Flow Characteristics and Environmental Flow Requirement of Gorai River in Bangladesh.

By

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DECLARATION

This is to certify that the thesis work entitled "Flow Characteristics and Environmental Flow Requirement of Gorai River in Bangladesh" has been carried out by Md. Mahmudul Hasan in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of it has not been submitted anywhere for the award of any degree or diploma.

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ABSTRACT

Environmental flow requirement certifies natural condition prominence of a river. Due to terrestrial location, rivers in Bangladesh have faces precise high flow in wet season and low flow in dry season. Since the current condition of a river flow characteristics has proven on historic flow data, so estimation of environmental flow requirements for the rivers are censoriously important for Bangladesh. The purpose of the research is to assess environmental flow requirement of Gorai River and to evaluate flow characteristics of the river through the comparison between past and recent time. Two stations are selected to assess the environmental flow circumstance for Gorai River system. The selected stations are Gorai Railway Bridge and Kamarkhali Transit station. There are several methods for calculating the environmental flow requirements of a river system. Three popular methods are used here for estimation of the environmental flow on the selected stations. The three methods are Mean Annual Flow (MAF) method, Flow Duration Curve (FDC) method and Constant Yield (CY) method. These methods are appropriate for hydrological attitude and in use of chronological flow data.

Daily discharge data of selected stations recorded by Bangladesh Water Development Board (BWDB) has been collected and analyzed for two periods i.e. G1 period (for the year 1984 to 1999) and G2 period (for the year 2000 to 2016), and IHA software (version 7.1) has been exercised. The analysis has been done according to MAF, FDC and CY methods. It is observed from the analysis that, the Mean annual flow of Gorai Railway bridge station is 1012 Cumec during 1984 to 2016, and Mean annual flow of Kamarkhali transit station is 795.1 Cumec during 1984 to 2016. As low flow season is the main concern, about 202.4 Cumec flow is required to maintain good condition for Gorai Railway bridge station and 159 Cumec flow is required for Kamarkhali transit station in MAF method. The relationship between the magnitude and duration of stream flows is presented by flow duration curve (FDC). FDCs are used mainly to set environmental flow purposes. Flow duration intervals are stated as percentage of exceedance, with zero corresponding to the highest stream discharge in the record (i.e. flood conditions) and 100 to the lowest (i.e. drought conditions). As low flow season is the main concern, the environmental flow requirement based on FDC in LFS is found as 290 Cumec for Gorai Railway bridge station and 167 Cumec flow is required for Kamarkhali transit station in FDC method. During the low flow season the minimum requirement based on FDC method is retained during both intermediate and high flow seasons but not for low flow season which is the main concern. Environmental flow considering CY method for Gorai Railway bridge station is found as 221.4 Cumec and for Kamarkhali transit station it is found as 162.85 Cumec. The flow found in CY method is close enough to environmental flow requirement obtained from MAF and FDC methods.

It is found that the estimated environmental flows of Gorai River at Gorai Railway Bridge station are 202.4 Cumec, 290 Cumec and 221.4 Cumec for MAF, FDC & CY method, respectively. By averaging these values, the environmental flow is estimated as 237.93 Cumec. In the Kamarkhali transit station of Gorai River the environmental flows are estimated as 159 Cumec, 167 Cumec and 162.85 Cumec for MAF, FDC & CY method, respectively. Thus the average value of environmental flow is estimated as 162.95 Cumec. It shows that insufficient flow condition remains from December to May in both of the stations according to the estimated environmental flow requirement. August and March are the highest and lowest flowing months respectively for both of the stations.

It is observed that, the river condition is good at the high flow season but when the flow comes in low flow season it becomes lower than the environmental flows required for good habitat quality. The flows in the month of January to May are less than the EFR required. The flows of these months are less than the severe degradation flow. It shows severe problems for both the stations. For the Gorai river, it is necessary to maintain the flow values more than the severe degradation throughout the year to sustain the habitat quality for the river. The three methods show different values for environmental flow requirement. The flow requirements in the low flow season for three methods are found lower than the required flow in both stations. It shows that the river is endangered for habitat quality in low flow seasons. In every method it proved that, the Gorai River has flow scarcity because of the low flows from upstream.

The chloride concentration is generally found higher in the month of November to June. These are the low flow season that includes post-monsoon and pre-monsoon period. It shows a higher value of chloride concentration. The highest individual one day chloride concentration is found as 511 ppm, and the average monthly highest chloride concentration is found as 152.8 ppm in the month of February. At high flow season the flows are higher in the month of July to October. It shows a lower value of chloride concentration. The lowest individual one day chloride concentration is found as 20 ppm, and the average monthly lowest chloride concentration is found as 37.5 ppm in the month of October. The chloride concentration at low tide and high tide shows no significant difference for the same day.

The chloride concentration in high flow season is not much less than the concentration of the low flow season for the exceedance 0% to 30%. For the exceedance probability 30% to 100%, it shows a big difference of chloride concentration among the seasons. The salinity for less than 100 Cumec discharge is higher and the salinity decreases with increase in the fresh water discharge up to 500 Cumec. The salinity shows lower value with high discharge upto 60% of probability of exceedance. After that from 60% to 100% probability of exceedance freshwater discharge value did not shows significant effect on salinity change. Small increase in fresh water discharge cause large change in salinity concentration from 5% to 60% probability of exceedance.

The environmental flow highlights the basic need of a river to sustain the assortment of natural status of hydrologic systems in order to defend native biodiversity. Indicators are anticipated to assess the complete ecological health of the river and the degree of hydrologic alteration triggered by a particular functioning policy. The condition of a river systems eventually rest on environmental flow constituents, which may change seasonally.

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NOMENCLATURE

BWDB	Bangladesh Water Development Board
CY	Constant Yield
EFA	Environmental Flow Assessment
EFC	Environmental Flow Constituents
IFIM	Instream Flow Incremental Methodology
EFR	Environmental Flow Requirement
FDA	Flow Duration Assessment
FDC	Flow Duration Curve
HFS	High Flow Season
IHA	Indicators of Hydrologic Alteration
IFS	Intermediate Flow Season
LFS	Low Flow Season
MAF	Mean Annual Flow
MMF	Mean Monthly Flow
NWMP	National Water Management Plan
RVA	Range of Variability Approach
SWR	South Western Region

CHAPTER I

Introduction

1.1 General

Rivers afford several belongings and amenities for nature. The river comprises a source of water used for domestic, trade and agricultural purposes, a means of power generation and unwanted discarding, directions for navigation and locates for recreational and spiritual accomplishments. The recent time river flow system in freshwater discharge is reflected as a main variable by the river scientists due to its durable guidance on the environmental aspects. But hydrologic systems show a foremost role in determining the biotic configuration, erection, and function of aquatic, wetland, and riparian ecologies (Richter et al., 1996). The Environmental flow requirement is an assessment for how much of the original flow establishment of a river should endure to flow down it and onto its floodplains in order to sustain indicated valued geographies of the ecosystem, hydrological commands for the rivers.

The environmental flow requirement shows a scheduled objective in terms of the ecosystem’s future circumstance. Furthermost rivers in southwestern region (SWR) of Bangladesh governed on water flow from Ganges River. Gorai river system is the right bank merchant of the Ganges River which delivers edge between freshwater and brackish water in the estuary. It is the main source of upland freshwater supply in the SW region of Bangladesh (Moly et al., 2015). The Environmental flow requirement is different for dissimilar regions. Moreover, the impact of the identical flow requirement is not same for all the areas. However, for the awareness and protection against threat as well as for the mitigation of danger, it is necessary to assess the temporal and spatial changes in flow characteristics of Gorai River and to estimate the Environmental Flow Requirement (EFR) of the river that can be used for future orientation in management purposes.

Salinity situations in the River are extremely reliant on patterns of mixing and circulation and on the volumetric influences of saltwater and freshwater. The stream flow and wind condition causes deviations in the relative contributions of saltwater and freshwater to the estuary, ensuing in wide-ranging variations in salinity. The wind swiftness and direction, water temperature, tidal discharge, freshwater discharge, and downstream salinity generally affect salinity in an estuary. Enormous tidal inflows of highly saline water from the sea are considerably greater in volume than the small freshwater inflows to the estuary from surface and ground water discharges.

1.2 Background

Bangladesh comply topographic, physiographic and climatic settings with dynamic hydrological, and environmental characteristics ruled by the world's three great river systems - the Ganges, the Brahmaputra and the Meghna. The Ganges is a transnational river pooled by China, Nepal, India and Bangladesh. With concern to the supply of the 109.5 x 10^6 ha basin area, India has 79%, Nepal 14%, Bangladesh 4% (this is comparable to 37% of total basin area of Bangladesh) and China 3%. The mean annual runoff of the Ganges at Farakka in India is 410 mm and at the Hardinge Bridge in Bangladesh 357 mm, respectively. The river has great reputation for the socio-economy of the co-basin states. It is assessed that about 410 x 10^6 people (in 1991) are unswervingly or secondarily reliant on the Ganges River (Verghese and Iyer, 1993). This has joint peak discharge in the flood season of over 180,000 Cumec, the second highest in the world after the Amazan. Each year, around 114.4 km^3 of water is essential to support the agricultural, domestic and industrial activities of the people in the Ganges basin (Sharma et al., 2010). This study is aimed to find out the environmental flow required for Gorai River to sustain the ecosystem in different approaches. This study also evaluates the salinity conditions of water flows at different seasons on the Gorai river system. The present condition of salinity of river water in southern part of Bangladesh has been investigated for selected two stations.

1.3 Objectives

The main objective of this study is to assess the temporal and spatial changes in flow characteristics of Gorai River and to estimate the Environmental Flow Requirement (EFR) of the river that can be used for future reference in management purposes. The specific objectives of research are outlined as below:

- To study the changes of flow characteristics for several stations in Gorai river system through the comparison between past and recent times.
- To analyze the discharge of Gorai river system through Mean Annual Flow (MAF), Flow Duration Curve (FDC) and Constant Yield (CY) methods.
- To estimate the environmental flow requirement of the Gorai River with the primary objective of protecting natural ecosystem.
- To study the effect of upstream discharge on the salinity concentration of the river.

1.4 Scope of the Study

The southern zones of Bangladesh have been encrustation with salinity problem, which is estimated to be intensified by environment change and aquatic level rise. In dry season, the flows commencing upstream water reduced significantly, the brackish water moves 240 kilometers to the upstream and extents to Magura district.

Currently about 31 Upazilas of Jessore, Satkhira, Khulna, Narail, Bagerhat and Gopalganj districts are encrusted severe salinity problem. Agricultural accomplishments as well as harvesting in those Upazilas have been changes. Hence as a result farmers cannot produce multiple crops in a year. Additional 30% of the cultivable land in Bangladesh is in the coastline zones. Around 1.0 million hectare of cultivable lands is exaggerated by variable notches of salinity. Agronomists grow generally traditional rice during the monsoon. Most of the lands remain unplanted in the dry season (December–May) because of high soil salinity and the lack of good quality irrigation system. Overall topsoil salinity is assumed to be mainly accountable for low land use and cropping concentration in the particular area.

The decrease in flow causes an increase in salinity in the gorai river system. This intensification of salinity in the Gorai River has a great control to ecological impacts on the world's biggest mangrove forest the Sundarbans, a UNESCO World Heritage Location. It is situated at the end of the southern Ganges delta and it is about 10,000 km^2 in southwest Bangladesh and West Bengal of India. A total area of 62% lies in the Khulna district of the south western part of Bangladesh, while the outstanding 38% is in India (Siddiqi et al., 2001). The Sundarbans covers an area of 6017 km^2 of mangrove forests in Bangladesh portion. The wildlife reservations and sand bars, out of this 1905 km^2 are made up rivers, creeks and canals. The terrestrial area of Bangladesh Sundarbans is about 4112 km^2 (Katebi, 2001). Salinity levels increased in the Sundarbans area when intake of the Mathabhanga, Kobadak and other rivers that used to take fresh water from the Ganges to the south were silted up and thus misplaced their connection with the Ganges.

Therefore the result of increase salinity has damaged vegetation, cropping pattern and changing the landscapes in the Sundarbans region. The fresh water discharge from upstream decreasing day by day, which cause an increase in Salinity condition in Gorai river system. It is required to give a serious attention in this matter. Based on the above situation, a research has been taken to measure the present level of fresh water discharge and salinity in the Gorai river system, also to identify the correlation between the discharge and salinity.

1.5 Rationale of this Study

The rationale for river flows to achieve environmental objectives is based on sound logical and socioeconomic status of natural flow regimes to river ecosystem health and facilities to the society. A range of environmental and socioeconomic benefits have been renowned in response to different types and examples of managed environmental flow components. While environmental flow management can be remarkably beneficial, its effectiveness in improving ecosystem health and services is limited where structural constraints or conflicting operational demands prevent reestablishment of critical components of natural flow, or where other threats limit ecosystem responses to flow management. This document recapitulates types and gradations of benefits that have been recognized from monitoring impacts of environmental flow management, providing empirical evidence to draw from for developing impact goals and objectives, informing monitoring and measures approaches more broadly.

1.6 Organization of Report

The study comprises of Introduction, literature review, location of the study area, methodology and theories related to the salinity intrusion, 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 the theories regarding this research work and a review of related previous studies is presented.

Chapter 3 - Describes the study area which includes the data collection and data analysis of the study and Location of flow stations are presented in this Chapter. The methodology of flow calculation and its approaches are also explained in this Chapter.

Chapter 4 - The results obtain from the study and related discussions are presented in Chapter Four. It includes the assessment of environmental flow requirement of Gorai River system and to evaluate flow characteristics of the river through the comparison between past and recent time and analysis regarding salinity intrusion due to discharge variation in various seasons.

Chapter 5 - Provides the overall conclusions and to recapitulates the outcomes of the thesis and suggests about recommendations for forthcoming study.

CHAPTER II

Literature Review

2.1 General

Bangladesh is one of the coastal peripheral countries of the Bay of Bengal. Salinities in the Bangladesh coast are reliant on the annual rainfall, evaporation, freshwater flows discharging from upstream and the effect of environment change. The flow of the Ganges in Bangladesh reduced considerably due to extraction of water in the upstream. The decrease of water in low flow season in the Ganges has controlled to various ecological and hydrological problems in Gorai river system. Due to decrease in freshwater discharge from the upstream, The Normal salinity at the coastal zones is higher in the low flow season corresponding to the wet season (Joardar, J Razir, S Islam, and Kobir, 2018).

The literature review discussed the present river system, upstream flow condition and surface water salinity condition of the Southwest region of Bangladesh. Based on the previous study reports, Journals, research papers relevant to the salinity intrusion and salinity modelling it can observe that the effect of salinity intrusion with the changes of trans-boundary flow without any intervention at upstream boundary will be the vital issue at present scenario of Southwest region of Bangladesh. The present study will be useful for exploring the demand of upstream flow to push down the salinity line for safe drinking water and enhance crop production.

2.2 Gorai River System in Bangladesh

The greater rivers attend as a key source of water for agronomy and as the primary routes of passage. The rivers water also affords fish as a source of protein. Inundation of the rivers throughout the monsoon season origins massive damage and hampers improvement, but fresh water deposits of rich silt refill the soil with high fertility.

The Ganges rises from the Gongotri glacier on the southern slope of the Himalyas at an elevation of above 7000 m. west of Nanda Devi range in Himachal Pradesh and northernmost Uttar Pradesh, west of Nepal. The river comes out of the Himalyan and Siwalik range near Dehradun and enters into the plains at Hardwar. The Ganges has an easterly course and receives tributaries from the North in Nepal (Mahakali, Karnali, Gandak, Kosi etc.) and from the south in Rajasthan and northern slope of Vindhya parbat (Tons, Sone, Punpun etc.). The river enters into Bangladesh from the west some 18 km east of the Farakka Barrage in India and flows further about 95 km between India-Bangladesh border before entering fully into Bangladesh. Once upon a time the main drift of the Ganges castoff was discharged by this river, although earlier Hugli-Bhagirathi was the unique course of the Ganges. The Gorai takes off from the Ganges at Talbaria, north of kushtia town and 19 km downstream from Hardinge Bridge (Islam and Gnauck, 2011). South of Kushtia its first sprout the Kaliganga branches off to join the Kumar near Shailkupa.

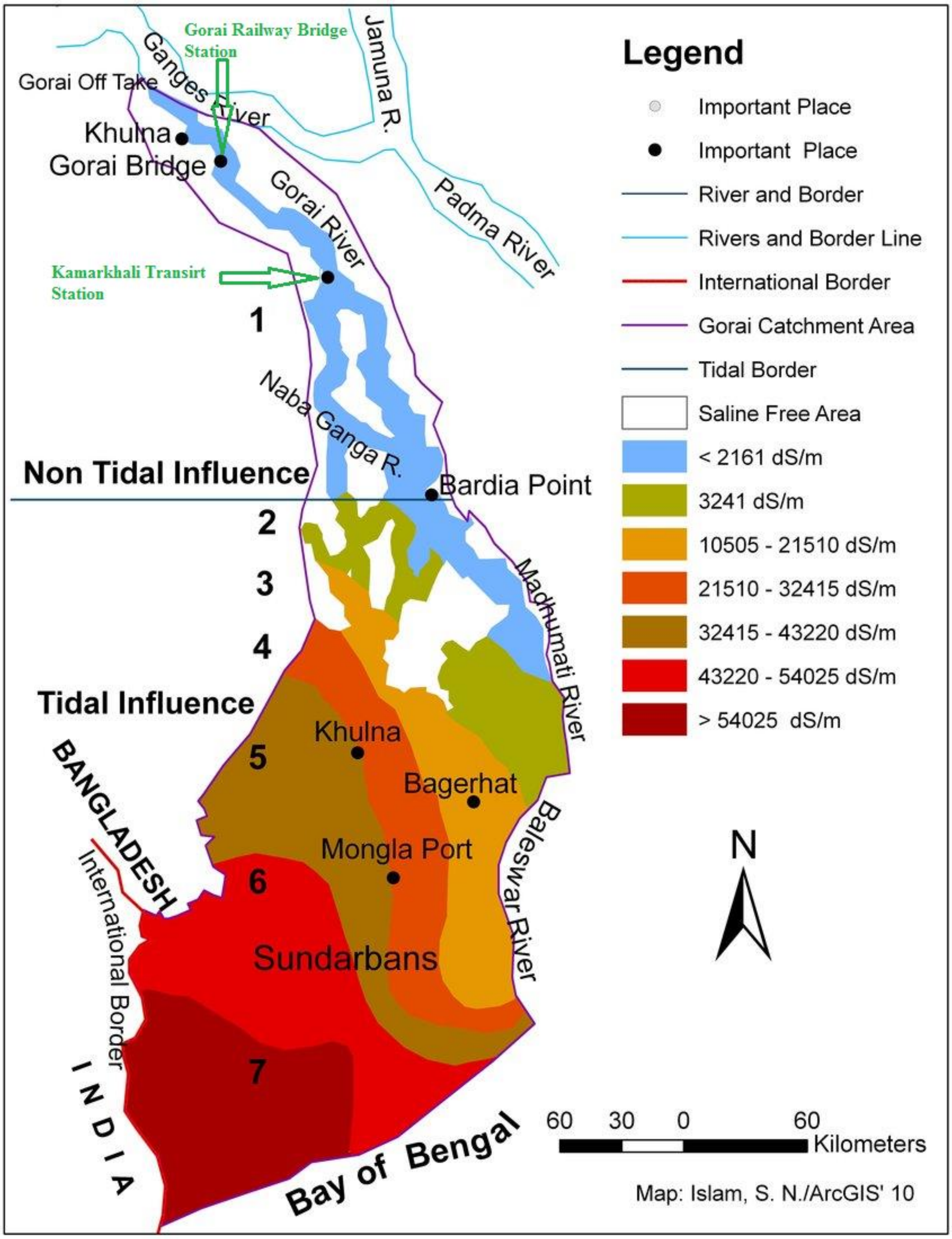

Figure 2.1: Gorai river system in south-west region of Bangladesh. (Islam and Gnauck, 2011)

This river has been obstructed by one of the main canals of the ganges-kobadak irrigation project (G-K Project) and the lower half of the course is now almost a dry bed. Ganges-Kobadak Irrigation Project or G-K Project is a large surface irrigation system of Bangladesh to serve the Southwestern part of Bangladesh. Kushtia, Chuadanga, Magura & Jhenaidah District are served by this project. The length of the channel is 193 kilometres. The main river splits and rejoins a number of times as its flow southeast to Mohammadpur upazila in Magura district. From here it has modifications its name to Madhumati. The Kumar, the nabaganga and the chitra join it through several channels south of Mollahat upazila. There it changes its name to Baleshwar, which in turn changes to Haringhata from the Bogi forest outpost of the sundarbans. The Gorai-Madhumati has a flood discharge of nearly 7,000 Cumec but in winter its flow goes down to five Cumec (Banglapedia, 2006).

The Gorai is a very ancient river. Its initial name was Gauri. The legendary geographer and astronomer Ptolemy remarked about five estuarine mouths of the Ganges. One of those, the 'Kambari Khan', was possibly the Gorai (Banglapedia, 2006). The course of the Gorai is wide, long and meandering. It is navigable by boats in the monsoon, but in the dry season it becomes non-navigable. In the downstream it is navigable throughout the year. Maximum recorded flow at Kamarkhali is 7,932 cumec. The breadth of the river increases as it flows down and at the end it is about 3 km.

The Gorai is one of the longest rivers in Bangladesh and its basin is also very wide and extensive. It flows through Kushtia, Jessore, Faridpur, Khulna, Pirojpur and Barguna districts. Agriculture and irrigation in these areas are very much dependent on the Gorai-Madhumati. Kumarkhali, Janipur, Sheuria, Ganeshpur, Khulumbari, Langalbandh, Shachilapur, Nacole, Lohagara, Pangsha, Baliakandi, Boalmari, Kashiani, Bhatiapara, Nazirpur, Kachua, Pirojpur, Sarankhola, Mathbaria, Patharghata and Morrelganj are the important places on the banks of the Gorai-Madhumati river (National Encyclopedia of Bangladesh). The greater districts of Kushtia, Jessore, Khulna, Faridpur and Barisal on the right bank of the course of Ganges-Padma-lower Meghna is known as the Gangetic delta in Bangladesh. The discharge is mainly contributed by the snowmelt of the Himalayas and the monsoon rainfall. In general, the peak flood occurs between the mid-August and mid-September. The bed material of the river consists of fine sand. The river is very dynamic and the channel of the river shifts between meandering and braided. Table 2.1 shows the key hydrological characteristics of the Ganges River (Maminul et al, 2003).

Table 2.1: Key hydrological characteristics of the Ganges

Parameters	Ganges (Hardinge Bridge)
Catchment Area (1000 sq. Km)	1000
Average annual rainfall (mm)	1200
Average Annual Discharge (m^3/s)	11300
Average maximum Water level (m,PWD)	13.7
Slope (cm/km)	5
Total Sediment Transport (M tons/y)	550
Bed Material Transport (M tons /y)	195
Bed material size (D_{50}) (mm)	0.15

Source: (BWDB, 2012)

2.3 Shortage of discharge and increase of salinity in south-west part of Bangladesh

The huge freshwater discharge from the Ganges, the Jamuna and the Meghna bring a large zone of saline water in the coastal region of Bangladesh. The salinity conditions in the northern-most part of the Bay of Bengal are run by seasonal movements of the opposite between sea water and the saline water. These movements are predominantly governed by the variations in freshwater discharge, coastal currents and mixing process. The salinity Intrusion due to fresh water scarcity in the Ganges Catchment and the challenges for urban drinking water and Mangrove Wetland Ecosystem in the Sundarbans Region (Urban Water Reuse Handbook, 2015). Freshwater is the sustaining force for all life on this earth. It is integral not only the sustenance of our ecosystems but also to the survival of humans. The reduction of freshwater in the Ganges catchment has created environmental problems in urban drinking water supply at small towns in the Sundarbans region in southwestern Bangladesh. It is also one of the main threats for mangrove ecosystems. Since the diversion of Ganges water at Farakka Barrage in India from early 1975, salinity level has increased drastically in the south western part of Bangladesh. Due to reduction of fresh water flow urban drinking water supply, industrial production, agriculture, fisheries, navigation, hydro morphology and mangrove wetlands ecosystems have been affected.

The study is intended to explore the changes in salinity due to discharge variation in different flow season of Gorai River. This study also intends to quantify the Environmental flow of Gorai River in different methods. In the Gorai river maximum salinity levels occur during March-April. Present salinity concentration has already put a threat to the crop production and a significant yield loss has already been observed in the dry season. In the changing scenario of fresh water, it has been predicted that the increasing concentration of salinity will create more pressure to the farmer by reducing yield on one hand and income generation and food security on the other hand. (WARPO, 2001) studied that the Options for

Ganges Dependent Area to assess the surface water demand in GDA and to select the alternative cost effective development strategies by identifying various improvement options. A wide range of 21 development options was considered in OGDA study involving interventions both with and without augmentation from the Ganges. Some options that were considered for diversion and distribution of Ganges flow are: restoration of Gorai River as pilot priority works, construction of offtake structure at Gorai, diversion through pumping, construction of Barrage in the Ganges and different water management options. From these findings OGDA study formulates some key strategy to relieve drainage congestion within the polder area through development of a sustainable river and drainage system, control salinity intrusion and relieve water shortages in the area. This is to be achieved by a combination of river and drainage improvement programs, augmentation of dry season upland flows and improved management of trans-regional wet season flood flows. In line with these implementation of Gorai River Restoration Project and rehabilitations of the GK scheme were recommended.

Bangladesh is dominated by tides and salinity from the bay. The southwest region bounded by Ganges-Padma River on the north, the Gorai-Madhumati and Baleswar-Haringhata River on the east. High salinity, associated with sedimentation of rivers, rendered the SW region into a challenging hydro-morphological situation. The region consists of a very intricate river system where strong tidal effects appear even about 150 km upstream of the coast. The only significant upstream freshwater to the region is the Ganges water, which flows into the Gorai river. However, during the dry season, the mouth of the Gorai is almost dry. The salinity levels at sea during that period are comparatively high; consequently, the region is severely affected by salinity intrusion. Many studies and projects were carried out, but the adverse effects could not be removed. On the other hand, the situation in the adjacent south central region seems to be much better, as the salinity levels remain low in that region throughout the year. This is due to the fact that a considerable fraction of the freshwater discharge from the Padma River is diverted into the region through different branches of the Meghna River and then flow through large rivers in the south namely the Bishkhali, the Buriswar and the Baleswar.

From the discussion it can be said that salinity depends on Discharge from upstream. In monsoon Gorai river gets enough water and the salinity decreases as fresh water dilutes the concentration. In post-monsoon, soil salinity starts to increase because of lower rainfall and higher evaporation of moisture from surface water. Increasing soil salinity continues up to pre-monsoon when soil becomes water stressed. The SRDI (1997) reported that, soil salinity levels south of Khulna and Bagerhat towns ranged between 8 to 15 dS/m during the low flow season. The continuous reduction and deterioration of quality of the Ganges fresh water in the catchment is the root cause of salinity intrusion and damage of the Sundarbans ecosystems. (Uddin and Haque, 2010) studied about the salinity response in southwest coastal region of Bangladesh due to hydraulic and hydrologic Parameters. This study assessed how salinity is influenced by the upstream fresh water discharge, local rainfall and mean tide level in the Sibsa and Pussur River of Paikgacha and Rampal, Bangladesh. Furthermore, the study aims to determine the relative influence of the different factors on salinity and identify key factors that control the salinity level in those rivers. Hence it was hypothesized that the resulting salinity levels reflect the combined result of multi-components. Paikgacha and Rampal experienced high and moderate salinity through the Sibsa and Pussur River respectively. Linear regression showed a significant correlation within salinity-river discharge as well as salinity-rainfall in the Pussur and Sibsa Rivers respectively. Again multivariate analysis showed that rainfall and river discharge are the key factors influencing salinity in the Sibsa and Pussur Rivers in Paikgacha and Rampal regions respectively.

2.4 Review on Environmental Flow Requirement (EFR)

Since the mid-1970s, there has been a rapid proliferation of methods for estimating EFR for a given river, ranging from relatively simple, low-confidence, desktop approaches, to resource-intensive, high-confidence approaches (Tharme, 2003). Comprehensive methods are based on detailed multi-disciplinary studies that often involve analysis of large amounts of hydrological, geomorphological and ecological data and experts from different disciplines. Typically, such studies may take many months, sometimes years, to complete.

The last couple of decades have seen the evolution of various methods and approaches to estimate EF. Based on evolution, Tharme presented a classification of methods to estimate EFR hydrological methods, hydraulic rating methods (HRM), habitat simulation methods (HSM), and holistic methods. Since hydrology provides the foundation for water resources management, hydrological methods are frequently employed to get initial estimates of EF. Generally, time series of river flow data are available at many places, and indices based on these can be easily calculated. Allocation based on percentage of MAR or values read from flow duration curves (FDC) fall in this category. The Tennant method shows the likely status of the habitat from various levels of EFs in two six-monthly groups by separating the entire range of MAR at a site into several ecologically relevant ranges. Tennant specified percentages of the MAR that provide different quality habitat for fish. Although Tennant developed the indices for the USA, these have been used in other countries. In the UK, Q95 (flow which is equaled or exceeded 95% of the time) is often used to define EFs (Acreman and Dunbar, 2004). Richter developed the range of variability approach which uses 32 indices to reflect different aspects of flow variability.

The first hydrological methods were simple, low-resolution estimates of the percentage of annual, seasonal, or monthly flow volume (often termed the minimum flow) that should be left in a river to maintain minimal fish habitat and/or acceptable stream condition. e.g., single figure flow recommendations based on low-flow indices, derived from flow duration curves such as Q95; (Tharme, 2002). Hydrological methods are often called fixed-percentage or look-up table methods, as they rely on formulae linked to historical flow records to estimate desirable discharges. Unusual for its time, the Montana method (Tennant, 1976) stands apart from such desktop approaches inasmuch as the look-up table of percentages of average annual flow, which correspond to different degrees of desired river condition, was derived from an empirical base of field-level flow habitat and ecological (fish) studies of many small US streams of specific bio-physical character. Without appropriate validation for streams in new geographic regions or of different types, the use of the tabulated flow levels carries the risk of setting environmental water recommendations that are unsuitable (e.g., too high or too low) for local conditions; untested extrapolations of this kind remain a challenge common to many environmental flows assessment methods.

Hydrology-based methods have been variously elaborated over the years, and in the last decade or so have substantively advanced by taking a more regime-based approach that estimates a range of ecologically relevant streamflow characteristics such as magnitude, frequency, timing, and the duration of specific flood and low-flow events. Hydraulic rating methods emerged in parallel, with the intent to quantify how flowing water interacted with channel boundaries to create aquatic habitats of varying depth, velocity and cover characteristics that varied over time with discharge pattern (Richter et al, 1997).

However, Tharme traced the evolution of environmental flow methodologies worldwide. He noted that the USA was at the front position of research in this arena (Tharme et al, 2002). A series of techniques has documented emerging in the late 1940s and 1970s. Table 2.2 demonstrate that Instream Flow Incremental Methodology (IFIM) became the most widely used method in the United States, followed by other easiest method which are appropriate for insignificant schemes and basin wide forecasting. In furthermost other portions of the world, Environmental Flow Assessment (EFA) practices became conventional far later. Other notable works on Environmental flow calculation that are based on use of river water for fish, wildlife, ecological developments and other ecological, recreational and aesthetic purposes have been published by many researcher (Lamb and Doersken, 1987).

In Bangladesh, flood control and irrigation development have been the main focus of water resources management without due attention to the low flow and Environmental flow management. Historically water has been managed from supply perspective with an emphasis on maximizing the economic return from its use. As the degradation of water related environment started to manifest itself, the environmental concerns have started to gain strength. Nowadays, the term 'minimum flow' is assumed as a flow, which is needed, to be out downstream of the dams for environmental preservation. The first scientific effort to evaluate environmental water demand for the entire India has been recently done (Sharma et al, 2005). It was made independently for major river basins/drainage regions of India. The estimate turned out to be about 476 km3 which constitutes approximately 25% of the total renewable water resources in the country. This was not an estimate of environmental flows per sec, but moderately an estimate of the total volume of environmental flows.

Table 2.2 Various Methods and the Number of States using them for assessing EFR in the U.S.A.

Method	Number of States using the method
Instream Flow Incremental Methodology (IFIM)	38
Tennant Method	16
Wetted Perimeter	6
Aquatic Base Flow	5
7-day, 10-year Low Flow (7Q10)	5
Professional Judgment	4
Single Cross-section (R-2 CROSS)	3
USGS Toe-width	2
Flow records/duration	2
Water Quality	2
Average Depth Predictor (AVDEPTH)	1
Habitat Quality Index	1
Oregon fish-flow	1
Water Surface Profiles (HEC-2)	1

Source: (Lamb BL and Doersken HR, 1987).

There are a variety of environmental flow methods available to determine the impact of water flow on aquatic biota, but the use of the Instream Flow Incremental Methodology (IFIM) has become one of the predominant methods for establishing instream flow criteria. Some states use a hierarchical approach for selecting the methodology for determining instream flows, with IFIM selected for the most complex projects that: 1) are expected to have significant impacts on the aquatic biota, 2) impact a valuable fishery, 3) are peaking facilities, and 4) involve complex negotiations. One major drawback to using IFIM is that this approach is the most costly and time consuming of the most frequently used instream flow methodologies.

The **IFIM** was developed in the late 1970's (Bovee and Milhous, 1978) and has continually been refined amid constructive criticism. The methodology is based on habitat quality, as dictated by stream hydraulics, and the relationship between incremental changes in water flow as it affects available habitat (area that is suitable for a particular organism). Available habitat is based on the quality of microhabitat variables (water velocity, water depth, substrate and cover) and macro habitat variables (water temperature, dissolved oxygen, and other water quality variables), depending on an individual organism's preference for these variables. The methodology can be used to determine available habitat for fish and wildlife, as well as determine suitability for recreational uses such as canoeing.

The **Wetted-Perimeter method** assumes that there is a direct relation between the wetted perimeter in a riffle and fish habitat in streams (Annear and Conder, 1984). The wetted perimeter of a stream, defined as the width of the streambed and stream banks in contact with water for an individual cross section, is used as a measure of the availability of aquatic habitat over a range of discharges. The Wetted-Perimeter method is based on a plot of the relation between wetted perimeter and discharge. The point of maximum curvature in this relation is used to determine the streamflow required for habitat protection. On a stream cross section, this point theoretically corresponds to the break in slope at the bottom of a stream bank where the water surface would begin to recede in a more horizontal direction from the stream banks when flows are decreasing, or to rise up the banks when flows increase. On plots of wetted perimeter versus discharge, the breaks in slope on such graphs are most distinct in riffle channels with rectangular or trapezoidal cross sections. In these cases, water levels that rise above the bottom of the bank cause smaller rates of increase in wetted perimeter for each unit increase of discharge; water levels that fall below the bottom of the bank cause larger rates of decrease in wetted perimeter for each unit decrease in discharge.

The **Aquatic Base Flow** method uses historic flow data to determine the median flow for the lowest flow month (typically August or September), and applies that level to the remainder of the year. This approach assumes that a specific flow rate per unit of watershed area will provide an adequate minimum flow. It is not simple to use, if historic data is available, but cannot account easily for site-specific biological concerns; nor can the method adequately and defensibly adjust for spawning or incubation (Public Works and Government Services Canada, 2019).

The 7-day, 10-year Low Flow (7Q10) is the lowest 7-day average flow that occurs (on average) once every 10 years. Low flow values are defined on a hydrologic design or biological design basis. Low flow values are expressed in terms of their averaging period (for example, a 4-day average flow or a 7-day average flow) and their recurrence frequency (generally once in 10 years for hydrologically based flows and once in 3 years for biologically based flows). A hydrologically based low flow is computed using the single lowest flow event from each year of record, followed by application of distributional models (typically the Log Pearson Type III distribution is assumed) to infer the low flow value. The 1Q10 is the lowest one-day average flow that occurs (on average) once every 10 years. A biologically based low flow is computed based on all low flow events within a period of record, even if several occur in one year, and reflects the empirically observed frequency of biological exposure during a period of record. The 7Q10 values for Illinois streams are presented in the form of 11 regional maps. The maps were originally developed for Illinois streams in 1973 by the Illinois State Water Survey (Singh, 1971).

The **Water Surface Profiles (HEC-2)** program is intended for calculating water surface profiles for steady gradually varied flow in natural or man-made channels. Both subcritical and supercritical flow profiles can be calculated. The effects of various obstructions such as bridges, culverts, weirs, and structures in the floodplain may be considered in the computations. The computational procedure is based on the solution of the one-dimensional energy equation with energy loss due to friction evaluated with Manning's equation. The computational procedure is generally known as the standard step method. The program is also designed for application in floodplain management and flood insurance studies to evaluate floodway encroachments. Also, capabilities are available for assessing the effects of channel improvements and levees on water surface profiles. Input and output may be either English or metric units. A data edit program (EDIT2) checks the data records for various input errors. An interactive summary printout program (SUMPO) and graphics program (PLOT2) are available for MS DOS computers. An input edit program (COED) is available with an HEC-2 input help file.

