Estimation of Chenab River Water Losses using Mass Balance Approach

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Syed Usama Imtiaz

To my loving parents and siblings Maryam, Ali and Samrat!

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Abstract

Pakistan is one of the three weakest regions in the world risks of increasing frequency and severity of floods due to climate change. With an annual population growth rate of more than 2%, as well as rapid and unorganized population growth, Pakistan has already been placed in the category of water pressure countries with less than 1000m^3per capita availability. Water is a necessity of life that requires effective management. Large-scale equilibrium approach is useful for testing water equilibrium in water bodies. However, this approach has not yet been applied in developing countries due to the poor supply and quality of data. This research work includes using PCRWR measured data of infiltration from riverbed and calculating evaporation from 300km length of River Chenab by using mass balance approach. Many components of water balance cannot be measured directly or are difficult to estimate. Despite the limitations, experience has shown that even an overall estimate of water balance can be very useful for water managers. Furthermore, a GIS and remote sensing technique is also considered to be the most feasible tool for monitoring inaccessible areas to provide cost-effective distribution of vapors over a wide range of areas.

Chapter 1

INTRODUCTION

1.1 Background

Water is among the greatest blessing of Allah, as says “And we created from water every living thing” Holy Quran (21:30). Water had remained a valuable commodity throughout the ages, with different civilizations pursuing for development and management. Water scarcity has compelled people to migrate on a large scale throughout history, even the disappearance of advanced civilizations such as the Mozanjodaro, Harappa and Hakkara valleys were due to prolonged water shortages.

Pakistan is among the most arid countries in the world with an average annual rainfall of less than 240 mm (Farooq et al., 2007). The rivers that flow largely emerge from neighboring countries and are mainly derived from the snowmelt in Himalayas. Altering natural flows of transboundary rivers, as has happened in the subcontinent of Pakistan and India, threatens the management of water. In 1960 the governments of Pakistan and India signed the Indus Waters Treaty (Treaty, 1960). According to this, Pakistan was given its right for three western rivers, namely Indus, Chenab and Jehlum, while India could use the waters of eastern rivers, namely Ravi, Beas and Sutlej. Shortly after the treaty, India built several storage dams on eastern rivers which caused severe water shortages in Pakistan downstream areas. The agricultural land in Pakistan's Punjab province were previously irrigated from these eastern rivers. After treaty, to irrigate these lands many connecting canals were built which provided water from western rivers to eastern rivers. Hence these rivers serve as cornerstone to Pakistan water resource.

To quantify the amount available for water use and water balance components for a given area is crucial especially for semiarid and sub humid regions, where resources are scarce in comparison to its demand. The mass balance estimation technique can make a quantitative evaluation of river gain and loss. Increased public awareness, stricter measures and the enactment of new laws in the field of water resources have made the use of advanced technologies essential. In addition to this, Geographic Information Systems

(GIS) is effective tool for managing, storing and displaying spatial data and is now also often required in water resources management (Tsihrintzis et al., 1996). The application of GIS in water resource management is constantly on the rise. GIS applications includes surface and groundwater modeling, water balance modelling and other related applications. The extraction of river area can hence be done by processing satellite images using GIS techniques. The collected metrological data can then be extrapolated upon extracted water surface area to quantify water loss in terms of seepage & evaporation loss.

According to World Bank 2019 report, Pakistan water security is compromised due to poor water resource management (Kalair et al., 2019). This includes insufficient data, analysis on water and weak water resource planning. The water resource is an important element to life. Water resource planning in Pakistan has historically focused on increase of supply and has not addressed the sustainable use of available resources. Although shares of water are formally defined among provinces, they have shown to be economically suboptimal and there is no clarity on risk sharing in times of scarcity. These gaps are expected to become more pronounced with increasing water demand and climate change.

Problem Identification is a prerequisite to any solution. This study is intended to identify the shortcomings in water resource management of country in relevance to open water sources by estimating the water losses of river Chenab that includes losses through evaporation & seepage and commuting unaccounted gain/loss through mass balance approach. These estimates are extremely important as its variability effect water resource and for efficient distribution and advance planning for sustainable water resource use.

1.2 Problem Statement

The International Monetary Fund (IMF) placed Pakistan third, among nations that have severe water shortage. According to Nabi et al., (2019) per capita availability of water in 1950 was around 5000 m^3 per annum which is now reduced to below 1000 m^3, this is considered a threshold for water scarcity as defined by Falkenmark indicator for water stress (Perveen and James, 2011). Pakistan depends on Indus System & its tributaries as major source of water supply for most of its needs making it vulnerable in terms of water security.

The estimation of water losses is an integral part of water resource management and these losses can be estimated by water mass balance equations. This study undertakes the estimation of water losses in given Chenab River reach in terms of evaporation, seepage loss & unaccounted losses.

1.3 Significance of study

Many regions of Pakistan have been bestowed with different water resources, in respect of rainfall, surface water and ground water. Climate change and increase in population has substantially stressed management on sharing of water resources among different stake holders. The rise in temperature significantly increases rate of evaporation and decreases level of soil moisture which then leads to enhance water demand especially for agriculture sector, that already is deemed water stressed.

The estimation of water losses in terms of evaporation & seepage will provide high insight for efficient water resource distribution & management among stakeholders. Estimation of water losses through integrated evaporation and seepage loss for any river to our knowledge have never been extrapolated especially where there is a disagreement among provinces and stakeholders for distribution of water. Hence it is necessary to develop a mass balance to quantify potential water losses.

1.4 Objectives

Following are the main study objectives:

1. To estimate Evaporation & Seepage losses in given Chenab River Reach.
2. To compute & compare water losses in given Chenab River Reach using Mass Balance Approach.

1.5 Scope of Study

River Chenab is among the largest river in Indus basin and flows between important cities of Punjab. The focus of this study is to gain an insight of water losses in open area. In order to obtain losses, a river mass balance equation is developed considering all major parameters of river. This study is limited to River Chenab between Marala headworks and Trimmu headwords comprising around 300 km length using limited available meteorological data and extraction of two years river area using ArcGIS. Many components of water balance cannot be measured directly or are difficult to estimate. Despite these limitations, experience has shown that even an overall estimate of water losses can be very useful for water managers.

Chapter 2

LITERATURE REVIEW

Despite having more glaciers anywhere in the world, Pakistan is at risk of severe water shortages. Surface and underground resources are under increasing stress and severe drought persists in some parts of the country due to lack of rainfall. At the same time, Pakistan has a large agricultural sector that uses flood irrigation methods to grow crops above water. Water infrastructure in Pakistan is old and in poor condition, which wastes a lot of water, while storage is very low due to lack of construction of reservoirs and sewerage in existing facilities. Available water is often unclean, pollutes human, agricultural and industrial waste, and there is little infrastructure to provide clean water.

The problem is exacerbated by poor management of the water sector. Although there are laws governing water, they are outdated and have a colonial history. Other efforts to reform water management have included only one new bureaucracy in the upper echelons of the existing framework, creating organizations with overlapping duties.

Although the adoption of a national water policy in 2018 has been a source of joy in Pakistan, its vague and sometimes contradictory words have raised fears that the nation's water crisis will continue unabated.

2.1 Water Cycle

Groundwater is always in motion, as is the natural water cycle, also called the hydrological cycle (Chahine, 1992). The constant movement of water above and below the surface of the earth is described. Water always changes the states between liquid, vapor and ice, and this process has been going on for millions of years in the blink of an eye (Schlesinger and Jasechko, 2014).

Ancient Earth was a bright world made of magma, but all magmas contain water. The discharge of water through the magma began to cool the Earth's atmosphere until it remained as a liquid on the surface. Volcanic activity is maintained and water still enters the atmosphere, thus increasing the surface of the earth and the volume of groundwater. There is no starting point in the water cycle. Starting from the oceans because this is where the most water on earth is. The sun, which is an important part of the water cycle, heats the water in the oceans. Some of it evaporates like air vapor. Ice and snow can melt directly into water vapor. Rising winds evaporate from vapor to vapor, which contains water vapor, which transfers water from plants and evaporates from soil. Vapors rise in the air where cold temperatures penetrate it into the clouds (Ryder, 2002).

Wind currents move clouds around the world, cloud particles collide with each other, rise, and fall from the sky like rain. Some rain falls like snow and can accumulate like ice caps and glaciers, which can preserve frozen water for thousands of years. In hot weather, snow often melts in the spring, and as the snow melts, molten water flows into the ground.

Majority of the rain falls on the oceans or on land, there because of gravity, rain flows to land as surface flow. Part of the flow enters rivers in landscaping valleys, with the water flowing into the oceans. Run-off, and groundwater drainage, accumulates and is stored in lakes as fresh water. However, not all streams flow into rivers. Most of it penetrates the ground as an infiltration. Some water penetrates deep into the earth and fills aquifers, storing large quantities of freshwater for extended duration of time.

Small quantities of infiltrations remain in proximity to groundwater and may return to surface aquifers (and oceans) as groundwater discharges, and some groundwater is detected at groundwater and arises as freshwater springs. With the passage of time, whole of this water moves, while a little remains to enter the ocean (Huntington, 2006).

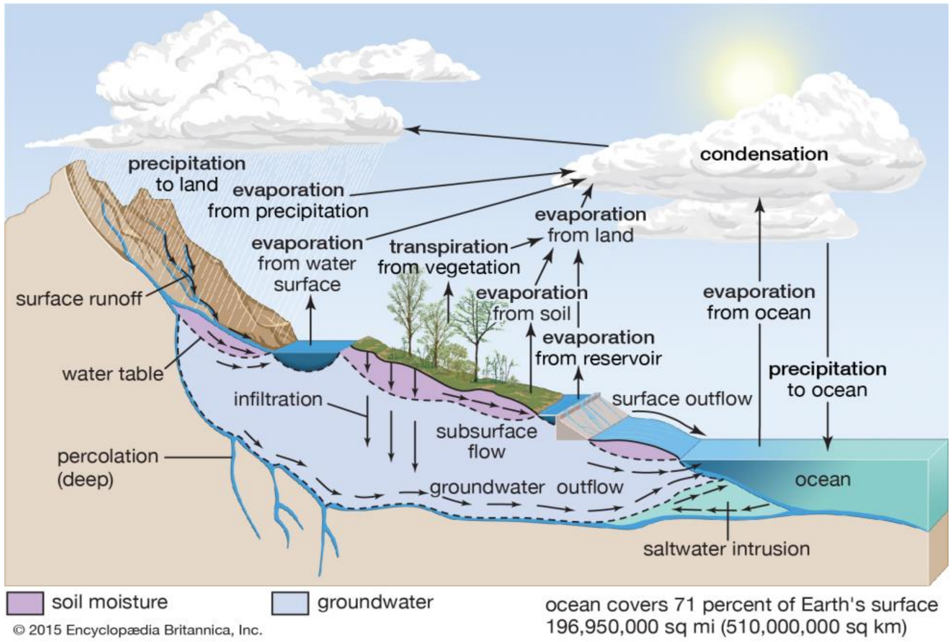

Figure 2.1 Water Cycle

2.1.1 Indus Basin System

Surface water reserves in Pakistan are based upon the flow of River Indus and its offshoots which include Ravi, Chenab, Beas, Jhelum, and Sutlej and Kabul River. The entire span of the Indus is 2900,000 meters and the drainage area is $9.66e^{9}$ m^{2} .The flow of these rivers is mainly due to the melting of snow, melting of glacier and the rain falling in its catchment area. Outside the Indus Basin, most of the rivers are only streams, that only flow throughout the rainfall season and, like other rivers, the water needs of the Indus Basin are not met even in the basin (Laghari et al., 2012).

The irrigation system covers an area of 16.85 million hectares, of which 14 million are cultural areas where water is allocated. Twelve rainwater canals are available for up to 8.6 million hectares, while the rest of the area is only eligible for irrigation during the summer crop season. The River Indus and its offshoots bring a mediocre of 175 B.C.M of water per year, 165 B.C.M from the three Rivers in the West (Sindh, Jhelum and Chenab) and 10 B.M from the Rivers in the East (Ravi, Sutlej and Beas). C.M included. Majority of it, 128 B.C B.C.M, has been averted for irrigation. 35 B.C.M flows into the ocean and 12 B.C.M system is lost like waste (Qureshi, 2011)

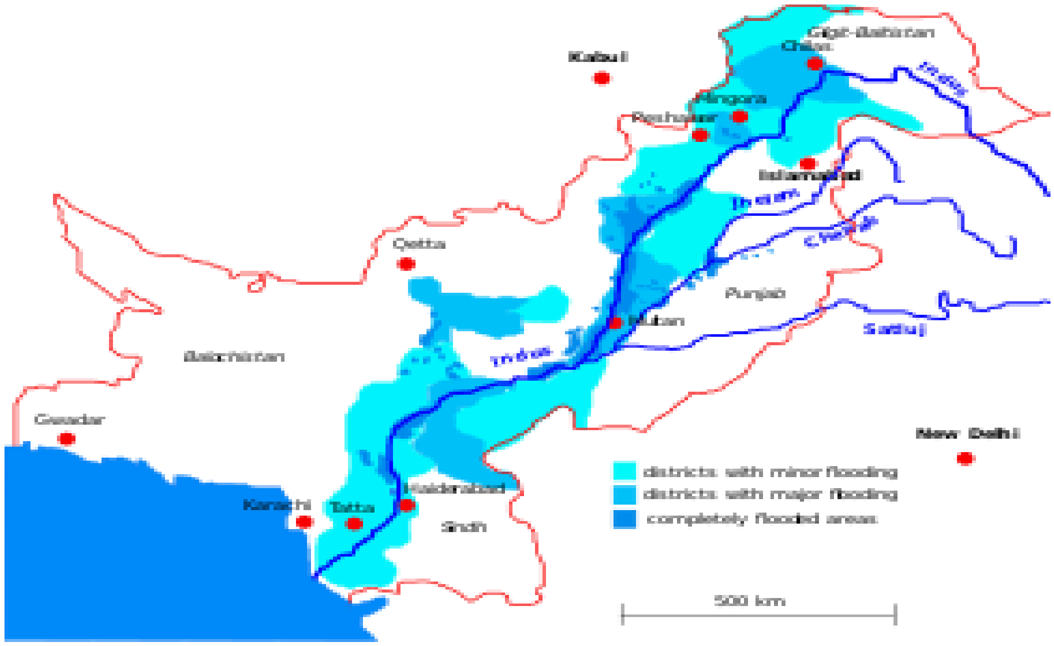

Figure 2.2 Indus Basin System

2.1.1.1 River Chenab

River Chenab sprouts in the Kangra and Kulu regions of the Indian province of Himachal Pardesh. Two (02) main streams of River Chenab are Bhaga and Chandra; originate on the side which is opposite to Baralcha Pass at an altitude of almost 16,000 feet. They meet at Tandi in the state of Jammu and Kashmir, almost at an altitude of 9,090 feet from the sea level. Filled with countless offshoots on its stretched journey from the source, the river gathers tremendous strength and motion when it enters the region of Jammu / Kashmir that is above Kishtwar area. (Siddiqui et al., 2018).

From the Kishtwar area to Tatri (almost 50000 meters), Chenab passes through and through the gorges of class 05 and 06. The conjugated brooks, crossing almost 217.215 kilo meters, sharply turn at Pir-Panjal around Kishtwar. After that the River Chenab flows alongside the northern foot of the Pir Panjal ridge before moving into the Doda region in Jammu & Kashmir. It then crosses the ridge through an impressive gorge, then moves alongside its southern foot, and then flows south and out onto the flat grounds. After moving through near to length of 645 km through hilly areas and moving approximately at 7 meters/km, Chenab reaches the grounds near Achnur. Then the river Chenab makes its way into Pakistan through the area of Sialkot, by the village of Diawara.

