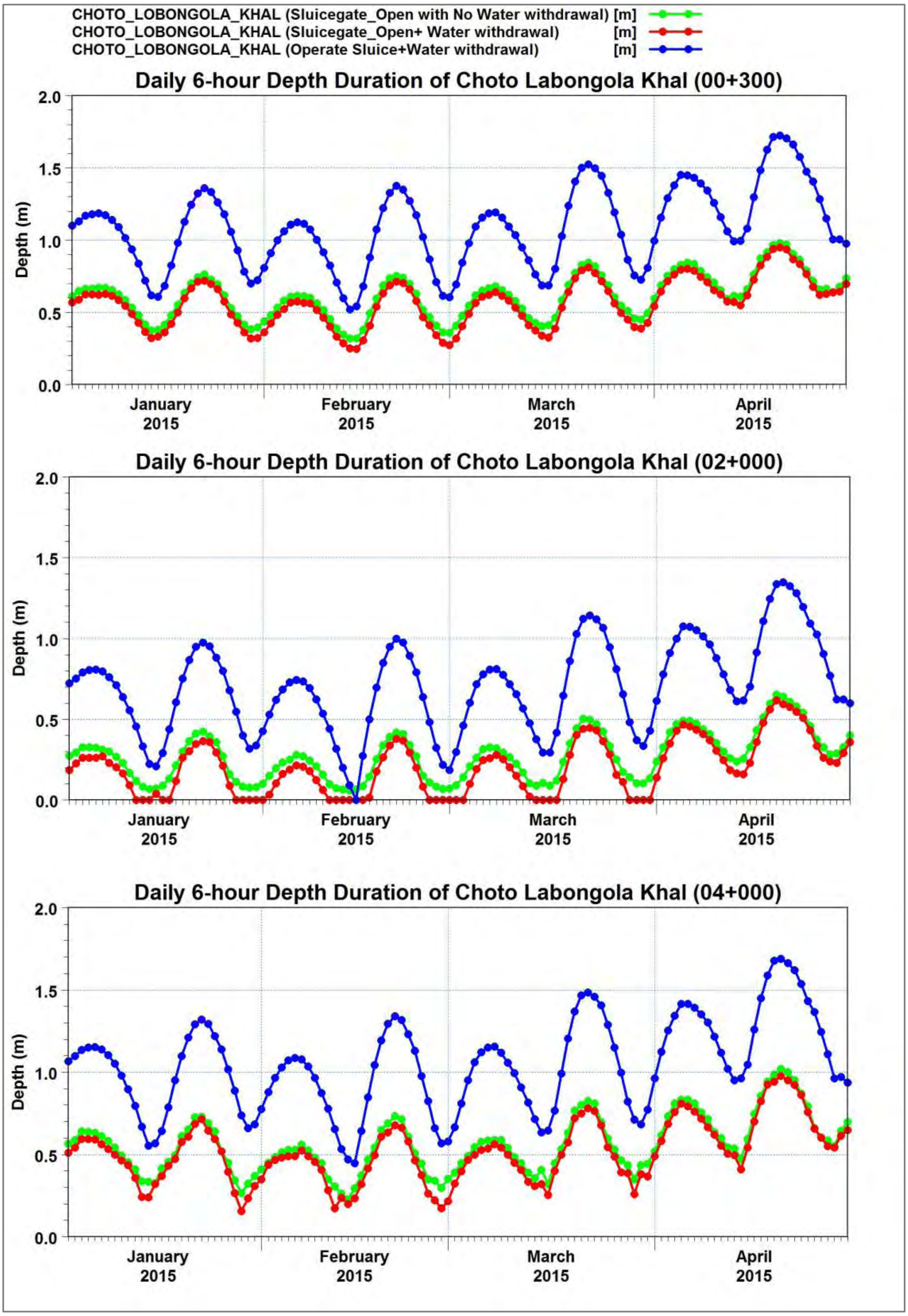


Figure 5.34: Choto Labongola Khal 6-hour depth duration

In neap tide it is not possible to irrigate some area because water level of neap tide is lower than spring tide. In most of the places it is not possible to keep the water depth greater than 0.50 m. In scenario-3 most of the canal 6-hour depth duration is greater than 1 meter. But in neap tide, 6-hour water depth is less than 0.50m in some place. The depth gets below 0.5m for 1-6 days in neap tide. But without operating regulator 6-hour depth duration is less than 0.5m around 10days to 3 months both in spring tide and neap tide. Irrigation can be hold up to 7-10 days by keeping standing water in the field. Irrigation opportunity get limited in scenario-2.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 General