Flood Action Plan studies highlighted on water management taking into consideration the environmental viewpoint of water resources management. Environmental effect of water resources development has been recognized in the National Water Policy and the National Water Management Plan (NWMP, 2004). In Bangladesh no methodical study and investigation has been done for describing the environmental flow requirement. The Environmental requirement set forth in different Plan and project related studies, until now, has been on an ad-hoc and empirical basis. From a river management point of view, scientifically justified methods and guidelines are needed for determining flow requirement to safeguard the aquatic environment, livelihood of subsistence users and requirement of downstream users. In this regard water management in Bangladesh lags behind in the improvement of appropriate management tools for indorsing the flow regimes considering environmental and ecological features (Bari and Marchand, 2006).

CHAPTER III

Study Area and Methodology

3.1 General

The Gorai River is the key distributary of the Ganges River and the primary source of upstream freshwater discharge to the southwestern area of Bangladesh. The Environmental flow requirement and salinity condition determination of Gorai River is the main focus of this study. It includes two different stations namely Gorai Railway Bridge and Kamarkhali Transit point. Necessary data required for the present study of Gorai River at different stations have been collected from Bangladesh Water Development Board (BWDB).

Environmental flow requirement of a river demonstrates the quantity, timing, and inferiority of water flows necessary to endure fresh water and estuarine ecosystems and the human livelihoods and wellbeing that depend on these bionetworks. The health and integrity of river systems ultimately depend on environmental flow Constituents, which may vary seasonally (Mathews and Richter, 2007). It is a valuation of how much of the original flow establishment of a river should remain to flow down it and onto its floodplains acceptable to maintain specified features of the ecosystem for the rivers. The environmental flow requirements in each river linked to a predetermined objective in terms of the biota's future circumstance.

3.2 Study Area

The Gorai River catchment area is 15160 km² and is located between 21° 30′ N to 24° 0′ N latitude and 89° 0′ E to 90° 0′ E longitude. It runs through Kushtia, Jessore, Faridpur, Khulna, Pirogpur, Borguna districts of south western section of Bangladesh. Gorai river is very ancient river and is shaped of three offshoots of the Padma. The channel of Gorai River is varied, and meandering (Bari et al., 2012). The River used to expulsion into the Bay of Bengal through the Madhumati and Baleswar Rivers and thus attends as a essential appliance for conserving both the environment and economy of the region (Islam and Gnauck, 2011). Due to excessive extraction from the Ganges River in its upstream inside India, its distributaries inside Bangladesh are gradually fallen to death for not receiving their dry season flow. Implementation of the Farakka Barrage results in reduction of flow through the Gorai River and deposition started ensuing in the off-take. As a result, two types of environmental impacts have been created in the Gorai catchment area. The sediment particles are settling down on the river bed rapidly, which is one of the major problems of Gorai River morphology. On the other hand the saline sea water is pushed up in the upstream area due to capillary upward movement. Figure 3.1 shows the locations of the study area.

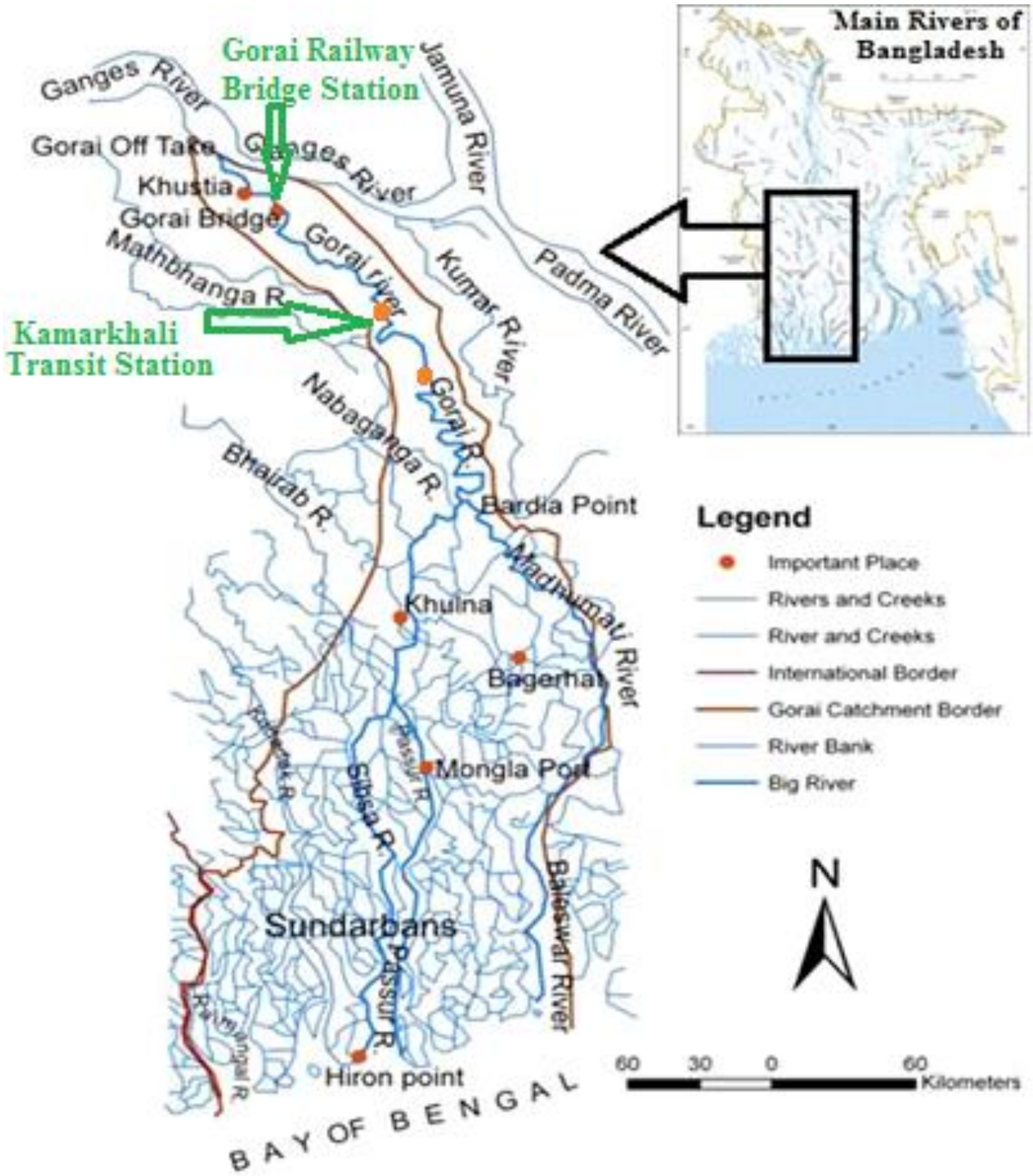

Figure 3.1: Location of study areas in south-west region of Bangladesh. (Modified after Islam and Gnauck, 2011)

3.3 Data Collection

Necessary data required for the present study of Gorai River at different station have been collected from Bangladesh Water Development Board (BWDB). A summary of the data collected as well as those used in the present study is presented in Table 3.1

Table 3.1: Summary of Data collection with river station

S.N.	RIVER NAME	Station ID	Station Name	Type of data
1	Gorai-Madhumati-Baleswar	SW99	Gorai Railway Bridge	Discharge in Cumec
2	Gorai-Madhumati-Baleswar	SW101	Kamarkhali Transit	Discharge in Cumec
3	Gorai-Madhumati-Baleswar	SW101.5	Kamarkhali Transit	Salinity concentration High & Low tide in PPM

It is mentioned that the discharge data is available in the upstream of Gorai river and salinity data is available in the downstream with BWDB. Water level data is available instead of discharge data in downstream statons. But both Salinity data and Discharge data is available for only Kamarkhali Transit station. The discharge data has been collected from BWDB for Gorai Railway Bridge and Kamarkhali Transit stations. The distance between two stations is about 60 km, the Gorai Railway Bridge station is located at upstream. Considering of data availability, discharge data, salinity data and water level data for last 30 years has been used in this study.

3.4 Methodology

Environmental Flow Requirement (EFR) for Gorai river has been assessed using three methods, they are (i) Mean Annual Flow (MAF) method, (ii) Flow Duration Curve (FDC) method and (iii) Constant Yield (CY) method. All the methods belong to hydrological approach and use historical flow data.

3.4.1 Mean Annual Flow Method

This technique is commonly acknowledged as Tennant method. It is possibly the furthermost extensively known and used method of similar categories. It is the second greatest common method in the USA and is used or accepted by 16 states. According to this method, EFR is set at different percentage of the mean annual flow. The percentages vary from 10% to 200% of the mean annual flow. The percentage is set considering the anticipated habitat quality. The different percentages that have been used for calculating EFR for various habitat potentials are shown in Table 3.2.

To determine the EFR using the mean annual flow (MAF) method, the discharge data of Gorai Railway Bridge and Kamarkhali Transit stations has been collected from BWDB. The last thirty years flow was analyzed using IHA Software for two periods: G1 period (for the year 1984 to 1999) and G2 period (for the year 2000 to 2016).

Table 3.2: Percentage of MAF for various Habitat Qualities

Habitat Quality	Percent of Mean Annual Flow (MAF)	
	Low Flow Season	High Flow Season
Flushing or maximum	200	200
Optimum	60-100	60-100
Outstanding	40	60
Excellent	30	50
Good	20	40
Fair	10	30
Poor	10	10
Severe degradation	<10	<10

3.4.2 Flow Duration Curve Method

A flow duration curve (FDC) shows the correlation between the amount and duration of river flows. The duration in this circumstance denotes to the overall percentage of time that an individual flow is exceeded. The outline of the FDC for any river hence intensely reflects the type of flow establishment and is influenced by the character of the upstream catchment including geology, urbanization, simulated effects and groundwater. According to the FDC method, EFR has been set at the 50th (for high flow season) and 90th (for low flow season) percentile flow of the monthly flow duration curve. For this purpose, flow duration curve for each month of the year has been constructed. The flow duration curve illustrates the percentage of time during which a specified flow is corresponded or exceeded. For determination of EFR using the Flow Duration Curve (FDC) method, the discharge data of Gorai Railway Bridge and Kamarkhali Transit stations has been collected from BWDB. The flow for last thirty years was analyzed using IHA Software for two periods: G1 period (for the year 1984 to 1999) and G2 period (for the year 2000 to 2016).

The FDC results in the development of a flow exceedance probability curve, which shows the percentage of time that the stream flow is likely to equal or exceed a flow value of interest. The flow exceedance probability curve is developed using existing hydrologic flow data from a specified time period of interest, and can be formatted to fit daily, weekly or monthly data. To create the curve, flow values for the time period of interest are first ranked by magnitude. Then, exceedance probability is calculated by determining the percentage of time that the stream flows is likely to equal or exceed a specified value. Exceedance probabilities are plotted against flow values, and the curve reflects average flow characteristics of a stream throughout the range of discharge.

FDC is performed by first obtaining a chronological record, typically 30 years or more, of flow data for a given stream recorded by a fixed gaging station (USGS 1969). The FDC is more robust when longer periods of hydrologic data records can be used. First, flows are sorted by magnitude and assigned rank numbers, then the exceedance probability for each flow is calculated, and finally the calculated exceedance probabilities are plotted against flow values to create a flow exceedance probability curve. The probability of exceedance is calculated as

P = [M / (n + 1)] x 100%

P = the probability that a given flow will be equaled or exceeded (% of time)
M = assigned rank number
n = the total number of days for whole period of record

The use of moving-day averaged flow duration curves has been found to be a useful indicator of the quality of river flow information held in a database. The method indicates the most profitable range in which gauging's should be obtained. This allows better planning of data collection. The FDC is a very convenient tool for evaluating the overall chronological deviation in flow, though one drawback is that it deals little evidence about the judgement or persistence of low flow measures. The impact of probable perceptions from the river discharge can be reviewed by assembling an influenced FDC which can then be linked to the target, enabling documentation of flow assortments where further abstraction might be acceptable. For example, it might be necessary to possess the flow regime of a specific river as usual as possible and a mark of 90% of the natural flow transversely the full range of flow might be stated. This means that the mutual consequence of any simulated impacts should not result in a modification in flow regime such that the actual flow duration curve differs from the natural flow by greater than 10% at any point.

3.4.3 Constant Yield Method

According to the Constant Yield method, Environmental flow requirement for the Gorai River has been set at 100% of the median monthly flows for each month. For this persistence, median monthly flow for each month has been calculated in two dissimilar ways. According to the 1st method, the median flow of each month has been considered in view of the data convenience period. In the 2nd method, median monthly flow for each month of each year has been considered individually. Thus, a number of median values are accomplished for each month, and then the median of these values has been taken as the median for the given month over the whole period of record. For determination of EFR using the Constant Yield (CY) method, the discharge data of Gorai Railway Bridge and Kamarkhali Transit stations has been collected from BWDB. The flow for last thirty years was analyzed using IHA Software for two periods: G1 period and G2 period.

Since Gorai River is an unregulated river and the availability of flow record is more than 30 years, median monthly flows can attend as the datum for valuation of Environmental flow requirement. Thus the Environmental flow constraint for each month has been taken as 100% of the average of the median monthly flows calculated according to the two dissimilar methods. In Bangladesh, this procedure has been used for assessment of Environmental flow requirement for Surma, Kushiyara and Teesta River (Bari et al, 2006).

3.5 Range of Variability Approach (RVA)

The Range of Variability Approach (RVA) described in Richter et al. (1997). The RVA uses the pre-development natural variation of Indicators of Hydrologic alteration (IHA) parameter values as a reference for defining the extent to which natural flow regimes have been altered. The pre-development variation can also be used as a basis for defining initial environmental flow goals. Richter et al (1997) suggest that water managers should strive to keep the distribution of annual values of the IHA parameters as close to the pre-impact distributions as possible. RVA analysis also generates a series of Hydrologic Alteration factors, which quantify the degree of alteration of the 33 IHA flow parameters. Note that RVA analysis is only available for IHA parameters, and not for Environmental flow constituent (EFC) parameters. The Range of Variability Approach (RVA) has been adopted for the interpretation of IHA indicator results. In an RVA analysis, the pre-impact data for each parameter is divided into three different categories. The RVA uses 33 hydrologic parameters to evaluate potential hydrologic alterations. The boundaries between categories are based on either percentile values (for non-parametric analysis) or a number of standard deviations away from the mean (for parametric analysis). RVA algorithm computes the frequency with the "post-impact" annual values of IHA parameters actually fell within each of the three categories. This expected frequency is equal to the number of values in the category during the pre-impact period multiplied by the ratio of post-impact years to pre-impact years. Finally, a Hydrologic Alteration (HA) factor is calculated for each of the three categories as:

HA (%) = (Observed frequency – Expected frequency) / Expected frequency

A positive Hydrologic Alteration value means that the frequency of values in the category has increased from the pre-impact to the post-impact period (with a maximum value of infinity), while a negative value means that the frequency of values has decreased (with a minimum value of -1).

The Range of Variability Approach is one of several new methods that are considered to hold considerable merit for further investigation. It aims to provide a comprehensive statistical characterization of ecologically-relevant characteristics of a flow regime. Briefly, the natural range of hydrological variation is described using 32 different hydrological indices derived from long-term daily flow records (Richter et al., 1997). The indices, termed Indicators of Hydrologic Alteration (IHA), are grouped into five categories based on the regime characteristics; magnitude, timing, duration, frequency and rate of change of discharge. Flow management targets, which can be monitored and refined over time, are set as ranges of variation of each hydrological parameter. The RVA is the most sophisticated form all of the hydrological index methodologies. It is aimed at providing a comprehensive statistical characterization of the ecologically relevant features of the flow regime, recognizing the crucial role of hydrological variability in maintaining ecosystems. The method is intended to be applied to rivers where protection of the natural ecosystem functioning and conservation of the natural biodiversity are the primary management objectives. This method is a good method for impact assessment. The methodology comprises six basic steps.

1. The first of which is the characterization of the natural range of hydrological variation using a number of ecologically relevant hydrological indices, termed Indicators of Hydrologic Alteration (IHA). These are summarized in Table 3.3.

2. The second step is to select management targets for each of the IHA parameters. The fundamental concept is that the river should be managed so that the annual value of each IHA parameter falls within the range of natural variation of that parameter. The management targets should be based on available ecological information. In the absence of adequate ecological information it is recommended that ±1 standard deviation is used as the default for the initial setting of targets.

3. Step 3 is to use the flow based management targets, known as the Range of Variability (RVA) to set up management rules that will enable the targeted flow conditions in most, if not all, years.

4. Step 4 involves implementing a monitoring programme to assess the ecological effects of the new management system.

5. The fifth step is to characterize the actual stream flow variation using the same hydrologic parameters and compare then to the RVA targets.

6. The final step is to repeat the first five steps incorporating the results of the preceding year's management and any new ecological research or monitoring information to revise either the management system or the RVA targets.

The tools named Indicators of Hydrologic Alteration (IHA) are used for this method. This software is developed by The Nature Conservancy (TNC) as an easy tool for calculating the characteristics of natural and altered hydrologic regimes. This tool require at least 20 years of flow data. In some cases hydrological simulation models may be used. The RVA approach was designed to bridge the gap between applied river management and current aquatic ecology theories. The power of the IHA method is that it can be used to summarize long periods of daily hydrologic data into a much more manageable series of ecologically relevant hydrologic parameters.

Table 3.3: Hydrological parameters for RVA used in the IHA software

IHA statistics group	Regime characteristics	Parameters
Group 1: Magnitude of monthly water conditions	Magnitude Timing	Mean value for each calendar month
Group 2: Magnitude and duration of annual extreme water conditions	Magnitude Duration	Annual minimum and minimum 1 day means Annual minimum and minimum 7 day means Annual minimum and minimum 30 day means Annual minimum and minimum 90 day means
Group 3: Timing of annual extreme water conditions	Timing	Julian date of each annual 1 day minimum and maximum
Group 4: Frequency and duration of high and low pulses	Frequency Duration	Number of high and low pulses each year Mean duration of high and low pulses
Group 5: Rate/frequency of consecutive water condition changes	Rates of change	Means of all positive differences between daily values Means of all negative differences between daily values

The fundamental concept is that the river should be managed in such a way that the annual of each IHA parameter falls within the range of natural variation for that parameter, as defined by inter annual measure of dispersion. The RVA targets are means to achieving biological goals.

3.6 Approach of Analysis

The main objective of this study is to assess the flow characteristics of Gorai River and to estimate the Environmental Flow Requirement (EFR) of the river that can be used for future reference in management purposes. The research is outlined as to study the changes of flow characteristics for several stations in Gorai river system through the comparison between past and recent times. The analysis of discharge on Gorai river system will be carried out through Mean Annual Flow (MAF), Flow Duration Curve (FDC) and Constant Yield (CY) methods. From the analysis, the environmental flow requirement of the Gorai River will be estimated to sustain natural ecosystem. The effect of upstream discharge on the salinity concentration of the river has studied. For determination of EFR, IHA (Indicators of Hydrologic Alteration) software is used, the software program was originally developed by The Nature Conservancy in the 1990s to quickly process daily hydrologic records to enable characterization of natural water conditions and facilitate evaluations of human-induced changes to flow regimes. The evolution of the IHA software is discussed, including recent revisions and additions to the IHA that have improved its utility in environmental flow-setting processes. Drawing from holistic methodologies developed around the world, the ability to calculate characteristics of five components of flow important to river ecosystem health extreme low flows, low flows, high-flow pulses, small floods and large floods has been added to the IHA. A practical advantage of these environmental flow components is that an environmental flow prescription based upon them can be readily implemented in most water management.

3.7 Analysis by IHA software

The IHA software contains 67 parameters, which are sectioned into two groups, 33 IHA parameters and 34 EFC (Environmental Flow Component) parameters. These hydrologic factors were established based on their capability to reveal changes in flow regimes across a wide-ranging of impacts including dam acts, flow diversions, groundwater driving, and landscape amendment (Mathews and Richter 2007). These signs focus on the flow regime that will think to be important to the biological and physical characteristics of a river (Richter et al. 1996). But many of the indicators of IHA are correlated promoting a level of arithmetic dismissal and potentially complicating environmental flow valuations. Therefore, identification of a small set of the most suitable indicators is necessary to evaluation of river health. Classifying a minor set of significant indicators will (a) simplify an attitude for describing flow alteration, (b) decrease statistical redundancy and computational and (c) facilitate to obtain optimal solutions. Previous studies have sought to explore redundancy among hydrologic metrics. For example, a small subset of hydrologic indicators has been identified by (Yang et al., 2008), where six IHA parameters (i.e., date of minimum, rise rate, number of reversals, 3-day maximum, 7-day minimum and May flows) identified as the most ecologically relevant hydrologic indicators.

Mean daily discharge (Cumec) data have been collected from the Bangladesh Water Development Board (BWDB) for the years 1984 to 2016. All hydrologic indices have been calculated from daily mean flow records using the Indicators of Hydrologic Alteration (IHA) software (version 7.1). A common approach to assess hydrologic alteration involves a comparison of flow regimes between past and more recent time. As 30 years mean daily discharge data are available, for convenience in analysis two periods having 15 years data.

Moreover depending on mean monthly flow, Gorai flows can be categorized in three separate seasons named low flow season for the months of February to May (mean annual flow ≤100 Cumec), high flow season from July to October (mean annual flow ≥1000 Cumec) and intermediate flow season from November to January and June (mean annual flow from > 100 to < 1000 Cumec) (Moly et al., 2015).

According to Mullick, the flow seasons of Teesta are categorized as high flow season for the months of June to September, intermediate flow season for October, November, April and May and low flow season for the months of December to March. (Mullick, 2010),

In this study of Gorai river system, the same seasonal variation approach (used in the Teesta River case) is adopted. The seasons are categorized as high flow season for the months of June to September, intermediate flow season for October, November, April and May and low flow season for the months of December to March.

3.8 Missing Data and Data Interpolation by IHA Software

Hydrologic records often have some days with missing data, which can cause problems for the calculation of some hydrologic parameters, such as rise and fall rates. For this reason, the IHA estimates a flow value for days with missing data by linear interpolation. Interpolated values will be generated for all days with missing data that are in water years that have at least one valid flow value. This means that water years with no valid flow data will be skipped during any analysis, and as such will not appear in the Annual Summaries Table or the EFC Daily Table.

The interpolation algorithm will interpolate across water year boundaries. If the adjacent water year is missing, the last good datum is duplicated to the year boundary. Any water years with no valid flow data will be excluded from analysis in the IHA (i.e. flow values will not be interpolated). In years with very large gaps in the data, the many interpolated values can lead to odd results for rise/fall rates, pulses, and other parameters. If your data has such problems, the graphical output should be examined carefully before you place confidence in the results. The IHA is set up to issue a warning if there is a consecutive block of missing data greater than a user-defined length, which will appear in the Message Report. The default length used to generate this warning is 10 days, but sees Setting Up and Managing an Analysis for how to alter this default. Specific warnings will also be issued identifying water years in which more than 30 values are interpolated.

When viewing your flow data in the Hydrologic Data file editor, selecting Hydro Data Review Recorded and Missing Date Ranges will bring up a summary of the dates of both missing and recorded data. Long periods of interpolated data can also usually be easily discerned in the daily data graph, since they will be straight lines. Examining this graph is also a useful way to inspect your data for outliers, gaps, incorrect data entries, and other anomalies in the data. Because water years without any valid flow values are excluded from all calculations, there are some special issues having to do with high and low pulse events and EFC events that begin or end immediately after or before a water year that is entirely missing data. For events that begin on the first day of a water year after an entire missing water year, the pulse or EFC event is assumed to have started in the previous water year and will be ignored. Events that include the last day of a water year prior to an entire water year of missing data will be included in the statistics for that water year, but a warning is issued to warn the user that these events may have been truncated. Identical rules are applied to pulses and events that apparently extend beyond the beginning or end of shortened water years and seasons.

If there is doubt about how much data is enough, some tests to see how different record lengths affect IHA statistics would be prudent. Richter also discuss various methods for extending hydrologic records, filling in missing data, or estimating daily hydrologic data from simulation modeling (Richter, 1997). The IHA automatically does linear interpolation over gaps in the data; therefore, users should regard any IHA results from datasets with missing records with appropriate caution! In some cases a missing water year of data or the end of the dataset may truncate a pulse that is counted in the statistics. When this happens, a warning is issued in the Message Report, so that the user knows that one event has a truncated duration. Note that events that start on the first day of the dataset or the first day after a missing water year are not counted in the statistics, because it is assumed that these events actually began in the prior water year that is not in the data.

In cases where a flow dataset has one or more water years of missing data, and the Advanced Calibration method is being used, the initialization procedure described above is rerun after each period of missing data. Note also that the occurrence of missing water years of data means that some EFC events may be truncated either at their beginning or end. Our convention is to count any events in the statistics that are truncated by the end of a water year, but ignore events that are truncated by the beginning of a water year. In either of these situations, a warning is issued in the Message Report. Be aware that the truncated events that are counted may have errors in flow parameters such as peak flow, duration, timing, and rise and fall rates, due to the fact that not the entire event is present in the flow data.

3.9 Factors Affecting the EFR Value

EFR depends on a number of factors, including the size of river, the desired state, sensitivity of river ecosystem, preference of the society, and the uses of river water. Consequently, before computing EFR, broader objectives must be determined to indicate the type of river desired. For some rivers, EFR are set to achieve specific predefined ecological, economic, or social objectives. This is called objective-based flow setting (Acreman and Dunbar, 2004). The concept of environmental flow is based on the recognition that aquatic ecosystems are adapted to natural flow conditions and modification of the flow regime will impact on the ecosystem. Additionally, the geomorphological structure of streams is largely determined by the flow regime, with flow-on effects on stream biota through changes to substrate type and available habitat. Flow regime refers not only to the quantity of water but also to the variability of flow and incidence of flood and low flow events. For long term viability of some ecosystems there may be a need for periods of low flow. In practice it may be difficult to determine the effect of an 'environmental flow' component in isolation from other factors such as water quality. The environmental flows have been determined by relating the Territory Plan requirements to protect specific aquatic ecosystems to the scientific basis for sustaining significant ecosystems or species. The Cooperative Research Centre for Freshwater Ecology (CRCFE) provided advice on the effectiveness of the 1999 Environmental Flow Guidelines and on improvements that could be made in the general approaches and actual flow rules for sustaining ecological values. The CRCFE review assessed the effectiveness of the prescribed environmental flows by reference to monitoring data and research on rivers within the ACT and through the advice of local and national river ecologists. The CRCFE review was informed by the extensive monitoring and research conducted on the Cotter River since the environmental flow guidelines were first adopted in 1999.

Both water quality and water quantity characteristics have effects on ecosystems, and in some areas these are strongly interrelated. Although these environmental flow guidelines focus on water quantity, some water quality factors should not be ignored in this discussion. In particular, water quality problems can arise when water is released from impoundments to meet downstream environmental flow requirements. Water from the lower layers of deep, stratified reservoirs can have a much lower temperature and oxygen content than surface waters. If this bottom water is released to meet environmental flow requirements, its quality may compromise its value in the maintenance of aquatic ecosystems. For example most native fish species use both water temperature and flow as cues for reproduction, and the temperature of water released to meet an environmental flow requirement may severely disrupt spawning, migrations, and reproductive activity. In catchments where reservoir releases are made to meet environmental flow requirements, the water quality of the release is to match as closely as possible to that of the water flowing into the reservoir.

The provision of flows, including volumes and timings, to maintain downstream aquatic ecosystems and provide services to dependent communities has been recognized in developed countries for more than two decades and is increasingly being adopted in developing countries. These services include the following:

- Clean drinking water
- Groundwater recharge
- Food sources such as fish and invertebrates
- Opportunities for harvesting fuelwood, grazing, and cropping on riverine corridors and floodplains
- Biodiversity conservation (including protection of natural habitats, protected areas, and national parks)
- Flood protection
- Navigation routes
- Removal of wastes through biogeochemical processes
- Recreational opportunities

But the impacts of development on communities downstream are often diffuse, long term, poorly understood, and inadequately addressed. Assigning water between environmental flows and consumptive and non-consumptive purposes is a social, not just a technical, decision. However, to achieve equitable and sustainable outcomes, these decisions should be informed by scientific information and analysis. The causes of changes in river flow can also be broader than just the abstraction or storage of water and the regulation of flow by infrastructure; upstream land-use changes due to forestry, agriculture, and urbanization can also significantly affect flows. The impacts of environmental flow can extend beyond rivers to groundwater, estuaries, and even coastal areas.

CHAPTER IV

Results and Discussion

4.1 General Features of the Gorai River Flow

The river data had been analyzed using IHA software in two different ways, first is single period analysis and second as a two period analysis. For the Gorai river, the flow discharge data (1984 – 2016) has been collected from BWDB for two stations. The period has been taken as G1 period (1984-1999) and G2 period (2000-2016) for the IHA software analysis. The river characteristics of G1 are compared with G2. For further investigation of the flow data, annual flow have been categorized in three dispersed seasons subjected on the amount of mean monthly discharge. The seasons are categorized as high flow season (HFS) for the months of June to September, intermediate flow season (IFS) for October, November, April and May and low flow season (LFS) for the months of December to March. For investigation of flow data Range of Variability Approach (RVA) method is also used which offers a flow target that resembles the expected flow regime with the primary objective of protecting natural ecosystem (Mullick et al., 2010). The flow characteristics and RVA are analyzed by the IHA software.

In the LFS, the discharge is the lowest in the Gorai River system. By considering mean monthly annual flows of Gorai railway Bridge station, it is found that August has the highest discharge of 5089 Cumec as a single period analysis as shown in Table 4.1. For two period analyses, it is found 5633 Cumec for G1 period (1984-1999) and 4577 Cumec for G2 period (2000-2016) as shown in Table 4.2. Here the March is found to be the lowest flowing month having a discharge of 23.22 Cumec as a single period analysis and 11.26 Cumec for G1 period and 34.47 Cumec for G2 period.

On the other hand, in the mean monthly annual flows at Kamarkhali Transit station, August has the highest discharge of 3467 Cumec as a single period analysis as shown in Table 4.1. For two period analyses, it is found 3942 Cumec for G1 period (1984-1999) and 3159 Cumec for G2 period (2000-2016) as shown in Table 4.2. Here the March is found to be the lowest flowing month having a discharge of 14.05 Cumec as a single period analysis and 19.08 Cumec for G1 period and 10.8 Cumec for G2 period.

Some other general characteristics are also shown in Table 4.1 and 4.2. The mean annual flow for Gorai Railway Bridge is found as 1012 Cumec and for Kamarkhali transit 795 Cumec. The extreme lowest flowing season is found in March and highest flowing season found in August. For Gorai Railway Bridge station the low flow threshold estimated by IHA is 5.783 Cumec and high flow threshold is 1390

Table 4.1: General Characteristics of flows in Gorai Railway Bridge and Kamarkhali Transit stations as a single Period analysis

River Characteristics	Gorai railway bridge	Kamarkhali Transit
Period	**Total**	**Total**
Mean annual flow (Cumec)	1012	795.1
Annual C.V.	1.5	1.45
Flow predictability	0.46	0.48
Constancy/Predictability	0.29	0.29
% of flood in 60d period	0.88	0.91
Flood-free season	236	238
1-Day minimum flow	23.22	14.025
1-Day maximum flow	5089	3467
Base flow index	0.0348	0.0366
Rise rate	44.86	30.03
Fall rate	-33.93	-26.08
High flow threshold	1390	1128
Extreme low flow threshold	5.783	12.54

Table 4.2: General Characteristics of flows in Gorai Railway Bridge and Kamarkhali Transit stations as two period analyses

River Characteristics	Gorai railway bridge		Kamarkhali Transit	
Period	**G1**	**G2**	**G1**	**G2**
Mean annual flow (Cumec)	1086	942.6	888.7	734.5
Annual C.V.	1.55	1.42	1.54	1.34
Flow predictability	0.53	0.49	0.5	0.53
Constancy/Predictability	0.31	0.27	0.29	0.28
% of flood in 60d period	0.91	0.91	0.83	0.88
Flood-free season	253	247	252	270
1-Day minimum flow	11.26	34.47	19.08	10.8
1-Day maximum flow	5633	4577	3942	3159
Base flow index	0.0281	0.0413	0.0587	0.0223
Rise rate	53.93	36.86	34.6	27.34
Fall rate	-41.11	-27.18	-34.67	-20.52
High flow threshold	1593	1593	957	957
Extreme low flow threshold	1.36	1.36	17.55	17.55

Cumec. Whereas for Kamarkhali Transit station, the low flow threshold estimated by IHA is 12.54 Cumec and high flow threshold is 1128 Cumec. March is the lowest flowing month where flows are far lower than high flow threshold. The annual CV found for both the stations are nearly same; for Gorai Railway Bridge it is 1.5 and for Kamarkhali Transit station it is 1.45. The flow predictability is also nearly same as 0.46 and 0.48; the constancy/predictability is same for both as 0.29, percent of flood in 60 day period is found 0.88 for Gorai railway Bridge station and 0.91 for Kamarkhali Transit station. Flood free season is also nearly same 236 and 238; one day minimum flow is 23.22 for Gorai railway Bridge station and for Kamarkhali Transit station it is found 14.02. One day maximum flow for Gorai railway Bridge station is 5089 Cumec and Kamarkhali Transit station is 3467 Cumec, and rise rate is slightly higher for Gorai railway Bridge station (44.86) than the Kamarkhali Transit station is (30.03). The fall rate for Gorai railway Bridge station is 33.93 and for Kamarkhali Transit station is 26.08. The high flow threshold for the Gorai railway Bridge station is found as 1390 Cumec whereas for Kamarkhali Transit station it is found as 728 Cumec, this is lower than the Gorai railway Bridge station.

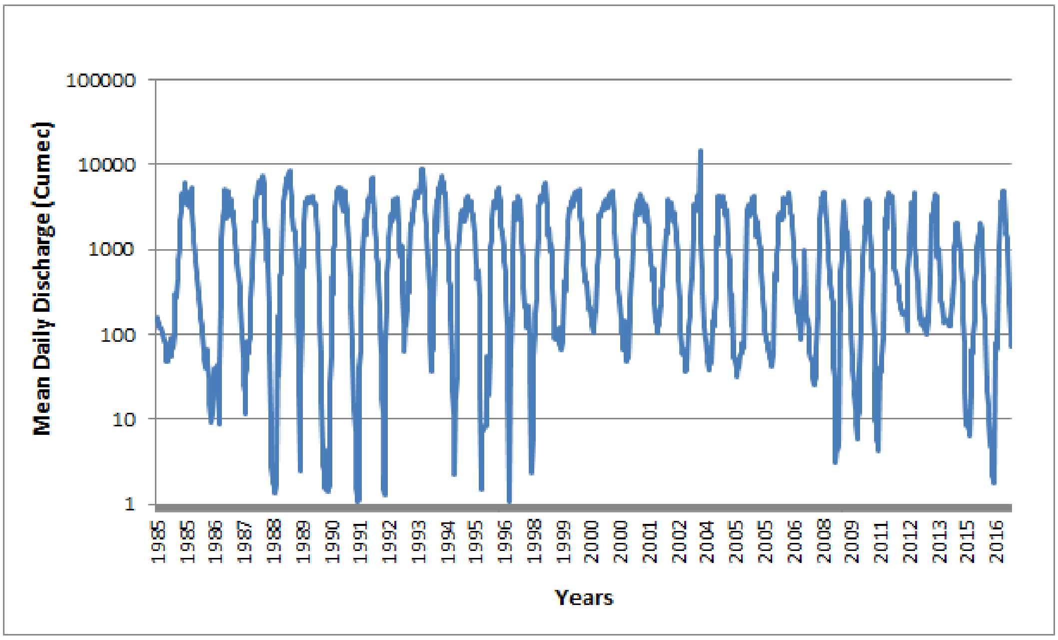

Figure 4.1: Daily Discharge Curve for Gorai Railway Bridge station of Gorai River

Figure 4.1 shows the Daily Discharge Curve for Gorai Railway Bridge station. For the years 1988, 1989, 1990, 1991, 1992, 1994, 1995, 1996, 1997, 1998, 2008, 2009, 2011, 2015 and 2016 the low flows are found lower than 10 Cumec.

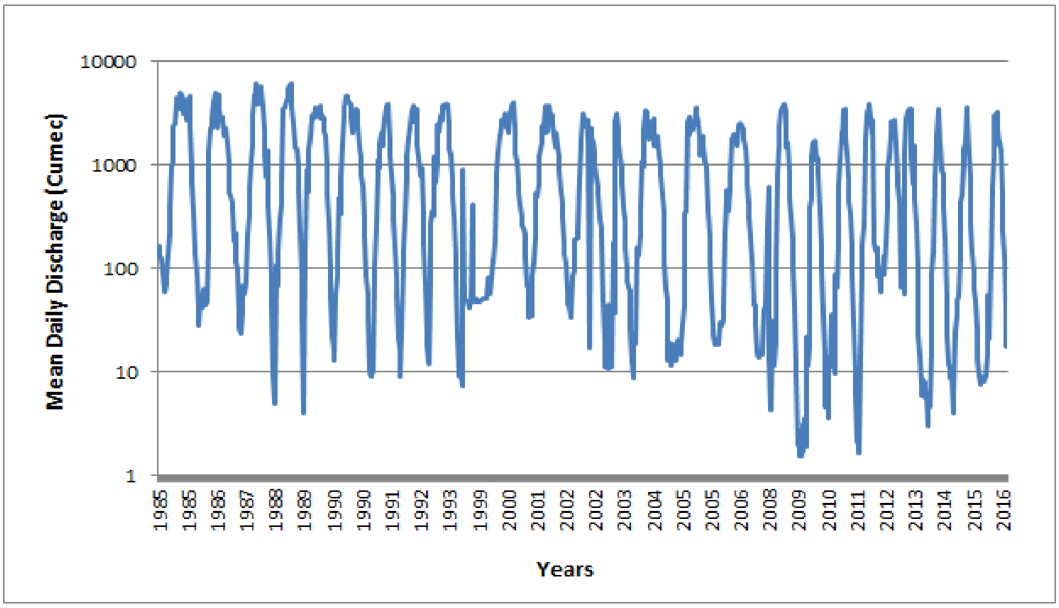

Figure 4.2: Daily Discharge Curve for Kamarkhali Transit station of Gorai River

Figure 4.2 shows the Daily Discharge Curve for Kamarkhali Transit station. For the years 1988, 1989, 1991, 1993, 1994, 2004, 2008, 2009, 2010, 2011, 2014, 2015 and 2016 the low flows are lower than 10 Cumec.