River Chenab flows through the muddy plains of the Pakistan's province of Punjab for 5,470 km. It is then connected by the River Jehlum at Trimmu Head Works. 65 km downstream of Trimmu, the River Ravi flows into it. The River Sutlej meets the u River Chenab at Penjnad and terminates into River Indus after 65 km at Mithankot.

2.1.1.2 Important Tributaries & their Catchment Areas

River Chenab has 12 major offshoots, which are: Bhaga, Chandra, Bhut Nullah, Maru, Jammu Tavi, Manavar Tavi, Dora Nullah 1, Dora, Nulla 2, Khalse Nallah, Bhimber Nullah, Palhu Nullah and Aik and Bhudi Nullah. Eight of the twelve offshoots flow into River Chenab in areas under state of Pakistan. (Manzoor Ahmad et al., 2009).

The cumulative span of the river is almost 1242000 meters, out of this almost 730000 meters flows through the state of Pakistan. The cumulative area of catchment of the river is about 674300000 m^2, out of this 281660000 m^2 is in Jammu and Kashmir State, 44950000 m^2 in state of India and 338850000 m^2 in state of Pakistan.

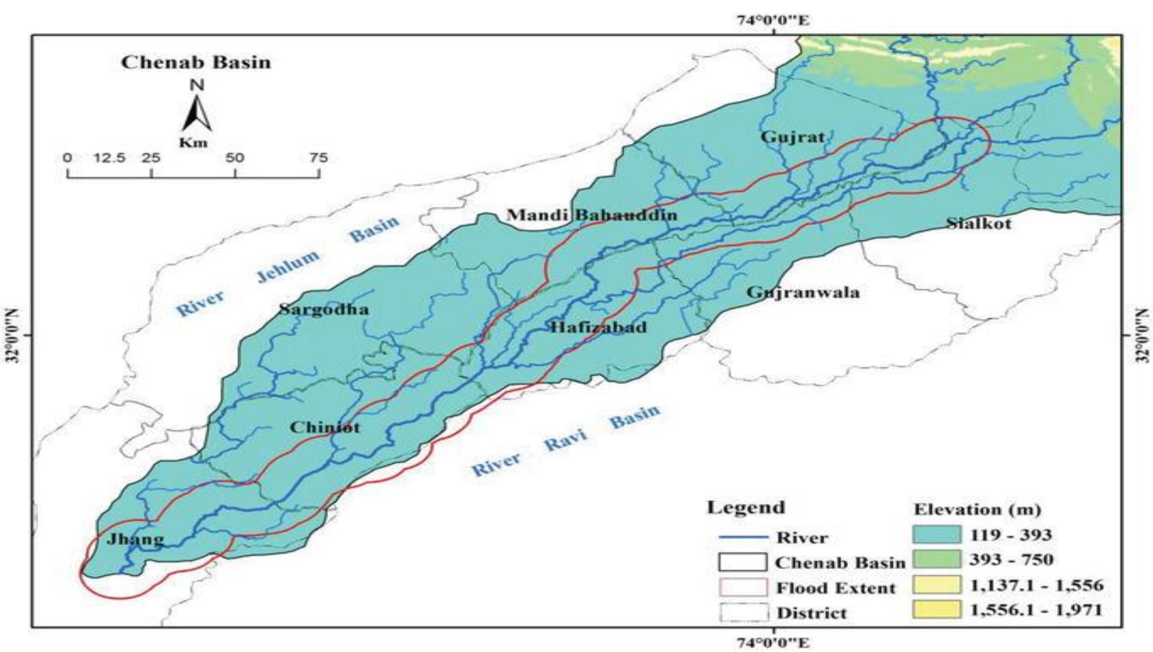

Figure 2.3 Tributaries and catchment areas

2.2 Pakistan Water Resources and Scarcity

Water of state of Pakistan comes from several sources, which include precipitation, glaciers, rivers, and groundwater. The rainfall in the monsoon makes 60 percent of the total precipitation, a substantial proportion is distributed during winter (December to March) seasonal patterns (Latif et al., 2018). Amount of rainfall is different in different areas because of varied geographical characteristics. Most of the state is dry semi-arid or arid, 75 percent of Pakistan's area receives below 250 mm of rainfall per year and drought is resides in most of the areas. (Farooq et al., 2007).

Due to lack of rain in winter and monsoon rain seasons, severe famine has been experienced in province of Sindh and Balochistan. Statics from thirty to fifty years show that rainfall statics have shown depression in areas including Balochistan and coastal areas (Latif et al., 2018). Considering this, an analysis conducted by UNDP also show that there is dire need of research into the effects of climate change on rainfall in Pakistan. (Ali et al., 2017).

The rate of melting of glaciers is greatly affected by the drastic change in climate which in turn has caused flooding. Snowfall and glacial flow also contribute 35 to 40 percent and 25 to 35 percent, respectively, to the Indus Basin, making their contribution to Pakistan's hydrological cycle inevitable (Ali et al., 2017).

2.3 River Water Loss

The main two means of water loss in open water surfaces is evaporation & seepage.

2.3.1 Evaporation

Evaporation is a phenomenon in which liquid is changed into vapor. Evaporation rate is affected by the amount of the energy available at water surface and on the fact how easily vapors can dispense into the atmosphere. (Abtew and Melesse, 2012).

The estimation of evaporation from open water surfaces are becoming increasingly for various Environmental agencies, especially Water resources. These estimates are mostly used in water balance studies for wetlands and water management and is now increasingly being used in modelling work.

Methods for estimation of open water evaporation varies, there is no generally adopted best method within regions. Moreover, approximations are subjected to large uncertainties and mismatches amid the precision of approximations given by existing approaches. Its significance of calculation is usually used as a base for decision making. Additionally, the uncertainty connected with methods used for approximating evaporation of open water, there is a lot of uncertainty over the significance of the measurements of water body (Abtew and Melesse, 2012).

The rate of evaporation is affected by two major factors Metrological and the properties of water body itself such as water depth, thermal stratification, and turbidity. In this study, only meteorological parameters are considered.

2.3.2 Meteorological factors affecting evaporation

2.3.2.1 Net radiation

The amount of radiation energy absorbed by the water body is the dominant factor that controls the rate of evaporation. The Rn (net radiation) is the amount of radiation energy put in (absorb) at the surface. Rn is the difference of radiation energy that is absorbed by the surface and amount of radiation energy reflected by it, and added to this is the difference thermal radiation that come in and go out (Borchman et al., 2009). The general net radiation equation is as follows:

$$Rn = (1 - \alpha)\, Rsi - L\uparrow + L\downarrow \qquad \text{(Eq. 2.1)}$$

From the equation Rn stands for the value of net radiation (W/m^2), α stands for soil surface albedo ($\alpha = 0–1$), Rsi stands for solar radiation (W/m^2), $L\uparrow$ stands for long-wave radiation (W/m^2) from Earth's surface, and $L\downarrow$ stands for long-wave radiation (W/m^2) from the sky. Due to unavailability of data, this parameter is not included in our study.

2.3.2.2 Diffusion Processes

The process through which water molecules diffuse from the surface of open water into air is diffusion of water molecules. When the air near the surface of water saturates with vapors it is replaced by the adjacent dry air so the movement and mixing of air takes place. Hence, the evaporation rate is influenced by turbulent air movement (Borchman et al., 2009).

According to a report on estimation of evaporation for open water by Environmental Agency UK in October 2001, the positive (directly proportional) the ratio of rate between wind speed and evaporation is only stable to a certain value called the critical value (Finch, 2001). Thus the humidity and available energy become core factors in establishing the rate of evaporation.

2.3.3 Method of Estimating Evaporation & Seepage

2.3.3.1 Pan evaporation

The method of using pans for determining evaporation goes back to 18th century. The understanding was easy as the open water evaporation was made visible. United Sates classify a pan as a circular tank of galvanized iron that has a diameter of 1.21 m and a depth of 255 mm. It is fixed on an open wood frame for smooth flow of air. 50 mm below the rim water level is maintained. Hook gauge is used to measure the levels per day (Sivapragasam et al., 2009).

Winter (1981) suggested that if data is taken from pans that are significantly away from water body then errors are more. Two of the major methods used for approximating the evaporation of water body are pan coefficient and pan conversion. A pan coefficient when calculating lake evaporation from Class A pan can be described as EL = Kp × Epan, where EL stands for the open-water surface evaporation (mm day^{-1}), Epan is Class A pan evaporation (mm day^{-1}) and Kp is called the pan-coefficient. If Kp amounts to between 0.65 and 1.10. It is taken between 1.10 and 0.90 for lake evaporation when pan evaporation is between 4mm to 5mm per day, and for lake evaporation when pan evaporation is around 10mm per day, the coefficient value varies between 0.75 and 0.65. The ratio is usually around 0.8 for the months during which the weather shifts.

2.3.4 Seepage Loss

Seepage is defined as the motion of fluid through any porous medium. In water resources, seepage is the percolation of water through soil. The water movement in soil plays a critical role in water resource management which majorly includes groundwater studies. Seepage is dependent upon many factors that include pressure gradient and soil permeability, gravity, and a combination involving forces that act on water under the influence of gravity. Soil permeability varies depending on the texture and structure of the soil, the width can change over a wide range (Sivapragasam et al., 2009).

The seepage of the river is complex because it depends on the interaction with many different local conditions and environments. Therefore, the seepage of the river is directly related to the transport of turbulence and sediment among other natural phenomena. To calculate river losses, estimation of seepage loss is of critical importance.

2.3.4.1 **Point Measurement**

It is usually done by supplying water to a particular area in a limited region and calculating soil intake. Infiltrometers have four types that include cylinder type, ferro type, tension type and sprinkler type.

2.3.4.2 **Ring Infiltrometer**

They are made up of rings of metal having a diameter of 30cm to 100cm and have a height of 20cm. The metal ring is inserted about 5 cm into the ground, water is supplied to the metal ring with a permanent head device and, intake readings are recorded till a stable rate of infiltration is reached (Bouwer, 1986).

Figure 2.4 Ring Infiltrometer

2.4 Water Balance Equation

The water balance can also be defined by general hydrological equation, which governs on law of conversation of mass (Zeng et al., 2012). The equation in its simplest form states as follows,

Inflows = Outflows + Change in Storage (Eq. 2.2)

This procedure is usually not realistic in the subject case of river or lake water balance analysis as error in recording storage, inflows & outflows are most of the time are bulky. Seepage, undetermined flow, and storage are uncertain and most of the time considered as immeasurable articles. Although, under particular conditions this process has put out outstanding outcomes that has provided the foundations for measuring the precision of aerodynamics and budgeting energy process (Zeng et al., 2012).

The water balance equations can be evaluated for any period and over any area. In the process of establishing the total water balance for a particular area, an assessment of all water components outlets, inlets and storage components of the flow domain is essential. Such as through the ground surface, through an impermeable base of underground reserves and through imaginary vertical planes within the boundaries of the area.

Rivers always have a pattern which they follow, in that some months will have higher discharge than other months. The water balance could also look at how the metrological data such as temperature or humidity equates to the value of water exiting the system as evaporation/seepage or runoff. The water equilibrium changes all through the year and affects the average climate of the region surrounding the river.

Take for an instance, in normal circumstances the precipitation is often matched by run-off and evaporation that gives a stable river level. But if during the hot summer season evaporation is greater on the other hand precipitation and run-off remain the same, the river shall flow below normal level according to the calculations (Khazaei and Hosseini, 2015). The net water balance will vary according to the periodic and nonperiodic variation of its inputs & outputs and is reflected in the fluctuations of the storage level. Because the major influencing factors will be meteorological. River areas increase generally coincide with seasons of high precipitation and falls of level generally coincide with summer seasons of high evaporation. The water balance of a river is an interplay of three main components namely, Infiltration (I) evaporation (E) and discharge (Q) as illustrated in below figure.

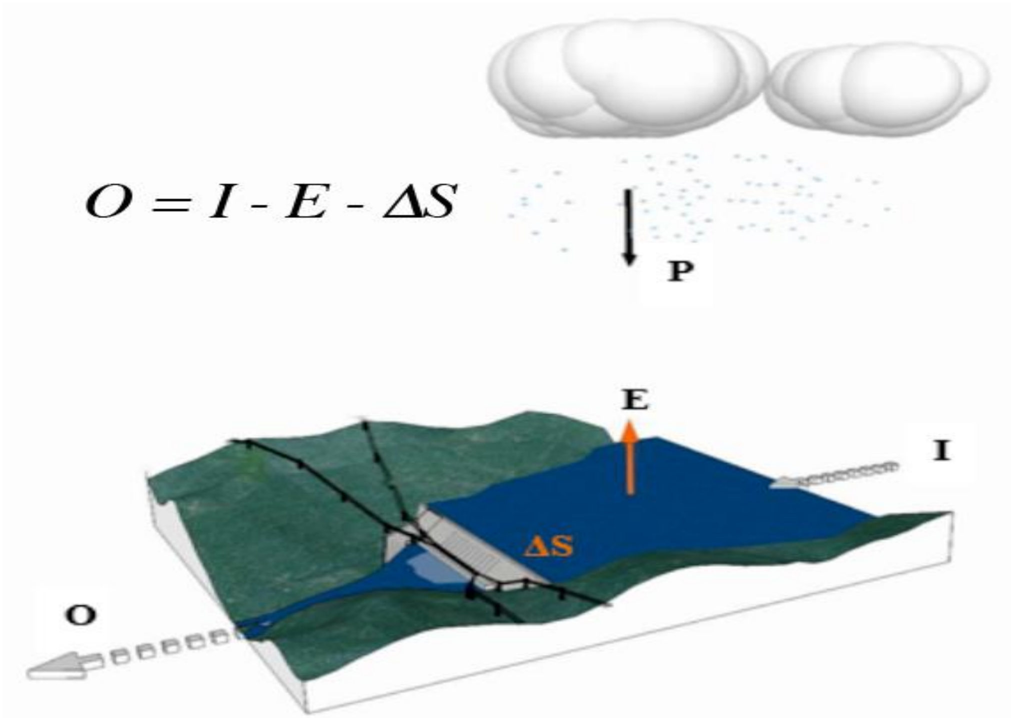

Figure 2.5 Water balance

2.4.1 Water Mass Equation in Determining Water Loss

High-level of spatial variations in river-surface exchange flow means that to estimate river loss or gain over hundreds of kilometers in length from rivers require regional water management in ways that can easily estimate river access. Groundwater chemistry, differential flow gauges, and stream are the head components that help in large scale estimation. Every procedure carries its own merits and demerits but a combination of processes can give out match more accurate and reliable results (Cook, 2015). The importance of river water loss estimation was highlighted in a study on Nile River. The estimate reflects that there was significant annual loss of evaporation, from 4.80 to 9.13 billion m^3. This manuscript is aimed at informing politicians and governments in the countries to the eastern part of River Nile (Ethiopia, Sudan and Egypt) that even if out of the total of additional evaporation losses if only half are reduced then there will be adequate quantities of water to irrigate more than 0.9 million acres of agricultural land (Khairy et al., 2019).