In this study a mathematical model has been developed for the polder 41/1 to assess the dry season irrigation water availability in the canal. Cropland and command area of existing khals are identified from existing Digital Elevation Model (DEM), high-resolution satellite image (Sentinel-2 and Google earth) and existing road network. In this study, three types of scenarios are developed for understanding the water availability at different condition. Scenarios are developed based on the local experience which are i) regulator gates are always open without water withdrawal ii) regulator gates are always open with water withdrawal and iii) regulator gates are used as flushing condition with water withdrawal.

6.2 Conclusions of the study

The effects all of the scenarios are summarized below in a nut shell.

1. The daily 6-hour depth duration defines that the available depth of water at khal maintain for at least 6 hours in a day. In the scenario-2, when the regulator gates are completely open with water withdrawal, irrigation water depth is not available for about 44 days from January-April. But it decreased to 11 days only after operating regulator gates in Scenario-3. If the gates operate (scenario-3) properly the water depth remains greater than 1.0m for 78 days at existing khal networks and it is only 35 days if the gates are always open (scenario-2). This analysis indicates that, there is plenty of opportunity for Boro rice by using surface water irrigation if the regulators operate properly considering the tidal water level.

2. 6-hour depth duration map has been prepared for the all khal of Polder 41/1. The analysis has been carried out for both Spring tide and Neap tide to understand the water availability in different tidal condition. Depth duration map presents the three types of different water depth i) 0.0 m to 0.50m ii) 0.50m to 1.0m and iii) >1.0 m depth of water. Analysis is done for two conditions i) Regular operation of sluice gates with water withdrawal and ii) Gates are always open with water withdrawal. The analysis presents that in spring tide, about 6.03km (9%) length

of khal has less than 0.50m depth of water or completely dry, 20.74km (30%) is 0.50 to 1.00m and 42.63km (61%) is greater than 1.00m depth without regulator gate operation with water withdrawal. Significant change observed after regulator operation, around 68.63km (99%) of khal has water depth greater than 1.0m.

3. In neap tide, tidal range is lower than spring tide that’s why irrigation is critical for both scenarios. Analysis shows that in the neap tide, water depth of 22.61km (33%) khal is less than 0.50m when gates are always operated with continuous water withdrawal. About 39.34km (57%) length of khal is less than 0.50m depth of water or not suitable for irrigation when gates are always open with water withdrawal. About 46.78km (67%) length of khal has the water depth of greater than 0.50m when gates are properly operated whereas only 29.03 (43%) km length of khal has similar depth of water when gates are always open with water withdrawal. As water level and tidal range in neap tide is lower from the spring tide, it is not possible to irrigate some area during the neap tide. In scenario-3, 6-hour depth duration of most of the canal is greater than 1 meter. But in neap tide 6-hour water depth of some places below 0.5m only for 1-6 days. But without operating regulator 6-hour depth duration is less than 0.5m for around 10days to 3 months both for spring tide and neap tide at different khals. Irrigation can be hold up to 7-10 days by keeping standing water in the field. Irrigation opportunity get limited in scenario-2. which implies that irrigation is feasible for boro crops by proper operating regulator.

4. Considering the average water depth from January to April irrigation is not possible in 10.09 km^2 area without regulator operation. After regulator operation irrigation is not possible in only 1.02 km^2 area.

5. Boro rice required huge amount of water, above 700 mm (CSIRO,2014). By using high tide and operate controlling gate of regulator farmers can get long time to irrigate and store maximum water depth in the canal.

6. In the polder system higher water depth is available in the Spring tide. In the neap tide, tidal range is very low in the river and many canals become dry during the neap tide. So it is better to utilize spring tide for irrigation and operate sluicegate as flushing condition so that more water can store in the canal.

6.3 Recommendations for further study

In the model, it is very easy to maintain the sluice gates properly. In the real field it is not an easy task to operate the sluice gates properly for proper water management. Time series sluice gate operation data is missing in the study which is very important to assess the actual water demand for the local farmer of the Polder area. There is an opportunity to improve this study further more using the long time series data.

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