Table 4.3: Mean monthly flows for different flow season at Gorai railway bridge station

Month	Season	G1 period (1984-1999) Cumec	G2 period (2000-2016) Cumec	Total period (1984-2016) Cumec
April	IFS	37.18	70.55	54.37
May		54.06	106.6	81.13
June	HFS	290.8	441.4	368.4
July		2239	1942	2086
August		3972	2925	3432
September		3925	2831	3362
October	IFS	1686	1784	1736
November		464.6	580.6	524.3
December	LFS	141.5	253.3	199.1
January		59.97	150.6	106.7
February		42.17	86.5	65.01
March		34.89	68.49	52.2

Table 4.3 shows the mean monthly flows for Gorai railway bridge station. It shows that the flows in January to May are lower than 100 Cumec for G1 period (1984-1999) and the flows in February to April are lower than 100 Cumec for G2 period (2000-2016). Whereas for total period (1984-2016) analysis the flows in February to May are lower than 100 Cumec. According to Mullick (Mullick et al,. 2010) the flows in December to March are low flow seasons for Gorai railway bridge station. The flow values in June found slightly higher than 100 Cumec; and July to September flows are the high flow season. These mean monthly flows are higher for Gorai railway bridge station as HFS occurs in the month of June to September. The flow again starts decreasing in October and November. The Intermediate flow season occurs in the month of April, May, October and November.

It is found for Gorai railway bridge station that, mean monthly flows satisfies LFS in November to June months. Whereas July to October flows are the high flow seasons. It is also observed in Table 4.3 that the March is the lowest flowing month and the flow is 34.89 Cumec in G1 period (1984-1999), 68.49 Cumec in G2 period (2000-2016), and for total period (1984-2016) the March flow is 52.2 Cumec in Gorai railway Bridge station. August is the highest flowing month and the flow is 3972 Cumec in G1 period (1984-1999), 2925 Cumec in G2 period (2000-2016), and for total period (1984-2016) the August flow is 3432 Cumec in Gorai railway Bridge station. The mean monthly flows of Gorai railway bridge station shows that HFS duration is 4 months and LFS duration is 8 months. In the 8 months of LFS duration, the June, November and December flows can be considered as intermediate flow season as per the mean monthly flows.

Table 4.4: Mean monthly flows for different flow season at Kamarkhali Transit Station

Month	Season	G1 period (1984-1999)	G2 period (2000-2016)	Total period (1984-2016)
April	IFS	137.3	44.64	81.05
May		154.1	100.4	121.5
June	HFS	324.5	397.2	368.6
July		1741	1580	1643
August		3177	2460	2742
September		2923	2197	2483
October	IFS	1496	1201	1317
November		397.5	459.6	435.2
December	LFS	112.4	182	154.6
January		54.35	68.09	62.7
February		39	38.66	38.8
March		40.15	28.25	32.93

Table 4.4 shows the mean monthly flows of Kamarkhali Transit station. It shows that the flows in January to March are lower than 100 Cumec for G1 period (1984-1999) and the flows in January to April are lower than 100 Cumec for G2 period (2000-2016). Whereas for total period (1984-2016) analysis the flows in January to April are lower than 100 Cumec. According to Mullick (Mullick et al,. 2010) the flows in December to March are low flow seasons for Kamarkhali Transit station. The flow values in June found slightly higher than 100 Cumec; and July, August, September flows are the high flow season. These mean monthly flows are higher for Kamarkhali Transit station as HFS occurs in the month of June to September. The flow again starts decreasing in October and November. The Intermediate flow season occurs in the month of April, May, October and November.

It is found for Kamarkhali Transit station that, mean monthly flows satisfies LFS in November to June months. Whereas July to October flows are the high flow seasons. It is also observed in Table 4.4 that the March is the lowest flowing month and the flow is 40.15 Cumec in G1 period (1984-1999), 28.25 Cumec in G2 period (2000-2016), and for total period (1984-2016) the March flow is 32.93 Cumec in Kamarkhali Transit station. August is the highest flowing month and the flow is 3177 Cumec in G1 period (1984-1999), 2460 Cumec in G2 period (2000-2016), and for total period (1984-2016) the August flow is 2742 Cumec in Kamarkhali Transit station. The mean monthly flows of Kamarkhali Transit station shows that HFS duration is 4 months and LFS duration is 8 months. In the 8 months of LFS duration, the May, June, November and December flows can be considered as intermediate flow season as per the mean monthly flows.

The correlation between the magnitude and duration of tributary flows is presented by flow duration curve (FDC). The duration refers to the overall percentage of time that a specific flow is exceeded. FDCs are set environmental flow objectives. The X-axis represents the percentage of time that a particular flow value is equaled or exceeded. The Y-axis represents the quantity of flow at a given time in cubic meter per second (Cumec), associated with the duration. Flow duration intervals are expressed as percentage of exceedence, with zero corresponding to the highest stream discharge in the record (i.e. flood conditions) and 100 to the lowest (i.e. drought conditions).

Figure 4.3 shows the flow duration curve for Gorai railway bridge station as a single period (1984-2016). In this Figure it is found that, the 10% of time the flow exceeds the value 4000 Cumec flow and 20% of time it exceeds about 3000 Cumec and 30% of time the flow exceeds the value 2000 Cumec for the 50% of time it will be below the value of 500 Cumec flow and 90% time it will 20 Cumec. The flow duration curve is helpful to explain the overall natural condition of a river flow. For high Flow season EFR has been set at the 50^{th} percentile discharge and for low flow season EFR has been set at the 90^{th} percentile discharge of the flow duration curve.

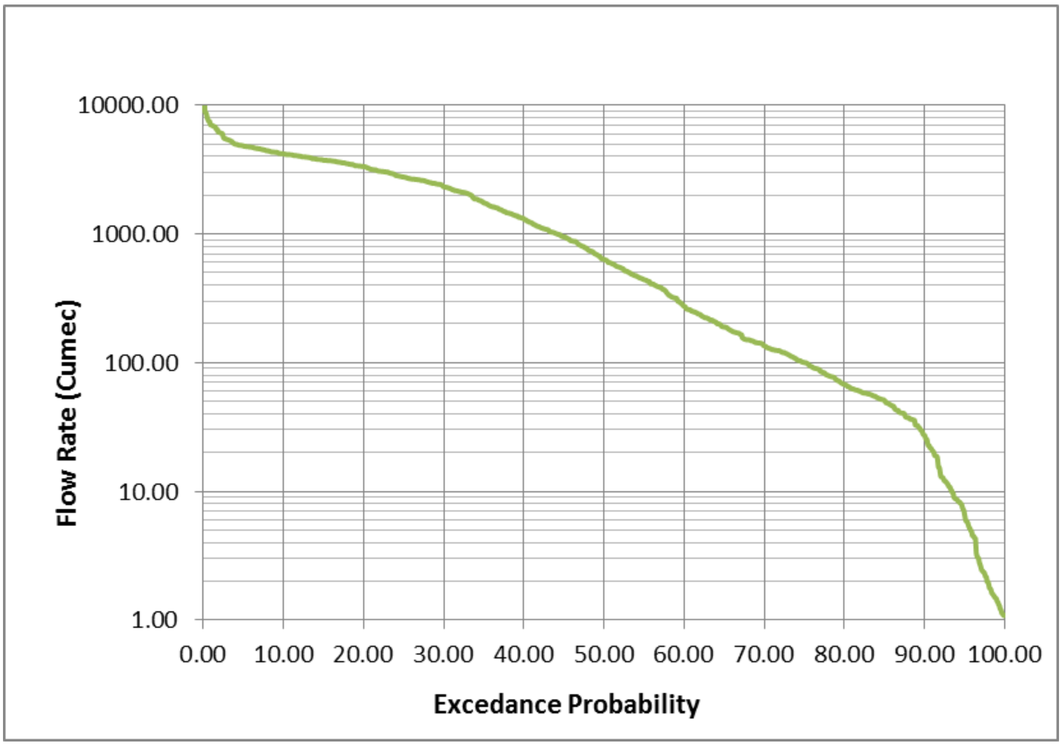

Figure 4.3: Flow Duration Curve for Gorai Railway Bridge station as a single period

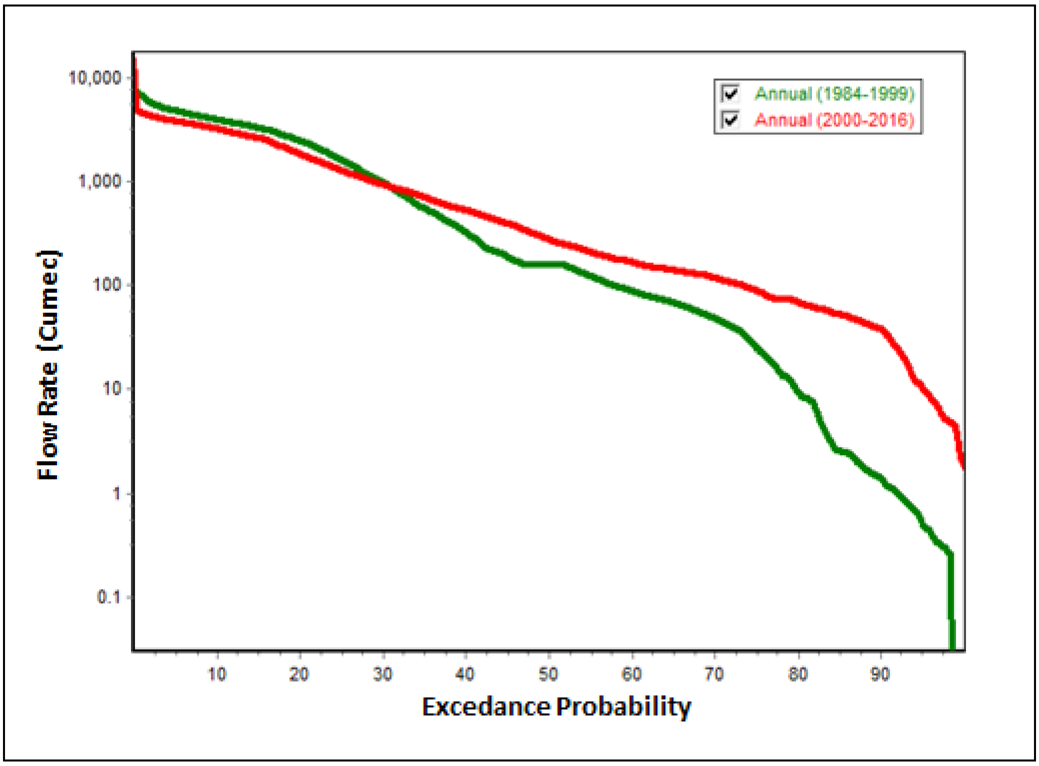

Figure 4.4: Flow Duration Curve for Gorai Railway Bridge station as two periods

Figure 4.4 shows the flow duration curve for Gorai railway bridge station as two periods, in G1 period (1984-1999) and in G2 period (2000-2016). In this Figure it is found that, the 10% of time the flow exceeds the value 4000 Cumec for G1 and G2 period, where G2 period flows is slightly lower. For 20% of time it exceeds about 3000 Cumec and 30% of time the flow exceeds the value 2000 Cumec. The Curve crosses each other at 30% point. For the 50% of time it will be below the value of 500 Cumec, where G1 period flows is slightly lower than G2 period flows. For 90% time the flow value is less than 10 Cumec.

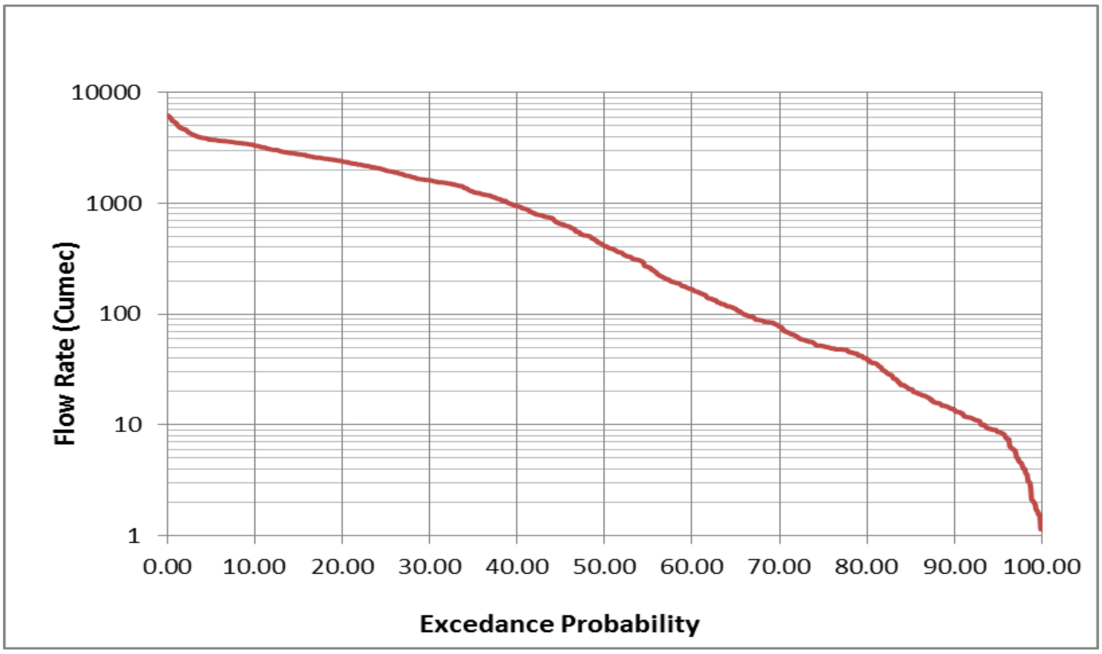

Figure 4.5: Flow Duration Curve for Kamarkhali Transit station as a single period

Figure 4.5 shows the flow duration curve for Kamarkhali Transit station as a single period (1984-2016). It is observed that 10% of time the flow will exceed 3000 Cumec and 20% of time it exceed about 2000 Cumec and 30% of time the flow below the value 2000 Cumec for the 50% of time it will be below the value of 600 Cumec flow and 90% time it will 20 Cumec.

Figure 4.6 shows the flow duration curve for Kamarkhali Transit station as two periods, in G1 period (1984-1999) and in G2 period (2000-2016). In this Figure it is found that, the 10% of time the flow exceeds the value 3000 Cumec for G1 and G2 period, where G2 period flows is slightly lower. For 20% of time it exceeds about 2000 Cumec and 30% of time the flow exceeds the value 2000 Cumec. The Curve crosses each other at 20%, 30% and 60% point. For the 50% of time it will be below the value of 600 Cumec, where G1 period flows is slightly lower than G2 period flows. For 90% time the flow value is less than 10 Cumec.

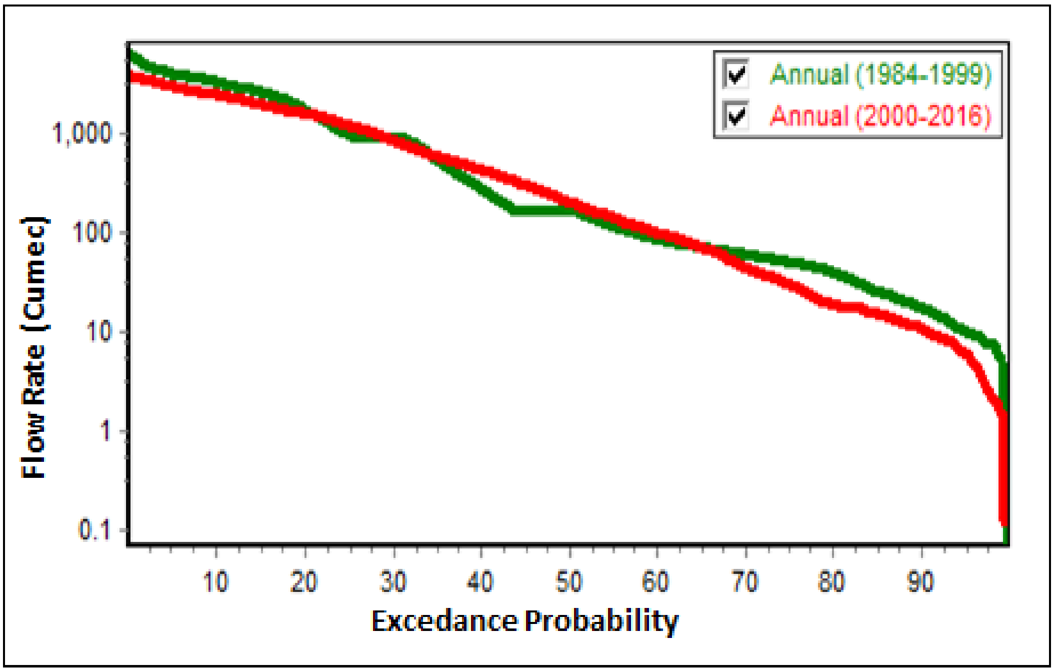

Figure 4.6: Flow Duration Curve for Kamarkhali Transit station as two periods

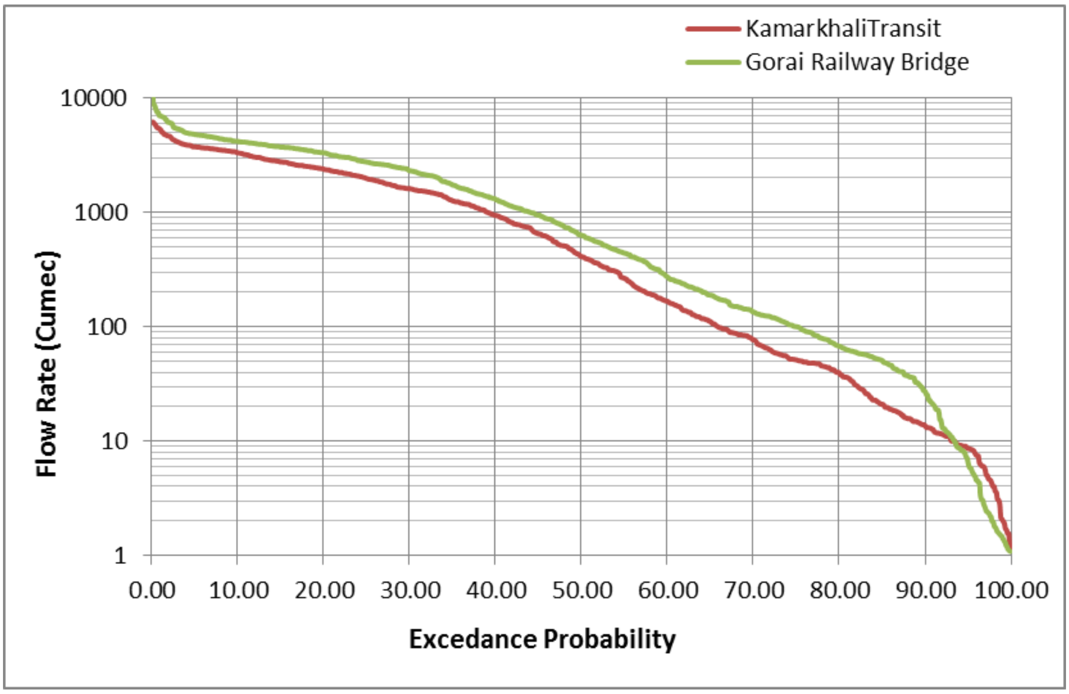

Figure 4.7: Comparison of Flow Duration Curve for Gorai Railway Bridge and Kamarkhali Transit stations

Figure 4.7 shows the comparison of flow duration curve for Gorai Railway Bridge and Kamarkhali Transit stations. From the Figure it is observed, for the Gorai railway bridge FDC values are higher than the Kamarkhali Transit station through all the years. The FDC values crosses the Gorai Railway Bridge when the value of flow is nearer to 10 Cumec and it occurs in 90% of time. The main reason of low flow is the less discharge from upstream. The flow values are lower than the minimum flow requirements for both the stations, which is dangerous for the aquatic ecosystem of the river.

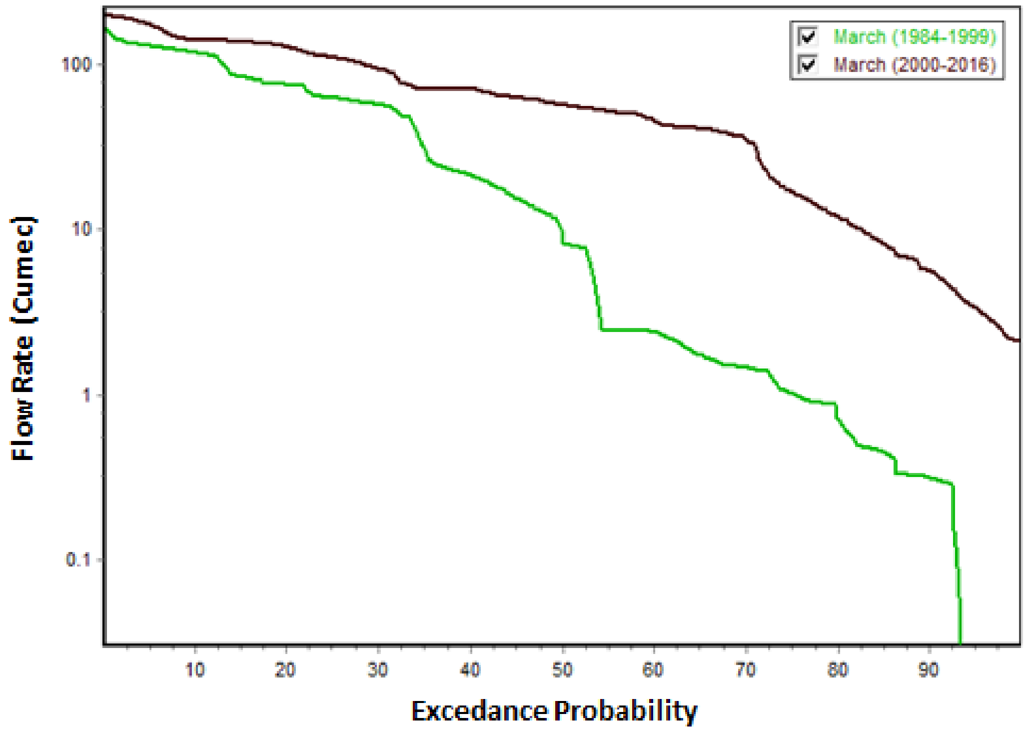

Figure 4.8: Monthly Flow Duration Curves for Gorai Railway Bridge station

Figure 4.8 shows the monthly flow duration curve for Gorai railway bridge station in the month of March as two periods, in G1 period (1984-1999) and in G2 period (2000-2016). The other months curve is attached in Appendix B. It is found that, the G2 period flows is higher than G1 period flows in the month of November to June. Again the G2 period flows is lower than G1 period flows in the month of July to October. The Curve crosses each other at 10% point in April, October and November, at 85% point in July, at 95% point in August and September.

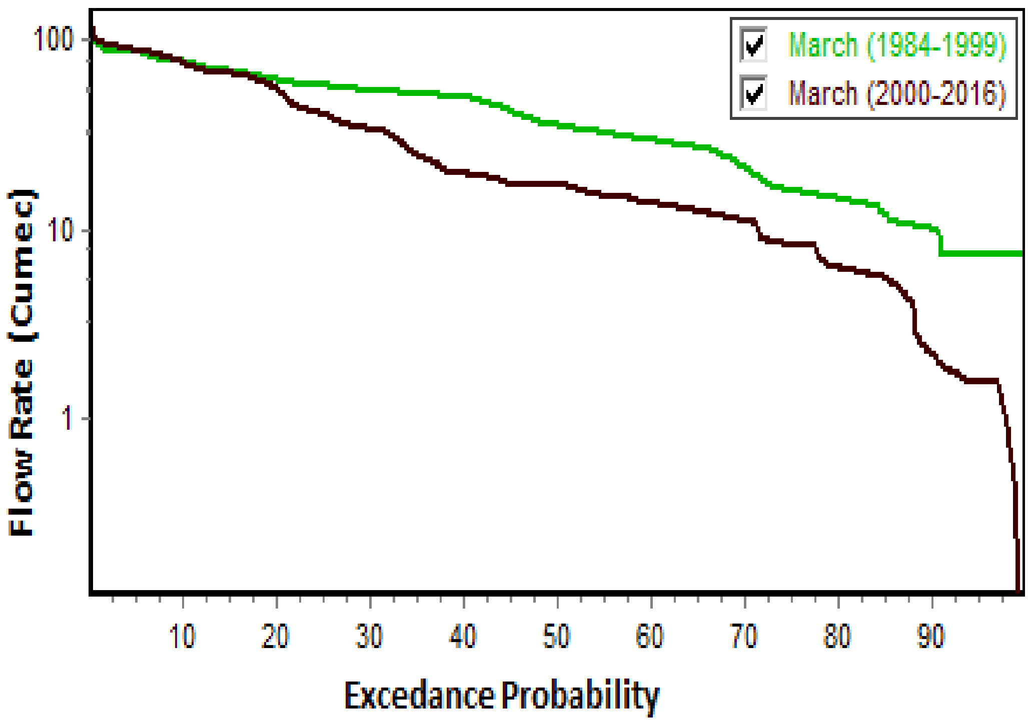

Figure 4.9: Monthly Flow Duration Curves for Kamarkhali Transit station

Figure 4.9 shows the monthly flow duration curve for Kamarkhali Transit station in the month of March as two periods, in G1 period (1984-1999) and in G2 period (2000-2016). The other months curve is attached in Appendix C. It is found that, the flows in G2 period are higher than G1 period in the month of November to January. Again the flows in G2 period are lower than G1 period in the month of February to May and August to October. The Curve crosses each other at 10% point in the months of March, May, June and November, at 20% point in the months of March, May, and November, at 80% point in the months of January and June to September.

4.2 Environmental Flow Constituents of the Gorai

EFC parameters are calculated by using IHA software and showed in Table 4.5 and Table 4.6. Low flow season is the main concern to assess the environmental flow considering environmental flow Constituents. Extreme low flow of the Gorai take place during the pre-monsoon period (at March) allowing to Julian date of peak flow for both stations. Again at August, during the monsoon period, highest peak take place for both stations. Low flow during pre-monsoon season could develop an unacceptable risk to the aquatic ecosystem of Gorai River.

Table 4.5: Environmental Flow Constituents and parameters of Gorai Railway Bridge and Kamarkhali Transit station (Considering median values)

Flow Description	Gorai railway bridge			Kamarkhali Transit		
Type #1: Monthly low flows	**G1**	**G2**	**Total**	**G1**	**G2**	**Total**
April Low Flow	33.49	51.5	54.26	46.6	32.05	37.55
May Low Flow	38.08	92.09	73.07	81.55	57.79	67.48
June Low Flow	197.2	248.7	236.4	203	216.9	217
July Low Flow	1200	1098	1055	790.3	698.2	844.3
August Low Flow	156	1245	1167	533.8	508.2	704.9
September Low Flow	803.1	1207	833.7	533.8	501.8	741.6
October Low Flow	1085	1037	989.1	768.5	748.3	825.1
November Low Flow	447.6	572.5	460.2	276.6	360.5	337
December Low Flow	89.58	226.9	195.9	61.87	113.6	108.7
January Low Flow	61.79	120.7	97.22	24.75	38.85	27.03
February Low Flow	47	79.8	75.82	41.77	62.09	41.77
March Low Flow	28.37	59.5	60.22	42.74	30.89	31.6
Type #2: Extreme low flows						
Extreme low peak	-	-	0.63	-	-	7.43
Extreme low duration	-	-	105	-	-	37
Extreme low timing	-	-	84	-	-	65
Type #3: High flow pulse						
High flow peak	4290	4521	4170	2520	3402	2613
High flow duration	92	80	88	56.5	96	74.5
High flow timing	241.5	247	245	246	244	242
High flow rise rate	66.57	57.93	55.42	72.79	45.8	46.78
High flow fall rate	-73.8	-63.75	-60.27	-63.7	-52.44	-52.4
Type #4: Small Flood						
Small Flood peak	-	-	5315	-	-	3895
Small Flood duration	-	-	104	-	-	113.5
Small Flood timing	-	-	248	-	-	244.5
Small Flood rise rate	-	-	73.66	-	-	52
Small Flood fall rate	-	-	-105.3	-	-	-63.72
Type #5: Large flood						
Large flood peak	-	-	8880	-	-	6130
Large flood duration	-	-	116	-	-	100.5
Large flood timing	-	-	266	-	-	241.5
Large flood rise rate	-	-	118.5	-	-	101.4
Large flood fall rate	-	-	-209.4	-	-	-104.6

Table 4.6: Environmental Flow Constituents and parameters of Gorai Railway Bridge and Kamarkhali Transit station (Considering mean values)

Flow Description	Gorai railway bridge			Kamarkhali Transit		
Type #1: Monthly low flows	**G1**	**G2**	**Total**	**G1**	**G2**	**Total**
April Low Flow	49.58	70.55	69.41	137.4	60.01	91.26
May Low Flow	59.42	106.6	87.85	154.1	105.5	123.5
June Low Flow	292.8	401.8	343.7	300.4	349.9	347.6
July Low Flow	1081	1080	988.6	685.1	660.5	790.3
August Low Flow	156	1182	934.3	533.8	508.2	664.7
September Low Flow	803.1	1227	796.1	533.8	632.6	689.3
October Low Flow	1031	1010	945.5	708	753.8	804.2
November Low Flow	452.4	549	498.1	356.5	395.9	409.8
December Low Flow	141.5	253.3	199.4	113.7	178.8	155.1
January Low Flow	68.58	150.6	117.9	58.15	79.94	66.77
February Low Flow	52.04	86.5	82.78	57.84	66.28	54.62
March Low Flow	46.51	68.49	68.87	47.92	42.32	40.02
Type #2: Extreme low flows						
Extreme low peak	-	-	1.353	-	-	6.73
Extreme low duration	-	-	98.41	-	-	45.56
Extreme low timing	-	-	76.64	-	-	72.4
Type #3: High flow pulse						
High flow peak	3859	3924	3616	2506	3130	2535
High flow duration	70.7	73.83	73.8	53.3	97.93	64.79
High flow timing	247.7	246.1	246.4	240.9	245.2	241.7
High flow rise rate	76.5	78.83	75	72.61	56.98	68.1
High flow fall rate	-95.95	-99.69	-91.28	-61.95	-57.77	-60.24
Type #4: Small Flood						
Small Flood peak	-	-	5687	-	-	4097
Small Flood duration	-	-	105.5	-	-	108.6
Small Flood timing	-	-	247.8	-	-	244.1
Small Flood rise rate	-	-	76.97	-	-	60.67
Small Flood fall rate	-	-	-118.7	-	-	-68.55
Type #5: Large flood						
Large flood peak	-	-	10700	-	-	6130
Large flood duration	-	-	114.7	-	-	100.5
Large flood timing	-	-	269.7	-	-	241.5
Large flood rise rate	-	-	112.2	-	-	101.4
Large flood fall rate	-	-	-424.6	-	-	-104.6

Table 4.5 shows environmental flow constituent and parameters of Gorai Railway Bridge and Kamarkhali Transit considering median values. It can be observed from the type-1 parameters for monthly low flows, that the lowest flowing season is the March and the low flow for Gorai Railway Bridge is 28.37 Cumec and for Kamarkhali Transit station it is 30.89 Cumec. It is observed that the low flow starts increasing in June at both stations. The maximum flow observed in August as 1245 Cumec for Gorai Railway Bridge and for Kamarkhali Transit station it is found in July as 790.3 Cumec. Type-2 parameter shows extreme low flow duration, timing and frequency. Type-3 shows the high flow pulse. It is found that peak high flow is 4521 for Gorai Railway Bridge and for Kamarkhali Transit station peak high flow is found as 3402 Cumec. The high flow Rise rate is observed as 66.57 for Gorai Railway Bridge and for Kamarkhali Transit station it is observed as 72.79 Cumec. The high flow fall rate is observed as -73.8 for Gorai Railway Bridge and for Kamarkhali Transit station it is found as -63.7 Cumec. Type-4 parameter is small flood; the small flood peak is found as 7020 Cumec for Gorai Railway Bridge and for Kamarkhali Transit station is 5020 Cumec. Type-5 parameter is large flood; the peak found for Gorai Railway Bridge is as 14720 and for Kamarkhali it is observed as 6210 Cumec.

Table 4.6 shows environmental flow constituent and parameters of gorai Railway Bridge and Kamarkhali Transit considering mean values. It can be observed from the type-1 parameters for monthly low flows, that the lowest flowing season is the March and the low flow for Gorai Railway Bridge is 46.51 Cumec and for Kamarkhali Transit station it is 42.32 Cumec. It is observed that the low flow starts increasing in June at both stations. The maximum flow observed in September as 1227 Cumec for Gorai Railway Bridge and for Kamarkhali Transit station it is found in October as 753.8 Cumec. Type-2 parameter shows extreme low flow duration, timing and frequency.Type-3 shows the high flow pulse. It is found that peak high flow is 3924 for Gorai Railway Bridge and for Kamarkhali Transit station peak high flow is found as 3130 Cumec. The high flow Rise rate is observed as 78.83 for Gorai Railway Bridge and for Kamarkhali Transit station it is observed as 72.61. The high flow fall rate is observed as -99.69 for Gorai Railway Bridge and for Kamarkhali Transit station it is found as -61.95. Type-4 parameter is small flood; the small flood peak is found as 6898 for Gorai Railway Bridge and for Kamarkhali Transit station as 4946 Cumec. Type-5 parameter is large flood; the peak found for Gorai Railway Bridge is as 14720 Cumec and for Kamarkhali Transit station it is observed as 6210 Cumec.

4.3 Environmental Flow Requirement of Gorai River

The Environmental Flow Requirement of Gorai River is calculated in three different methods. The estimation of flows is describes as follows.

4.3.1 Mean annual flow (MAF) method

Table 4.3 and Table 4.4 shows summary of Mean monthly flows at low flow season (LFS), Intermediate flow season (IFS) and high flow season (HFS). It is observed that the lowest flow of Gorai Railway bridge station occurs in March as 34.89 Cumec in G1 period; and for Kamarkhali it is also observed in the March that is 28.25 Cumec in G2 period. The highest flow occurs for Gorai railway bridge Station in the month of August as 3972 Cumec in G1 period and for the kamarkhali station it is observed as 3177 Cumec in G1 period in the month of August as well.

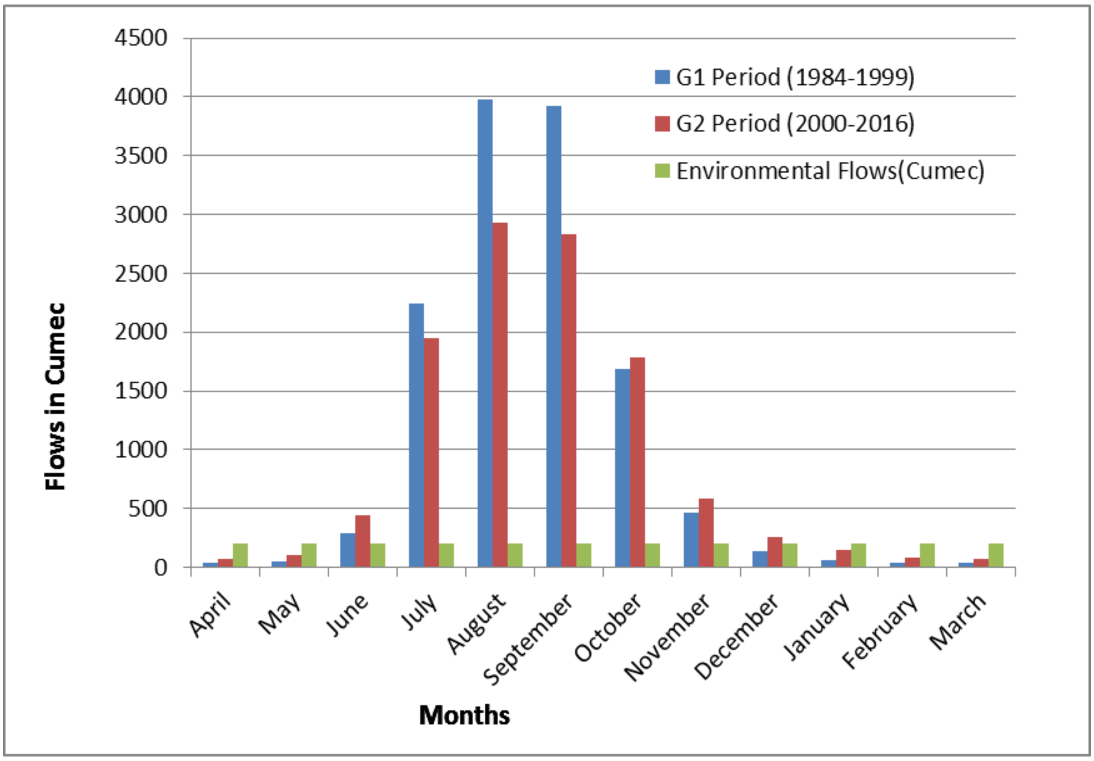

Figure 4.10: Comparison of Mean Monthly Flows with EFR in MAF method at Gorai Railway Bridge station

According to MAF method, November to June is found as the low flow season (LFS) in both the stations. Whereas the high flow season (HFS) According to MAF method are July to October in both the stations. The June and November are the month of Intermediate flow seasons (IFS) or flow transition season in both the stations. In these months the flows are changing their patterns. The high flow comes to decrease at the month of November after which low flow season starts. Whereas low flow comes to increase at the month of April and May after which high flow season settles. It is observed that the flow in pre-monsoon starts increasing in June. The peak highest flow is found in monsoon period in the month of August, and then it again starts decreasing in the month of October. After the monsoon, the flow comes to a minimum level in the month of March.