A simple methodology for estimating scheduled water balance components on a basin scale is use of water mass balance equation. This approach when applied to basin scale the individual monthly water balance components of the estimation in evapotranspiration losses when compared with inlet precipitation resulted in approximately 54% of rainfall, meaning approximately 22% of rainfall in the study area (Falalakis and Gemitzi, 2020). The countries where data is limited and because of simplicity in estimating evaporation, Class A pan can be considered as its widely accepted global reliable method, despite its limitations. Lake Evaporation loss using Class A pan data in comparison to lake inflow yielded an estimated average 70% of the quantity of water dumped in the lake and in 2007 the amount of water evaporated was higher than the amount of water retained in the lake (Sadiq, 2020).

Remote sensing and use of GIS have revolutionized the field of water resources. (Fashae et al., 2019) developed a water balance model that used remote sensing and GIS techniques to assess the water over a period of year (1996-2000) and (2010-2014) the water surplus and deficit periods respectively. The study endorsed the need to revitalize the framework of institutions responsible for assessing, conserving, managing, and planning water resources for sustainable use.

Moreover, the uncertainty linked with the procedures used for estimating water loss from open surfaces, a great deal of uncertainty is there over the significance to lake heat storage and thus on the rates of evaporation of water body. Reflecting that uncertainties in water mass balance cannot be overlooked. Different methods should be explored for minimizing the uncertainties in water balance the decision-makers should spend more in estimating precipitation, evapotranspiration, and seepage estimations among watersheds. No singular element of the water balance can be distinctly measured at watershed scale excluding extensive uncertainty (Kampf et al., 2020).

Chapter 3

METHODOLOGY

3.1 Study Area

3.1.1 River Chenab

The River Chenab flows with a length of around 960km among the proportional plains of Pakistan's province of Punjab. It then joins River Jhelum at the Headwork Trimmu. 65km down from the Trimmu River Ravi meets the River Chenab.

3.1.2 Chenab River Basin

The Basin of River Chenab covers an area of about 675000000 m^2 before the merging with River Indus. From its origin, about 35 km above Mithankot, in the village of Sarki to its confluence with the Indus River, its length is almost 1240000 meters. In the uphill reaches, firstly the river moves northwest to Benswar, where it joins the Maru Nalla. In the flow of Benswar, the river takes a quick turn towards southern direction while moving through the area of Pir Panjal range of mountains and continues on its path towards the west of Sall Dam site, thus flowing the southern slopes of the Pir Panjal boundary. Here it turns south again until it takes an inward turn towards the plains of Akhnur area, 34000 meters from the LOC (Line of Control) between India & Pakistan, to divert its route to the southwest. The upper surface area of Marala (point of entry into Pakistan) is about 28 28000 km^2. From Marala Barrage to the merging of River Indus, River Chenab moves further 576 km through Punjab. Numerous small tributaries join the river between Hilsi, Bhimber, Plukho and Ike Marala and Khanki barrages, covering a total area of 3437 km (Kalair et al., 2019).

3.1.3 Selection & Importance of River Reach

River Chenab flows 560000 meters among metropolitan and industrialized cities like Sialkot, Gujranwala, Faisalabad, Jhang , Khanewal, Gujarat and Multan. This is the main and the only source of providing water that fulfill all the water needs of these areas (Bhatti and Latif, 2011).

Our study area is limited to river area between Marala barrage and trimmer barrage and is divided in three parts; Marala – Khanki covering 56 Km of river length, second part is Khanki – Qadirabad covering around 25Km and the last part is Qadirabad – Trimmu covering around 220 Km of river length. Another reason of this selection was that the maximum intervention of drains is in the river segment upstream of Trimmu before confluence of river Jehlum.

After its entrance in Pakistan, the river Chenab traverses among thickly populous and highly developed and industrialized cities (e.g. Gujranwala, Sialkot, Hafizabad, Faisalabad, Gujrat, Jhang and Sargodha) in the province of Punjab. In reference to a fresh assessment, populace of mentioned areas is around 2 Carore 30 lacs and 50 thousand (GOP 2008).

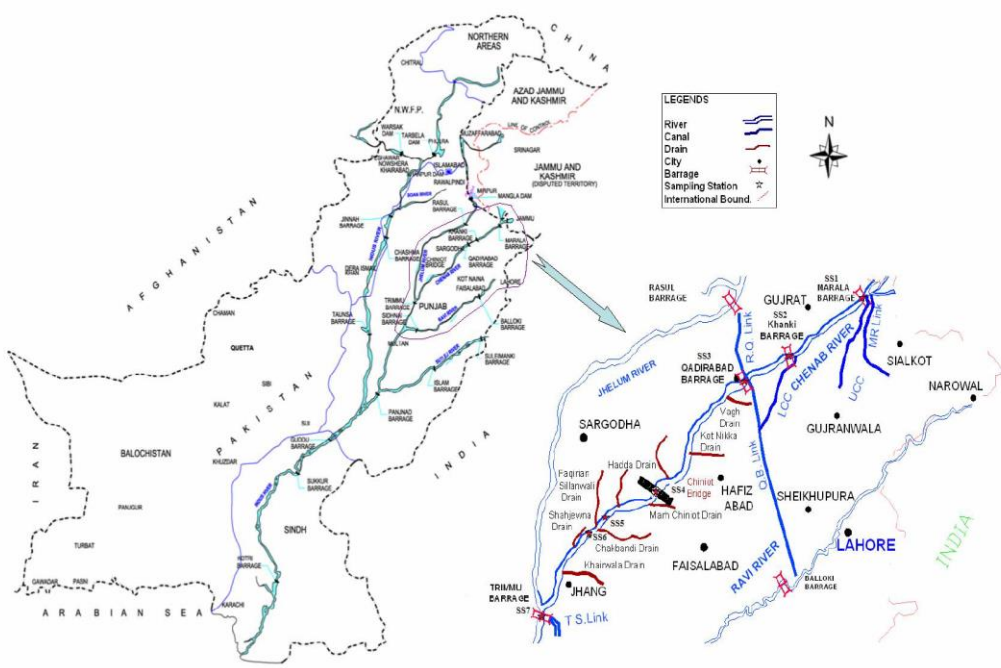

Figure 3.1 Chenab selection

3.2 Mass Balance Method

River surface area is extracted of year 2014 (Flood year) & 2017 using ArcGIS. The estimated surface area was then extrapolated with collected seepage rate & pan evaporation for calculation of losses. These losses were then added to daily river inflow at respective barrages and compared with river outflow to develop storage changes using water balance equation.

3.3 Methodology Chart

The estimation of water losses was divided in four major steps. The foremost step was extraction of river surface area by processing images of Landsat 8 using ArcGIS 10.8 (Kennedy, 2013). The collection & analysis of daily mean evaporation data of nearby river reach stations by meteorological department. Point seepage information was collected by PCRWR (Pakistan Council of Research in water resources). The data of evaporation and seepage was extrapolated over quarterly river extracted area to estimate river water loss. For establishment of river unaccounted gain and loss, mass balance equation was applied whereas daily river flow data at barrage was used as river inflow and outflow.

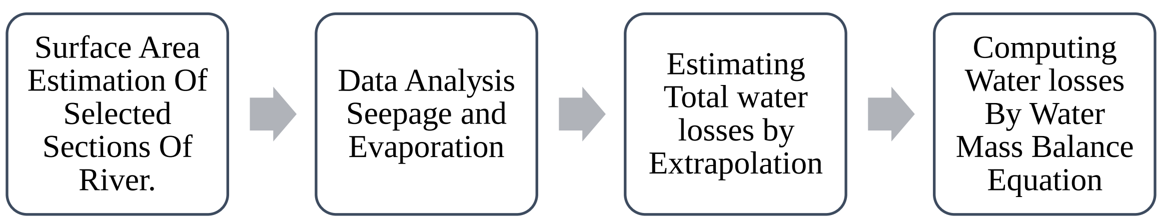

Figure 3.2 Methodology used to Study water loss in River Chenab

3.4 Water Balance Equation Derivation

The water balance can also be defined by general hydrological equation, which governs on law of conversation of mass. The equation in its simplest form states as follows:

$$\text{Inflows} = \text{Outflows} + \text{Change in Storage} \qquad \text{(Eq. 3.1)}$$

The water balance of a river is an interplay of three main components namely, Infiltration (I) evaporation (E) and discharge (Q) as illustrated in below figure.

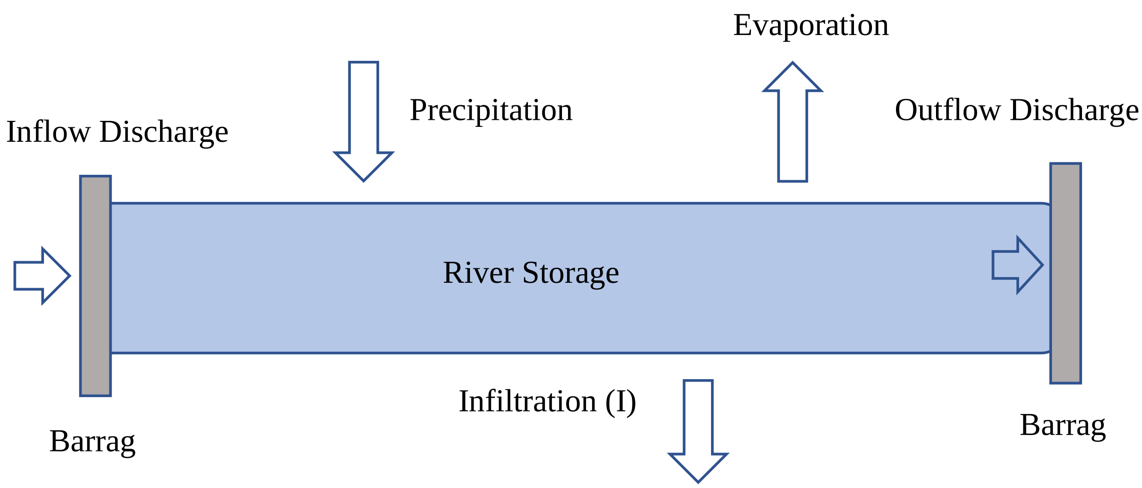

Figure 3.3 Water balance in open surface

From the above figure and using Eq. 3.1 water balance of open water surfaces can be expressed as follows:

$$\Delta S = Qi + P - (E + I + Qo)$$ (Wisler and Barter, 1959) (Eq. 3.2)

Precipitation can be considered negligible as the discharge value is considered daily it will already be added in River Inflow Discharge; hence, P =0

Eq. 3.2 can be rewritten as:

$$\Delta S = Qi - (E + I + Qo) \qquad \text{(Eq. 3.3)}$$

To develop realistic mass balance assessment in rivers, the outflow can be calculated independently by rearranging the equation as follows.

$$Qo = Qi - (E + I) \quad \text{(Eq. 3.4)}$$

The results of above equation can be then compared with collected Outflow barrage data, giving storage changes or total water loss. This will also allow a more simplified approach in estimation.it can be expressed in equation as below.

$$\Delta S = Qact - Qest \quad \text{(Eq. 3.5)}$$

3.4.1 Method of Extraction for River Surface Area Using ArcGIS

Classification surface cover types & analyzing the changes are among the common application of remote sensing. One of the most basic tasks of classification is to distinguish water body from dry land surfaces. Imagery by Landsat is the most widely used source of data in remote sensing of water resources.

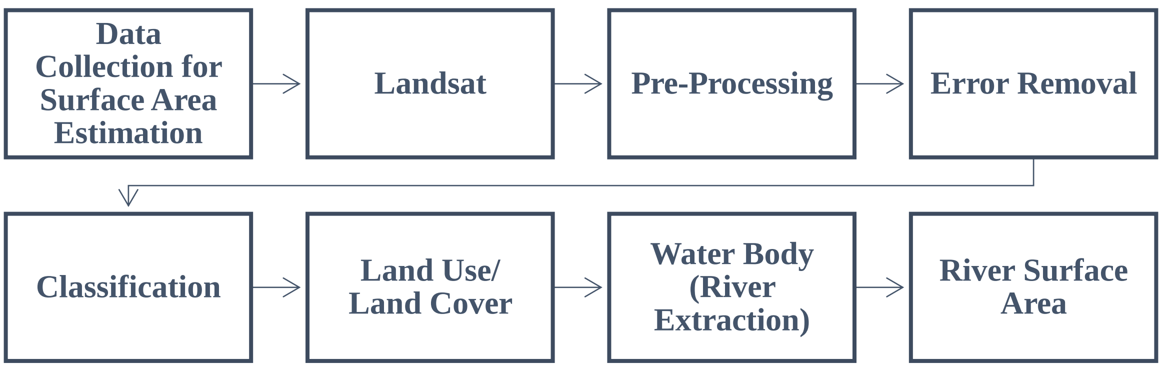

Figure 3.4 Methodology applied to extract River area for this Study

3.4.1.1 Landsat Images

The Landsat imagery data was acquired from USGS earth explorer. The generation of land use map was achieved using multi-spectral dataset imagery. The Landsat 8 level 2 imagery was used having 30m resolution for six bands (1-5, 7) when displayed as raster layer.

3.4.1.2 Imagery Pre-Processing

ArcGIS 10.8 software was used to apply for pre-processing of the images. To convert radiance of image into reflectance, radiometric calibration was performed. The tiles were then mosaicked using seamless mosaic method. After obtaining of mosaic image, the image was subset to get required river area shapefile.

3.4.1.3 Supervise Image Classification

For accurate extraction of water body from image, interactive supervise classification was done to produce land use map from multi temporal and multi- spectral datasets.

The image was classified in following three classes.

- Water
- Bare soil
- Vegetation

True color bands (7,5,3) were used for classification of land and vegetation. Ground truth data was collected to help in imagery classification as well as in validation of results. After classification, area was calculated using tool field geometry for each classified class.

3.5 Data Collection and Analysis

3.5.1 Pan evaporation

In this study, average monthly pan evaporation data was collected from the four surrounding nearest possible Pakistan Meteorological Department (PMD) stations of River Chenab to extrapolate on river surface area.

Table 3.1 River section and Area station

River Section	Area Station
Marala to Khanki	Sialkot
Khanki to Qadirabad	Mandi BahaUddin
Qadirabad to Trimmu	Faisalabad & Jhang

3.5.2 Seepage Loss

The collection of data of river Chenab seepage was obtained from a study by Pakistan Council of Research in Water Resources (PCRWR).

Table 3.2 River section and data points of location

River Section	Number of Data Points	Location Code
Marala to Khanki	02	P2, P20
Khanki to Qadirabad	02	P6, P21
Qadirabad to Trimmu	07	P3, P4, P5, P7, P8, P18 and P22

Following twelve data points are also marked in below map.