Figure.4.10 describes the Comparison of Mean Monthly Flows with EFR in MAF method at Gorai Railway Bridge station. Table 4.1 shows that, Mean annual flow of Gorai Railway Bridge station is 1012 Cumec during 1984 to 2016. The EFR value in MAF method for Gorai Railway Bridge is found as 202.4 Cumec. Mean monthly flows for April and May are lower than the environment flow required but the flows in June to November are more than the EFR by mean annual flow method. Again the flows in December to March are less than the required EFR value by mean annual flow method. Generally high flow seasons satisfies the EFR required flow but the flows in low flow seasons are normally less than the EFR by MAF method.

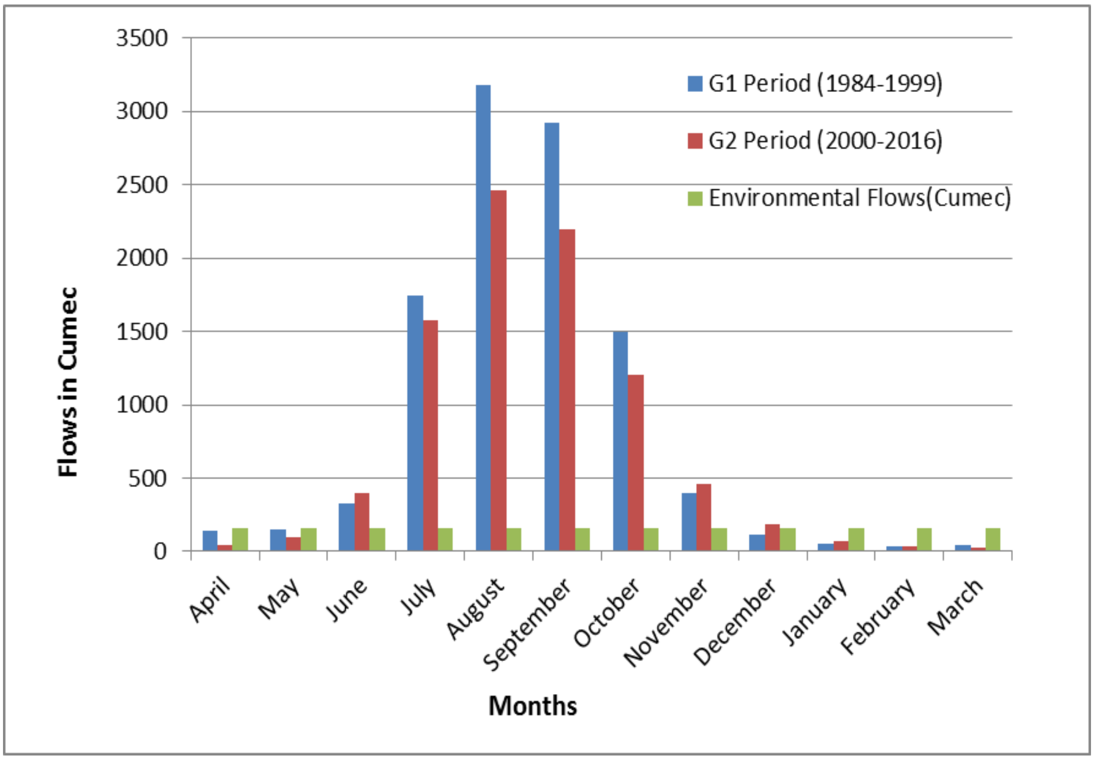

Figure 4.11: Comparison of Mean Monthly Flows with EFR in MAF method at Kamarkhali Transit station

Figure 4.11 describes the Comparison of Mean Monthly Flows with EFR in MAF method at Kamarkhali transit station. Mean annual flow of Kamarkhali transit station is 795.1 Cumec during 1984 to 2016. According to habitant quality, environmental flow requirement in MAF is found as 159.02 Cumec for kamarkhali transit station. Mean monthly flows for April and May are lower than the environment flow required but the flows in June to November are more than the

EFR by mean annual flow method. Again the flows in December to March are less than the required EFR value by mean annual flow method. Generally high flow seasons satisfies the EFR required flow but the flows in low flow seasons are normally less than the EFR by MAF method.

4.3.2 Flow Duration Curve (FDC) method

Table 4.7 shows summary for FDC values at different flow seasons. For the EFR in low flow season, this FDC values are taken at 90% value, for Intermediate flow season this FDC values are taken at 50% value and for high flow season it is taken 50% values of FDC. The lowest flow of Gorai Railway bridge station in FDC method is found in March as 127.1 Cumec in G1 period; and for Kamarkhali Transit station it is also observed in March flow that is 83.8 Cumec in G1 period. The highest flow occurs for Gorai Station in the month of August is 4051 Cumec in G1 period and for the kamarkhali station it is observed 3743 Cumec in G1 period in the month of August as well.

Table 4.7: Percentile flow of monthly FDC (90% for LFS and 50% for IFS and HFS)

Months	Season	Gorai railway bridge			Kamarkhali Transit		
		G1 (1984-1999)	G2 (2000-2016)	Total (1984-2016)	G1 (1984-1999)	G2 (2000-2016)	Total (1984-2016)
April	IFS	9.589	51.5	44.27	46.6	16.13	33.98
May		31.51	92.09	66.53	81.55	50.24	59.73
June	HFS	197.2	273	246.9	217	216.9	217
July		2517	2107	2247	1720	1597	1717
August		4051	3037	3516	3743	2366	2564
September		3785	3195	3529	2866	2444	2581
October	IFS	1481	1404	1438	1290	1124	1132
November		447.6	572.5	473.9	276.6	381.9	337
December	LFS	369.4	514.2	395.2	273.2	394.1	281.5
January		164.2	395.2	260.1	153.3	182.3	180.6
February		132.4	189.7	167	116.5	129.2	124.4
March		127.1	150.6	134.4	83.8	83.81	83.29

According to FDC method, November to June is found as the low flow season (LFS) in both the stations. Whereas the high flow season (HFS) According to FDC method are July to October in both the stations. The June, November and December are the month of Intermediate flow seasons (IFS) or flow transition season in both the stations. In these months the flows are changing its patterns. The high flow comes to decrease at the month of November after which low flow season starts. Whereas low flow comes to increase at the month of April and May after which high flow season settles. It is observed that the flow in pre-monsoon starts increasing in June. The peak highest flow is found in monsoon period in the month of August, and then it again starts decreasing in the month of October. After the monsoon, the flow comes to a minimum level in the month of March.

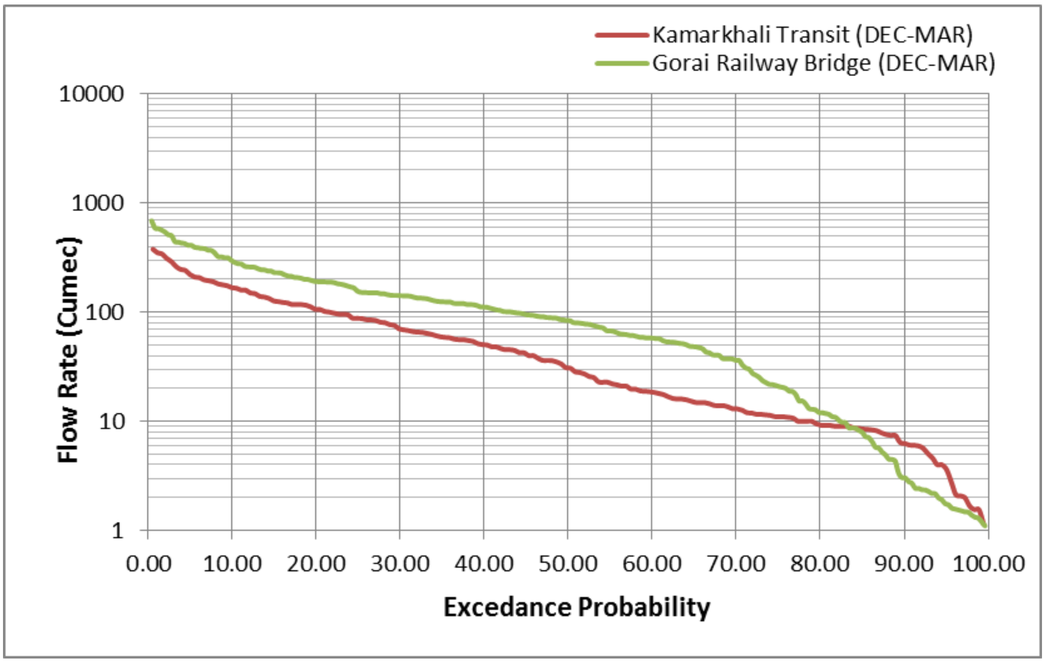

Figure 4.12: Flow Duration Curve at LFS for Gorai Railway Bridge and Kamarkhali Transit stations

Figure 4.12 shows the Flow Duration Curve for Gorai Railway Bridge and Kamarkhali Transit stations at LFS. From the Figure it is observed, for the Gorai railway bridge FDC values are higher than the Kamarkhali Transit stations FDC values through all the years. The FDC values crosses the Gorai Railway Bridge when the value of flow is nearer to 10 Cumec and it occurs at 83% of exceedence probability. According to FDC method the LFS requires 90^{th} percentile flow as EFR. The 90^{th} Percentile value on FDC for Gorai Railway Bridge station flow is found as 290 Cumec and the 90^{th} Percentile value on FDC for Kamarkhali transit station flow is found as 167 Cumec.

Figure 4.13 shows the Flow Duration Curve for Gorai Railway Bridge and Kamarkhali Transit stations at IFS. From the Figure it is observed, for the gorai railway bridge FDC values are higher than the Kamarkhali Transit stations FDC values through all the years. The FDC values crosses the Gorai Railway Bridge when the value of flow is nearer to 18 Cumec and it occurs at 90% of exceedance probability. According to FDC method the IFS requires 50^{th} percentile flow as EFR. The 50^{th} Percentile value on FDC for Gorai Railway Bridge station flow is found as

455 Cumec and the 50th Percentile value on FDC for Kamarkhali transit station flow is found as 315 Cumec.

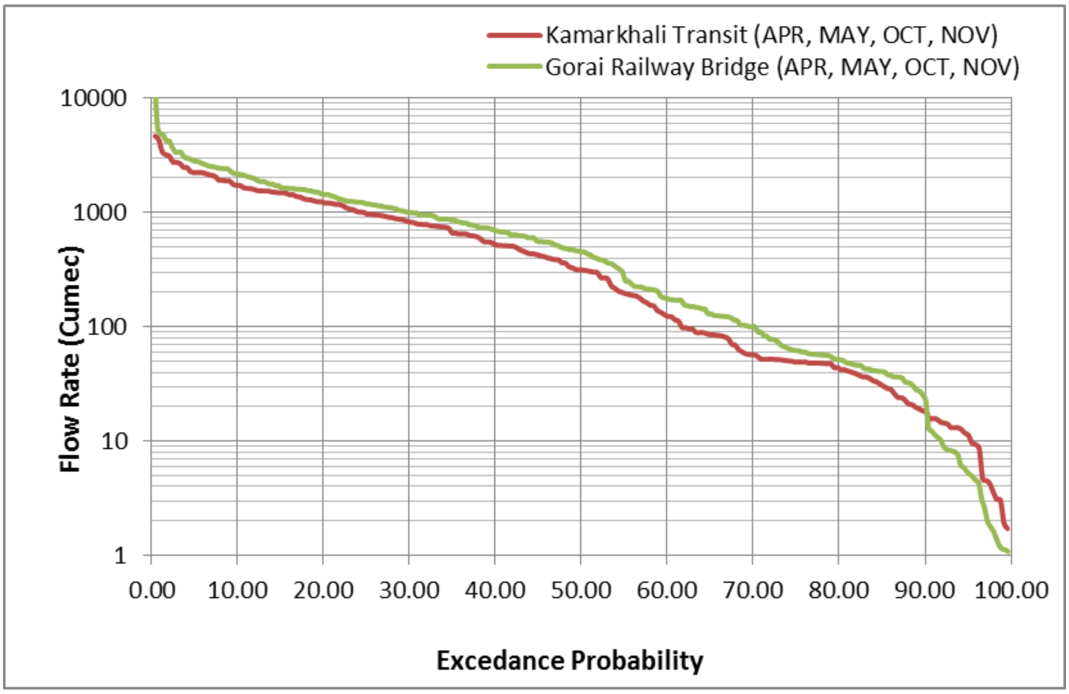

Figure 4.13: Flow Duration Curve at IFS for Gorai Railway Bridge and Kamarkhali Transit stations

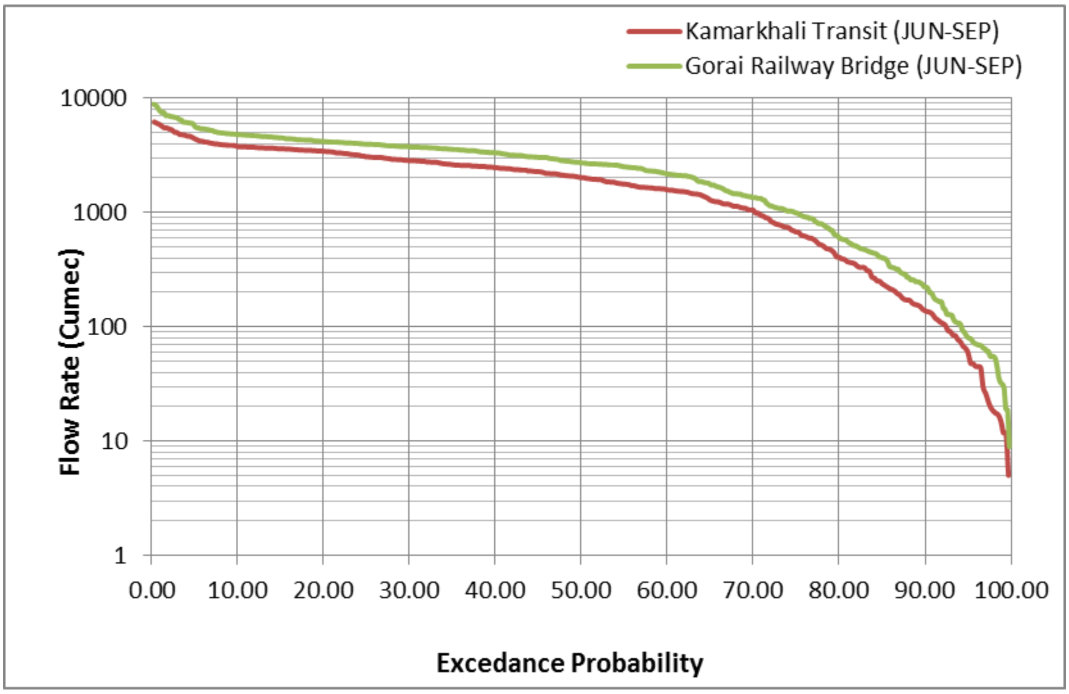

Figure 4.14: Flow Duration Curve at HFS for Gorai Railway Bridge and Kamarkhali Transit stations

Figure 4.14 shows the Flow Duration Curve for Gorai Railway Bridge and Kamarkhali Transit stations at HFS. From the Figure it is observed, for the gorai railway bridge FDC values are higher than the Kamarkhali Transit stations FDC values through all the years. According to FDC method the HFS requires 50th percentile flow as EFR. The 50th Percentile value on FDC for Gorai Railway Bridge station flow is found as 2715 Cumec and the 50th Percentile value on FDC for Kamarkhali transit station flow is found as 2026 Cumec.

Table 4.8: Environmental flow Requirements based on FDC method

Flow season	**Percentile value on FDC**	**Gorai Railway Bridge station Flow (Cumec)**	**Kamarkhali transit station Flow (Cumec)**
High Flow	50th	2715	2026
Intermediate Flow	50th	455	315
Low Flow	90th	290	167

Table 4.8 shows the environmental flow requirement for the Gorai Railway Bridge station and Kamarkhali transit station based on FDC method. In case of Bangladesh Mullick et al. (2010), Hossain and Hosasin (2011) and Rahman et al. (2013) have used 90% (or 90th percentile) for low flow season and 50% (or 50th percentile) for Intermediate and high flow season to calculate environmental flow requirement of Teesta, Dudhkumar and Turag River respectively.

Figure 4.15A, Figure 4.15B and Figure 4.15C describes the Comparison of Mean Monthly Flows with EFR in FDC method at LFS, IFS and HFS respectively at Gorai Railway Bridge station. EFR in FDC method at LFS, IFS and HFS is found as 290 Cumec, 455 Cumec and 2715 Cumec respectively at Gorai Railway Bridge station. The low flow season is the main concern to estimate the EFR of a river flow. The EFR value in FDC method for Gorai Railway Bridge station is taken as 290 Cumec. For this flow in the month of April and May the mean monthly flows are lower than the environment flow required but in June to November the flows are more than the EFR in FDC method. Therefore although the high flow season satisfies the flow required, the low flow season does not support this. Basically the flows in June and November are intermediate flow season where the flow season changes. Again the flows in December to March are less than the required EFR value in FDC method. Generally high flow seasons satisfy the EFR required flow but the low flow seasons are normally less than the EFR flow.

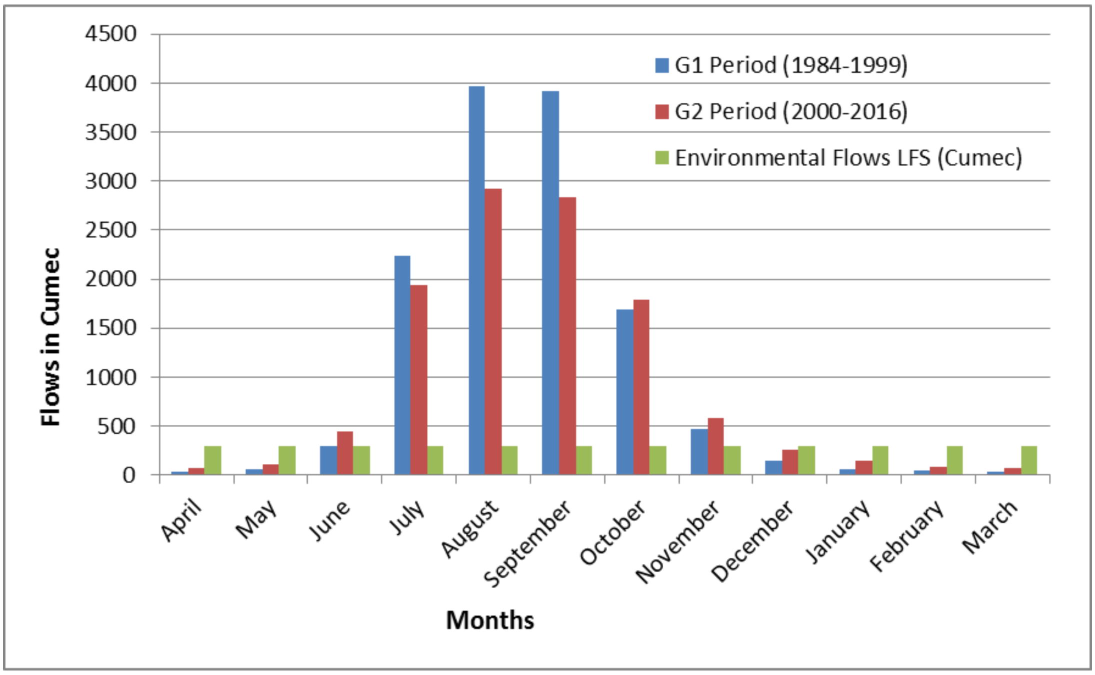

Figure 4.15A: Comparison of Mean Monthly Flows with EFR of LFS in FDC method at Gorai Railway Bridge Station

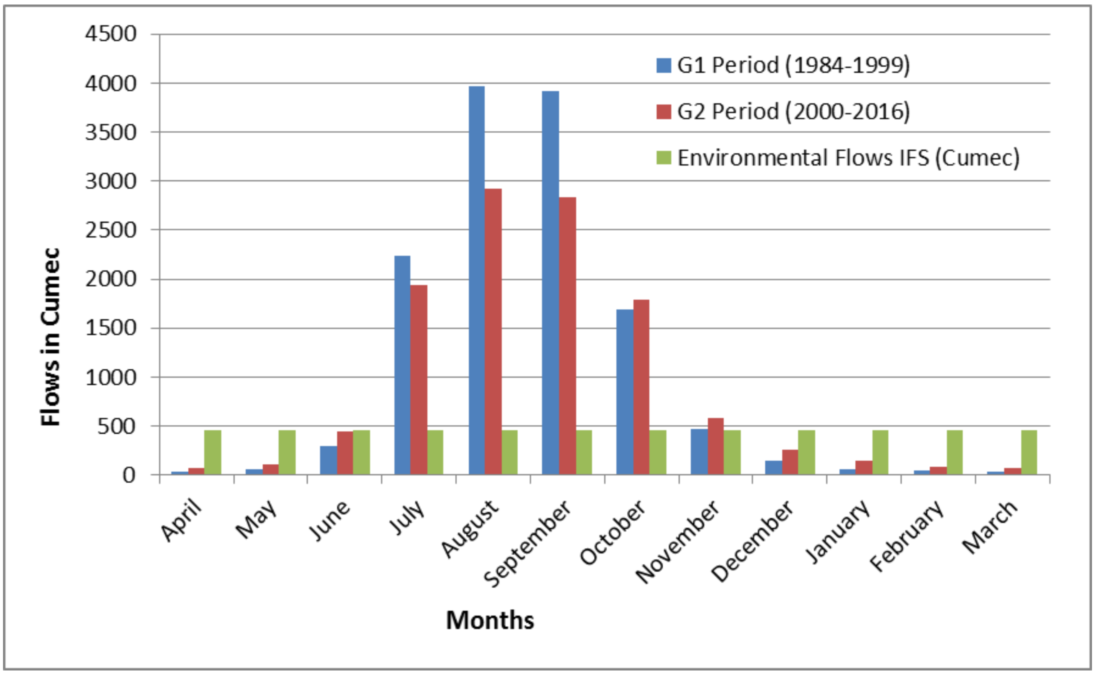

Figure 4.15B: Comparison of Mean Monthly Flows with EFR of IFS in FDC method at Gorai Railway Bridge Station

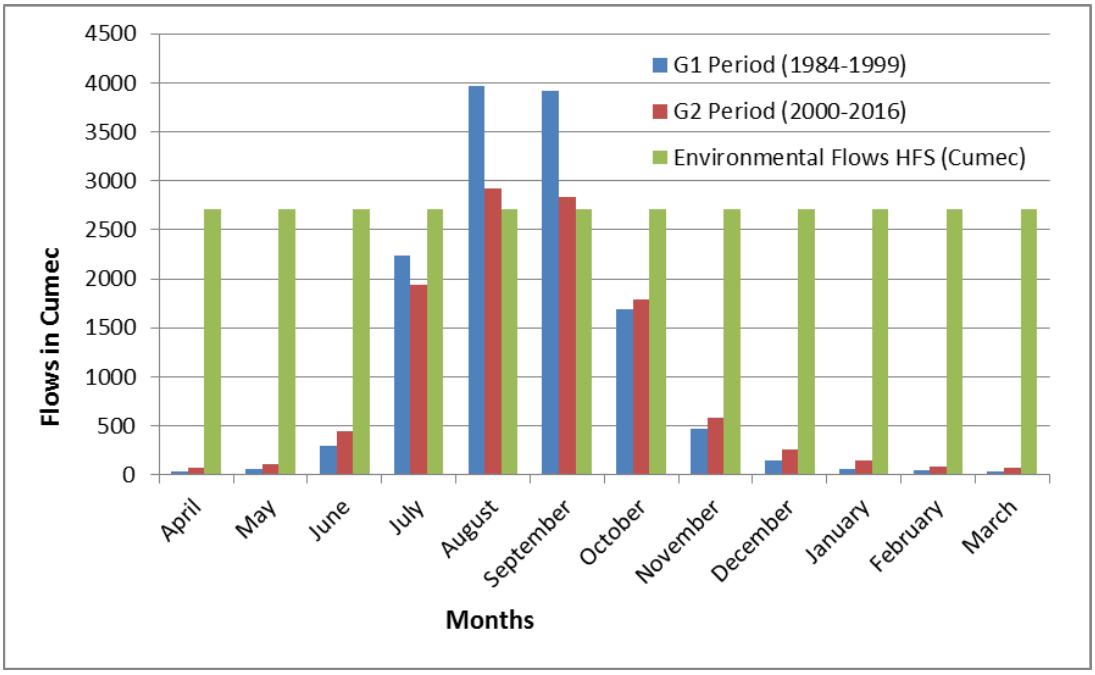

Figure 4.15C: Comparison of Mean Monthly Flows with EFR of HFS in FDC method at Gorai Railway Bridge Station

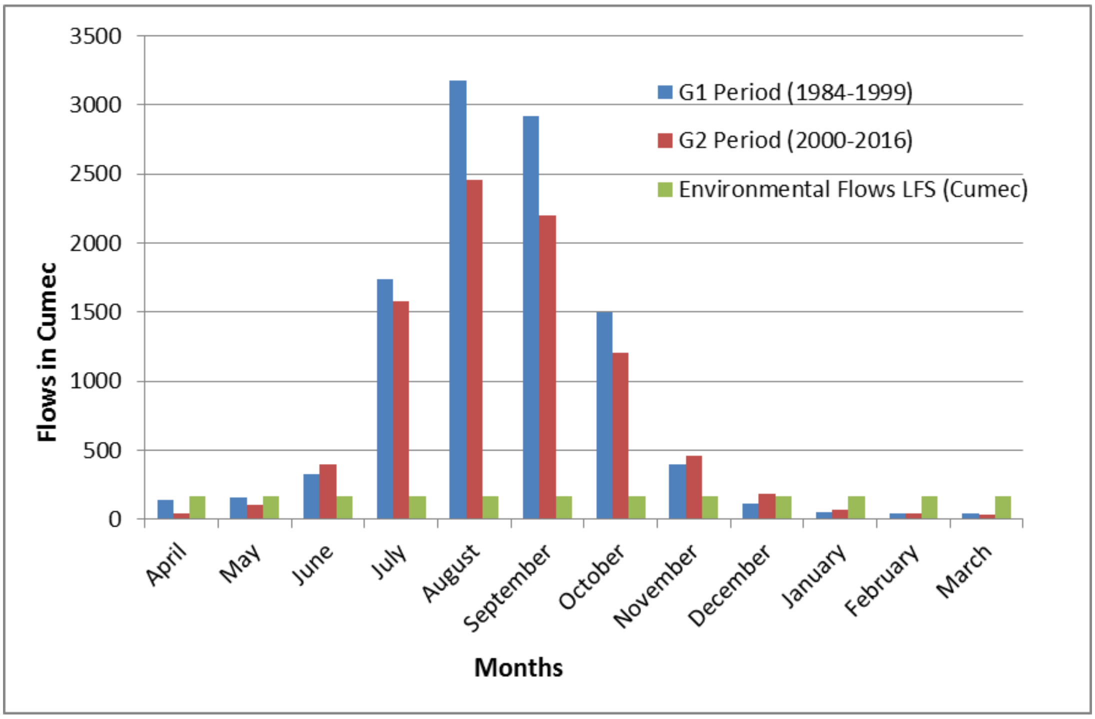

Figure 4.16A: Comparison of Mean Monthly Flows with EFR of LFS in FDC method at Kamarkhali Transit Station

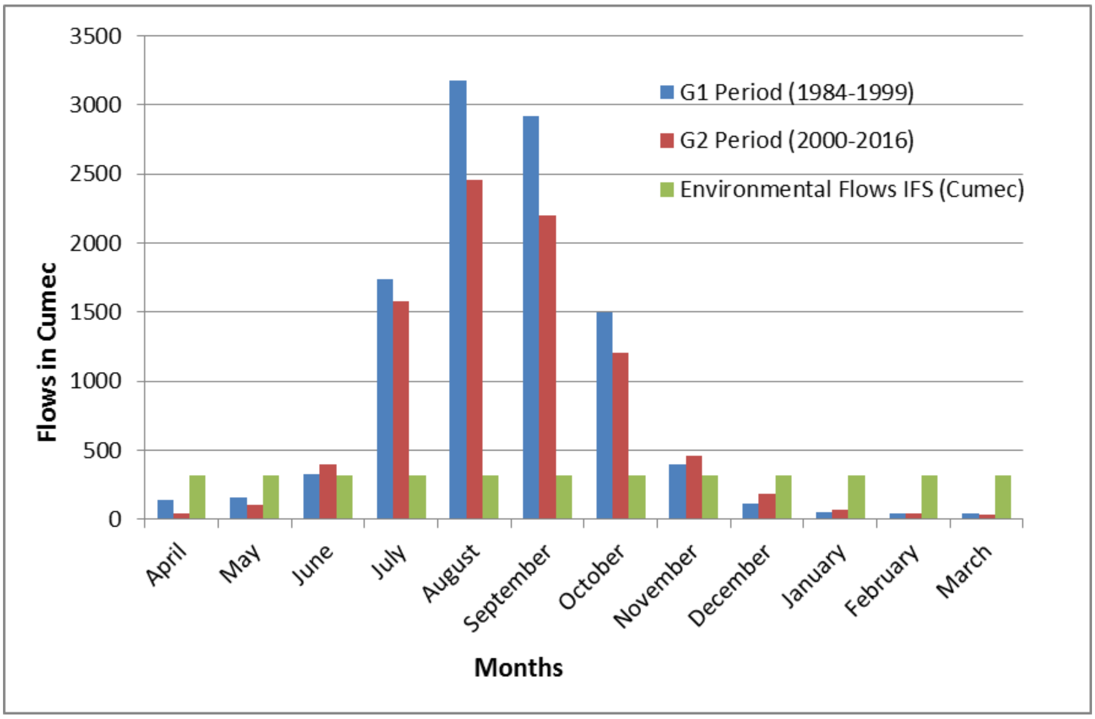

Figure 4.16B: Comparison of Mean Monthly Flows with EFR of IFS in FDC method at Kamarkhali Transit Station

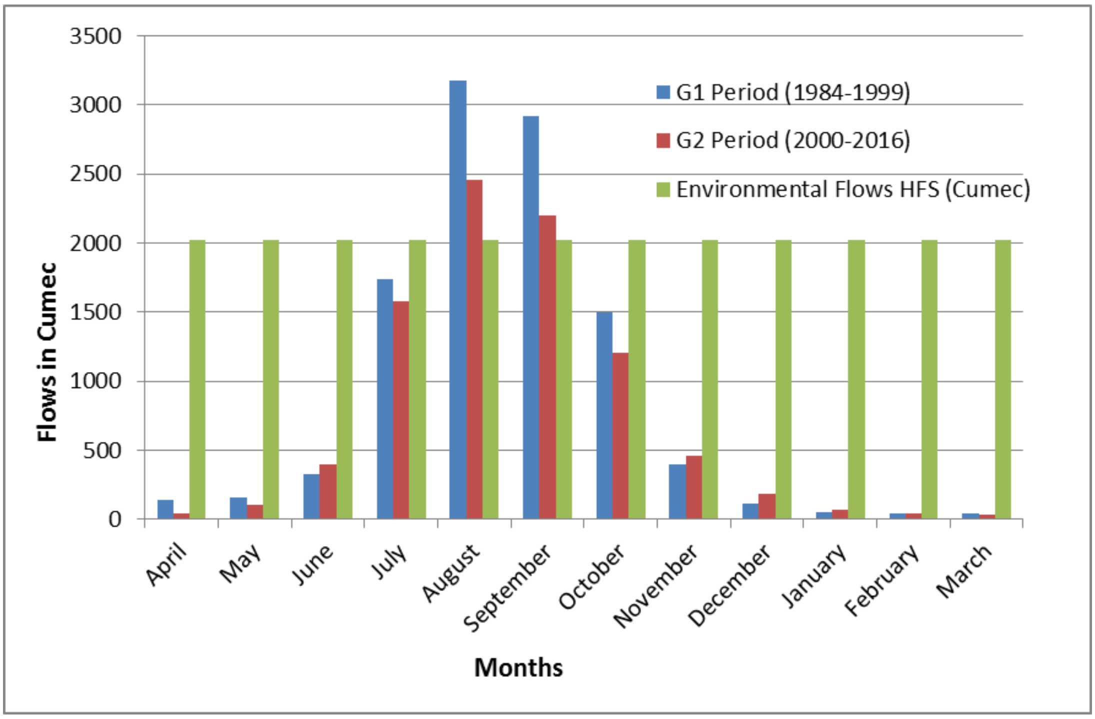

Figure 4.16C: Comparison of Mean Monthly Flows with EFR of HFS in FDC method at Kamarkhali Transit Station

Figure 4.16A, Figure 4.16B and Figure 4.16C describes the Comparison of Mean Monthly Flows with EFR in FDC method at LFS, IFS and HFS respectively at

Kamarkhali transit station. EFR in FDC method at LFS, IFS and HFS is found as 167 Cumec, 315 Cumec and 2026 Cumec respectively at Kamarkhali Transit station. The low flow season is the main concern to estimate the EFR of a river flow. The EFR value in FDC method for Kamarkhali transit station is found as 167 Cumec. For this flow in the month of April and May the mean monthly flows are lower than the environment flow required but in June to November the flows are more than the EFR in FDC method. Therefore although the high flow season satisfies the flow required, the low flow season does not support this. Basically the flows in June and November are intermediate flow season where the flow season changes. Again the flows in December to March are less than the required EFR value in FDC method. Generally high flow seasons satisfy the EFR required flow but the low flow seasons are normally less than the EFR flow.

4.3.3 Constant Yield (CY) method

Table 4.9 shows summary for Constant Yield at low flow season (LFS) Intermediate flow season (IFS) and high flow season (HFS). It is observed that the lowest flow of Gorai Railway bridge station occurs in February as 3.073 Cumec in G1 period; and for Kamarkhali it is found in the month of March as 15.29 Cumec in G2 period. The highest flow occurs for Gorai railway bridge Station in the month of August as 4051 Cumec in G1 period and for the kamarkhali station it is observed as 3743 Cumec in G1 period in the month of August as well.

Table 4.9: Summary of Constant Yield at LFS, IFS and HFS

Months	Season	Gorai railway bridge			Kamarkhali Transit		
		G1 (1984-1999)	G2 (2000-2016)	Total (1984-2016)	G1 (1984-1999)	G2 (2000-2016)	Total (1984-2016)
April	IFS	9.589	51.5	44.27	46.6	16.13	33.98
May		31.51	92.09	66.53	81.55	50.24	59.73
June	HFS	197.2	273	246.9	217	216.9	217
July		2517	2107	2247	1720	1597	1717
August		4051	3037	3516	3743	2366	2564
September		3785	3195	3529	2866	2444	2581
October	IFS	1481	1404	1438	1290	1124	1132
November		447.6	572.5	473.9	276.6	381.9	337
December	LFS	89.58	226.9	195.9	61.87	113.6	108.7
January		27.83	120.7	88.99	21.69	25.82	23.76
February		3.073	79.8	49.29	20.69	16.95	17.26
March		12.06	59.5	41.18	38.79	15.29	20.23

According to CY method, November to June is found as the low flow season (LFS) in both the stations. Whereas the high flow season (HFS) According to CY method is July to October in both the stations. The June and November are the month of Intermediate flow seasons (IFS) or flow transition season in both the stations. In these months the flows are changing its patterns. The high flow comes to decrease at the month of November after which low flow season starts. Whereas low flow comes to increase at the month of April and May after which high flow season settles. It is observed that the flow in pre-monsoon starts increasing in June. The peak highest flow is found in monsoon period in the month of August, and then it again starts decreasing in the month of October. After the monsoon, the flow comes to a minimum level in the month of March.