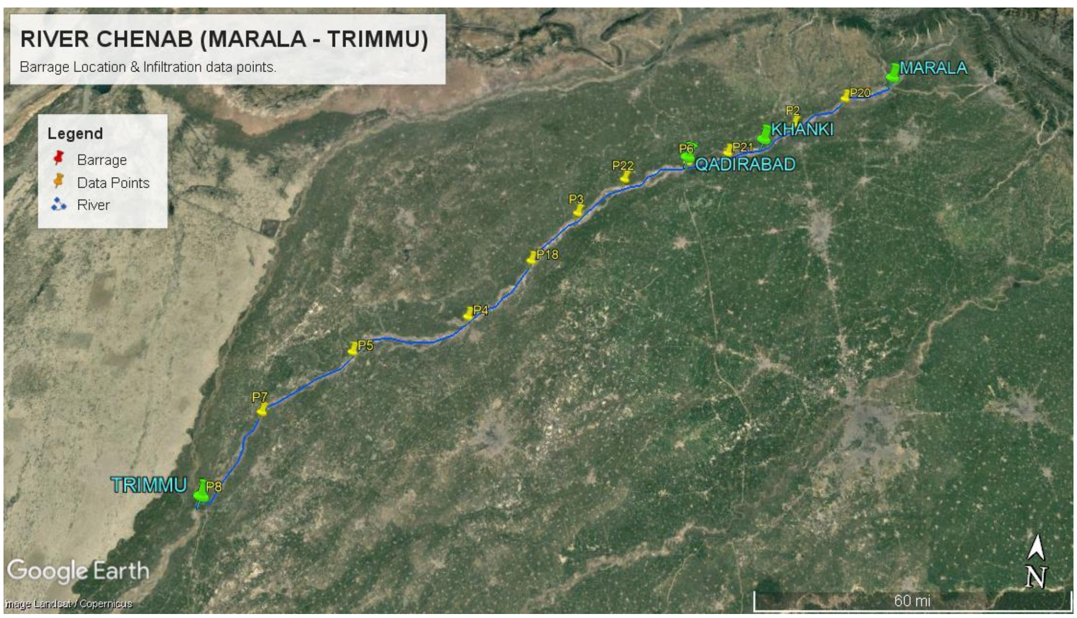

Figure 3.5 Satellite view of river Chenab

Chapter 4

RESULTS AND DISCUSSION

4.1 Surface Area Estimation of Selected Sections of River

To find the total river losses in Chenab, estimation of its area was essential. Primarily, river Chenab consisted of three river sections named as Marala – Khanki, Khanki – Qadirabad and Qadirabad – Trimmu. The areas of these sections were estimated by using ArcGIS 10.8 based on quarterly seasonal trend for year 2019.

At Marala – Khanki, the estimated area values obtained were comparable between winter seasons. During the months of Jan to Mar it was 22 km^2 and 28 km^2 from Oct to Dec, as depicted in Fig. 4.1. Similarly, during Apr to Jun and Jul to Sep almost similar values of area were observed which were 45 and 47 km^2 respectively. However, the mean yearly area observed in this river section was 35.5 km^2.

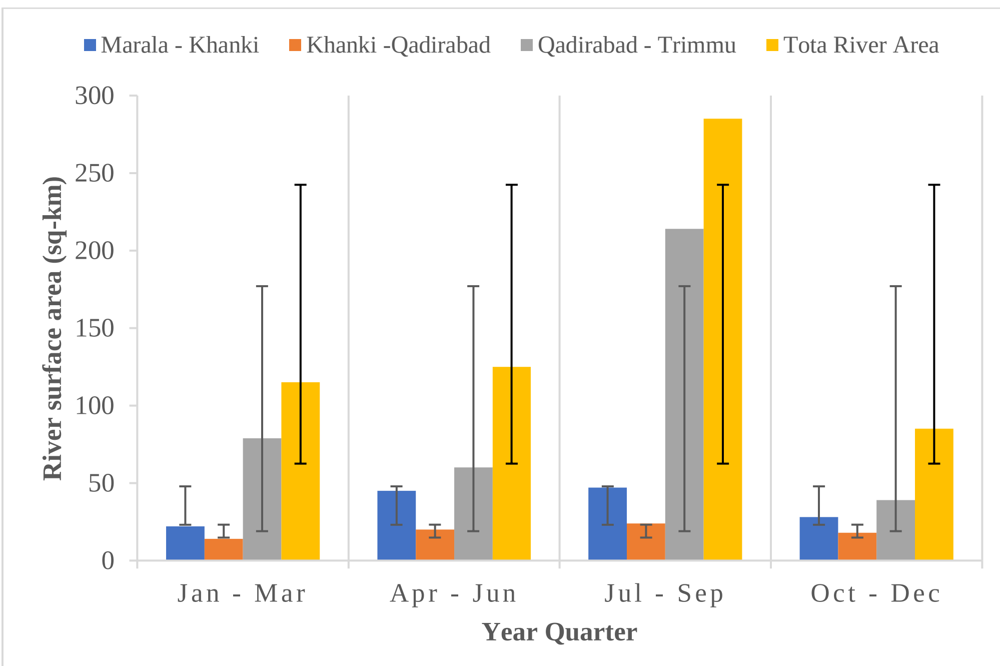

Figure 4.1 Quarterly Seasonal River Area Comparison

The river second section Khanki – Qadirabad, appeared to be the smallest area of the river section with mean value of 19 km^2. The mean area of the section Qadirabad –

Trimmu reach area was 98 km^2 which is the largest section of river with the maximum area of 214 km^2 during Jul to Sep. Area estimation for all the river sections and total river, are shown in Fig. 4.1. The quarterly estimated river areas for year 2019 are shown in Fig. 4.1.

4.1.1 Peak Flow Season River Area Comparison

After estimating the river surface areas, it was confirmed that Jul-Sep appeared as peak season. So, in order to see the variation among peak seasons over the years the estimation of area was extended for year 2014, 2017 and 2019.

Pakistan experienced flood during July-Sep in 2014 with estimated total river surface area of 351 km^2 which showed an increase of 21% from year 2019 i.e. 285 km^2. When compared with year 2017, the 2014 flood season depicted an increase of 8% i.e. 325 km^2. The total river area during peak season (Jul-Sep) ranges from 285 to 351 km2. It was observed that in 2019, the area of the river Chenab was least among all.

The higher area values during year 2014 in all sections are advocating the flood situation in this particular year, as shown in Fig. 4.2.

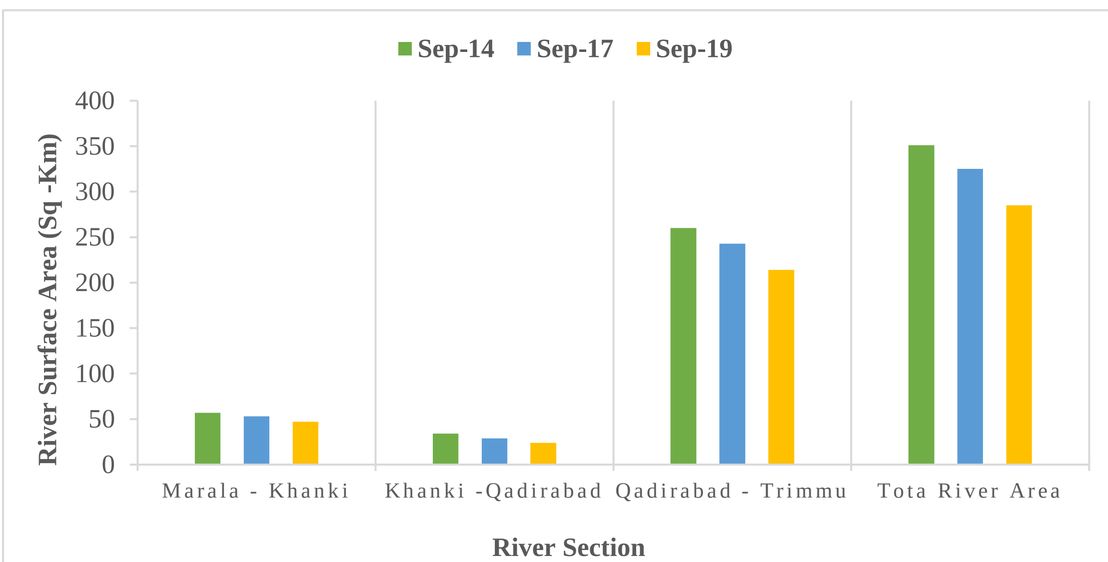

Figure 4.2 Peak Season (July - Sep) River Area Comparison

Below is the extracted water body using ArcGIS.

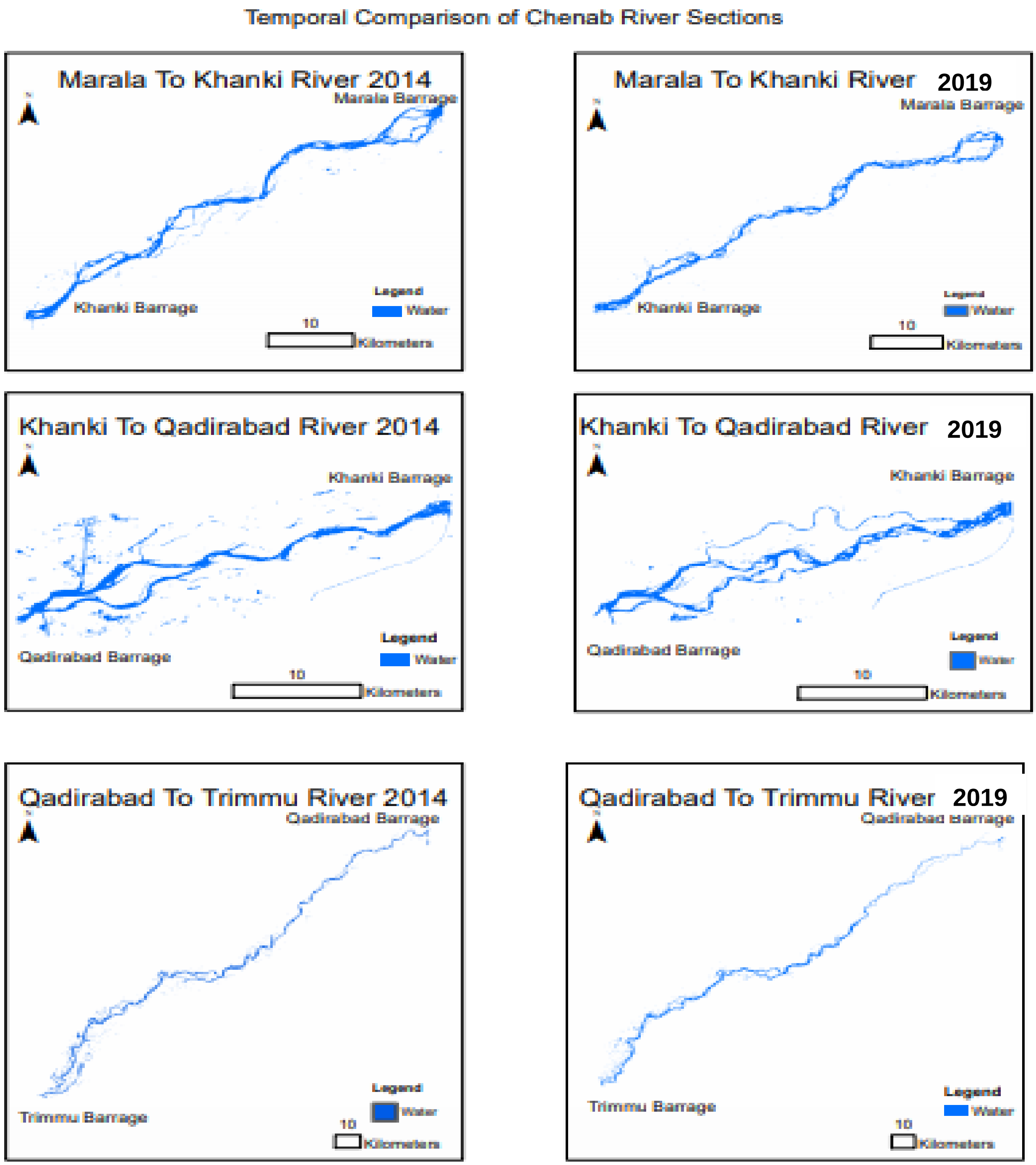

Figure 4.3 Extracted water body images using ArcGIS.

4.2 Evaporation Loss

The mean values of pan evaporation obtained for Marala to Khamki, Khanki to Qadirabad and Qadirabad to Trimmu were 3.4, 3.7 and 4.0 mm/day respectively, as depicted in Fig. 4.4. During May and June, the pan evaporation values were maximum at all three sections showing the peak summer or dry season of the year.

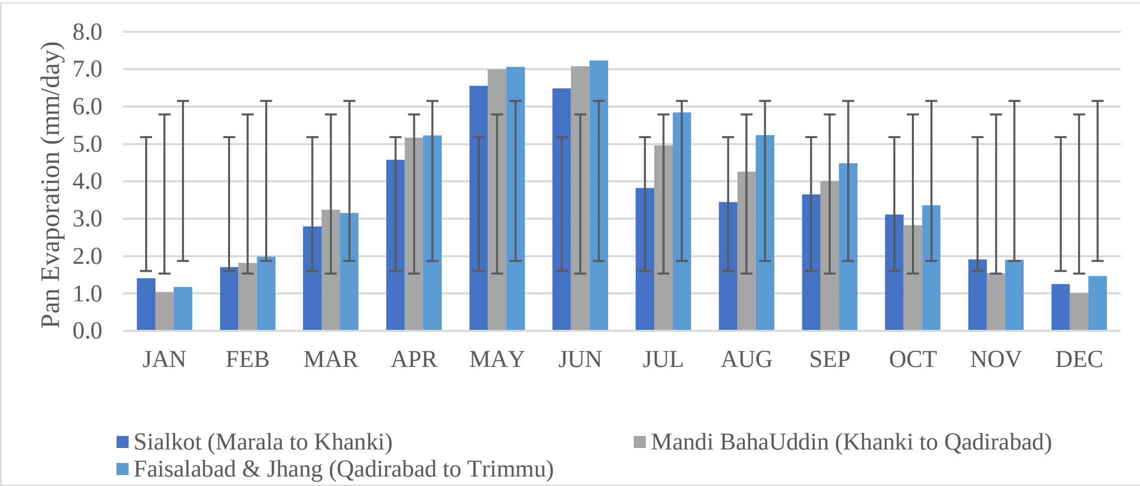

Figure 4.4 10-Year Monthly Average Pan Evaporation (mm/day)

During Jul to Sep, total river area had the maximum evaporation i.e., 16.05 m^3/sec (0.41 maf/year), as shown in Fig. 4.5.

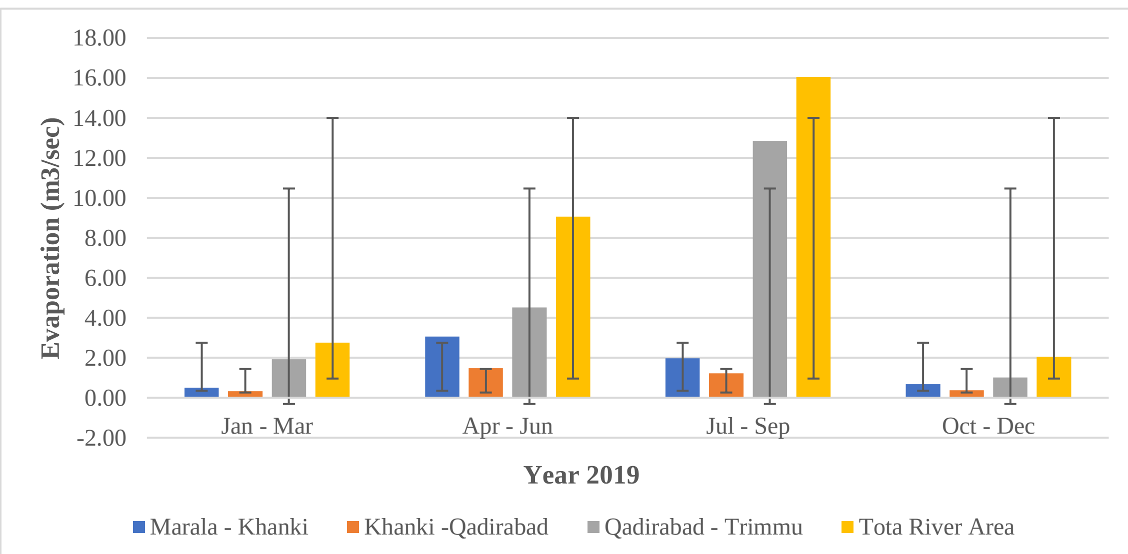

Figure 4.5 Average Chenab River Seasonal Evaporation (m^3/sec)

4.3 Seepage Loss

The highest mean seepage loss was observed at section Marala to Khanki which was 2.08 mm/day, with maximum value of 2.2 as shown in Fig. 4.6. The seepage losses at other sections are described in Fig. 4.7.

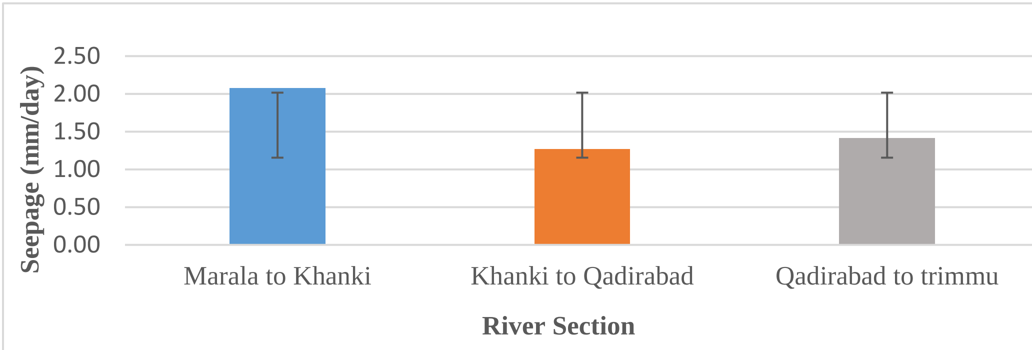

Figure 4.6 Average River Chenab Seepage Rate (mm/day)

During Jul to Sep, total river area showed the seepage loss was highest with 3.51 m^3/sec (0.13 maf/yr), thus the overall river seepage at each section was also highest during this part of the year, as depicted in Fig. 4.7.

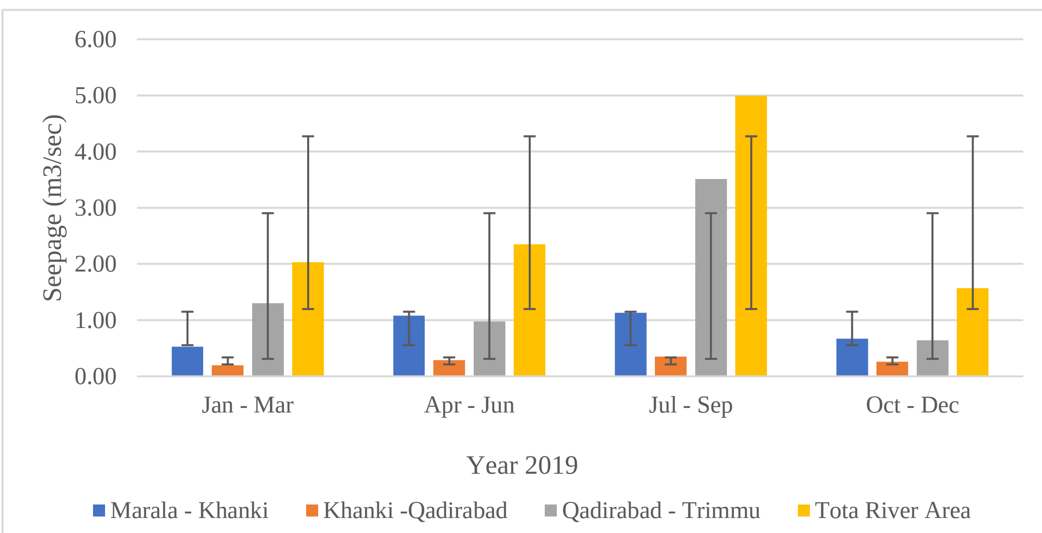

Figure 4.7 Average Chenab River Seasonal Seepage (m^3/sec)

4.4 Cumulative (Evaporation + Seepage) Loss

The cumulative section wise river losses are summarized in Fig. 4.8, 4.9 and 4.10. The highest cumulative (Evaporation + Seepage) loss was observed during at section Qadirabad - Trimmu during July to Sep, as shown in Fig. 4.10.

Moreover, the cumulative (Evaporation + Seepage) loss of overall river (Marala – Trimmu) was also highest during July to Sep, as depicted in Fig. 4.11.

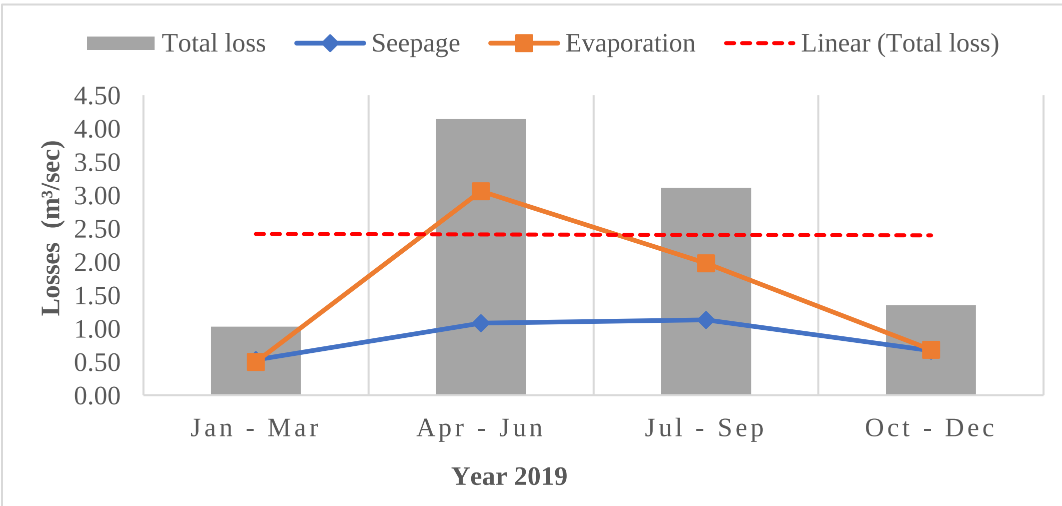

Figure 4.9 Marala to Khanki (2019)

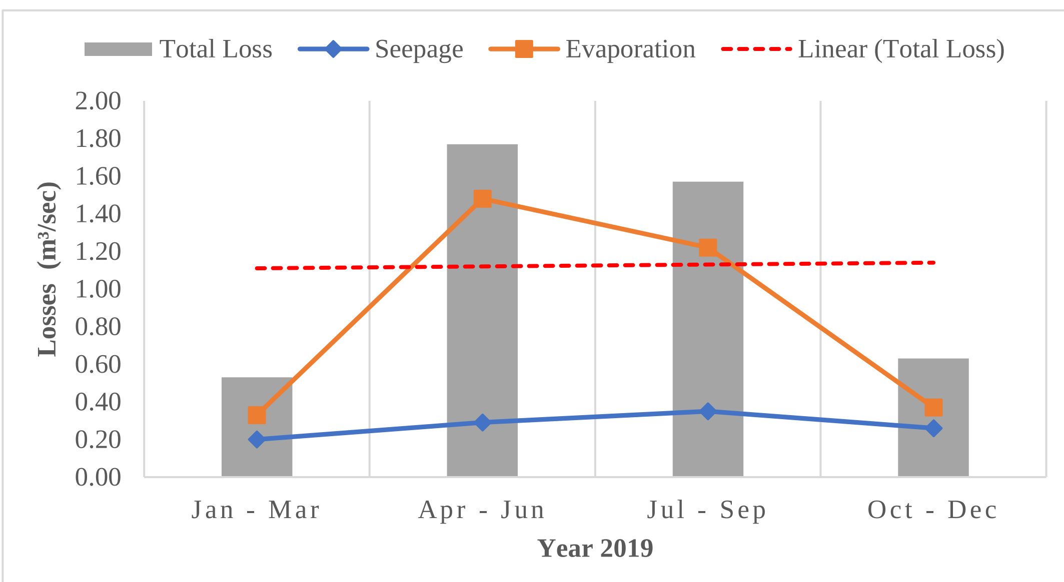

Figure 4.8 Khanki to Qadirabad (2019)

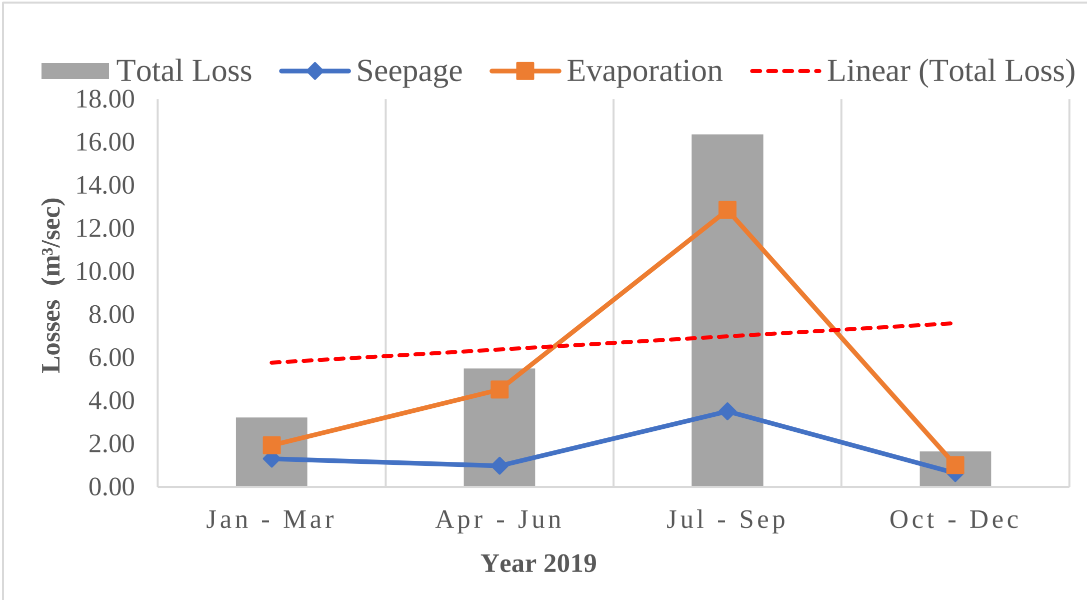

Figure 4.10 Qadirabad to Trimmu (2019)

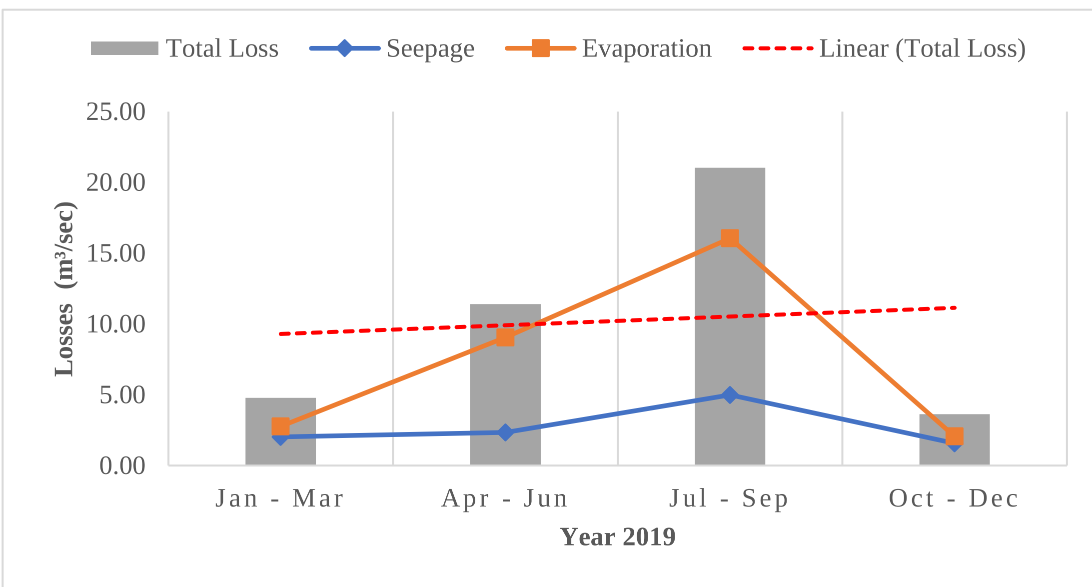

Figure 4.11 Marala to Trimmu (2019)

4.5 River Mass Balance (Marala – Khanki)

The (evaporation + seepage) loss was increased to 147 ft^3/sec (4.17m^3/sec) from 37 ft^3/sec (1.04 m^3/sec) on 51st day as shown in Fig. 4.11 which effected the outflow of the river. The out flow of the river decreased slightly after this point and then again rose to 16484 ft^3/sec (467 m^3/sec) from 22886 ft^3/sec (648 m^3/sec) on 115th day as also the losses decreased slightly on 97th day from 147 ft^3/sec (4.17m^3/sec) to 110 ft^3/sec (3.11 m^3/sec). The inflow and the outflow were maximum on day 119th as 113950 ft3/sec (3228 m^3/sec) and 113840 ft3/sec (3223m^3/sec), respectively as shown in Fig. 4.12.

The estimated and actual outflow values were quite similar during the year as shown in the Fig. 4.13 and were highest on 119th day. Unaccounted gain and loss are the difference between actual outflow and estimated outflow, it is summarized in Fig. 4.14

The Total inflow of the river was almost consistent during the whole year but showed peak on day 119th and was relatively high before and after this peak value, as shown in Fig. 4.15. It was also observed that fluctuation in river gain and loss was directly related to total inflow of the river.