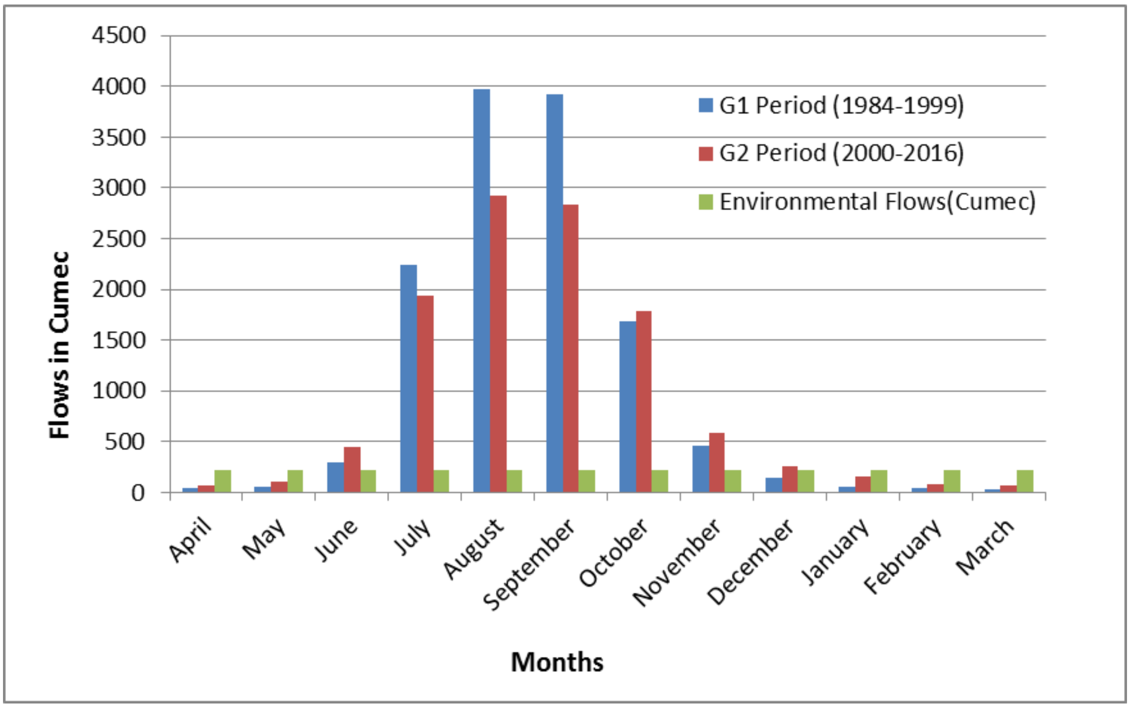

Figure 4.17: Comparison of Mean Monthly Flows with EFR in CY method at Gorai Railway Bridge station

According to Constant Yield (CY) method median monthly flow for each month has been computed in two different ways. According to the first method, the median flow of each month has been computed considering the data availability for the whole period (1984-2016). In the second method, median for each month of each year has been computed separately and from the obtained median values again median is determined for the given month over the entire period of record (Hossain and Hosasin, 2011). In Bangladesh, this procedure has been used for assessment of instream flow requirement for Surma, Kushiyara, Teesta (Bari and Marchand, 2006) and for the Ganges River (Rahman, 1998). Environmental flow considering only low flow season based on first CY method is not close enough to environmental flow requirement obtained from other MAF and FDC methods as described earlier. Therefore, the second method median of separate median values of twelve months is considered to calculate the EFR value. The ascending serial of median values is considered to find the EFR value in CY method.

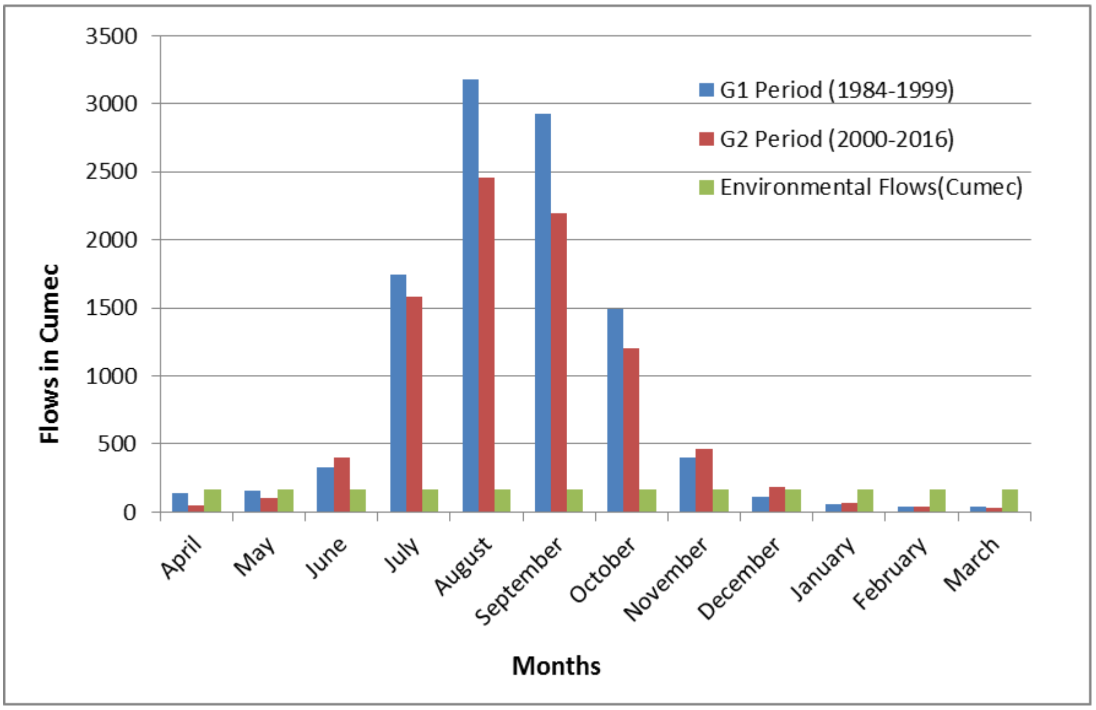

Figure 4.18: Comparison of Mean Monthly Flows with EFR in CY method at Kamarkhali Transit station

Figure 4.17 describes the Comparison of Mean Monthly Flows with EFR in CY method at Gorai Railway Bridge station. The EFR value in CY method for Gorai Railway Bridge station is found as 221.4 Cumec. For this flow in the month of April and May the mean monthly flows are lower than the environment flow required but in June to November the flows are more than the EFR in CY method. Therefore although the high flow season satisfies the flow required, the low flow season does not support this. Basically the flows in June and November are intermediate flow season where the flow season changes. Again the flows in December to March are less than the required EFR value in CY method. Generally high flow seasons satisfy the EFR required flow but the low flow seasons are normally less than the EFR flow by CY method at Gorai Railway Bridge station.

Figure 4.18 describes the Comparison of Mean Monthly Flows with EFR in CY method at Kamarkhali transit station. The EFR value in CY method for Kamarkhali transit station is found as 162.85 Cumec. For this flow in the month of April and May the mean monthly flows are lower than the environment flow required but in June to November the flows are more than the EFR in CY method. Therefore although the high flow season satisfies the flow required, the low flow season does not support this. Basically the flows in June and November are intermediate flow season where the flow season changes. Again the flows in December to March are less than the required EFR value in CY method. Generally high flow seasons satisfy the EFR required flow but the low flow seasons are normally less than the EFR flow by CY method at Kamarkhali transit station.

4.3.4 Comparison of EFR values in three methods

Figure 4.19 describes the Comparison of Mean Monthly Flows with average EFR of MAF, FDC and CY method at Gorai Railway Bridge station. In this Figure the average EFR value for Gorai Railway Bridge station is found as 237.93. For this flow in the month of April and May the mean monthly flows are lower than the environment flow required but in June to November the flows are more than the EFR. Therefore although the high flow season satisfies the flow required, the low flow season does not support this. Basically the flows in June and November are intermediate flow season where the flow season changes. Again the flows in December to March are less than the required average EFR value. Generally high flow seasons satisfy the average EFR required flow but the low flow seasons are normally less than the average EFR flow at Gorai Railway Bridge station.

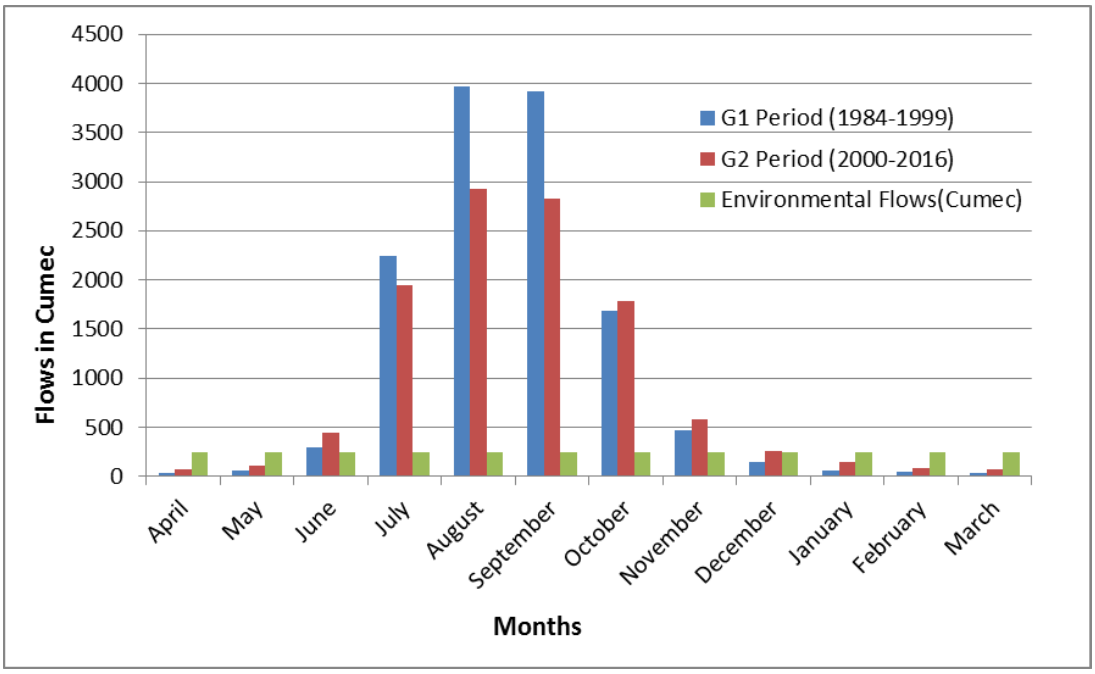

Figure 4.19: Comparison of Mean Monthly Flows with average EFR of MAF, FDC and CY method at Gorai Railway Bridge station

Figure 4.20 describe the Comparison of Mean Monthly Flows with average EFR of MAF, FDC and CY method at Kamarkhali Transit station. In this Figure the average EFR value for Kamarkhali Transit station is found as 162.95Cumec. For this flow in the month of April and May the mean monthly flows are lower than the environment flow required but in June to November the flows are more than the EFR. Therefore although the high flow season satisfies the flow required, the low flow season does not support this. Basically the flows in June and November are intermediate flow season where the flow season changes. Again the flows in December to March are less than the required average EFR value. Generally high flow seasons satisfy the average EFR required flow but the low flow seasons are normally less than the average EFR flow at Kamarkhali Transit station.

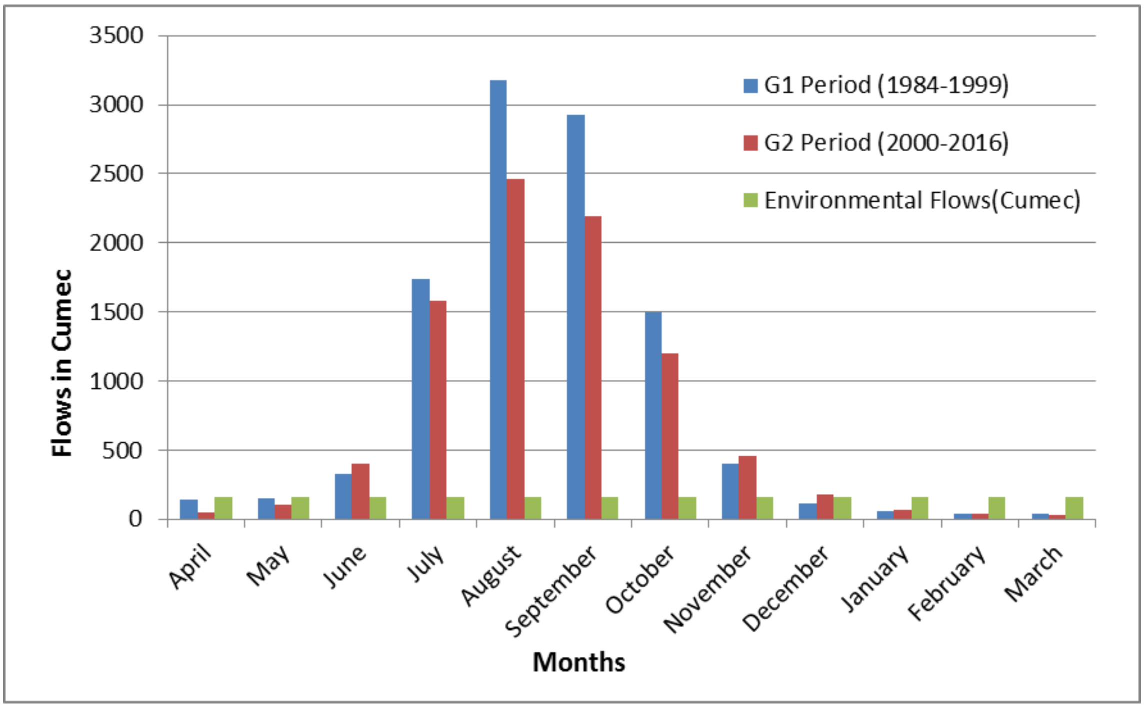

Figure 4.20: Comparison of Mean Monthly Flows with average EFR of MAF, FDC and CY method at Kamarkhali Transit station

Table 4.10 shows Summary of monthly Flow values computed by three methods for Gorai Railway bridge station, here in MAF method lowest flow occurs in March which is found as 52.2 Cumec, and the flow start increasing from April. The increasing rate is very slow from April to May, in June the flow has rapid increase and in July the flow has a high frequency. it continue the rapid high flow up to September, after September the flow again start decreasing and in October it has a downward slope of decrease. In November it has started drop the flow and decreases up to March. The low flow season (LFS) is December to March. Whereas the high flow season (HFS) found are June to September and the April, May, October and November are the month of Intermediate flow seasons (IFS) or flow transition season. In these months the flows are changing its patterns. The high flow comes to decrease at the month of October and November after which low flow season settles. Whereas low flow comes to increase at the month of April and May after which high flow season settles. In FDC method the lowest flow observed in April which is 44.27 and highest flow found in September which is found as 3529 Cumec and in CY method the lowest flow occurs in March is found as 41.18 Cumec and high flow found in September is found as 3529 Cumec. Among all methods the highest flow is 3529 found in September and the lowest flow is 41.18 found in March the overall flow condition are nearly same in above three described methods.

Table 4.10: Summary of monthly Flow values computed by three methods for Gorai Railway bridge station

Months	**Season**	**MAF Method**	**FDC Method**	**CY Method**
		Total	Total	Total
April	IFS	54.37	44.27	44.27
May		81.13	66.53	66.53
June	HFS	368.4	246.9	246.9
July		2086	2247	2247
August		3432	3516	3516
September		3362	3529	3529
October	IFS	1736	1438	1438
November		524.3	473.9	473.9
December	LFS	199.1	395.2	195.9
January		106.7	260.1	88.99
February		65.01	167	49.29
March		52.2	134.4	41.18

Figure 4.21 shows the comparison of Flow values computed by the Three Methods for Gorai Railway Bridge station. In this Figure at the peak of high flow season in September the constant yield method flow is the highest than other methods and in low flow season the flows in March to May in CY method is the lowest than other methods. Among other months the flows are crosses each other and in the month of June to August the flow is increases with a sharp slope and in the month of October to December the flow is decreases with a sharp slope as well. The flow values observed in three methods is nearly same. It is observed from this Figure that, the November to June flow values can be considered as LFS and July to October flow values can be considered as HFS by the Three Methods for Gorai Railway Bridge station.

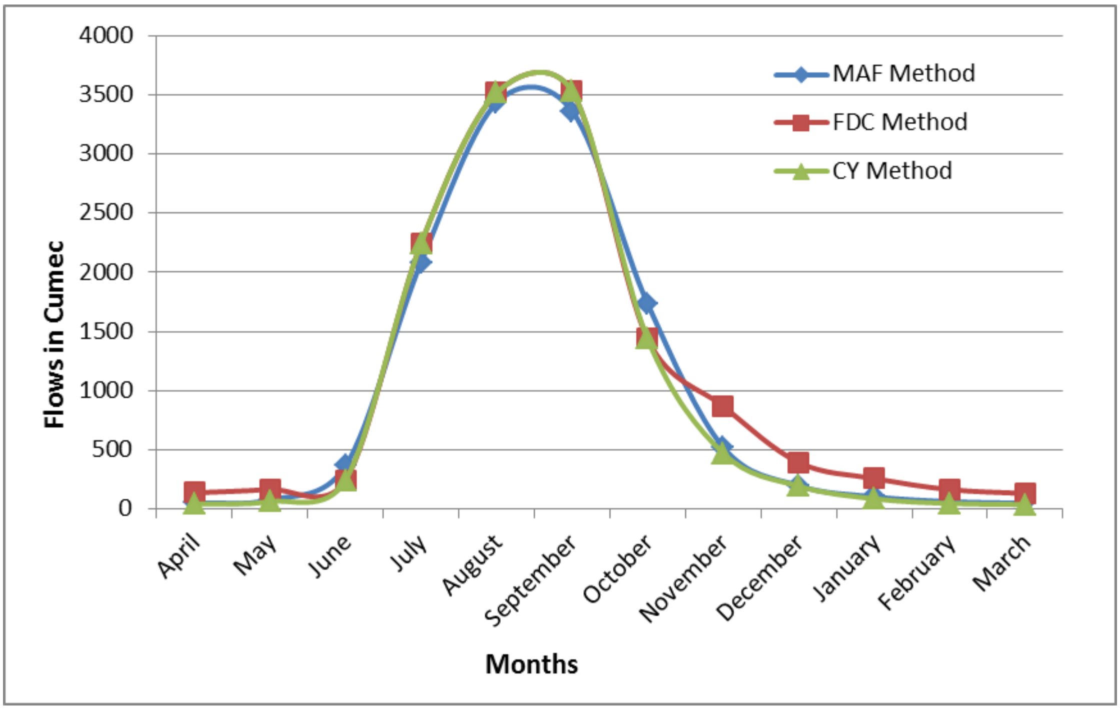

Figure 4.21: Comparison of Flow values computed by the Three Methods for Gorai Railway Bridge station

Table 4.11 shows summary of monthly Flow values computed by three methods for Kamarkhali Transit station, here in MAF method lowest flow occurs in March which is 32.93 the flow start increasing from April. The increasing rate is very slow from April to May, in June the flow has rapid increase and in July the flow has a high frequency. it continue the rapid high flow up to September, after September the flow again start decreasing and in October it has a downward slope of decrease. In November it has started drop the flow and decreases up to March. The low flow season (LFS) is December to March. Whereas the high flow season (HFS) found are June to September and the April, May, October and November are the month of Intermediate flow seasons (IFS) or flow transition season. In these months the flows are changing it patterns. The high flow comes to decrease at the month of October and November after which low flow season settles. Whereas low flow comes to increase at the month of April and May after which high flow season settles. In FDC method the low flow observed in April which is 33.98 and high flow found in September which is 2581 and in CY method the lowest flow occurs in February is 17.26 and high flow found in September is 2581 among all methods the highest flow is 2742 found in August and the lowest flow is 20.23 found in March the overall flow condition are nearly same in above three described methods.

Table 4.11: Summary of monthly Flow values computed by three methods for Kamarkhali Transit station

Months	Season	MAF Method	FDC Method	CY Method
		Total	Total	Total
April	IFS	81.05	33.98	33.98
May		121.5	59.73	59.73
June	HFS	368.6	217	217
July		1643	1717	1717
August		2742	2564	2564
September		2483	2581	2581
October	IFS	1317	1132	1132
November		435.2	337	337
December	LFS	154.6	281.5	108.7
January		62.7	180.6	23.76
February		38.8	124.4	17.26
March		32.93	83.29	20.23

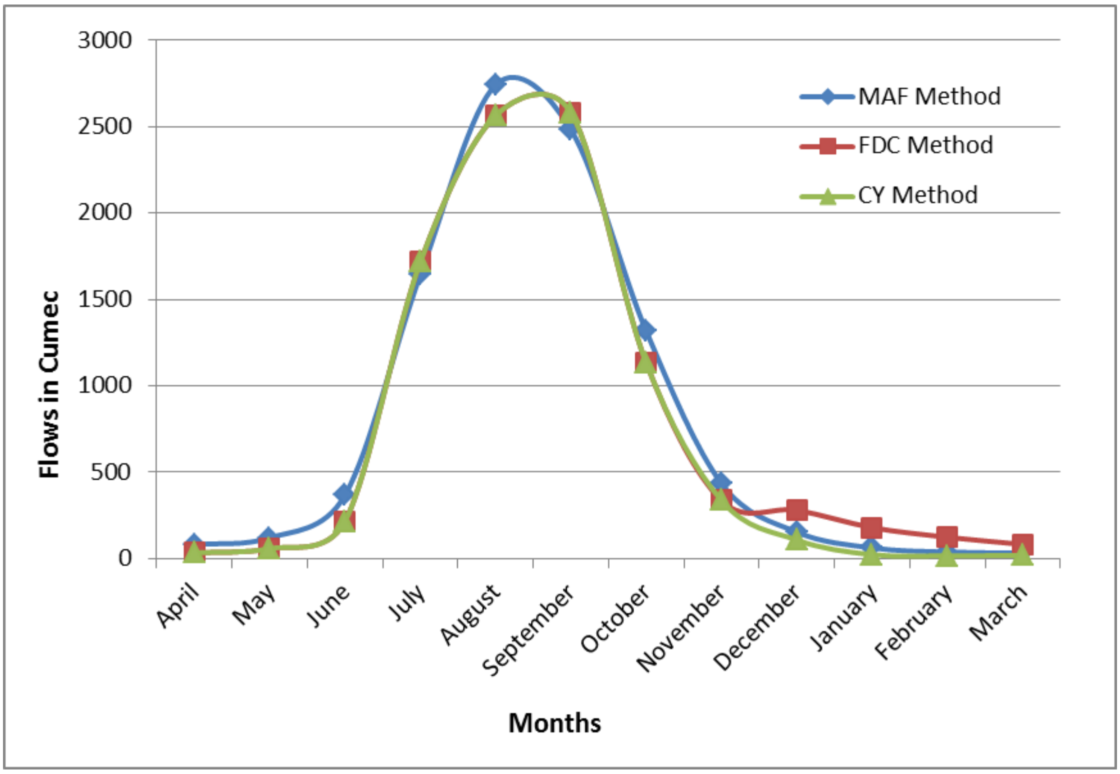

Figure 4.22: Comparison of Flow values computed by the Three Methods for Kamarkhali Transit station

Figure 4.22 shows the Comparison of Flow values computed by the Three Methods for Kamarkhali Transit station. In this Figure at the peak of high flow season in September the MAF method flow is the highest than other methods and in low flow season the March to May flows in CY method is the lowest than other methods. Among other months the flows are crosses each other and in the month of June to August the flow is increases with a sharp slope and in the month of October to December the flow is decreases with a sharp slope as well. The flow values observed in three methods is nearly same. It is observed from this Figure that, the November to June flow values can be considered as LFS and July to October flow values can be considered as HFS by the three Methods for Kamarkhali Transit station.

4.4 Shortage of flow in Gorai River and its significances

During the post-Farakka period major changes have occurred in the dry season flow, specially the flow between January to May. During the pre-Farakka period the minimum monthly average flow was 1,500 Cumec. The recorded minimum monthly average flow was 170 Cumec in April, 1997. However, the post-Farakka flood flows were of the same as the pre-Farakka flood flows (BWDB). Both wet and dry season stream flow in Gorai River has been reduced considerably after construction of Farakka barrage. The decrease in flow of Gorai river has affected agriculture, fisheries, and caused salinity interference in both surface and ground water. Such low flow in Gorai has commenced to siltation at Gorai mouth and Mongla port and increased flood and cyclones. The present flow in Gorai is about 5000 Cumec peak. Any further decrease may cut off Gorai river from the Ganges. The low flow for the Gorai river may cause Sea water intrusion, Increase in evaporation, Water scarcity in dry season.

This reduction of water has increased the frequency of severe floods over the last decade, causing enormous property damage and loss of life. A low flow frequency analysis evaluates the possibility of flows low threshold for a given length of time. The analyses show that considerable amount of flow reduction has taken place specially in the recent Daily Discharge in Gorai Railway Bridge station. For the years 1988, 1989, 1990, 1991, 1992, 1995, 1996, 1997 and 2015 flows are lower than 10 Cumec. And in Kamarkhali Transit station Daily Discharge for the years 1988, 1989, 1991, 1992, 1994, 2004, 2008, 2009, 2010, 2011, 2014, 2015 and 2016 are lower than 10 Cumec. Environmental flow requirements have been calculated using three methods and the results are consistent among the methods. The results suggest that flow about 150 to 200 Cumec for the dry season in the month of December to April is required for the existence of the river itself.

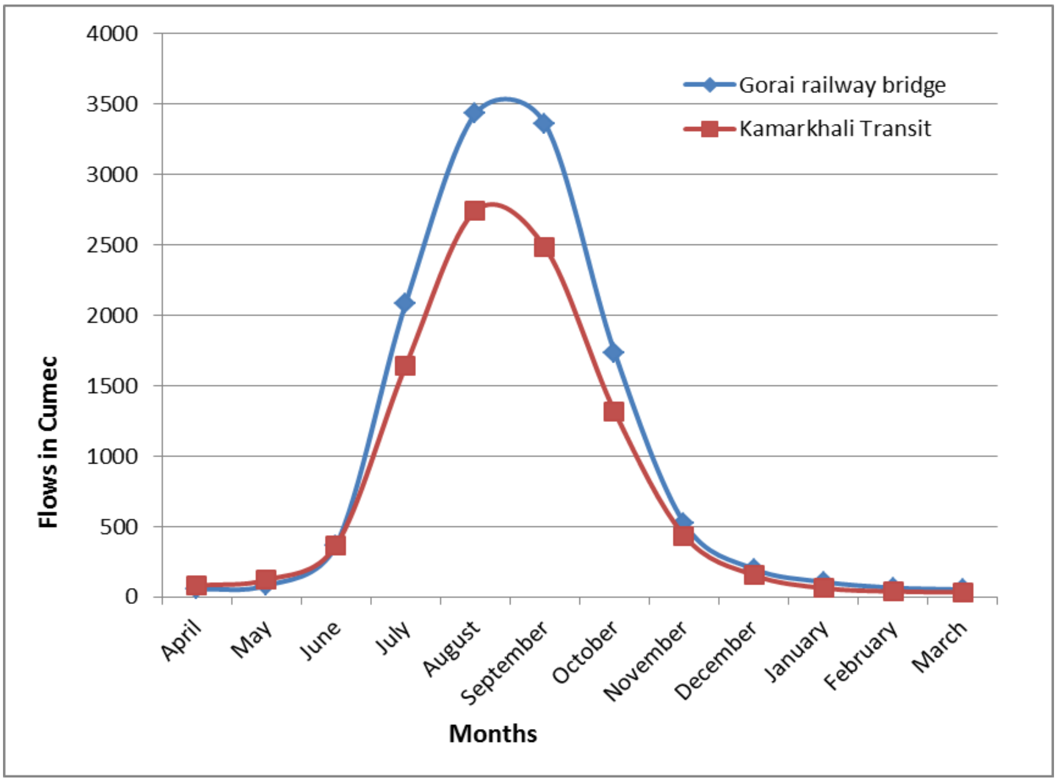

Figure 4.23: Comparison of Flow values computed by MAF Method for Gorai Railway Bridge and Kamarkhali Transit stations

Figure 4.23 shows the comparison of Flow values computed by MAF Method for Gorai Railway Bridge and Kamarkhali Transit stations. In this Figure August to October is the peak of high flow season. The flows in Gorai Railway Bridge station are higher than Kamarkhali transit station in HFS. In low flow season in the month of March to June, the flows in Gorai Railway Bridge station is lower than Kamarkhali transit station. Among other months the flows are crosses each other and in the month of June to August the flow is increases with a sharp slope and in the month of October to December the flow is decreases with a sharp slope as well. It is observed from this Figure that, the flows in November to June can be considered as LFS and the flows in July to October can be considered as HFS in both the stations by MAF method.

Figure 4.24 shows the Comparison of Flow values computed by FDC Method for Gorai Railway Bridge and Kamarkhali Transit stations. In this Figure August to October is the peak of high flow season. The Gorai Railway Bridge station flow is higher than Kamarkhali transit station in both HFS and LFS. In the month of November to June the flow values are lower than other months. The flows are crosses each other in the month of March to June. Again the June to August flow is increases with a sharp slope and in the month of October to December the flow is decreases with a sharp slope as well. It is observed from this Figure that, the November to June flow values can be considered as LFS and July to October flow values can be considered as HFS in both the stations by FDC method.

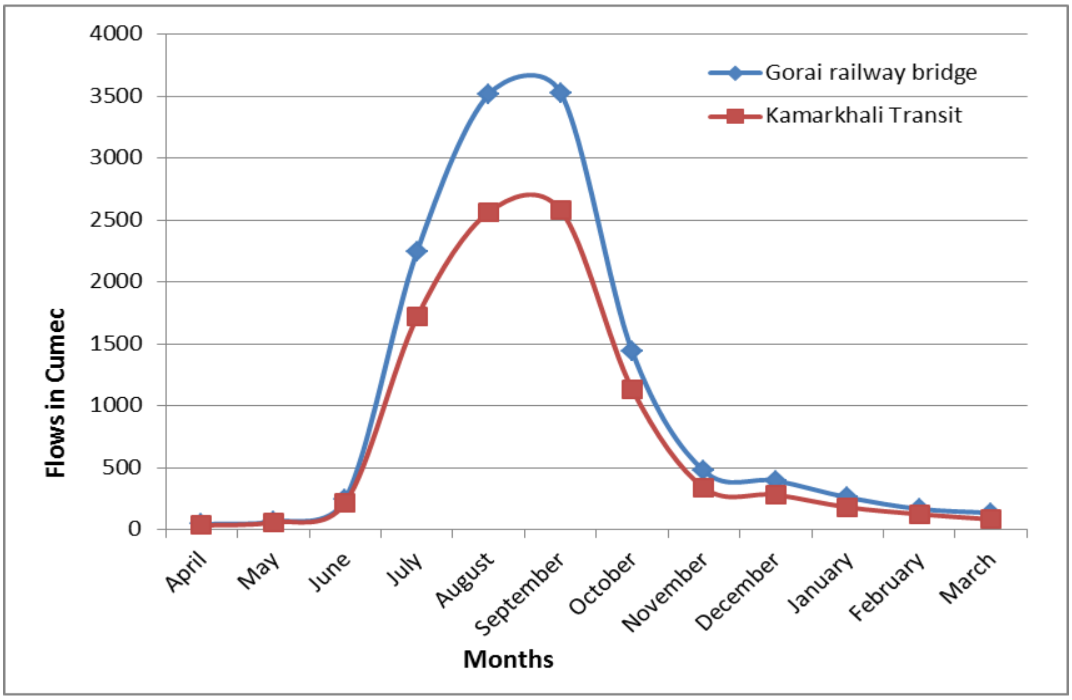

Figure 4.24: Comparison of Flow values computed by FDC Method for Gorai Railway Bridge and Kamarkhali Transit stations

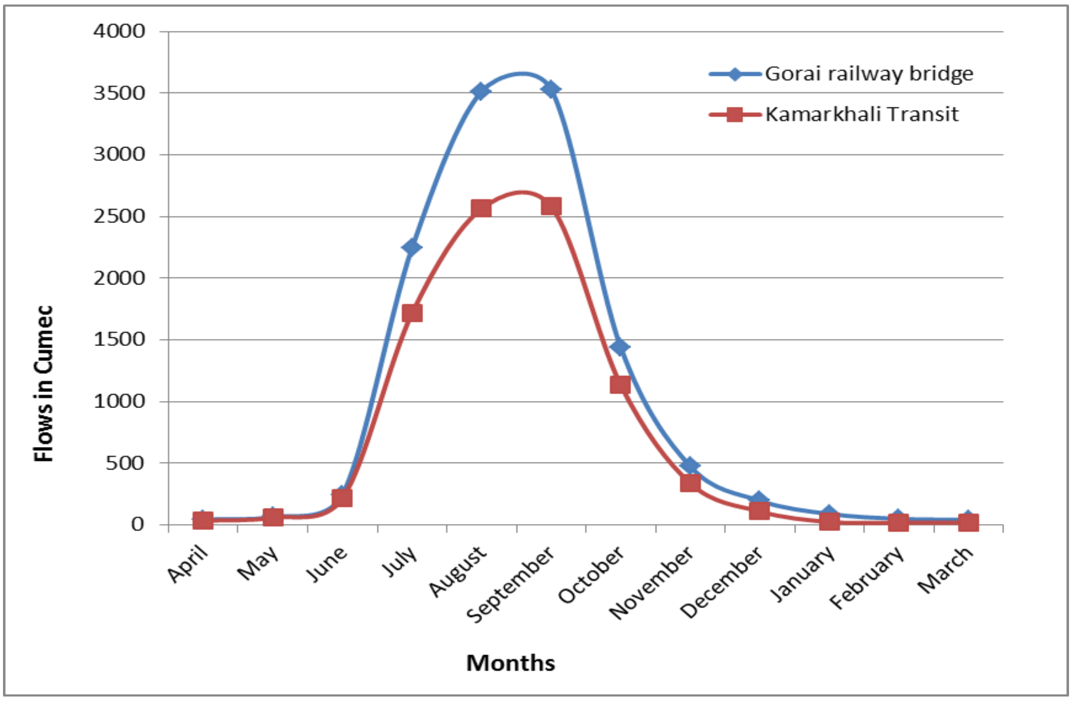

Figure 4.25: Comparison of Flow values computed by CY Method for Gorai Railway Bridge and Kamarkhali Transit stations

Figure 4.25 shows the Comparison of Flow values computed by CY Method for Gorai Railway Bridge and Kamarkhali Transit stations. In this Figure August to October is the peak of high flow season. The Gorai Railway Bridge station flow is higher than Kamarkhali transit station in both HFS and LFS. In the month of November to June the flow values are lower than other months. The flows are crosses each other in the month of March to June. Again from June to August the flow is increased with a sharp slope and in the month of October to December the flow is decreased with a sharp slope as well. It is observed from this Figure that, the November to June flow values can be considered as LFS and July to October flow values can be considered as HFS in both the stations by CY method.

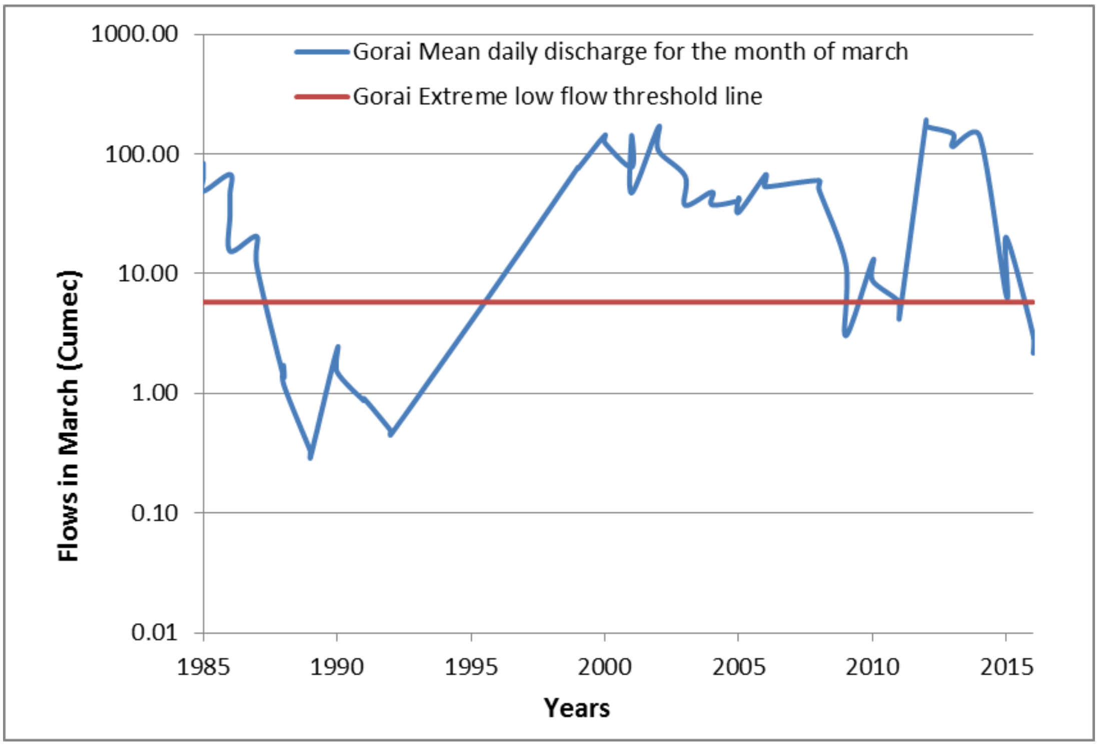

Figure 4.26: Comparison of March daily discharge with Extreme low flow Threshold of Gorai railway bridge station

Figure 4.26 describe the comparison of daily discharge of March with Extreme low flow Threshold for Gorai railway bridge station. The straight line shows the Extreme low flow Threshold of Gorai railway bridge and Zigzag line represents the mean daily discharge in the month of March. The Extreme low flow Threshold of Gorai railway bridge station is found as 5.783 Cumec in March. The flows from 1987 to 1996 are lower than the Extreme low flow threshold and 2009, 2010 and 2015 flows are also lower than the Extreme low flow threshold. In the other years, the flows in March are more than the Extreme low flow threshold.