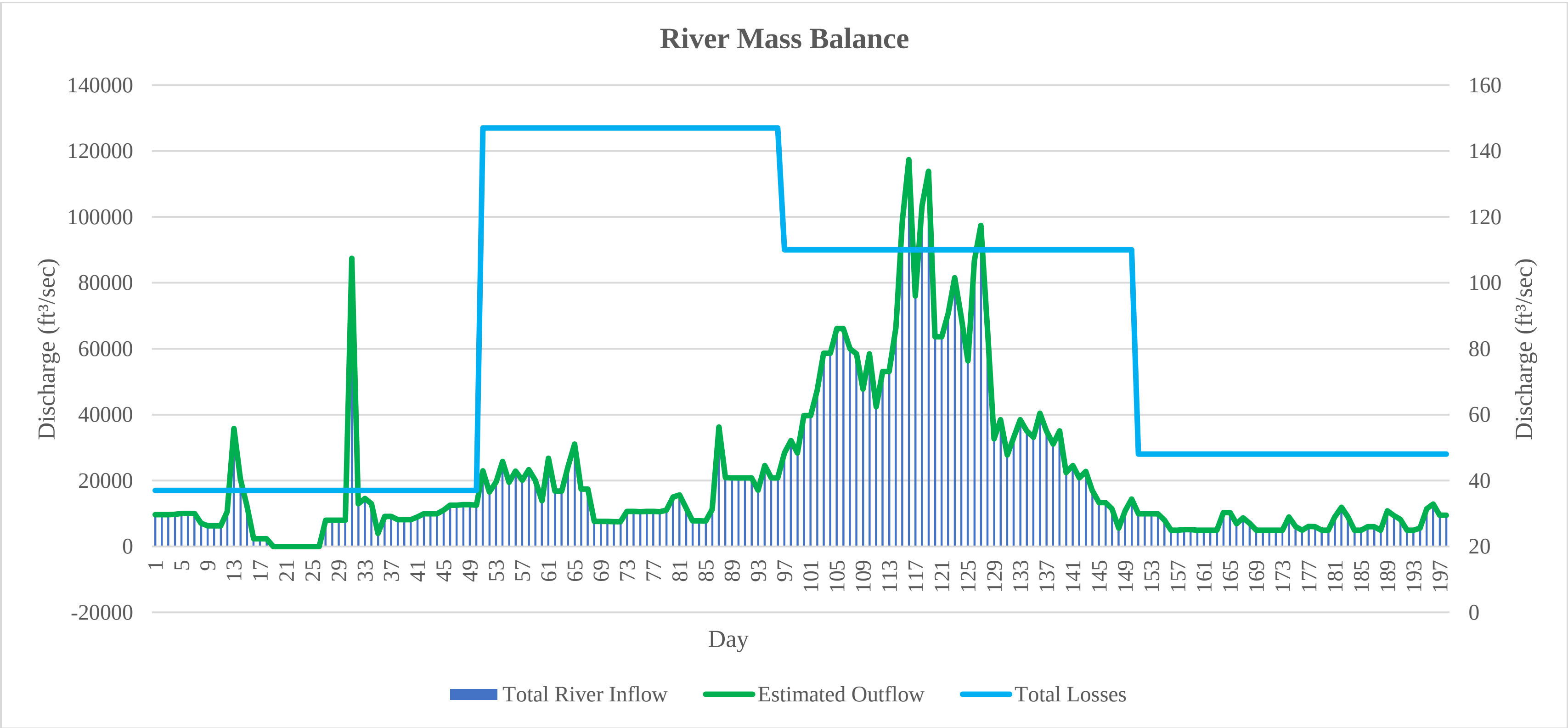

Figure 4.12 River Mass Balance

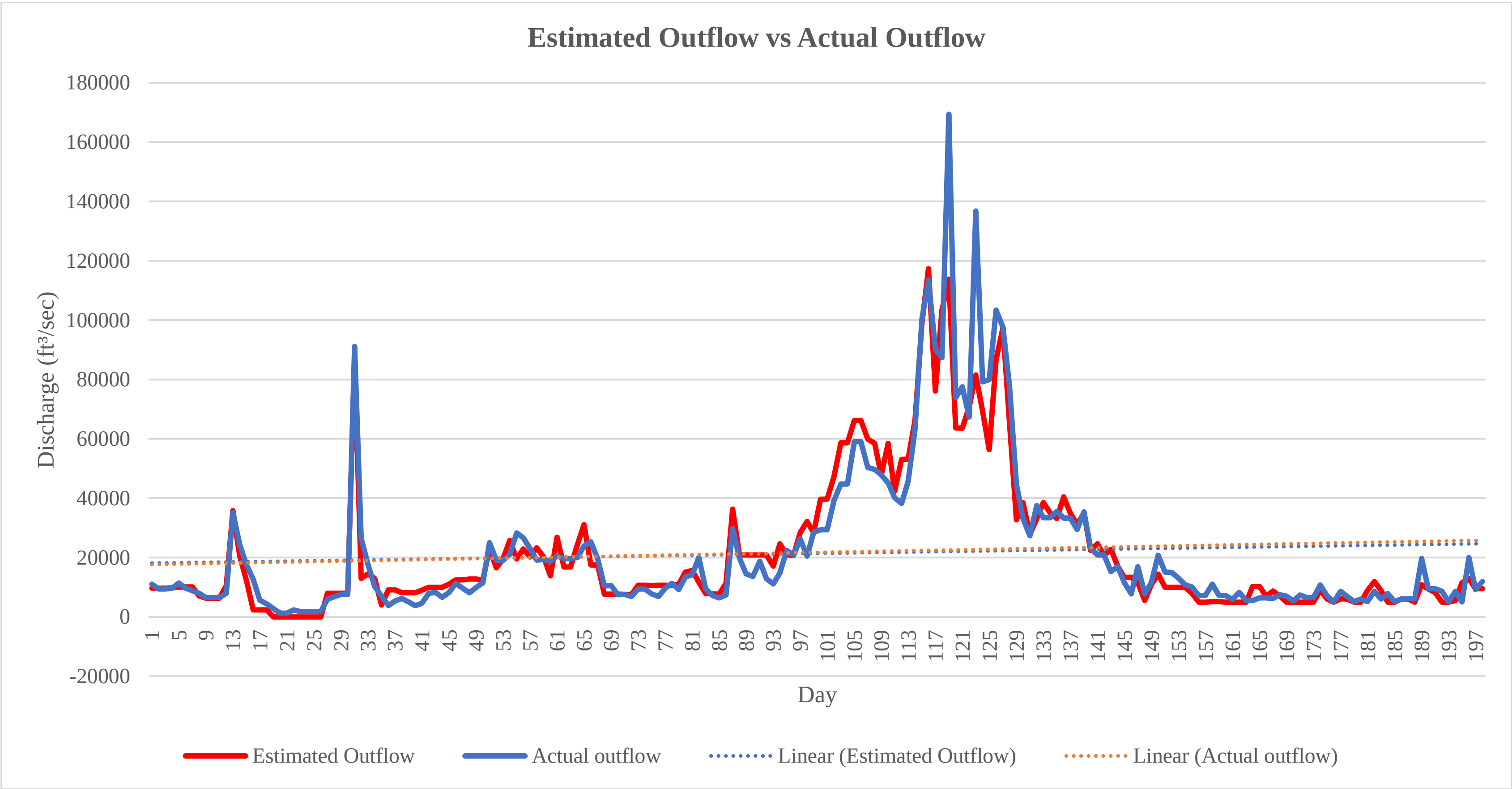

Figure 4.13 Estimated Outflow vs Actual Outflow

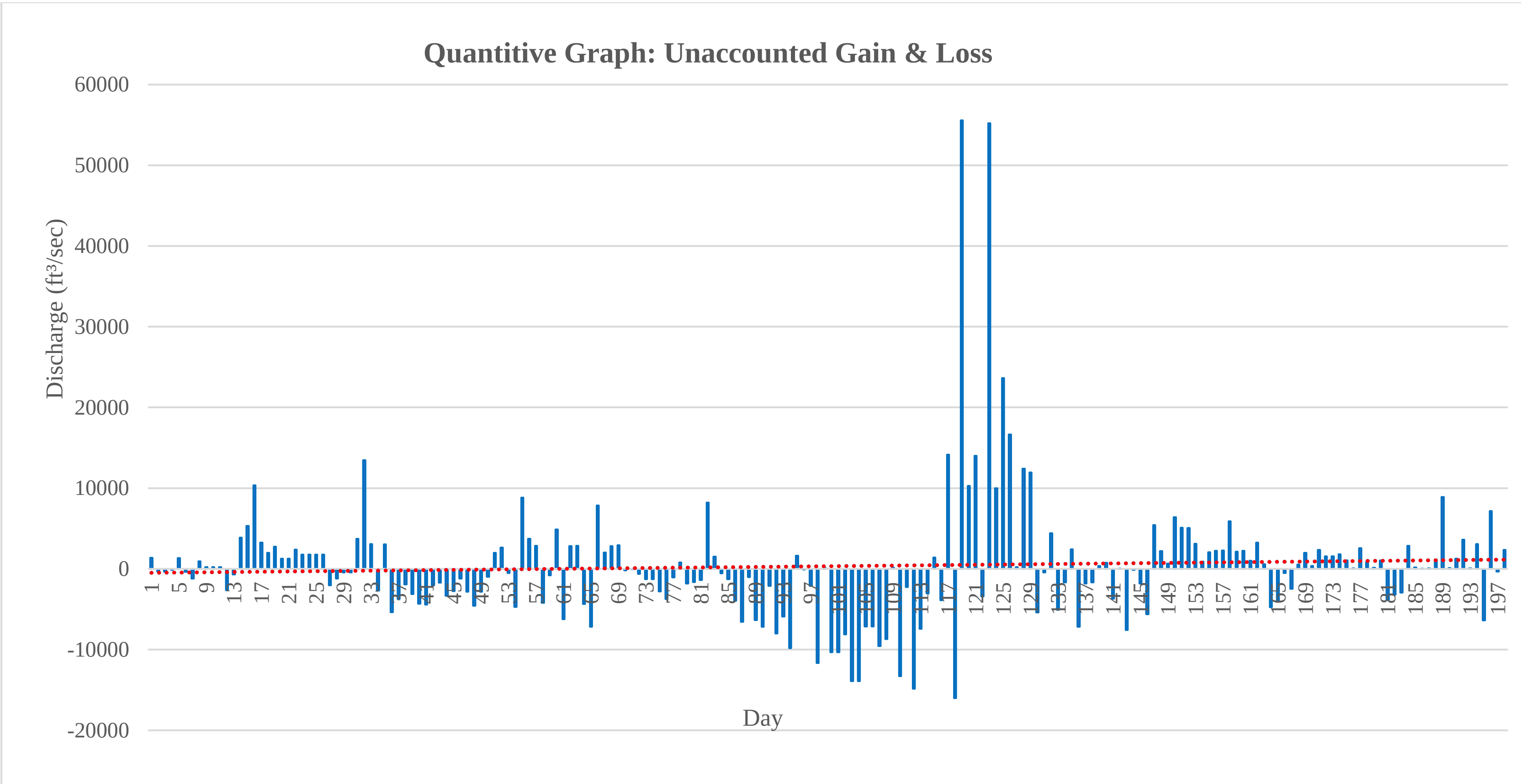

Figure 4.14 Quantitative Graph: Unaccounted Gain & Loss

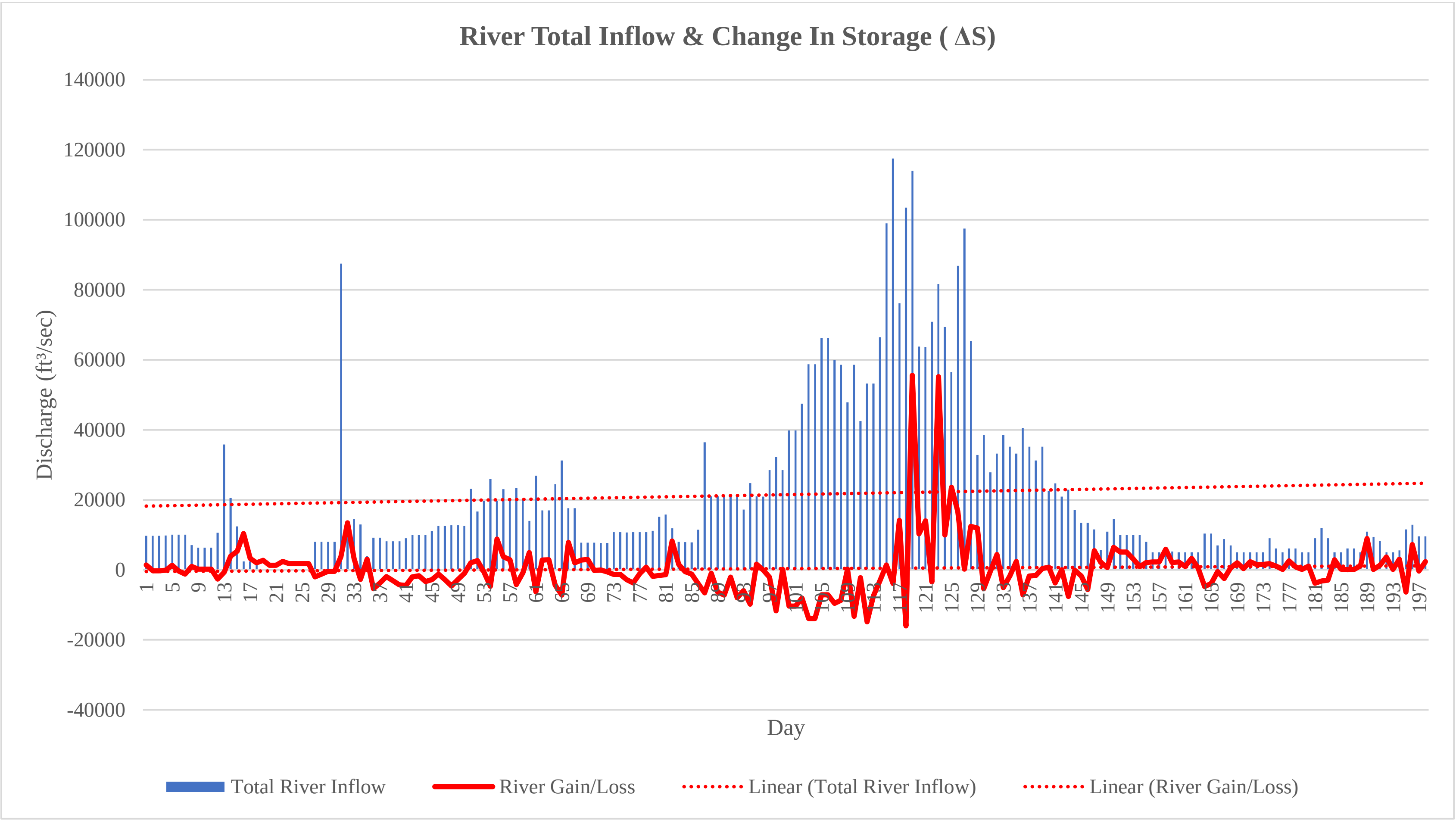

Figure 4.15 River Total Inflow & Change in Storage

4.6 River Mass Balance (Khanki – Qadirabad)

The (evaporation + seepage) loss was increased to 63 ft^3/sec (1.78m^3/sec) from 19 ft^3/sec (0.53m^3/sec) on 51st day as shown in Fig. 4.11 which effected the outflow of the river. The out flow of the river decreased slightly after this point and then again rose to 92894 ft^3/sec (2630m^3/sec) from 55645 ft^3/sec (1576 m^3/sec) on 115th day as also the losses decreased slightly on 97th day from 63 ft^3/sec (1.78m^3/sec) to 56 ft^3/sec (1.58m^3/sec). The inflow and the outflow were maximum on day 119th as 162125 ft3/sec (4591m^3/sec) and 162069 ft3/sec (4589 m^3/sec), respectively as shown in Fig. 4.16.

The estimated and actual outflow values were quite similar during the year as shown in the Fig. 4.17 and were highest on 119th day.

Total inflow of the river was almost consistent during the whole year but showed peak on day 119th and was relatively high before and after this peak value, as shown in Fig. 4.18.

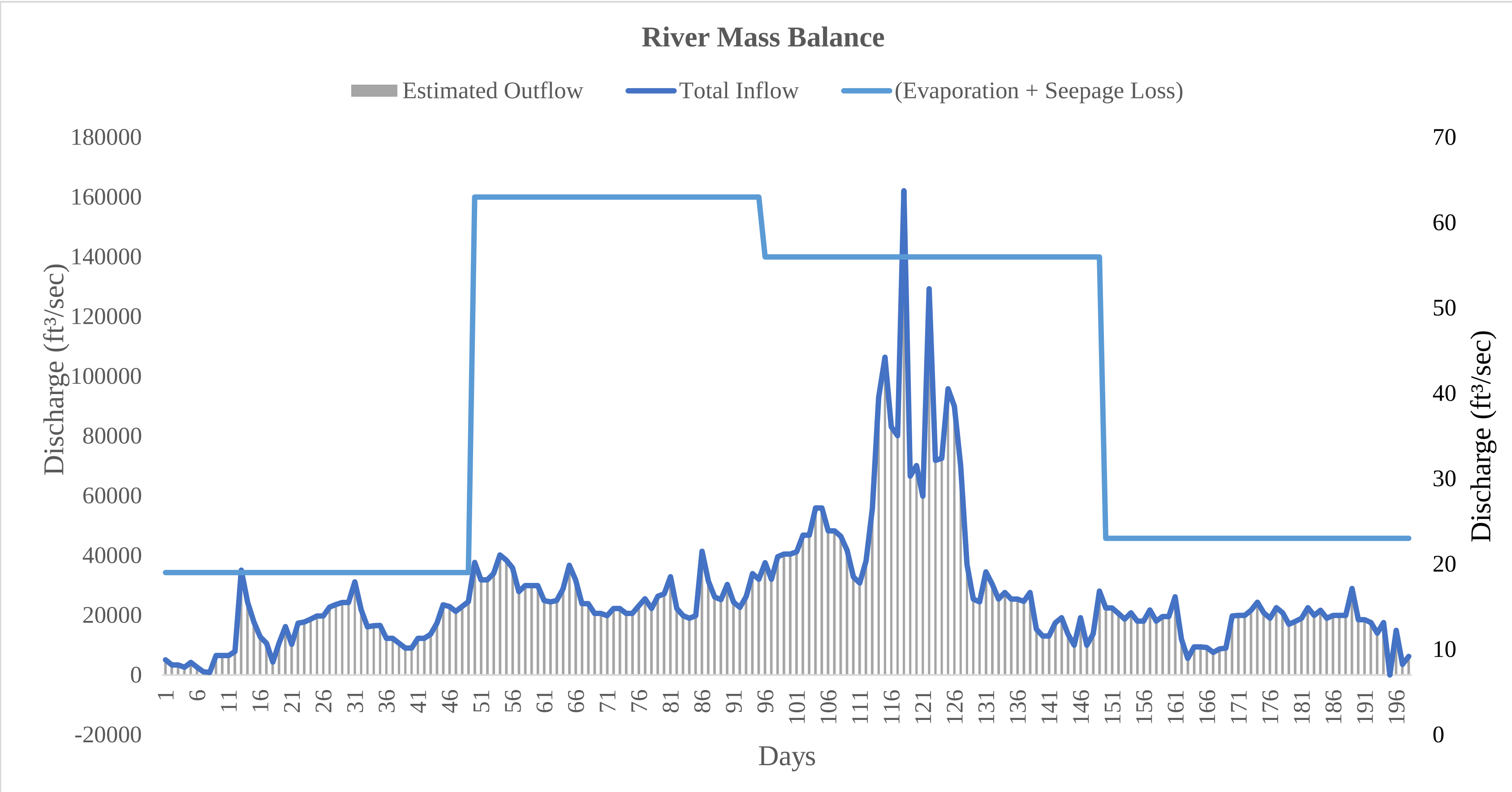

Figure 4.16 River Mass Balance

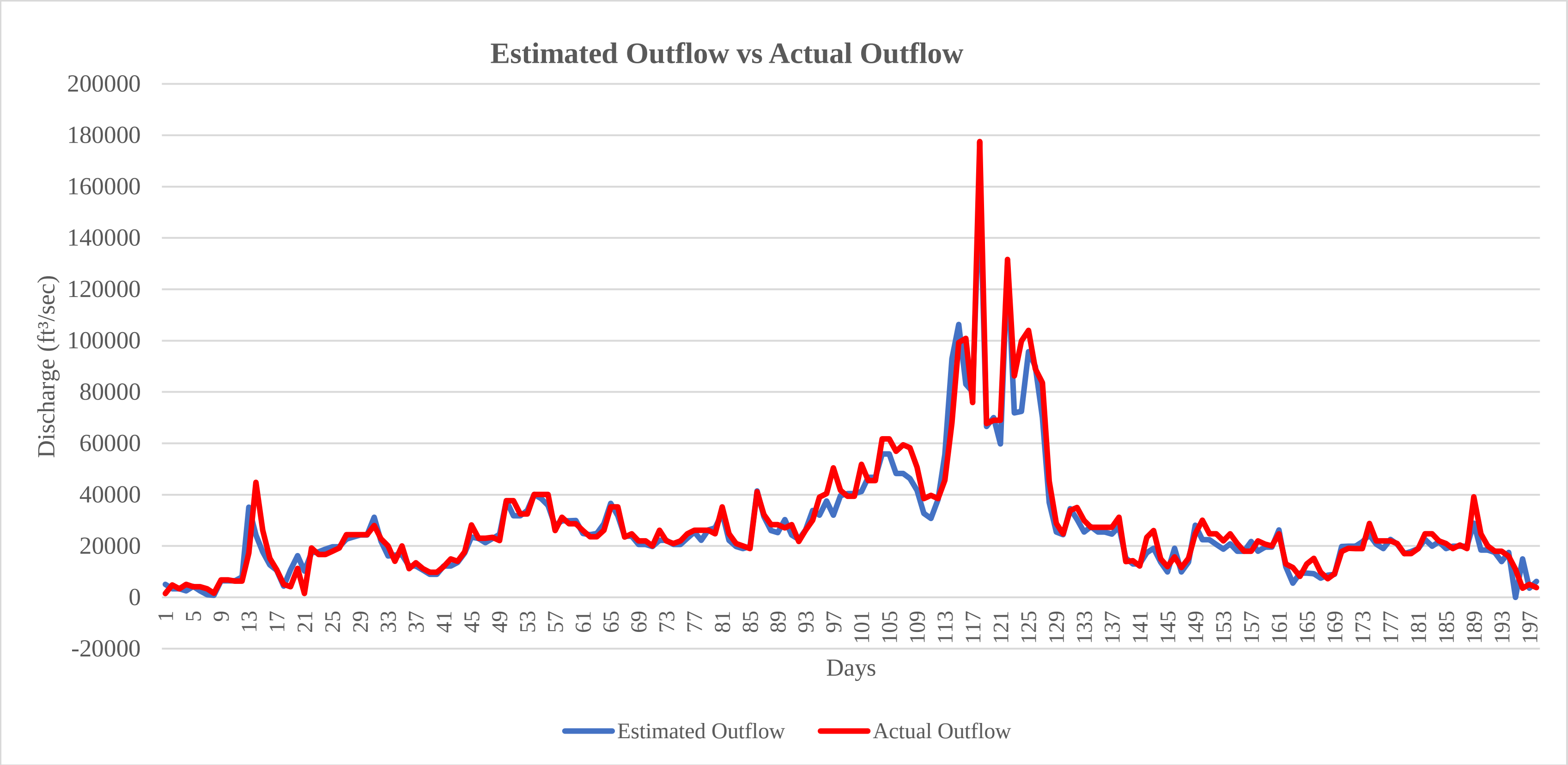

Figure 4.17 Estimated Outflow vs Actual Outflow

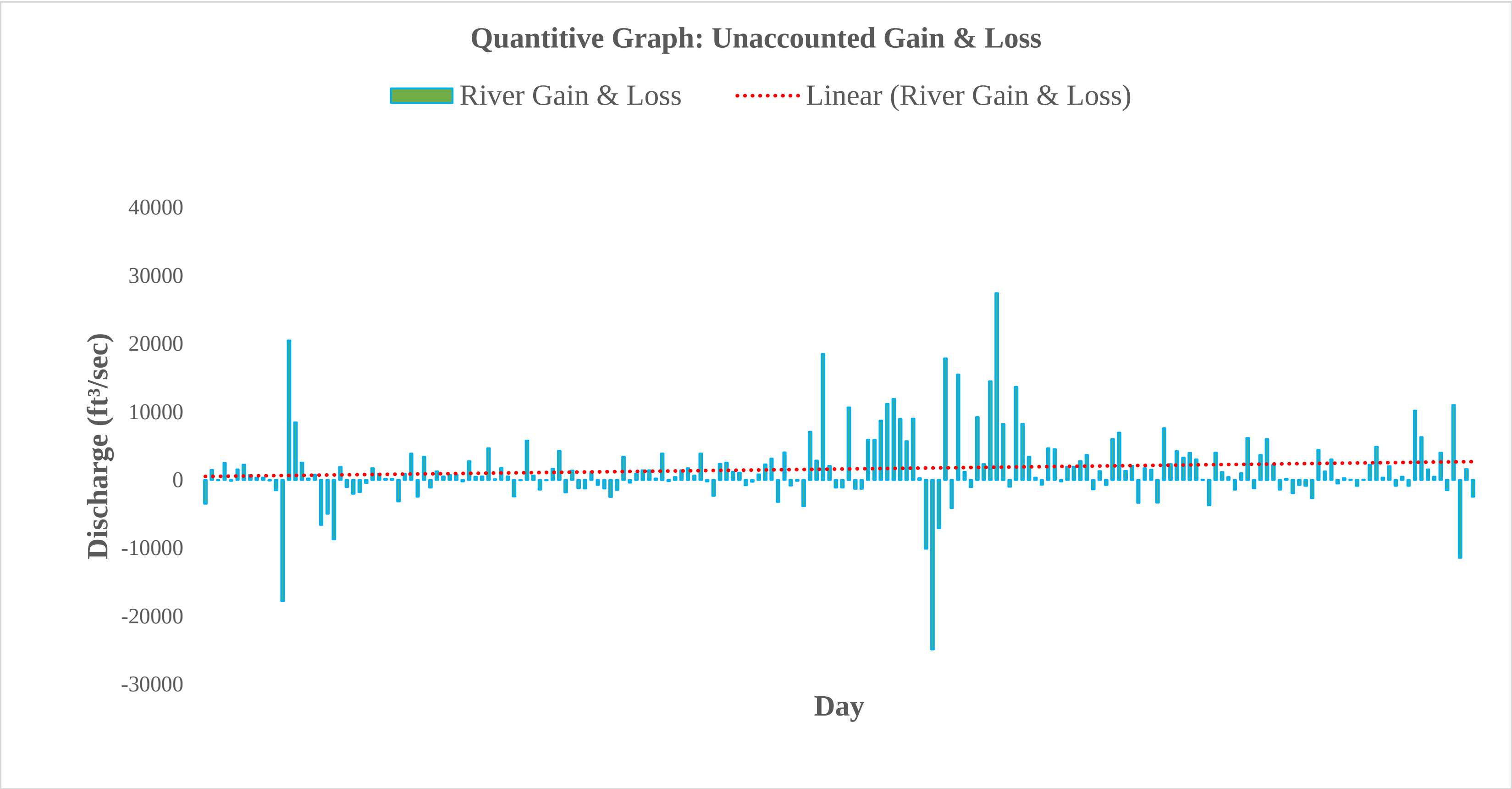

Figure 4.18 Quantitative Graph: Unaccounted Gain & Loss

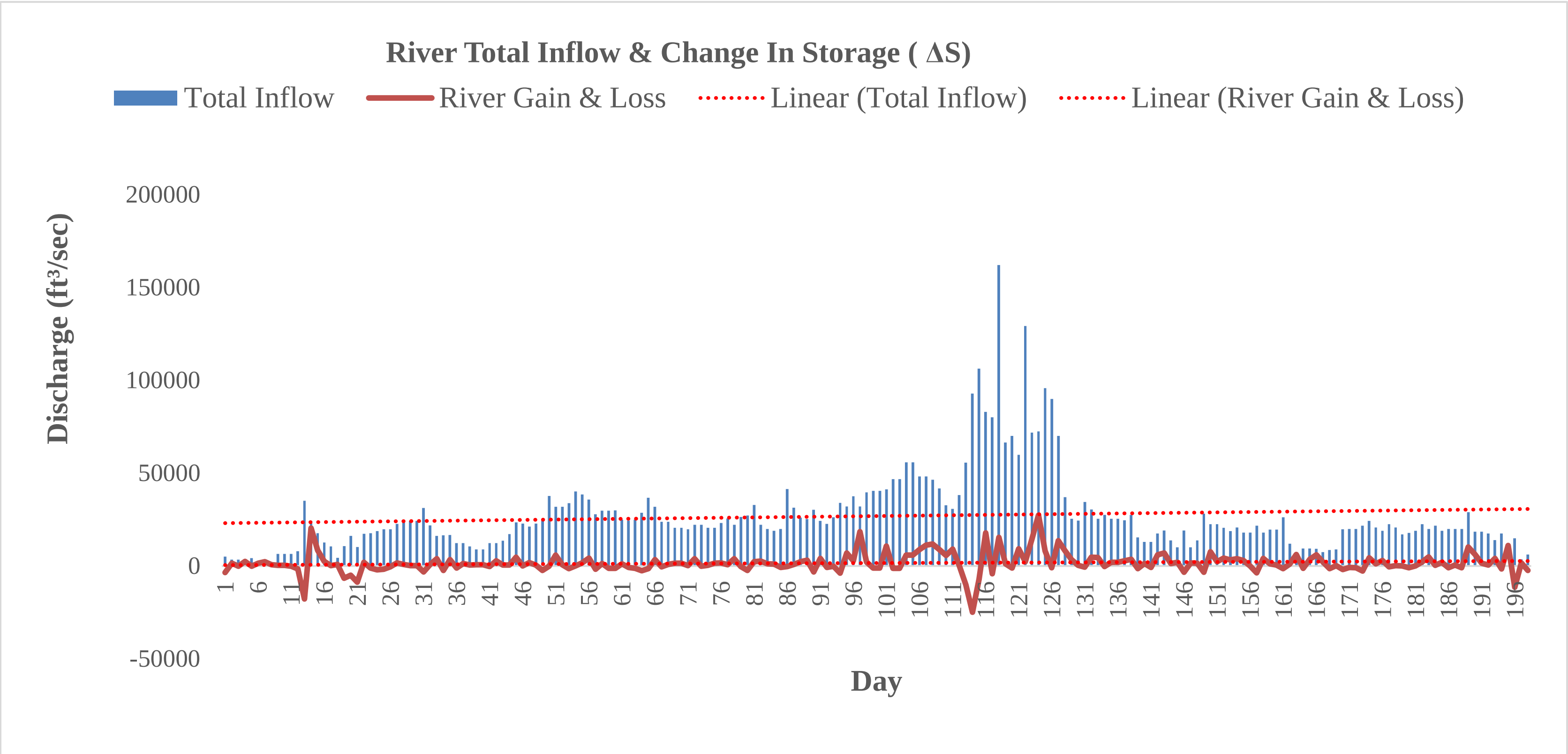

Figure 4.19 River Total Inflow & Change In Storage (ΔS)

4.7 River Mass Balance (Qadirabad - Trimmu)

The (evaporation + seepage) loss was increased to 194 ft^3/sec (5.49 m^3/sec) from 114 ft^3/sec (3.22 m^3/sec) on 51st day as shown in Fig. 4.20 which effected the outflow of the river. The inflow and the outflow were maximum on day 91st as 95291 ft^3/sec (2698 m^3/sec) and 75970 ft3/sec (2151m^3/sec), respectively as shown in Fig. 4.21. The estimated outflow showed less consistency's in comparison to previous sections. It is summarized in Fig 4.21.

Unaccounted gain and loss are the difference between actual outflow and estimated outflow, it is summarized in Fig. 4.22

Total inflow of the river was almost consistent during the whole year but showed peak on day 91 and was relatively high before and after this peak value, as shown in Fig. 4.23. It was also observed that river gain and loss was directly related to total inflow of the river.