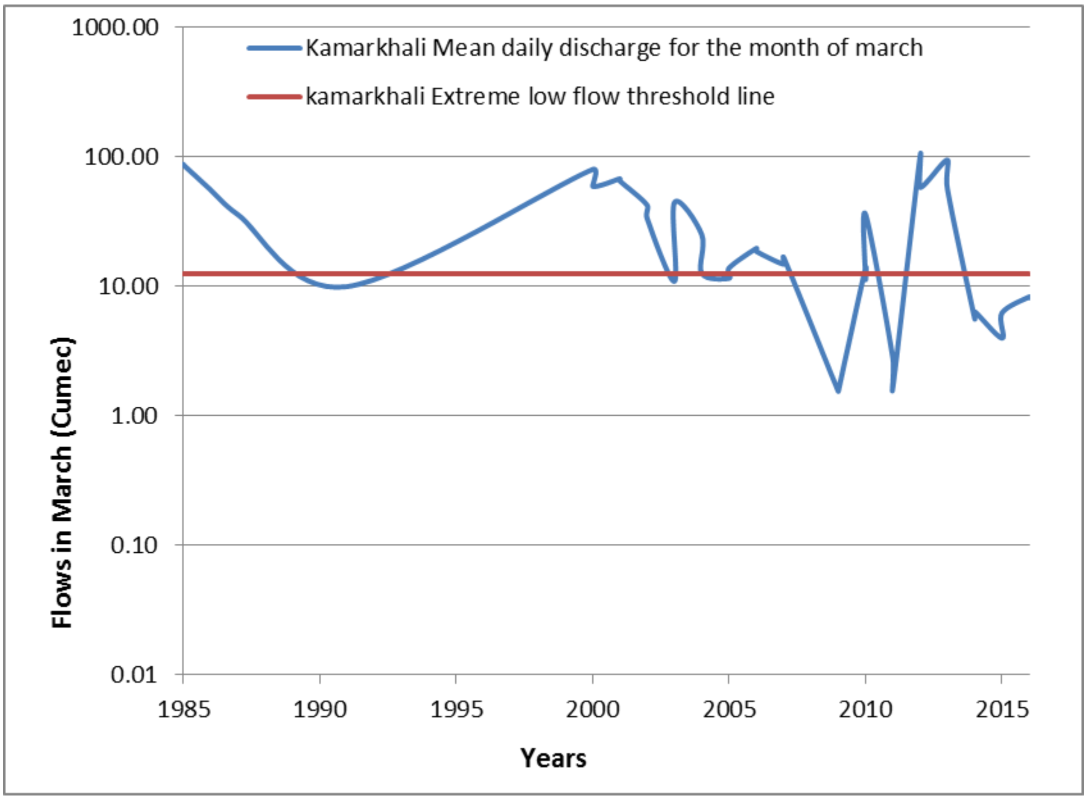

Figure 4.27: Comparison of March daily discharge with Extreme low flow Threshold of Kamarkhali Transit station

Figure 4.27 describe the comparison of daily discharge of March with Extreme low flow Threshold for Kamarkhali Transit station. The straight line shows the Extreme low flow Threshold of Kamarkhali Transit station and Zigzag line represents the mean daily discharge in the month of March. The Extreme low flow Threshold of Kamarkhali Transit station is found as 12.54 Cumec in March. The flows in 1989, 1990 are lower than the Extreme low flow threshold and 2007, 2008, 2009, 2010 and 2015 flows are also lower than the Extreme low flow threshold. In the other years, the flows in March are more than the Extreme low flow threshold.

4.5 Range of Variability Approach (RVA) Analysis

In IHA software RVA targets are computed setting at +/- 1 standard deviation. In setting such target it is implicitly assumed that values within these limits from the mean are not expected to have significant impact on stream ecology (Mullick et al., 2010). In an RVA analysis, the full range of pre-impact data for each parameter is divided into three different categories: the lowest category contains all values less than or equal to the 33rd percentile; the middle category contains all values falling in the range of the 34th to 67th percentiles; and the highest category contains all values greater than the 67th percentile (TNC, 2009). A positive HA value means that the frequency of values in the category has increased from pre- to post condition (with a maximum value of infinity), while a negative value means that the frequency of values has decreased (with a minimum value of -1) (TNC, 2009).

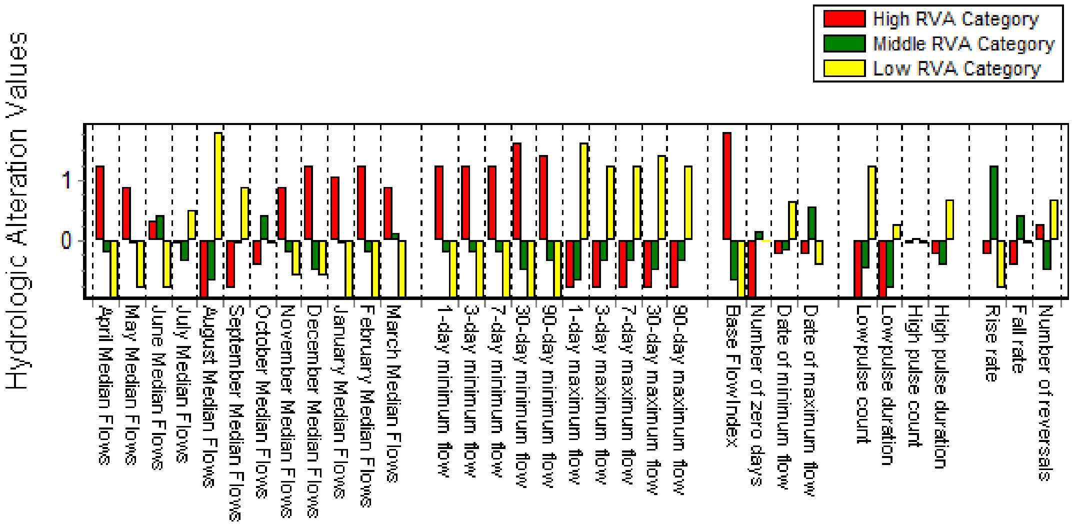

Figure 4.28: Category of Hydrologic alteration with RVA target for Gorai Railway bridge station

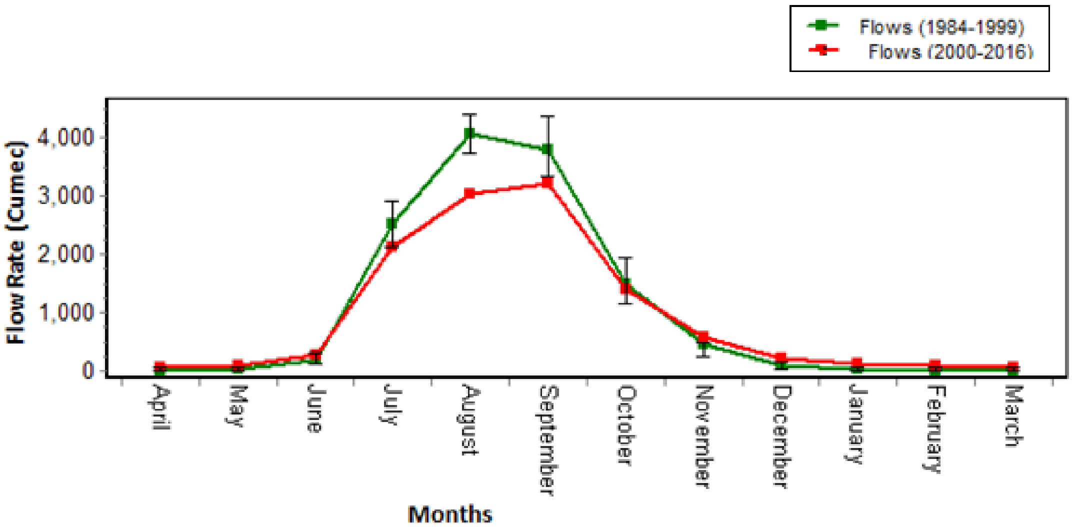

Figure 4.29: Monthly RVA Boundaries of Gorai Railway bridge station

Figure 4.28 shows the Category of Hydrologic alteration of Gorai Railway bridge station with RVA target. It is observed that the high RVA positive category occurs in the month of November to May, and high RVA negative category occurs in the month of August and September. The low RVA positive category occurs in the month of July to September, and low RVA negative category occurs in the month of

November to June. Again, low pulse count increases and rise rate decreases significantly. 3, 7, 30 and 90 day minimum flow increased with RVA high category, and 3, 7, 30 and 90 day maximum flow increased with RVA low category. 3, 7, 30 and 90 day minimum flow decreases with RVA low category, and 3, 7, 30 and 90 day maximum flow decreased with RVA high category. The Base flow index increases with high RVA category and decreases with low RVA category. Low pulse duration increases with low RVA category and decreases with high RVA category.

Figure 4.29 shows Category of Hydrologic alteration with RVA target for Gorai Railway bridge station. The RVA hydrologic alteration with their RVA category between the years 1984-2016 indicate that monthly flow is reduced mostly in high flow season in relation to G1(1984-1999) and G2 (2000-2016) period. The monthly RVA boundaries are changes highly at high flow season (June to September). It is observed that the G2 period flow rate is lower than G1 period flow rate in the month of June to October. The highest flow rate is found as 4000 Cumec in August in G1 period and in G2 period it is observed as 3000 Cumec in September. The monthly RVA boundaries are not changes too much at low flow season (December to March) and Intermediate flow season (April, May, October and November).

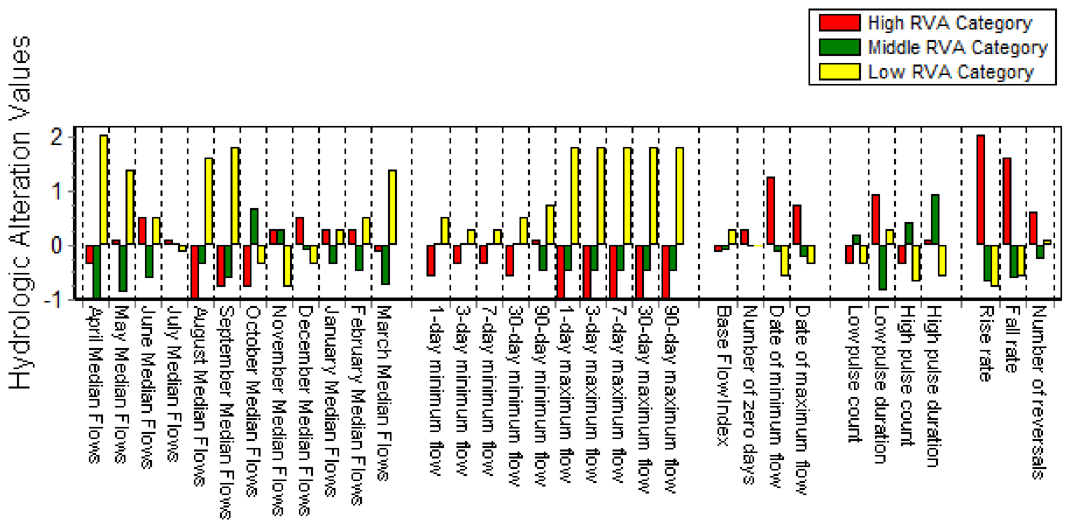

Figure 4.30: Category of Hydrologic alteration with RVA target for Kamarkhali Transit station

Figure 4.30 shows the Category of Hydrologic alteration with RVA target for Kamarkhali Transit station. It is observed that the high RVA positive category occurs in the month of November to February and June, and high RVA negative category occurs in the month of April and August to October. The low RVA positive category occurs in the month of February to June, August and September. The low

RVA negative category occurs in the month of October and November. Again, low pulse count increases and rise rate decreases significantly. 3, 7, 30 and 90 day minimum flow increased with RVA low category, and 3, 7, 30 and 90 day maximum flow increased with RVA low category. 3, 7, 30 and 90 day minimum flow decreases with RVA high category, and 3, 7, 30 and 90 day maximum flow decreased with RVA high category. The Base flow index increases with low RVA category and decreases with high RVA category. Rise rate and fall rate increases with high RVA category and decreases with middle and low RVA category.

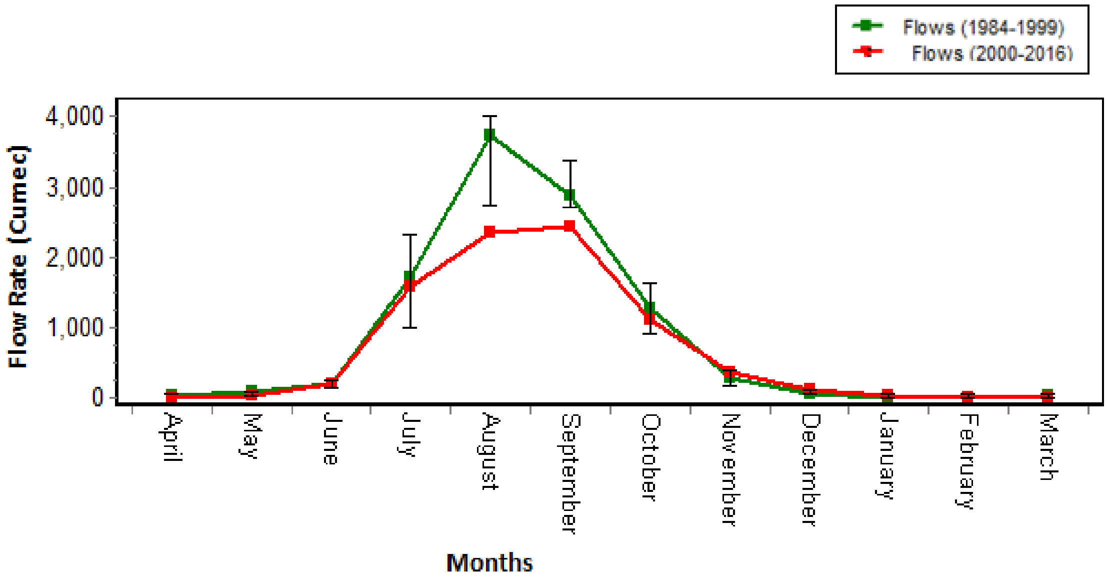

Figure 4.31: Monthly RVA Boundaries of Kamarkhali Transit station

Figure 4.31 shows Monthly RVA Boundaries of Kamarkhali Transit station. The RVA hydrologic alteration with their RVA category between the years 1984-2016 indicate that monthly flow is reduced mostly in high flow season in relation to G1(1984-1999) and G2 (2000-2016) period. The monthly RVA boundaries are changes too much at high flow season (June to September). It is observed that the G2 period flow rate is lower than G1 period flow rate in the month of June to October. The highest flow rate is observed as 3900 Cumec in August in G1 period and in G2 period it is observed as 2700 Cumec in September. The monthly RVA boundaries at low flow season (December to March) and Intermediate flow season (April, May, October and November) are not changes too much

4.6 Assessment of Environmental Flow

It is observed from the analysis that, the Mean annual flow of Gorai Railway bridge station is 1012 Cumec during 1984 to 2016, and Mean annual flow of Kamarkhali transit station is 795.1 Cumec during 1984 to 2016. As low flow season is the main concern, about 202.4 Cumec flow is required to maintain good condition for Gorai Railway bridge station and 159 Cumec flow is required for Kamarkhali transit station in MAF method. The relationship between the magnitude and duration of stream flows is presented by flow duration curve (FDC). FDCs are used mainly to set environmental flow purposes. Flow duration intervals are stated as percentage of exceedance, with zero corresponding to the highest stream discharge in the record (i.e. flood conditions) and 100 to the lowest (i.e. drought conditions). As low flow season is the main concern, the environmental flow requirement based on FDC in LFS is found as 290 Cumec for Gorai Railway bridge station and 167 Cumec flow is required for Kamarkhali transit station in FDC method. During the low flow season the minimum requirement based on FDC method is retained during both intermediate and high flow seasons but not for low flow season which is the main concern. Environmental flow considering CY method for Gorai Railway bridge station is found as 221.4 Cumec and for Kamarkhali transit station it is found as 162.85 Cumec. The flow found in CY method is close enough to environmental flow requirement obtained from MAF and FDC methods.

The calculated environmental flow requirement based on Tennant method (MAF), FDC method and CY method are 202.4 Cumec, 290 Cumec and 221.4 Cumec respectively for Gorai Railway bridge station, whereas for Kamarkhali transit station it is found as 159 Cumec, 167 Cumec and 162.85 Cumec, respectively. By taking the average of these three values, the needed environmental flow of the Gorai Railway bridge station is found as 237.93 Cumec for Gorai Railway bridge station and for Kamarkhali transit station it is found as 162.95 Cumec. The river flow meets the environmental flow requirement in high flow season and intermediate flow season.

Table 4.12: Flow requirement according to habitat quality for Gorai Railway Bridge and Kamarkhali Transit station

Flow Requirement	**High Flow Season (HFS) (Cumec)**		**Low Flow Season (LFS) (Cumec)**	
(% of MAF)	**Gorai station**	**Kamarkhali station**	**Gorai station**	**Kamarkhali station**
Flushing flow (200%)	2024	1590.2	2024	1590.2
Optimum range (60-100%)	607.2 - 1012	477.06 - 795.1	607.2 - 1012	477.06 - 795.1
Outstanding (60% at HFS, 40% at LFS)	607.2	477.06	404.8	318.04
Excellent (50% at HFS, 30% at LFS)	506	397.55	303.6	238.53
Good (40% at HFS, 20% at LFS)	404.8	318.04	202.4	159.02
Fair (30% at HFS, 10% at LFS)	303.6	238.53	101.2	79.51
Poor (10%)	101.2	79.51	101.2	79.51
Severe degradation (<10%)	<101.2	<79.51	<101.2	<79.51

Table 4.12 shows the Flow requirement according to habitat quality for Gorai Railway Bridge and Kamarkhali Transit station. Here the flow requirement according to habitat quality are shown in high flow season and low flow season for both the Gorai Railway Bridge and Kamarkhali Transit station, the percentage of mean annual flow for flushing flow is 200%. For Gorai Railway bridge station it is found as 2024 Cumec. For high flow season and low flow season both the requirement is same and for Kamarkhali Transit station it is found as 1590.2 Cumec. The optimum range is 60% to 100% for both low flow and high flow season and outstanding flow at HFS 60% and LFS will be 40% of the mean annual flow and for the excellent flow it is required 50% of high flow season and 30% at low flow season of the MAF and for a good quality of flow it is required 40% at HFS and 20% at LFS. For a fair quality of flow it is required 30% at HFS and 10% at LFS. The quality will be Poor if the flow is 10% in both HFS and LFS. Severe degradation is occurred if the flow less than 10% for both the seasons. Considering the habitat quality, it is found that, for Gorai Railway bridge station the severe degradation is occurred if the flow is less than 101.2 Cumec and for Kamarkhali transit station the severe degradation is occurred if the flow is less than 79.51 Cumec. The severe degradation is occurred if the flow is less than the lowest flow after which the river can be lost its environmental habitat quality below this flow level.

It is observed from Table 4.13 that, the river condition is good at the high flow season but when the flow comes in low flow season it becomes lower than the environmental flows required for good habitat quality. The flows in the month of January to May are less than the EFR required. The flows of these months are less than the severe degradation flow. It shows severe problems for both the stations. For the Gorai river, it is necessary to maintain the flow values more than the severe degradation throughout the year to sustain the habitat quality for the river. The three methods show different values for environmental flow requirement. The flow requirements in the low flow season for three methods are found lower than the required flow in both stations. It shows that the river is endangered for habitat quality in low flow seasons. In every method it proved that, the Gorai River has flow scarcity because of the low flows from upstream. The reason is the construction of farakka barrage in the upstream. It causes to decrease the flow in the low flow season. The other factors are the cultivation and water use of the local people from river. Construction of houses in the river bank and dumping of garbage in river side causes the narrowing of the flow channel which causes reduction of flow from upstream to downstream. This wide ranging difference of EFR is due to the variation of habitat quality and flow seasonality. A flushing habitat quality requires the largest amount of flow whereas a ‘fair’ habitat quality requires the minimum amount of flow.

Table 4.13 shows Long term flow characteristics of Gorai Railway bridge station. The Table shows the mean, minimum and maximum flow values as well as low and high RVA values for G1 and G2 period. The flows in G1 period are lower than the G2 period, except in the month of July to September. These maximum values of HFS flow are lower than the G1 period for Gorai railway bridge station. In the other months, maximum values in G2 period are higher than the G1 period. The minimum flow for both periods did not follow any trends for low flow or high flow season it is randomly changed in every month, but the mean value and maximum values are followed a trend. In High flow season of G2 period, maximum and mean values are lower, whereas the values for G1 period are lower in the low flow season for the Gorai railway bridge and RVA boundaries show low and high boundary values. The values are lower in the low flow season, but the RVA boundaries are exceptionally high in high flow season related to low flow season. The minimum low boundary values are found in the month of January, February, March and April. These values are nearly 1 whereas the other RVA values are higher in other months. The flow differences are very big in the same month for minimum and maximum values. In Table 4.13, the lowest maximum value for G1 period found in the month of March is 134 Cumec and the highest maximum value is found in the month of September as 6753 Cumec. The lowest maximum for G2 period observed in the month of April is 172.7 Cumec and the highest maximum is observed in the month of October as 8177 Cumec. The lowest RVA boundaries are found in the month of March as 1.07 and the highest RVA value is found in the month of August as 5391. Among the high RVA the lowest value is found as 80.68 in the month of March.

Table 4.13: Long term flow characteristics of Gorai Railway bridge station

Months	G1 period: 1984-1999			G2 period: 2000-2016			RVA Boundaries	
	Mean	Min.	Max.	Mean	Min.	Max.	Low	High
April	37.18	0.2676	156	70.55	4.56	170.7	1.151	88.31
May	54.06	0.41	165.2	106.6	16.5	255.2	10.08	109.3
June	290.8	8.687	579.5	441.4	127	1237	116.8	464.8
July	2239	156	3622	1942	591.6	3271	1387	3091
August	3972	156	6305	2925	786.8	4245	2553	5391
September	3925	156	6753	2831	661.5	4316	2498	5351
October	1686	156	4055	1784	352	8177	747	2624
November	464.6	156	1216	580.6	108.9	1424	181.3	747.8
December	141.5	11.36	419.2	253.3	22.66	619.6	18.76	264.2
January	59.97	0.8328	250.7	150.6	9.322	465.8	2.774	131.1
February	42.17	8.809	197.1	86.5	4.794	229.5	1.271	99.75
March	34.89	2.951	134	68.49	2.838	187.4	1.073	80.68

Table 4.14 shows long term flow characteristics of Kamarkhali Transit station. The Table shows the mean, minimum and maximum flow values as well as low and high RVA values for G1 and G2 period. The flows in G1 period are lower than the G2 period, except in the month of April, May and July to October. These maximum values of HFS flow are lower than the G1 period for Kamarkhali transit station. In the other months, maximum values in G2 period are higher than the G1 period. The minimum flow for both periods did not follow any trends for low flow or high flow season it is randomly changed in every month, but the mean value and maximum values are followed a trend. In High flow season of G2 period, maximum and mean values are lower, whereas the values for G1 period are lower in the low flow season and RVA boundaries show low and high boundary values.

Table 4.14: Long term flow characteristics of Kamarkhali Transit station

Months	G1 period: 1984-1999			G2 period: 2000-2016			RVA Boundaries	
	Mean	Min.	Max.	Mean	Min.	Max.	Low	High
April	137.3	18.38	901.7	44.64	0.3364	324.3	42.51	393.9
May	154.1	21.72	901.7	100.4	6.136	722.7	55.47	404.8
June	324.5	33.89	901.7	397.2	16.09	1121	85.55	563.4
July	1741	166	3240	1580	502.4	2483	777.8	2704
August	3177	166	5201	2460	508.2	3614	1610	4744
September	2923	166	4976	2197	444.2	3452	1549	4298
October	1496	166	3550	1201	380.2	2260	625.1	2367
November	397.5	156.6	1093	459.6	103	1478	179	670.6
December	112.4	19.29	299.5	182	28.73	695.2	51.23	206.7
January	54.35	7.972	157.3	68.09	8.437	187.2	12.77	112.1
February	39	2.167	122.8	38.66	2.951	134.8	9.77	77.44
March	40.15	7.43	84.31	28.25	1.434	83.07	15.27	65.04

The values are lower in the low flow season, but the RVA boundaries are exceptionally high in high flow season related to low flow season. The minimum low boundary values are found in the month of January to March. These values are nearly 10 whereas the other RVA values are higher in other months. The flow differences are very big in the same month for minimum and maximum values. In Table 4.14, the lowest maximum value for G1 period found in the month of March is 84.31 Cumec and the highest maximum value is found in the month of August as 5201 Cumec. The lowest maximum for G2 period observed in the month of March is 83.07 Cumec and the highest maximum is observed in the month of August as 3614 Cumec. The lowest RVA boundaries are found in the month of February as 9.77 and the highest RVA value is found in the month of August as 4744. Among the high RVA the lowest value is found as 65.04 in the month of March.

Table 4.15: Flow characteristics in G1 and G2 period in both stations

Months	Season	Gorai railway bridge			Kamarkhali Transit		
		MAF	FDC	CY	MAF	FDC	CY
April	IFS	G1<G2			G1>G2		
May		G1<G2			G1>G2		
June	HFS	G1<G2			G1≥G2		
July		G1>G2			G1>G2		
August		G1>G2			G1>G2		
September		G1>G2			G1>G2		
October	IFS	G1≤G2			G1>G2		
November		G1<G2			G1<G2		
December	LFS	G1<G2			G1<G2		
January		G1<G2			G1<G2		
February		G1<G2			G1≤G2		
March		G1<G2			G1<G2		

Table 4.15 shows the relation of discharge with G1 to G2 period for different flow seasons at Gorai Railway Bridge and Kamarkhali transit station. Observing all three methods it is found that, the discharge of G1 period is generally lower than G2 period in the month November to June, whereas the discharge of G1 period is generally higher than G2 period in the month July to October at Gorai railway Bridge station. On the other hand for Kamarkhali transit station, the discharge of G1 period is generally lower than G2 period in the month November to January, whereas the discharge of G1 period is generally higher than G2 period in the month February to October.

4.7 Salinity Features of Gorai River

Table 4.16 shows the co-relation of discharge with salinity for different flow seasons at Kamarkhali transit station. The salinity generally increases in the month January to June, November and December. These are the low flow season. It shows a higher value of chloride concentration. The highest individual one day chloride concentration is found as 511 ppm, and the average monthly highest chloride concentration is found as 152.8 ppm in the month of February. The salinity then starts decreasing. The low flow season (LFS) is December to March. Whereas the high flow season (HFS) June to September, shows a lower value of chloride concentration. The April, May, October and November are the month of Intermediate flow seasons (IFS) or flow transition season. In these months the flows are changing its patterns. The high flow comes to decrease at the month of October and November after which low flow season settles. Whereas low flow comes to increase at the month of April and May after which high flow season settles. The lowest individual one day chloride concentration is found as 20 ppm, and the average monthly lowest chloride concentration is found as 37.5 ppm in the month of October, The salinity then starts increasing up to the month of February.

Table 4.16: Co-relation of different flow seasons discharge with salinity at Kamarkhali transit station

Months	Season	Kamarkhali Transit Station	
		Discharge (Cumec)	Salinity (ppm)
April	IFS	81.05	117.5
May		121.5	123.0
June	HFS	368.6	105.7
July		1643	85.0
August		2742	59.7
September		2483	39.0
October	IFS	1317	37.5
November		435.2	101.9
December	LFS	154.6	121.2
January		62.7	140.2
February		38.8	152.8
March		32.93	138.4

Daily mean specific conductance values are calculated for Kamarkhali transition station. The statistics are computed for the entire study period and the data divided into three seasons HFS, IFS and LFS. The fresh water discharge is the only way to decrease the salinity of a river. The water salinity was dependent on the mixing of freshwater from upstream. The increase of water from upstream causes the decrease of salinity to the downstream and when the value of fresh water decreases the salinity goes rise at the downstream. Downstream sea water intrusion is also increase the salinity more rapidly.

The Figure 4.32 shows the Comparison of Chloride Concentration of Kamarkhali Transit station at LFS, IFS and HFS. At high flow season the flows are higher in the month of June to September and it shows a lower value of chloride concentration. The chloride concentration in high flow season is not much less than the concentration of the low flow season for the exceedance 0% to 30%. For the exceedance probability 30% to 100%, it shows a big difference of chloride concentration among the seasons. The month December to March is the low flow season, and fresh water discharge from upstream decreases in quantity that's why it increases the chloride concentration. For the reversed case at high flow season, the freshwater discharge is higher which causes a reduction in the chloride concentration throughout the years. Again the April, May, October and November are the month of Intermediate flow seasons or flow transition season. In these months the flows are changing its patterns. The high flow comes to decrease at the month of October and November after which low flow season settles. Whereas low flow comes to increase in the month of April and May after which high flow season occurred.

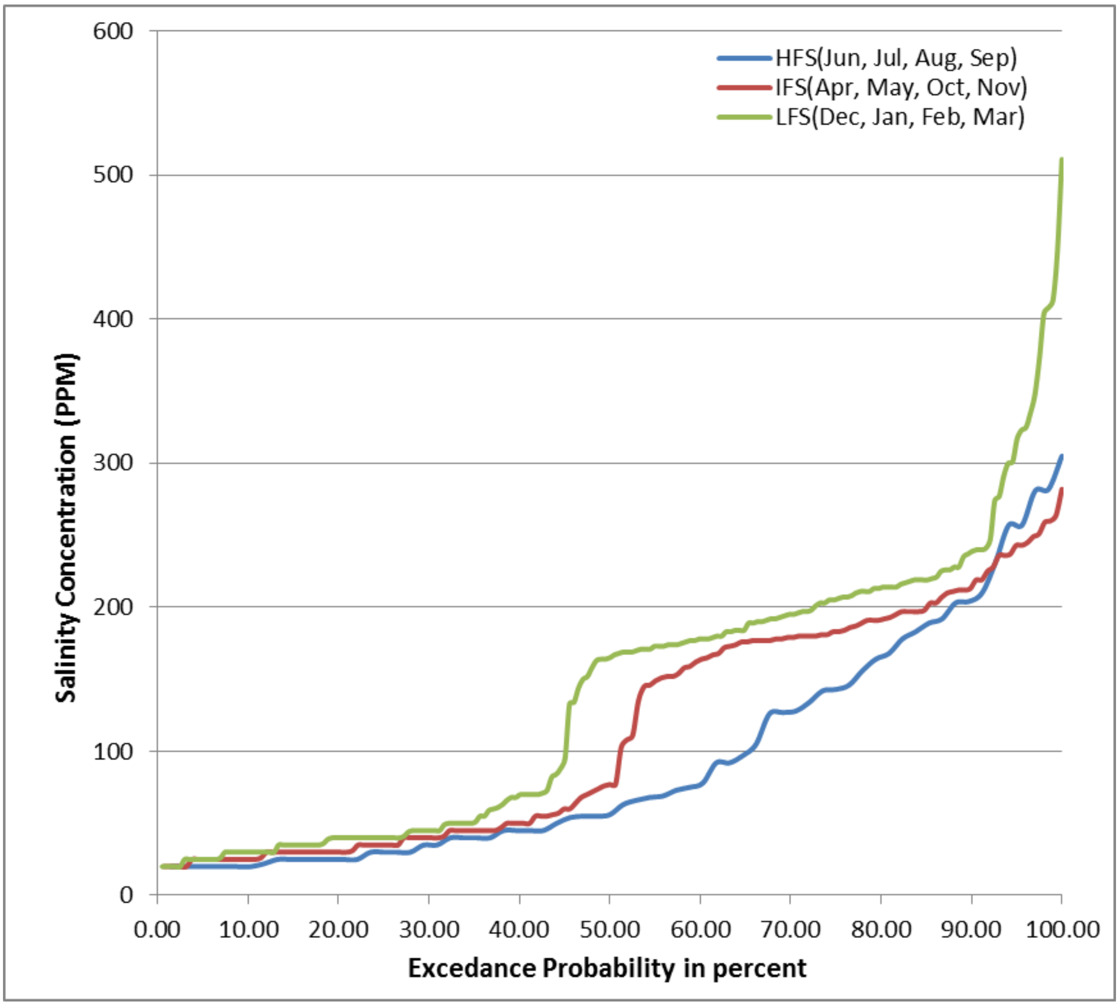

Figure 4.32: Comparison of Chloride Concentration of Kamarkhali Transit station at LFS, IFS and HFS

There are two possible ways for the high fresh water discharge in the month of June to September. The monsoon period in Bangladesh is in this period and the flows from the upstream and the surroundings drainage area falls in the river and the discharge increases rapidly. In Bangladesh, the rainy seasons contribute the overall rivers freshwater discharge and fulfill the environmental as well as habitat flow quality requirement. The fresh water discharge decreases from upstream to downstream due to the use of water for cultivation, loss due to evaporation and loss due to ground water infiltration.

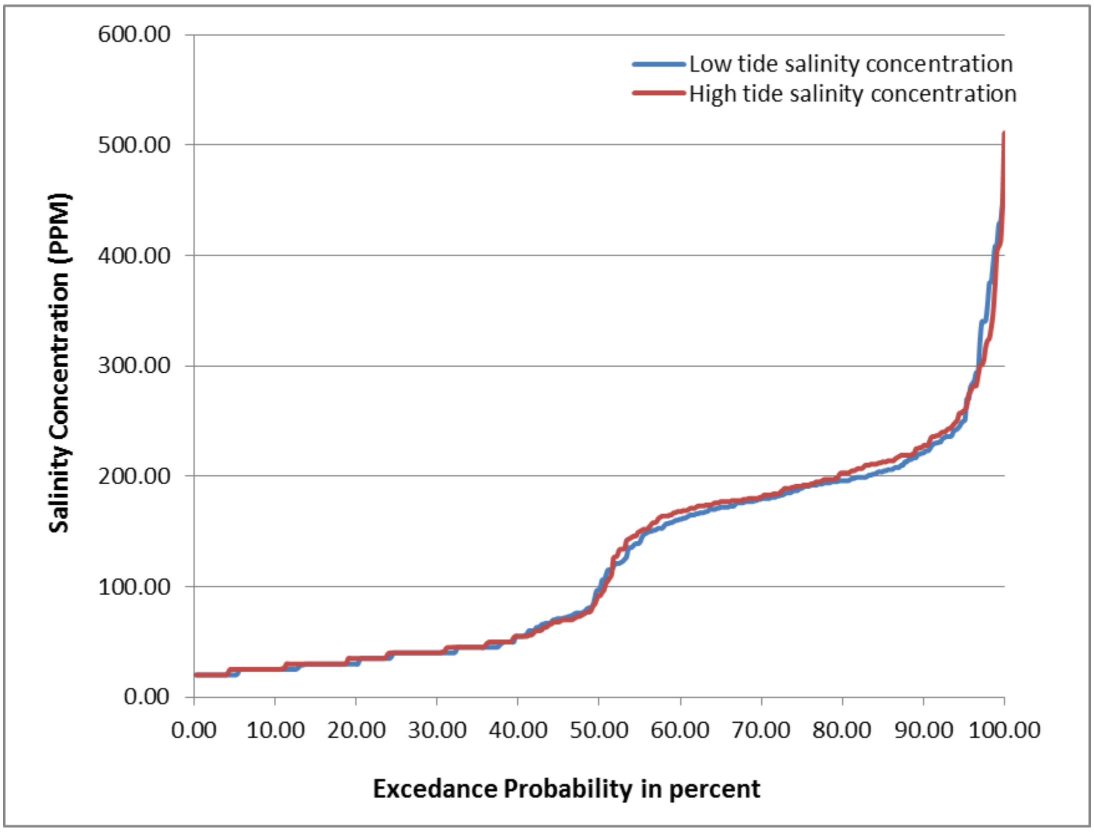

Figure 4.33: Comparison of Daily Chloride Concentration at Low Tide and High Tide Flow for Kamarkhali Transit station

Figure 4.33 shows Comparison of Daily Chloride Concentration at Low Tide and High Tide Flow for Kamarkhali Transit station. The flow conductance values are crosses each other at low tide and high tide. The graph shows no significant difference in chloride concentration at low tide and high tide in any of the sections throughout the year. The same concentration at low tide and high tide means it is independent of tide conditions. The differences in specific conductance from Low tide to High tide indicate an increase in vertical stratification as the water in the estuary is channeled in and out. Stratification of flow in the River has little effect on the daily mean specific-conductance values from lower to upper layers. In the analysis of the relation of Salinity to Freshwater Discharge in the River, the difference in daily mean specific-conductance values increases with distance downstream within the Gorai River.

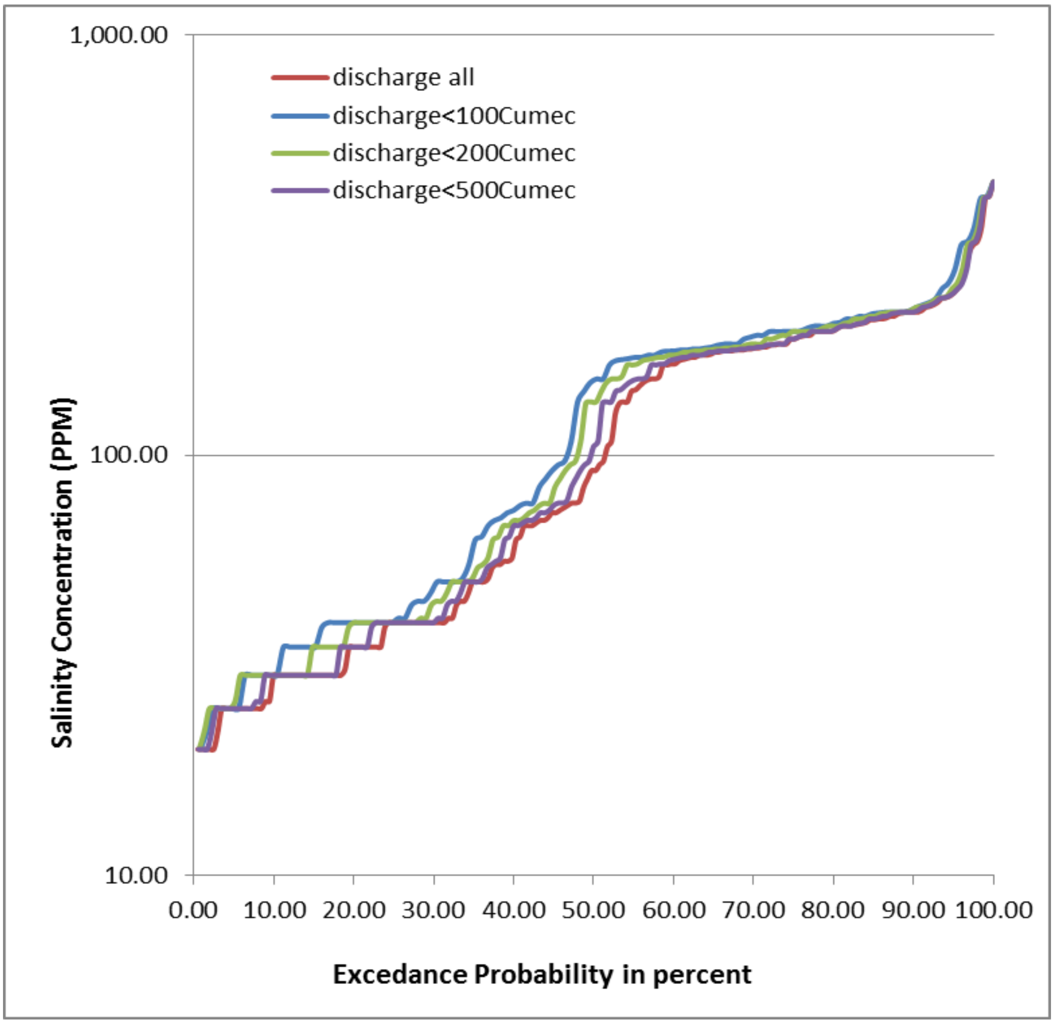

Figure 4.34: Specific-conductance duration curves for selected freshwater discharge at Kamarkhali Transit station

Salinity data shows correlation to the gradual mixing of water from upstream. Daily mean specific-conductance values were used for comparison and analysis in order to reduce the size of the data set, smooth the data set by averaging in outliers, reduce serial correlation, and maintain trends and characteristics of relatively short term events. The use of daily mean specific-conductance values represents the general trend of the data. The range in observed specific-conductance values may be characterized by duration curves. Daily mean specific-conductance duration curves indicate the number of days within a given period for which specific conductance is expected to be below a given value (Searcy, 1959).

Figure 4.34 shows Specific conductance duration curves for selected freshwater discharge at Kamarkhali Transit station. It is shown in the graph that, the discharges less than 100 Cumec, discharge less than 200 Cumec, discharge less than 500 Cumec and all discharge has followed a trend. The y-axis shows the conductance value and x-axis shows the exceedance probability in percentage in the Figure. The salinity for less than 100 Cumec discharge is higher and the salinity decreases with increase in the fresh water discharge up to 500 Cumec. The salinity shows lower value with high discharge upto 60% of probability of exceedance. After that from 60% to 100% probability of exceedance freshwater discharge value did not shows significant effect on salinity change. Small increase in fresh water discharge cause large change in salinity concentration from 5% to 60% probability of exceedance.

The correlation between the freshwater discharge and the salinity concentration shows that as the fresh water increases, the concentration of chloride or salinity decreases. The low flow season cause a reduction in the freshwater from upstream which causes a higher salinity in the River system of Gorai. Hence the salinity directly related to the fresh water as the low flow season have low freshwater and the salinity rises in the low flow season.

CHAPTER V

Conclusions and Recommendations

5.1 Conclusions

Environmental flow requirement of Gorai river represents the hydrological, cultural and morphological conditions as well as habitat condition of the river. The previous study shows a single point discharge or Salinity analysis, whereas in this analysis both the discharge and salinity values has taken for analysis and shown a co-relation of discharge and salinity effect on Gorai river route in different flow seasons.

The Salinity in river is found in the downstream tidal rivers of Bangladesh to the Bay of Bengal. These rivers are dependent on the volumes of freshwater discharging from upstream. Salinity concentrations at the Gorai river is higher in the dry season than in the monsoon due to the deficiency of freshwater flow from the upstream.

The major findings of this study are stated as follows:

1. The estimated environmental flow for the Gorai Railway bridge station is found as 237.93 Cumec, Which is the average of calculated environmental flow determined by MAF method (202.4 Cumec), Flow duration curve method (290 Cumec) and constant yield method (221.4 Cumec). The flows in June to November month meet the environmental flow requirement. From December to May, the river does not have sufficient discharge to meet environmental flow requirement. In the Gorai Railway bridge station, low flow season suffers in severe water shortage due to significant flow reduction in recent time.

2. In mean annual flow (MAF) method, August and March are the highest and lowest flowing months respectively for both the G1 (1984-1999) and G2 (2000-2016) periods for Gorai Railway bridge station. The MAF flow in March is found as 34.89 Cumec and 68.49 Cumec for G1 and G2 periods, respectively. The MAF flow in August is found as 3972 Cumec and 2925 Cumec for G1 and G2 periods, respectively.

3. In flow duration curve (FDC) method, August and September are the highest flowing months for G1 and G2 periods respectively and April is the lowest flowing months for both G1 and G2 periods for Gorai Railway bridge station. The flows in April are found as 9.589 Cumec and 51.5 Cumec for G1 and G2 periods, respectively. For G1 period the highest flows in FDC

method is found in August as 4051 Cumec; and for G2 period the highest flow is found in September as 3195 Cumec

4. In CY method August and September are the highest flowing months for G1 and G2 periods respectively and February and April are the lowest flowing months for G1 and G2 periods, respectively for Gorai Railway bridge station. For G1 period, CY flow is found in February as 3.073 Cumec and for G2 period, CY flow is found in April as 51.5 Cumec. The highest CY flow is found in August as 4051 Cumec in G1 period and for G2 period, it is found as 3195 Cumec in September. However, very high increase in flow occurs at July and high reduction occurs in October for all the methods.

5. The estimated environmental flow for the Kamarkhali Transit station is found as 162.95 Cumec, Which is the average of calculated environmental flow determined by MAF method (159 Cumec), Flow duration curve method (167 Cumec) and constant yield method (162.85 Cumec). The flows in June to November month meet the environmental flow requirement. From December to May, the river does not have sufficient discharge to meet environmental flow requirement.

6. In MAF method August is the highest flowing months for both the G1 (1984-1999) and G2 (2000-2016) periods, and February and March are lowest flowing months respectively for G1 and G2 periods for the Kamarkhali Transit station. The MAF flow in August is found as 3177 Cumec and 2460 Cumec for G1 and G2 periods, respectively. The MAF flow in February is found as 39 Cumec and MAF flow in March is found as 28.25 Cumec for G1 and G2 periods, respectively.

7. In FDC method August and September are the highest flowing months for G1 and G2 periods, respectively and April is the lowest flowing months for both G1 and G2 periods, for Kamarkhali Transit station. The flows in April are found as 46.6 Cumec and 16.13 Cumec for G1 and G2 periods, respectively. For G1 period the highest flow in FDC method is found in August as 3743 Cumec; and for G2 period highest flow is found in September as 2444 Cumec.

8. In CY method August and September are the highest flowing months for G1 and G2 periods, respectively and February and March are lowest flowing months for G1 and G2 periods, respectively for the Kamarkhali Transit station. For G1 period, CY flow is found in February as 20.69 Cumec and for G2 period, CY flow is found in March as 15.29 Cumec. The highest CY flow is found in August as 3743 Cumec in G1 period and for G2 period it is found

in September as 2444 Cumec. However, very high increase in flow occurs at July and high reduction occurs in October for all the methods.

9. For the Gorai Railway Bridge and Kamarkhali Transit stations the MAF is found as 1012 Cumec and 795 Cumec, respectively. The flow requirement according to habitat quality for the Gorai Railway Bridge and Kamarkhali Transit station for flushing flow is 200% of MAF. Therefore for Gorai it is 2024 Cumec and for Kamarkhali it is 1590.2 Cumec. For good quality the required flow will be 40% at HFS and 20% at LFS of MAF. For fair quality the required flow will be 30% at HFS and 10% at LFS. For poor quality the required flow will be 10% at both HFS and LFS. Severe degradation will occur if the flow will be less than 10% for both the HFS and LFS. it is found that, for Gorai Railway bridge station the severe degradation is occurred if the flow is less than 101.2 Cumec and for Kamarkhali transit station the severe degradation is occurred if the flow is less than 79.51 Cumec.

10. It is observed that, the river condition is good at the high flow season but when the flow comes in low flow season it becomes lower than the environmental flows required for good habitat quality. The flows in the month of January to May are less than the EFR required. The flows of these months are less than the severe degradation flow. It shows severe problems for both the stations. For the Gorai river, it is necessary to maintain the flow values more than the severe degradation throughout the year to sustain the habitat quality for the river. The three methods show different values for environmental flow requirement. The flow requirements in the low flow season for three methods are found lower than the required flow in both stations.

11. Observing MAF, FDC and CY methods it is found that, the discharge of G1 period is generally lower than G2 period in the month November to June, whereas the discharge of G1 period is higher than G2 period in the month July to October at Gorai railway Bridge station. On the other hand for Kamarkhali Transit station, the discharge of G1 period is generally lower than G2 period in the month November to January, whereas the discharge of G1 period is higher than G2 period in the month February to October.

12. The salinity is generally found higher in the month of November to June. These are the low flow season that includes post-monsoon and pre-monsoon period. It shows a higher value of chloride concentration. The highest individual one day chloride concentration is found as 511 ppm, and the average monthly highest chloride concentration is found as 152.8 ppm in the month of February. At high flow season the flows are higher in the month of July to October. It shows a lower value of chloride concentration. The lowest individual one day chloride concentration is found as 20 ppm, and the

average monthly lowest chloride concentration is found as 37.5 ppm in the month of October.

13. The chloride concentration in high flow season is not much less than the concentration of the low flow season for the exceedance 0% to 30%. For the exceedance probability 30% to 100%, it shows a big difference of chloride concentration among the seasons. The salinity for less than 100 Cumec discharge is higher and the salinity decreases with increase in the fresh water discharge up to 500 Cumec. The salinity shows lower value with high discharge upto 60% of probability of exceedance. After that from 60% to 100% probability of exceedance freshwater discharge value did not shows significant effect on salinity change. Small increase in fresh water discharge cause large change in salinity concentration from 5% to 60% probability of exceedance.

14. The chloride concentration at low tide and high tide shows no significant difference for the same day. The same concentration at low tide and high tide means salinity is independent for the low tide and high tide flow values.

5.2 Observation and Suggestions

It is observed that, the river is endangered for habitat quality in low flow seasons. In every method it proved that, the Gorai River has flow scarcity because of the low flows from upstream. The estimated environmental flow requirement found in FDC method is highest among three methods for both the Gorai Railway Bridge station and Kamarkhali Transit station. So considering the flow conservancy, the FDC method is the best for estimation of environmental flow requirement of a river. Again the EFR of LFS, IFS and HFS can be estimated in FDC method which is absent in MAF and CY methods.

From the study the following suggestions are strongly recommended for implementation of the better management and protection of Gorai River morphology in the basin area and mangrove ecosystems in the catchment.

1. Construction of barrages to be restricted in the upstream
2. Withdrawal of water from river to be limited
3. Construction of dams to be restricted in the upstream
4. International river water share rules to be followed
5. Agricultural stressors to be maintained properly
6. Sedimentation should not be allow to the river bed

5.3 Recommendations for further study

Due to seasonal variation having abundance of water during monsoon and little water during dry season, harnessing of the bounty of this water is very essential which requires storage of monsoon flows over space and time when and where required within a framework of sustainable development.

Based on the current study some recommendations for future study can be as follows:

1. The discharge data is not available in the downstream of Gorai River, but the water level data is available. So with the help of rating curve, discharge data can be reproduced and EFR can be calculated for downstream stations.

2. To calculate the spatial and temporal variation of salinity in the downstream of Gorai River, further study can be done.

3. In this study IHA software is used and EFR is calculated based on MAF, FDC and CY methods. EFR can be calculated by other available methods to compare with present study.

4. The EFR for any other rivers can be estimated using the method used in this study.

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Appendix A

Technical terms used in this analysis

Mean annual flow: Mean annual flow is the average flow for the individual year or multi-year period of interest. Mean annual flow is obtained by dividing the sum of all the individual daily flows by the number of daily flows recorded for the year. In other words MAF is the average amount of water that flows down a particular river point, per year.

Annual C.V.: The Annual CV (%) is an index of climatic risk, indicating a likelihood of fluctuations. The coefficient of variation (CV) is a statistical measure of the dispersion of data points in a data series around the mean. The coefficient of variation represents the ratio of the standard deviation to the mean, and it is a useful statistic for comparing the degree of variation from one data series to another, even if the means are drastically different from one another.

The Formula for Coefficient of Variation is CV = standard deviation/mean.

Flow predictability: Flow Predictability is a measure that represents how confident a particular outcome of flow can be determined ahead of time. Predictability ranges in value from 0 to 1 and is composed of two additive components: constancy (C), a measure of temporal invariance, and contingency (M), a measure of periodicity. The predictability of a stream with very constant flow will be mostly due to C, while the predictability of a stream with highly variable flow with a fixed periodicity will be mostly due to M.

Flow constancy / Flow predictability: C / (C+M).

Flood-free season: This is the length in days of the longest period common to all water years where flows are at or below the high pulse threshold in every year.

Base flow index: It is a measure of the amount of flow in a river during dry or low flow periods. baseflow index is defined as the ratio of long-term base flow to total stream flow.

Rise rate: Mean or median of all positive differences between consecutive daily values.

Fall rate: Mean or median of all negative differences between consecutive daily values.

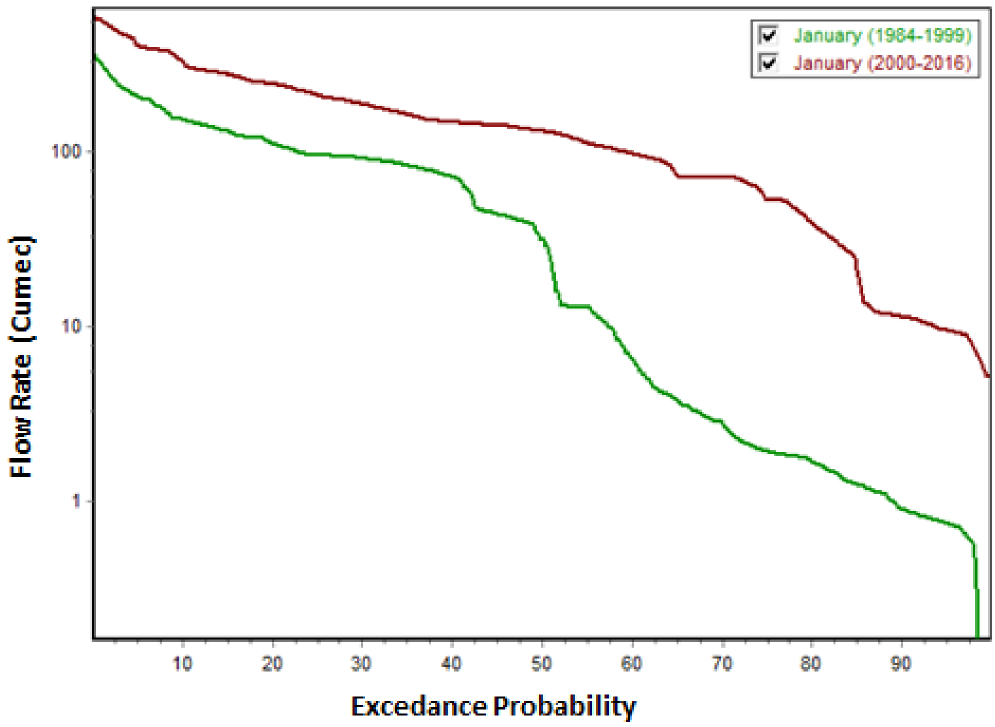
High flow threshold: All flows greater than this threshold are classified as high flows, and all flows less than or equal to this threshold are classified as low flows. This parameter can be specified as a percentile of all daily flows or as a flow value. The default value is the 75th percentile of daily flows.

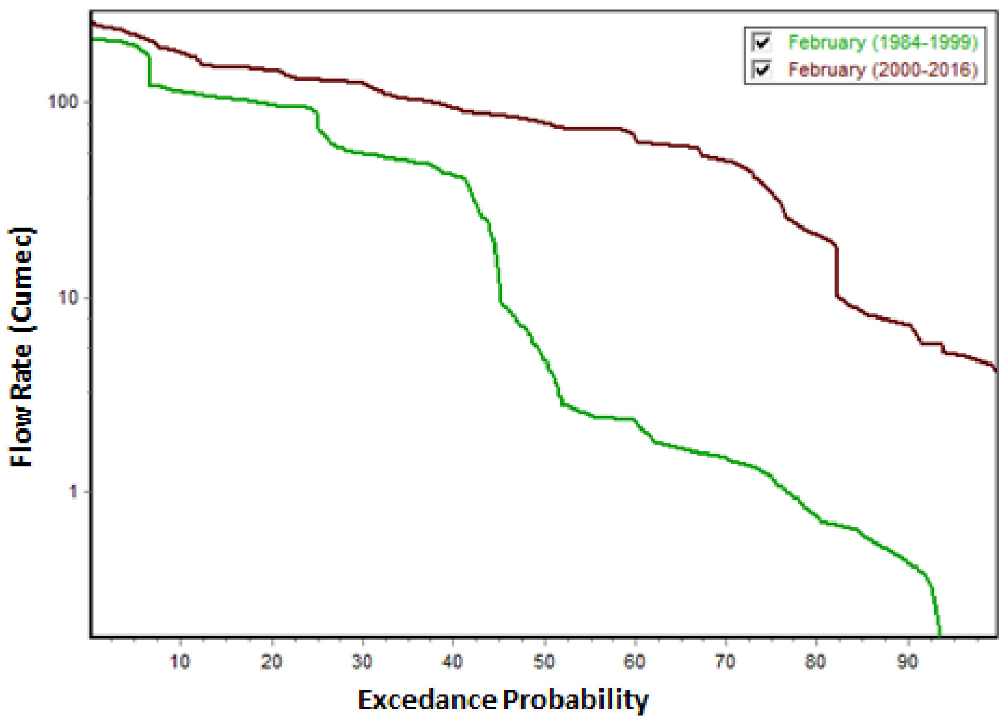
Low flow threshold: All flows less than or equal to this threshold are classified as low flow events. This parameter must always be less than the *high flow threshold.* This parameter can be specified as a percentile of all daily flows or as a flow value. The default value is the 50^{th} percentile of daily flows.

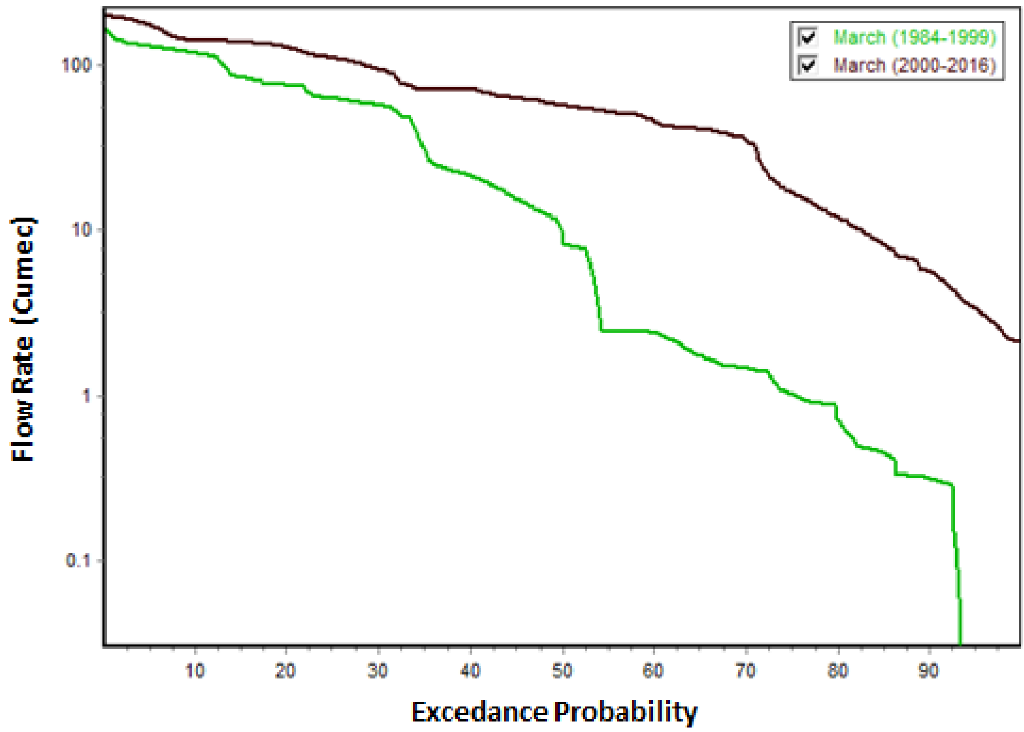
Extreme low flow threshold: All low flow days with a flow value less than or equal to this value will be classified as extreme low flows. The user has the option to enter this as a percentile of all daily low flows, as a percentile of all daily flows, or as a flow value. The default value is the 10th percentile of daily low flows.

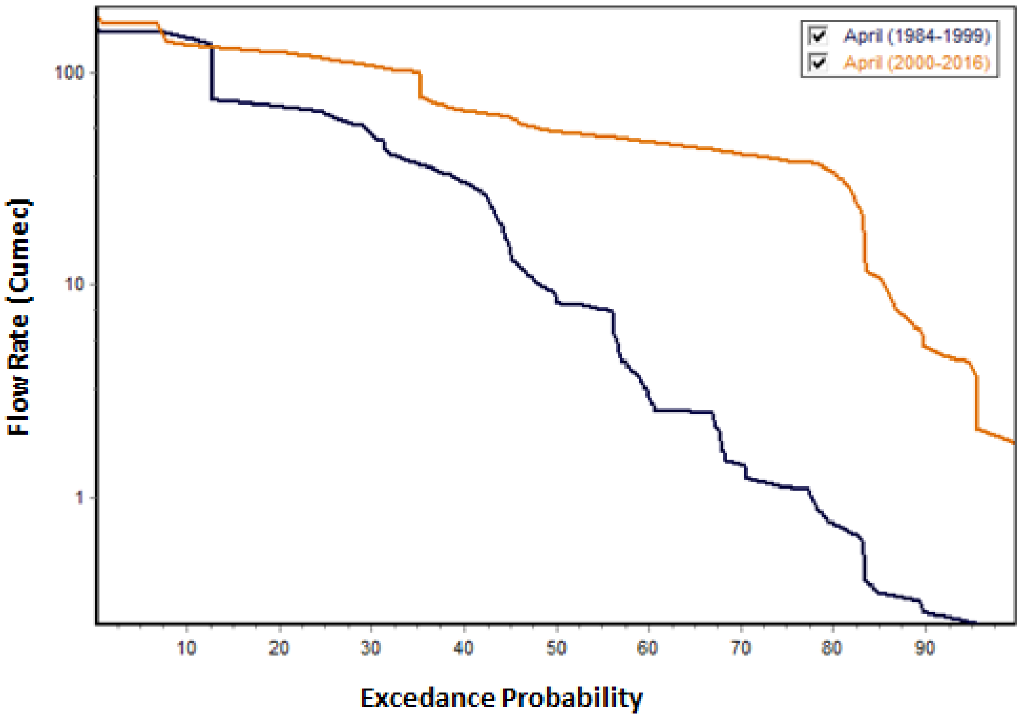
Appendix B

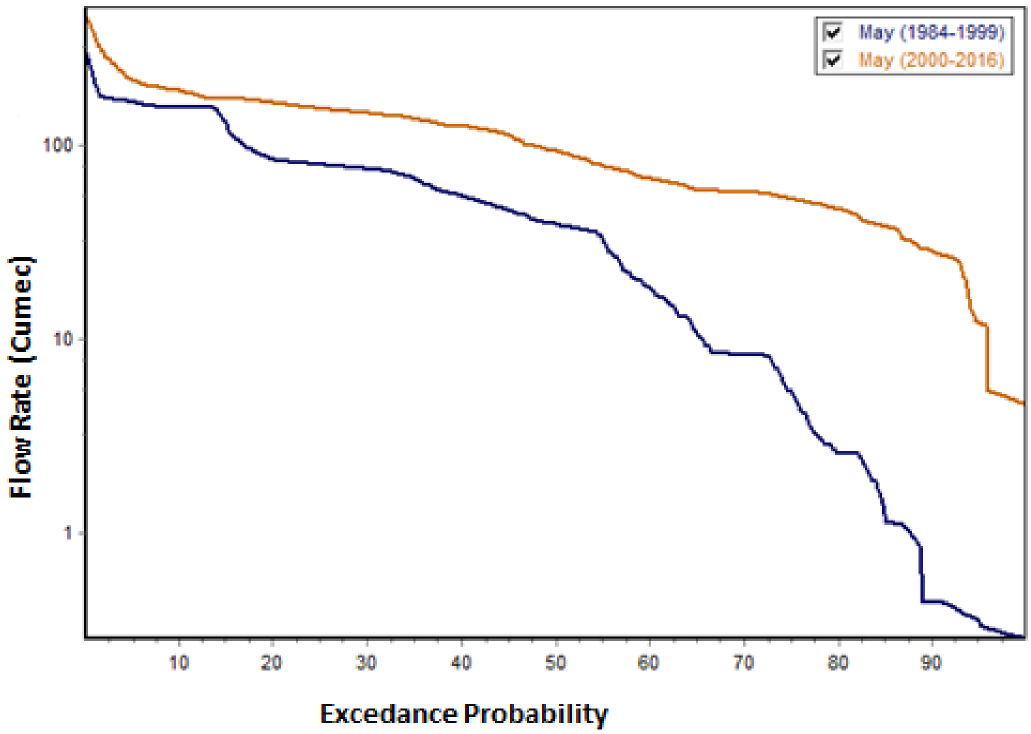
Monthly Flow Duration Curves for Gorai Railway Bridge station

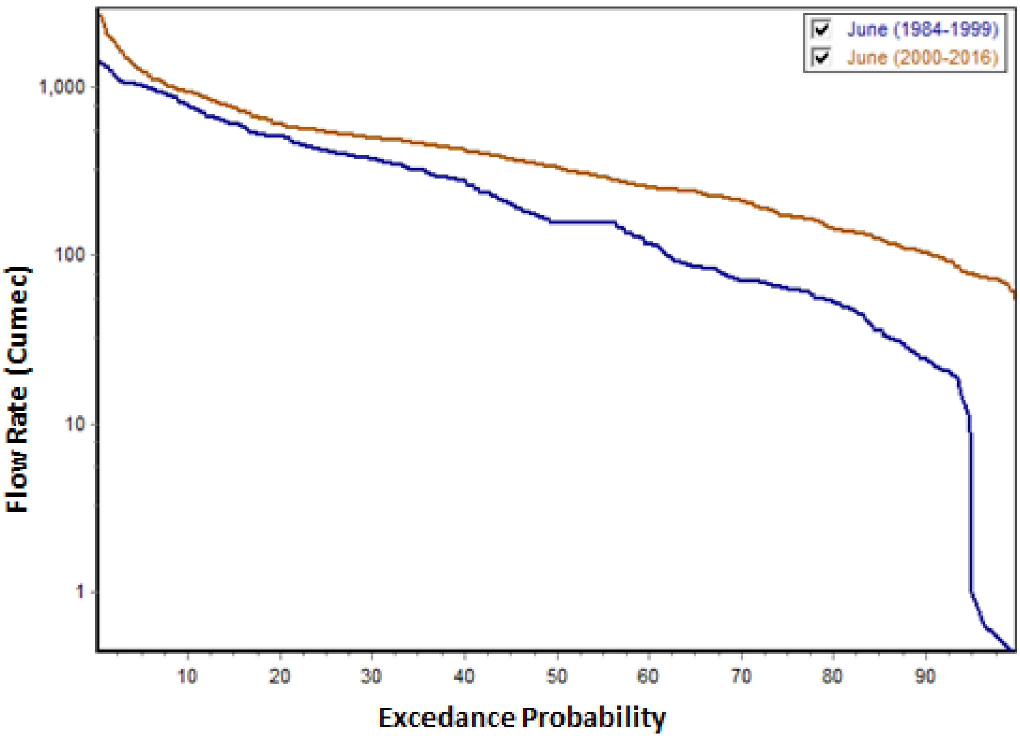


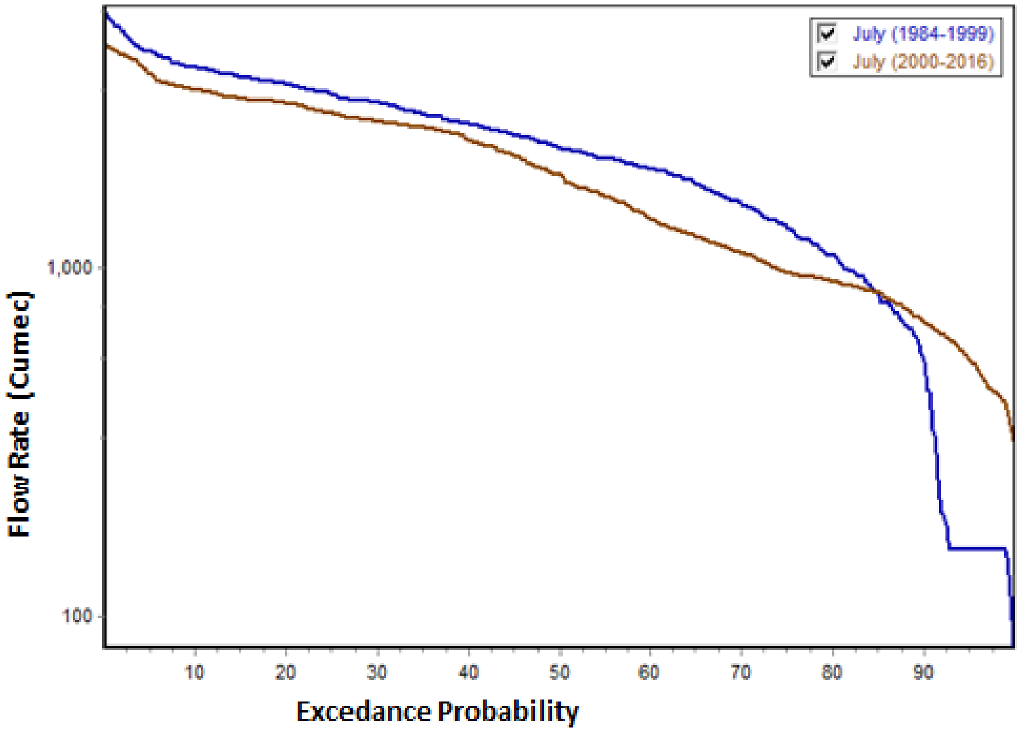


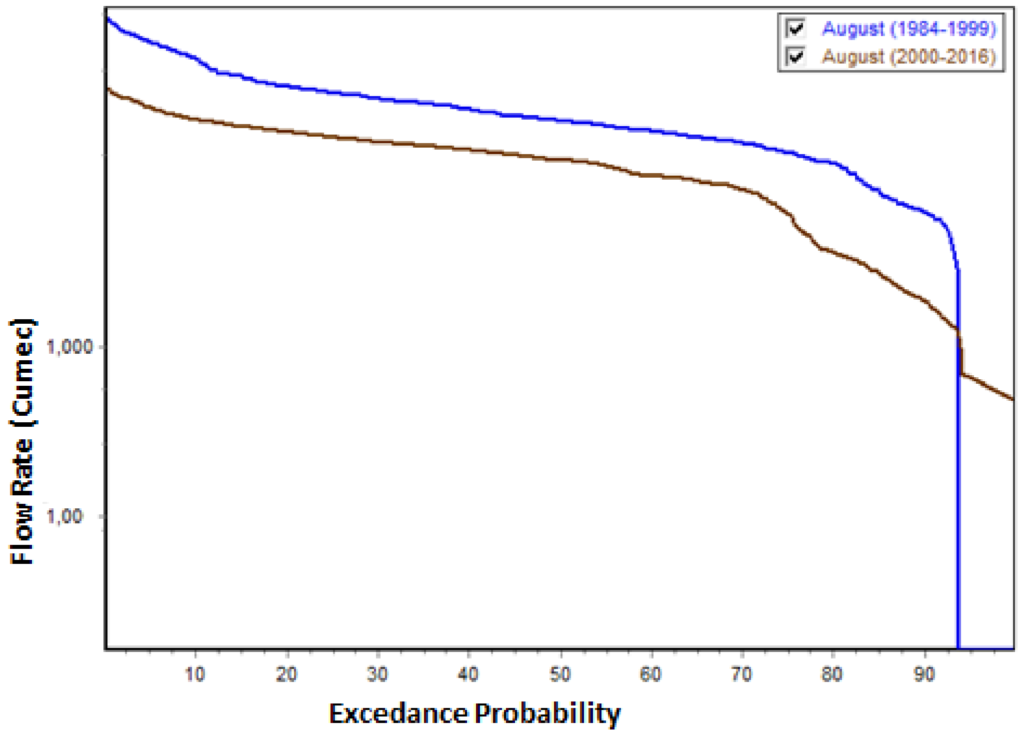

March (1984-1999)
March (2000-2016)
100
10
1
0.1
10
20
30
40
50
60
70
80
90
Flow Rate (Cumec)
Excedance Probability

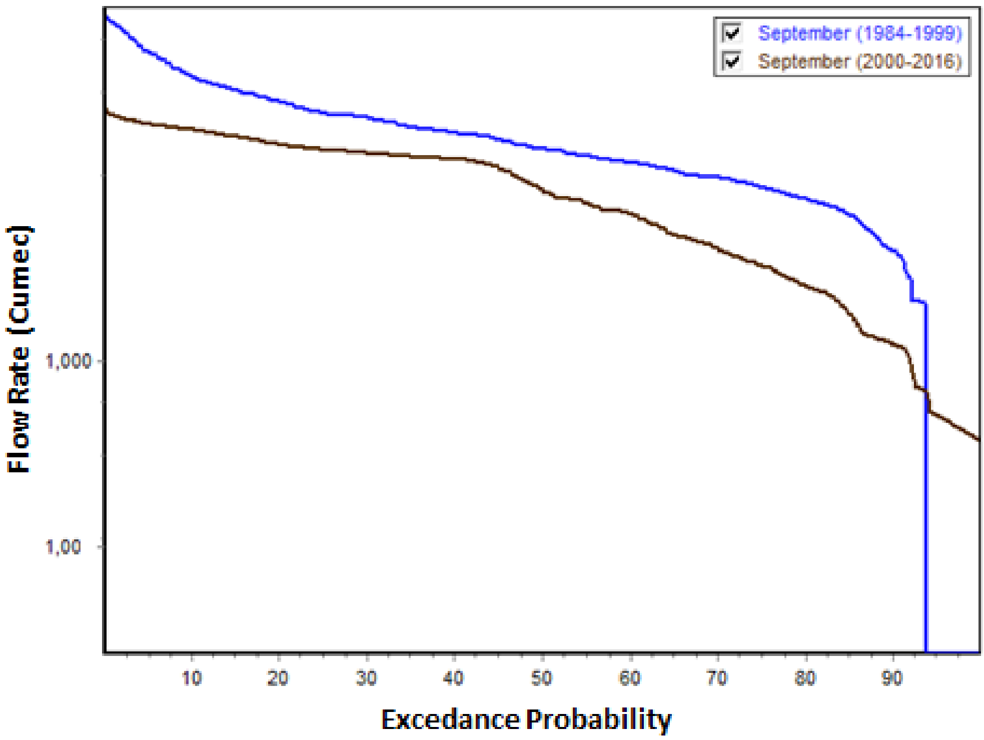

April (1984-1999)
April (2000-2016)
100
10
1
10
20
30
40
50
60
70
80
90
Flow Rate (Cumec)
Excedance Probability

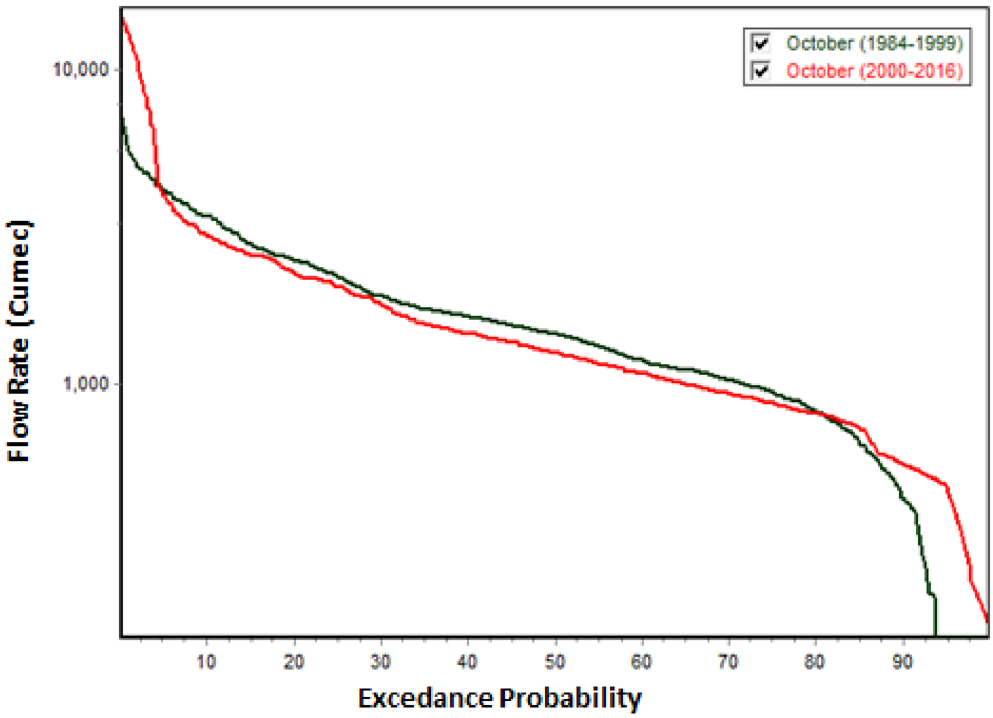

May (1984-1999)
May (2000-2016)
100
10
1
10
20
30
40
50
60
70
80
90
Flow Rate (Cumec)
Excedance Probability

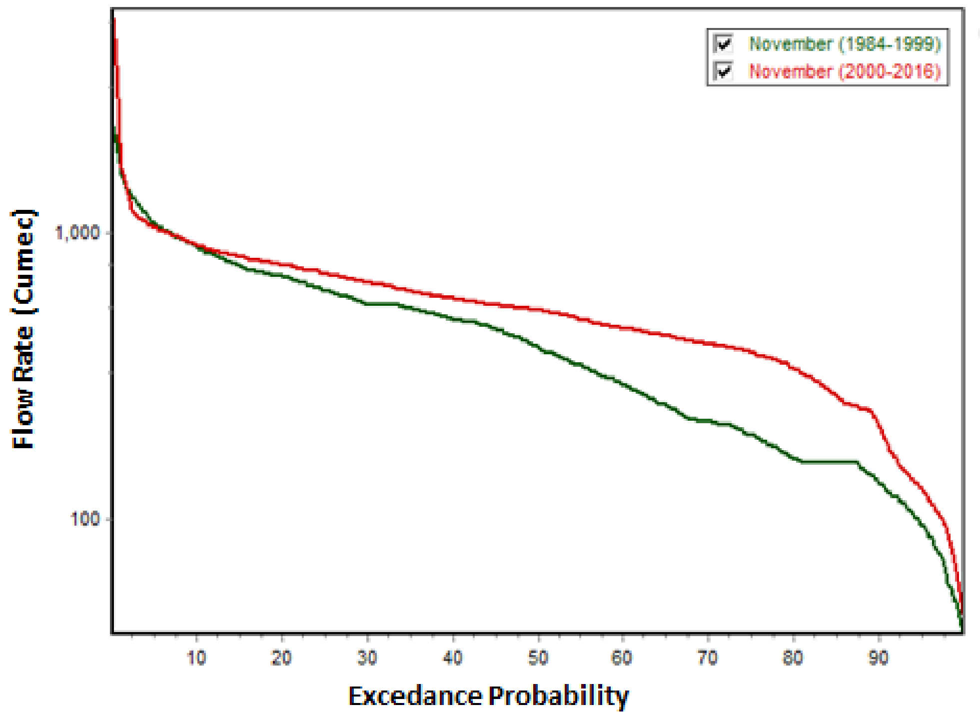

June (1984-1999)
June (2000-2016)
1,000
100
10
1
10
20
30
40
50
60
70
80
90
Flow Rate (Cumec)
Excedance Probability

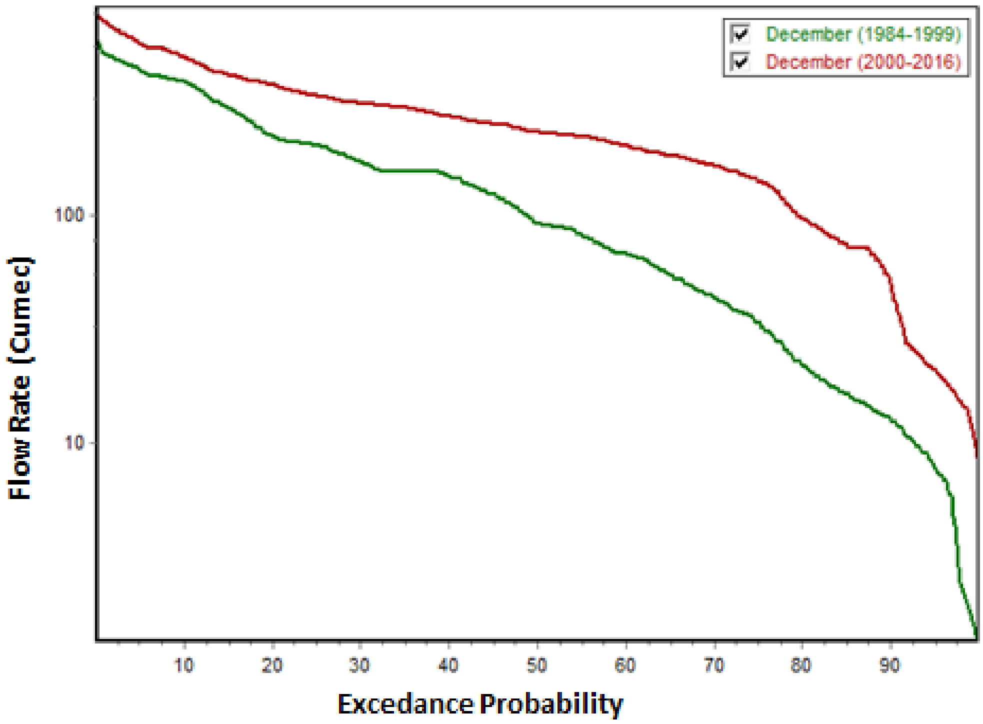

July (1984-1999)
July (2000-2016)
Flow Rate (Cumec)
1,000
100
10
20
30
40
50
60
70
80
90
Excedance Probability


August (1984-1999)
August (2000-2016)
Flow Rate (Cumec)
1,000
1,00
10
20
30
40
50
60
70
80
90
Excedance Probability


September (1984-1999)
September (2000-2016)
Flow Rate (Cumec)
1,000
1,00
10
20
30
40
50
60
70
80
90
Excedance Probability

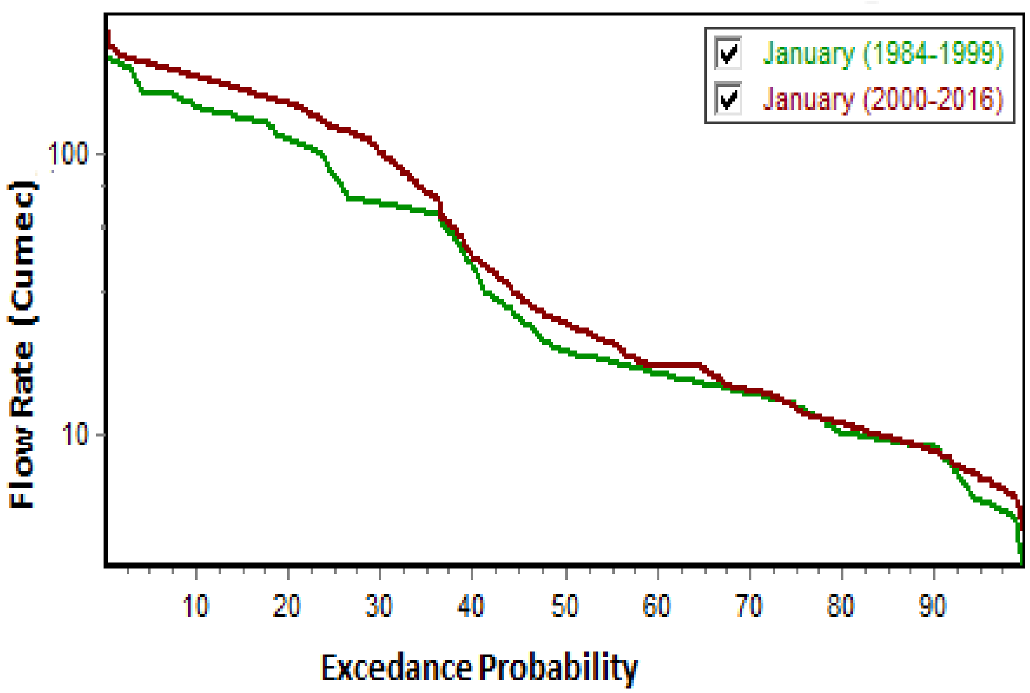

October (1984-1999)
October (2000-2016)
Flow Rate (Cumec)
10,000
1,000
10
20
30
40
50
60
70
80
90
Excedance Probability

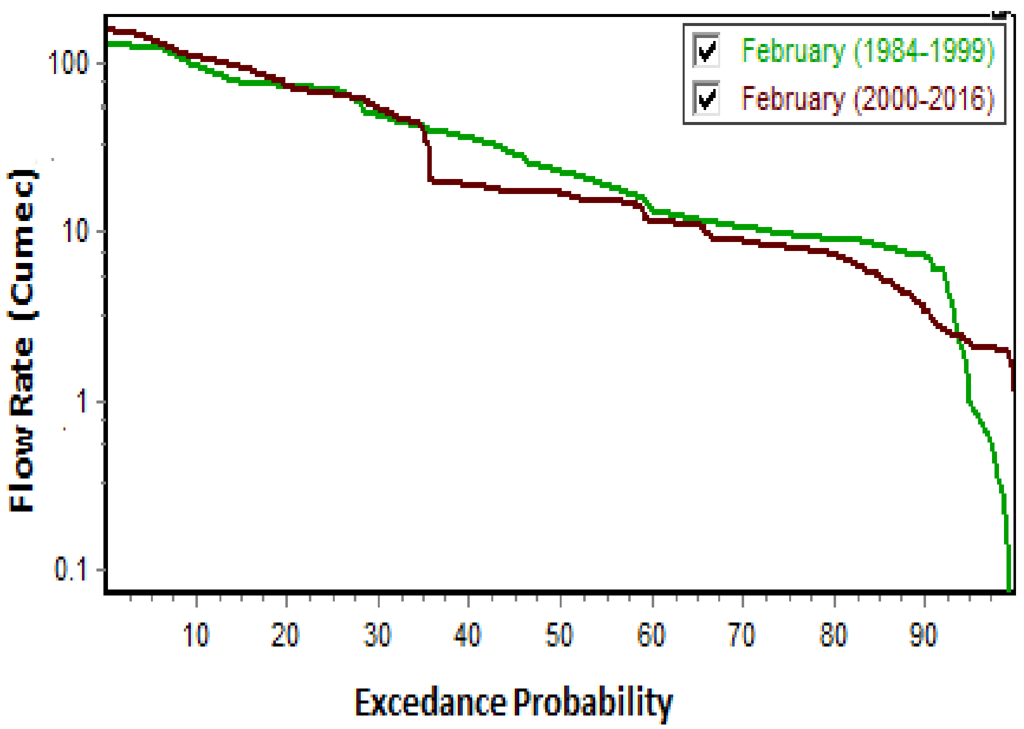

November (1984-1999)
November (2000-2016)
Flow Rate (Cumec)
1,000
100
10
20
30
40
50
60
70
80
90
Excedance Probability

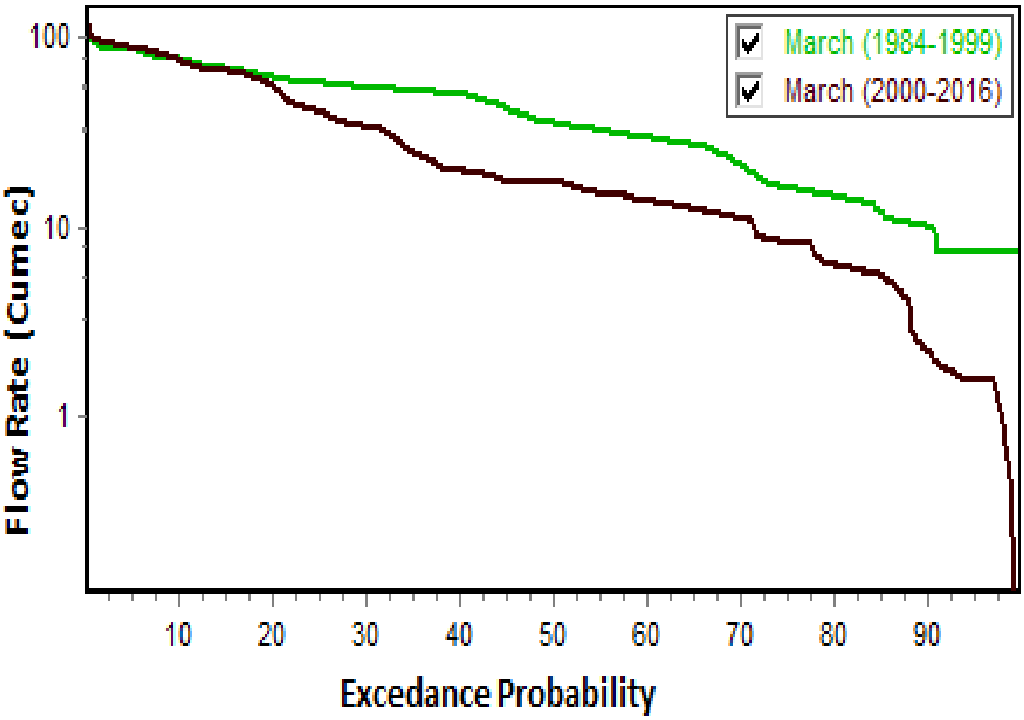

December (1984-1999)
December (2000-2016)
Flow Rate (Cumec)
100
10
10
20
30
40
50
60
70
80
90
Excedance Probability

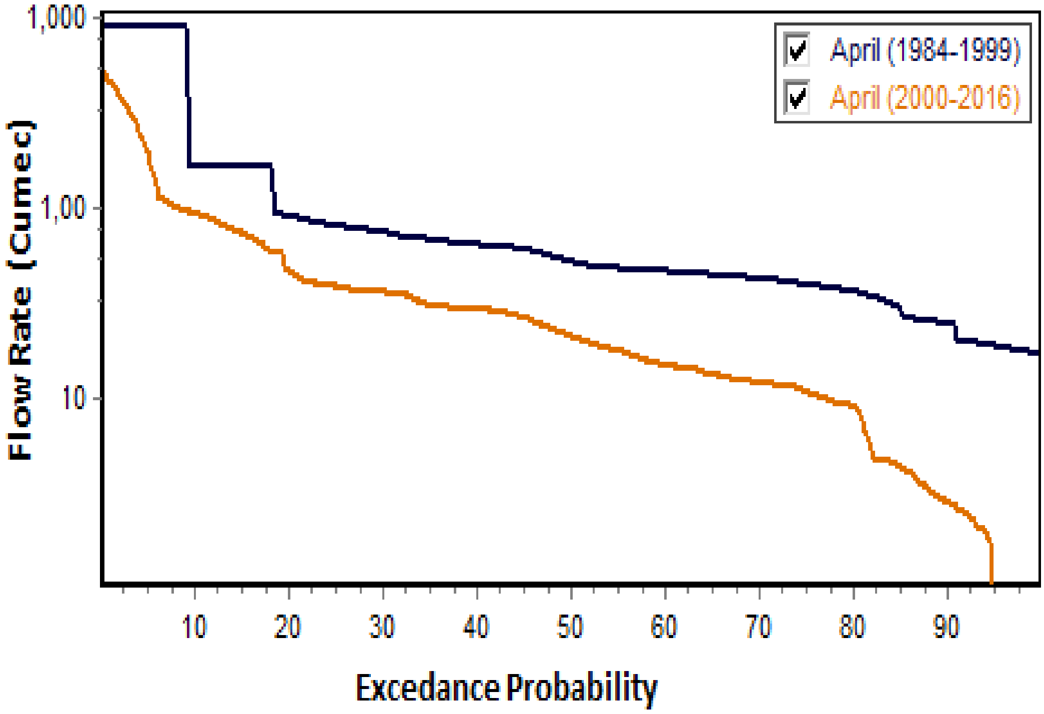
Appendix C

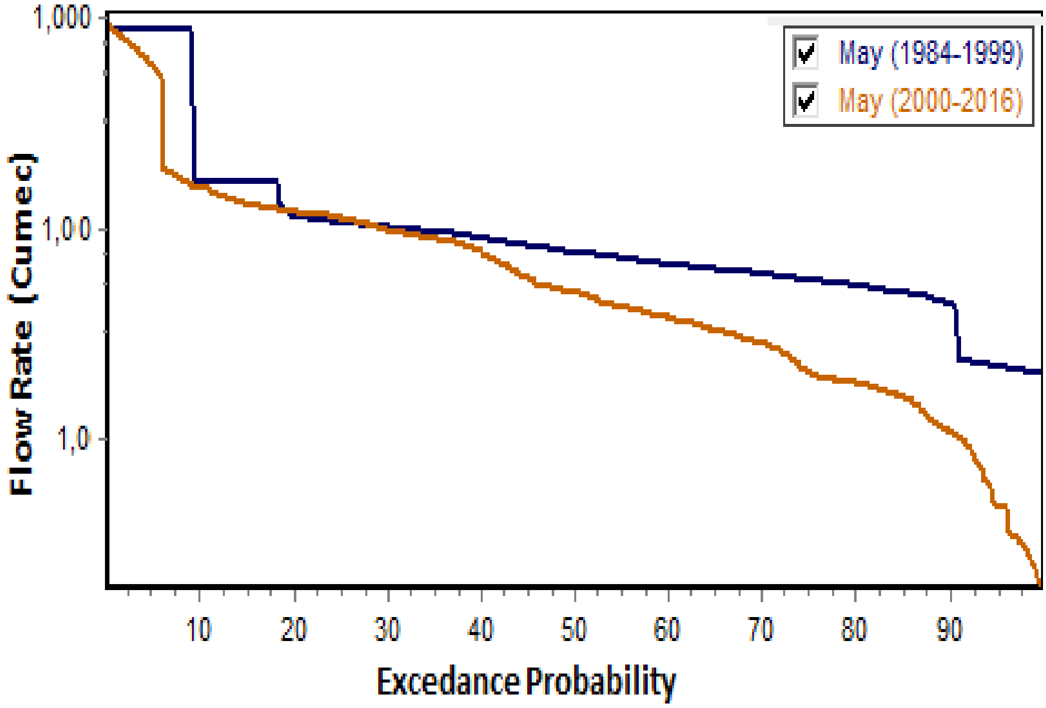
Monthly Flow Duration Curves for Kamarkhali Transit station



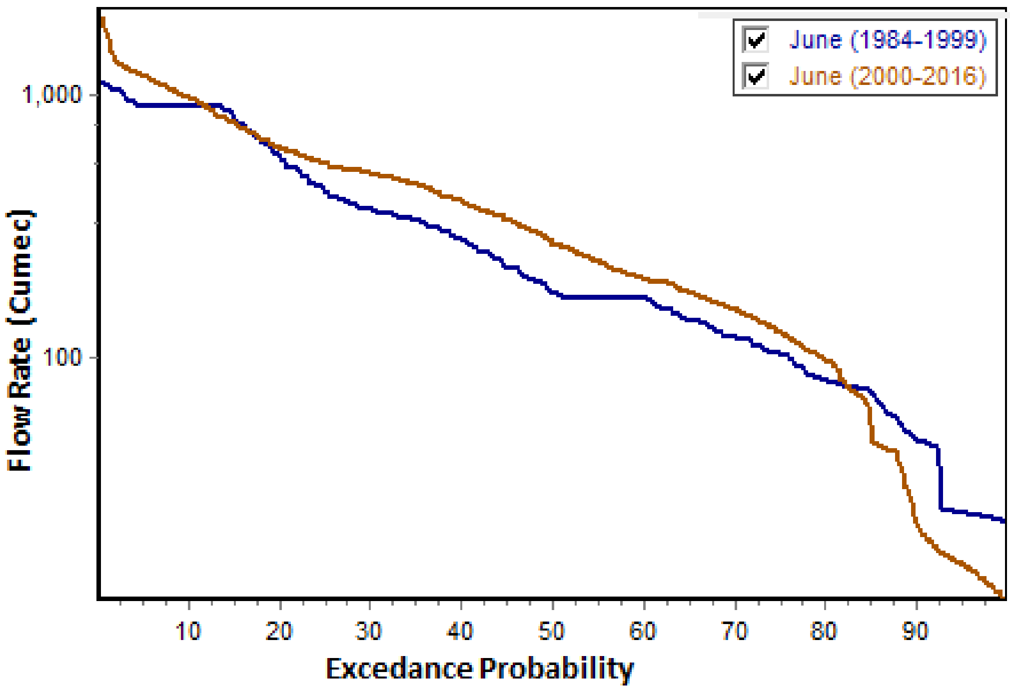



March (1984-1999)
March (2000-2016)
100
10
1
Flow Rate (Cumec)
10
20
30
40
50
60
70
80
90
Excedance Probability

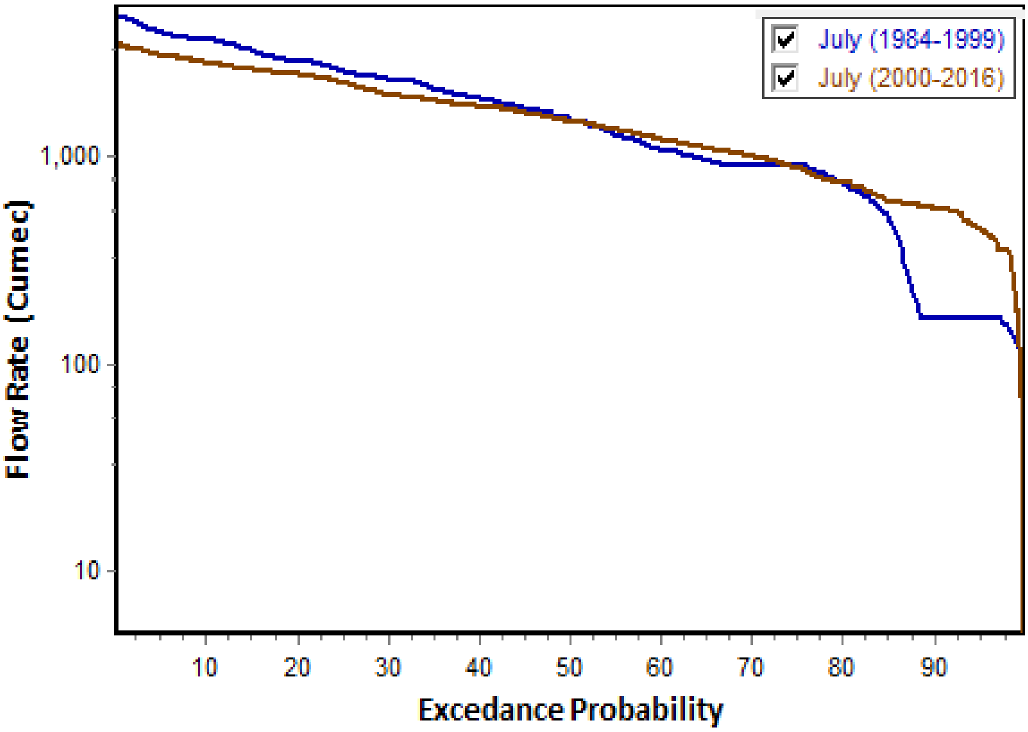

April (1984-1999)
April (2000-2016)
1,000
1,00
10
Flow Rate (Cumec)
10
20
30
40
50
60
70
80
90
Excedance Probability



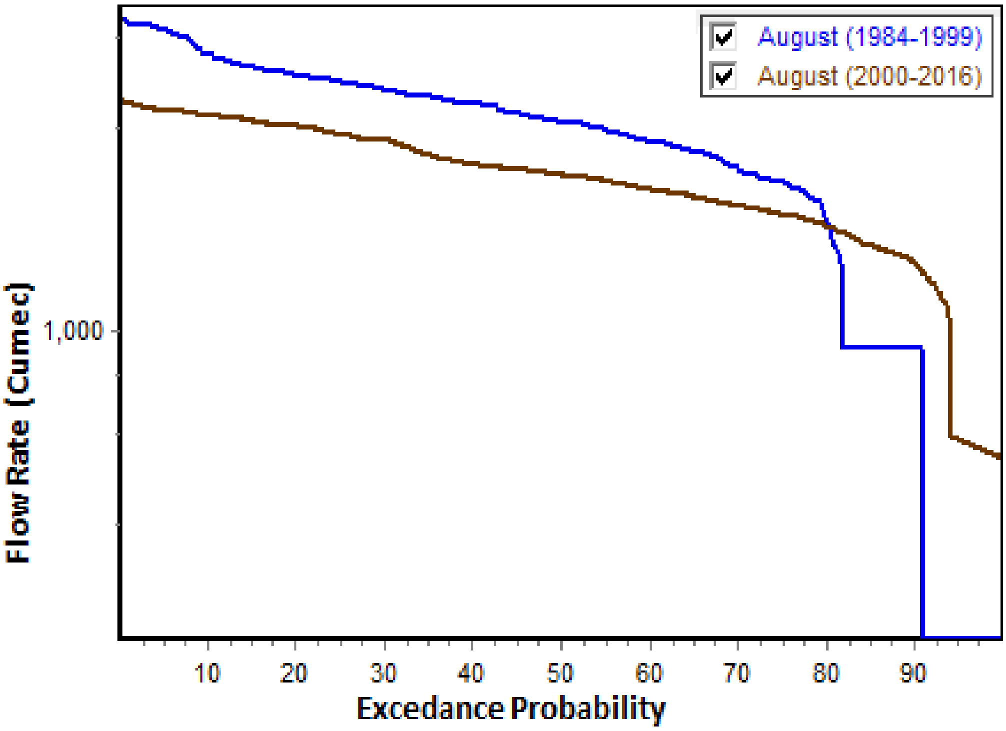
May (1984-1999)
May (2000-2016)
1,000
1,00
1,0
Flow Rate (Cumec)
10
20
30
40
50
60
70
80
90
Excedance Probability



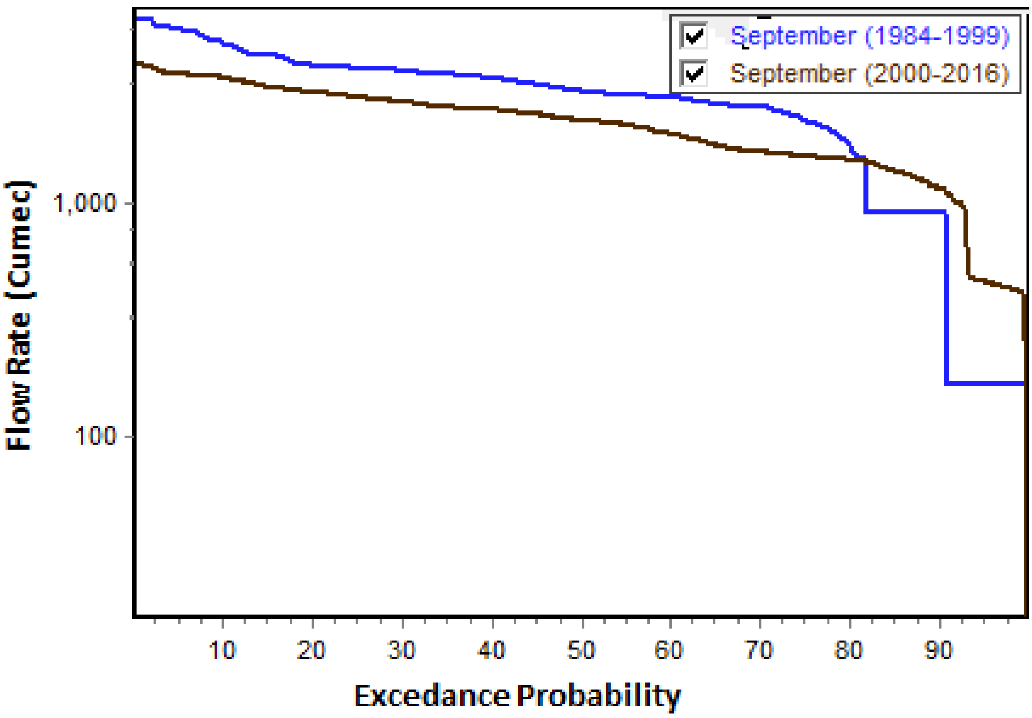
June (1984-1999)
June (2000-2016)
1,000
100
Flow Rate (Cumec)
10
20
30
40
50
60
70
80
90
Excedance Probability

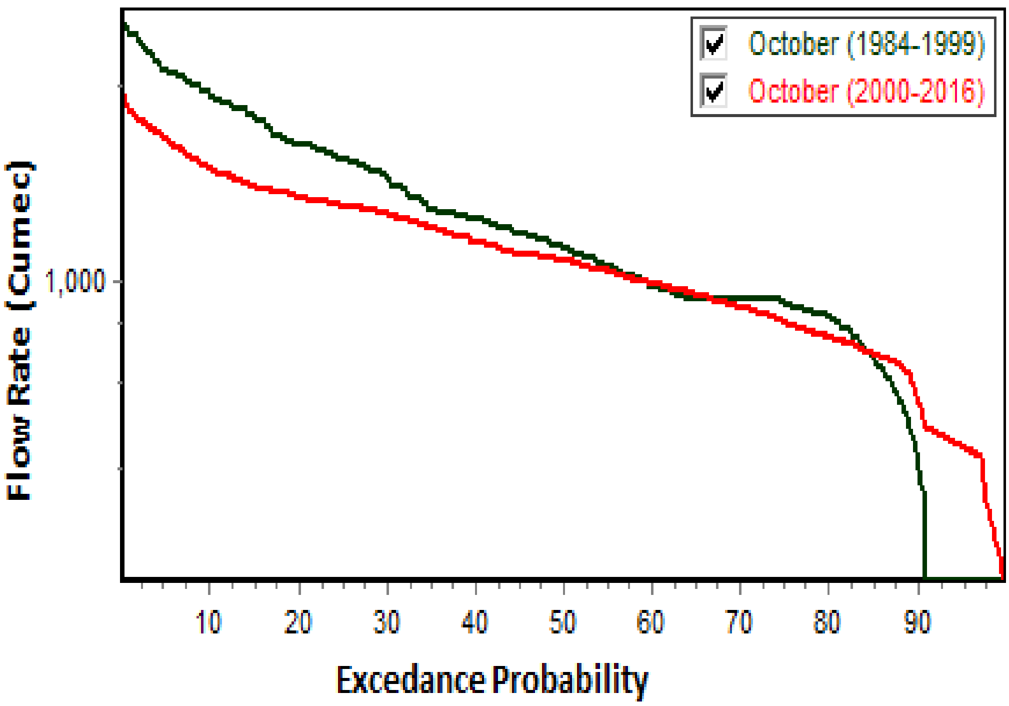


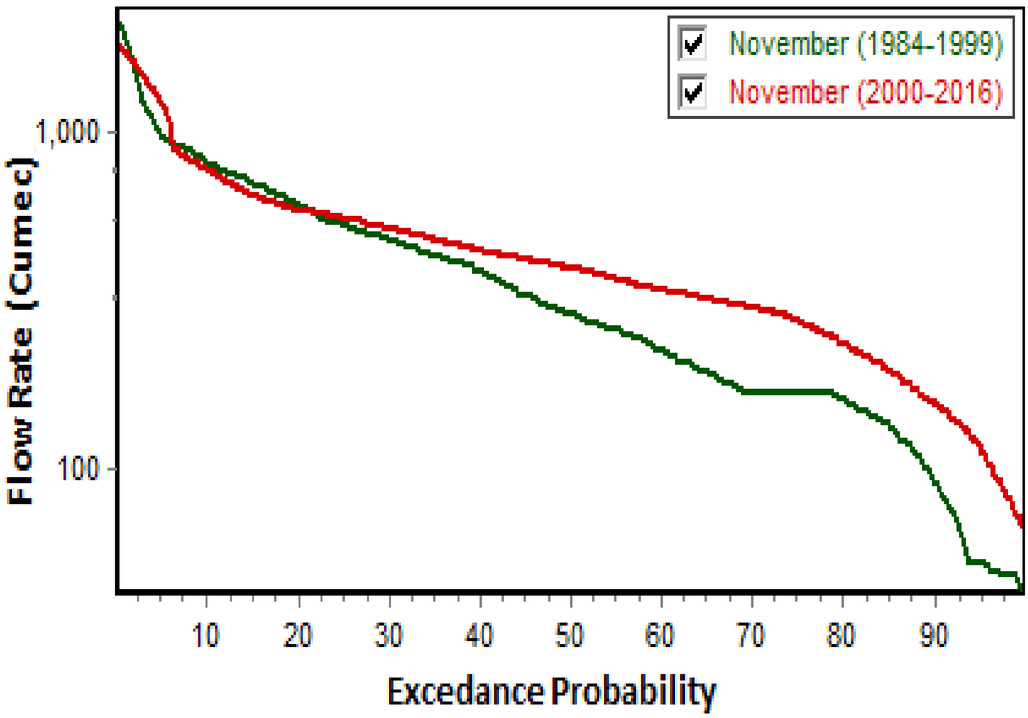
July (1984-1999)
July (2000-2016)
1,000
100
10
Flow Rate (Cumec)
10
20
30
40
50
60
70
80
90
Excedance Probability

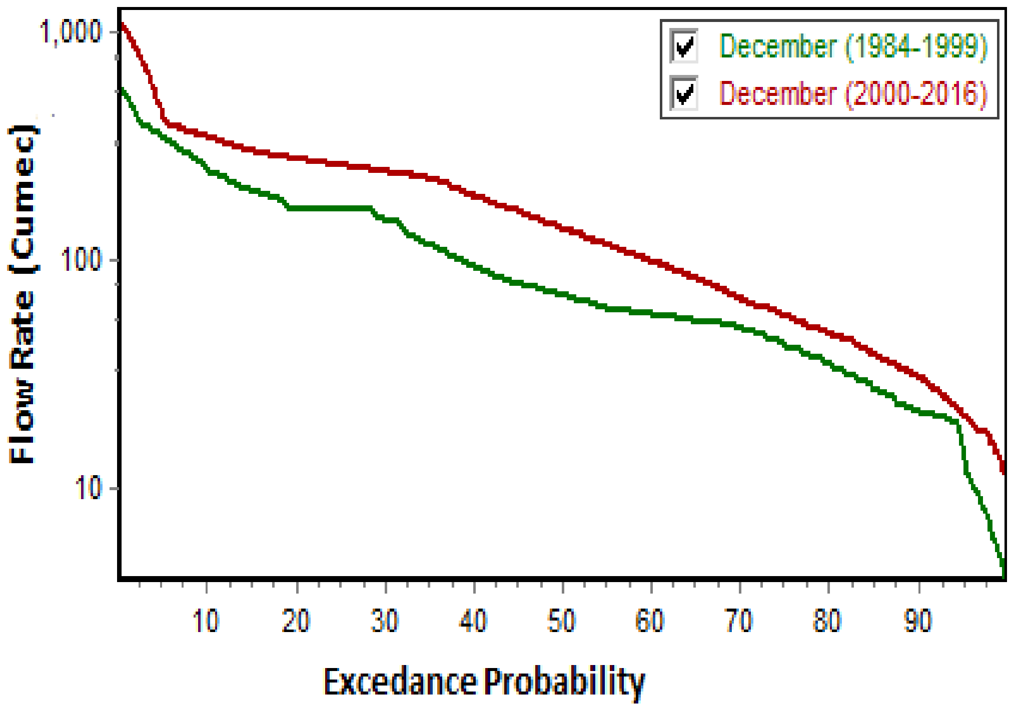


August (1984-1999)
August (2000-2016)
1,000
Flow Rate (Cumec)
10
20
30
40
50
60
70
80
90
Excedance Probability


September (1984-1999)
September (2000-2016)
Flow Rate (Cumec)
1,000
100
10
20
30
40
50
60
70
80
90
Excedance Probability


October (1984-1999)
October (2000-2016)
Flow Rate (Cumec)
1,000
10
20
30
40
50
60
70
80
90
Excedance Probability


November (1984-1999)
November (2000-2016)
1,000
100
Flow Rate (Cumec)
10
20
30
40
50
60
70
80
90
Excedance Probability


December (1984-1999)
December (2000-2016)
1,000
100
10
Flow Rate (Cumec)
10
20
30
40
50
60
70
80
90
Excedance Probability