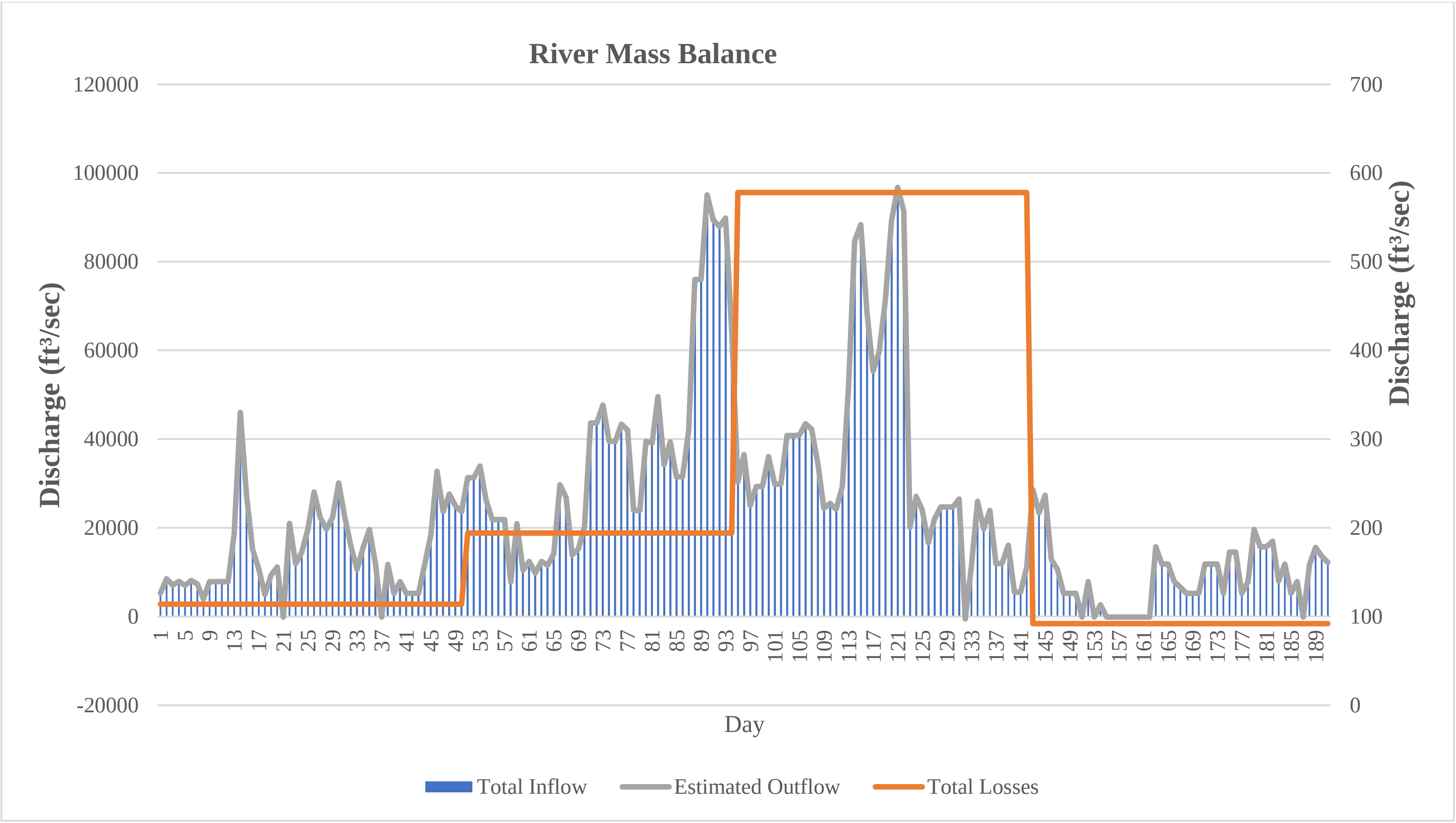

Figure 4.20 River Mass Balance

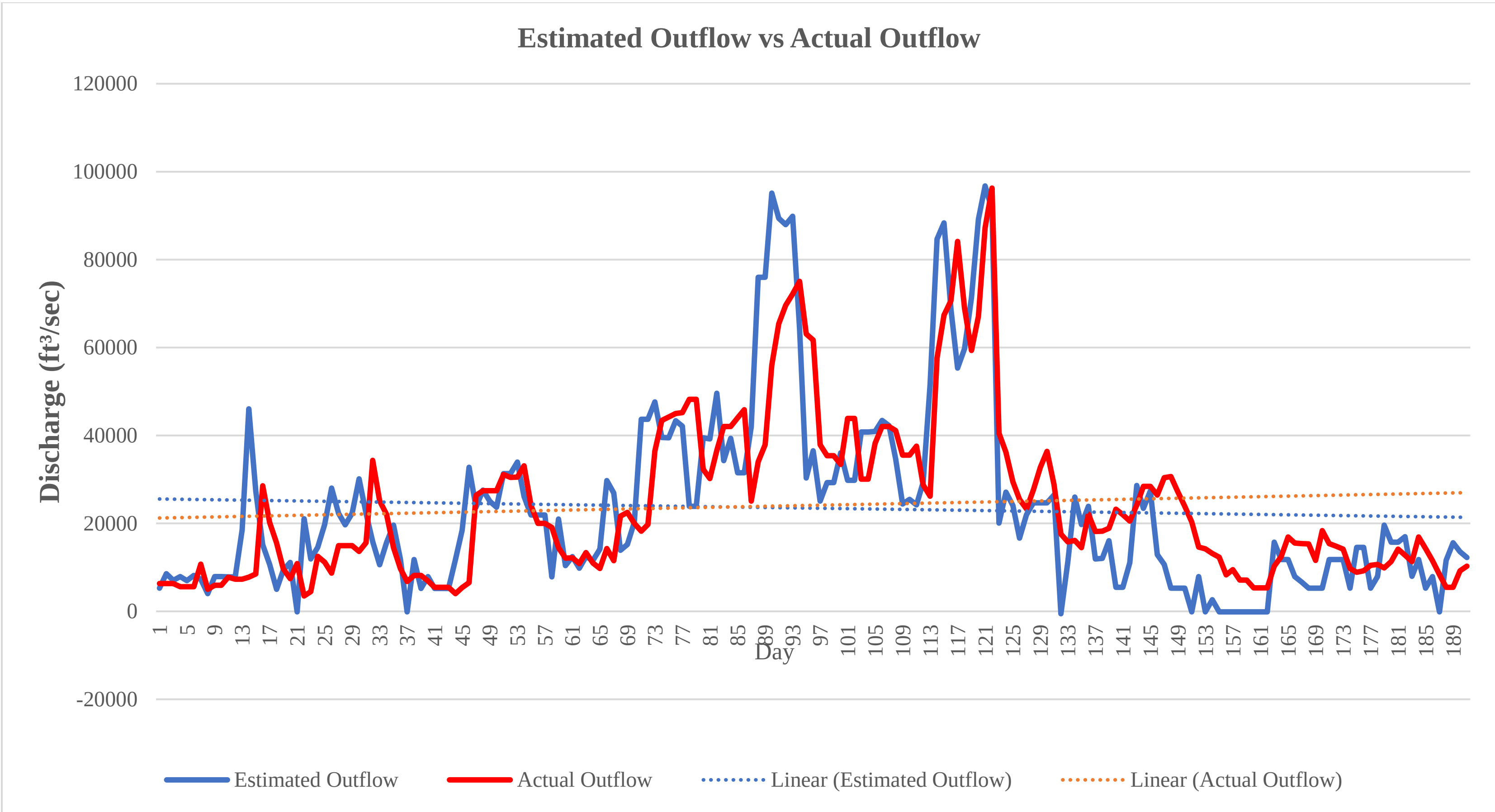

Figure 4.21 Estimated Outflow vs Actual Outflow

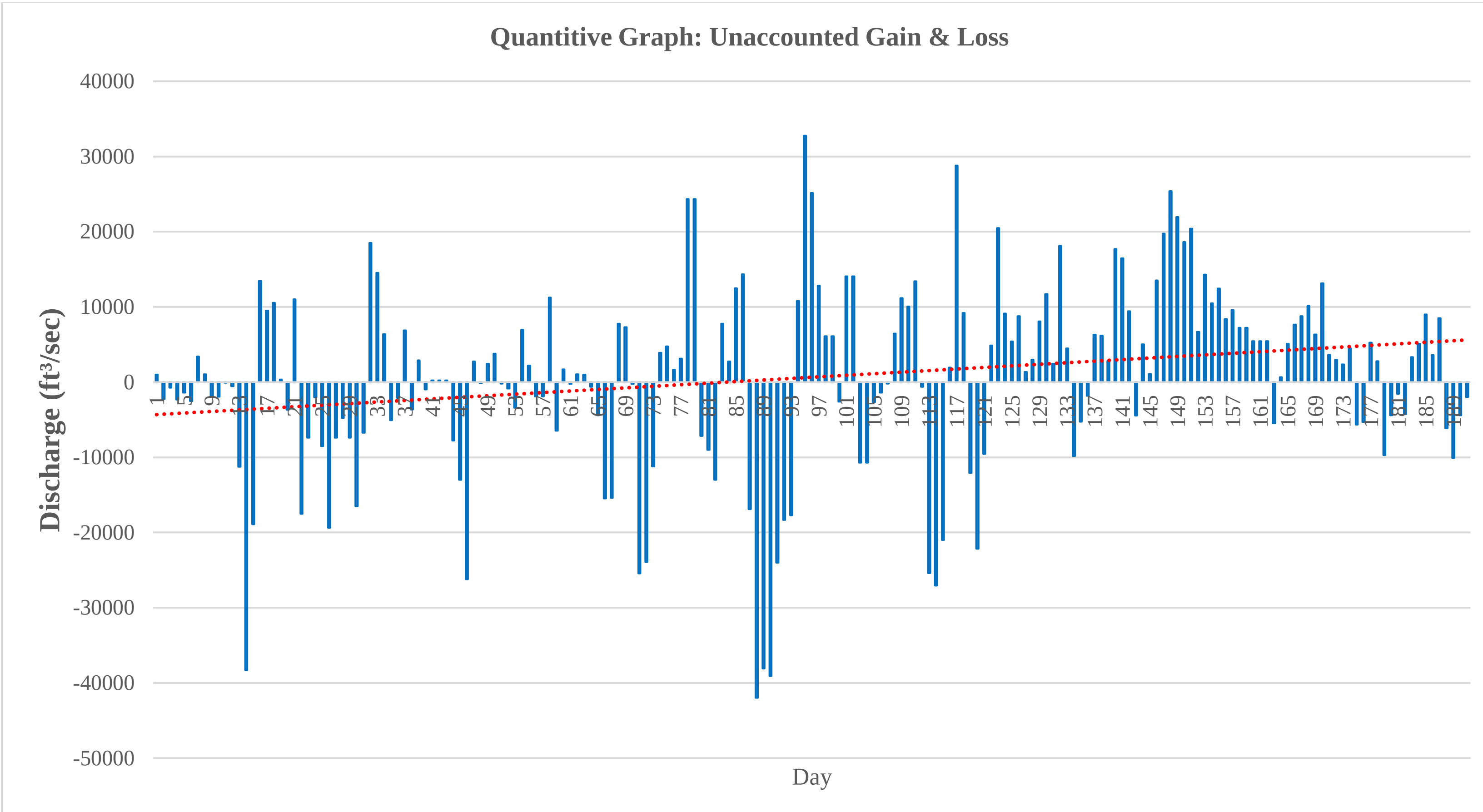

Figure 4.22 Quantitative Graph: Unaccounted Gain & Loss

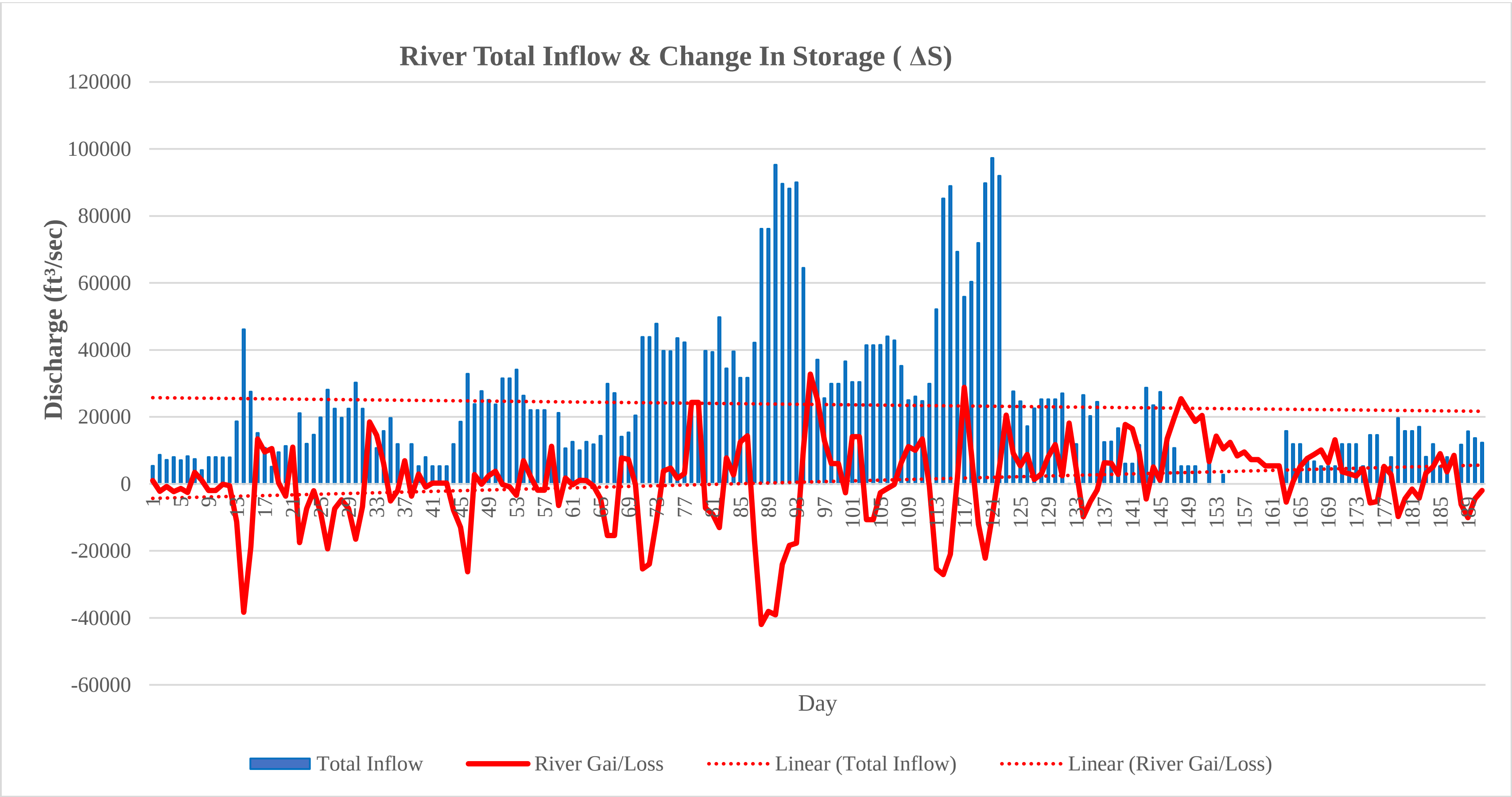

Figure 4.23 River Total Inflow & Change In Storage (ΔS)

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Pakistan now faces greater challenges in maintaining water and its quality and organizes the rising need of water assets. Mainly in Pakistan the chief consumer of water resources is agriculture as Pakistan is an agro based economy, it is predicted that in the near future more water may be scheduled for cities and industrial needs. Therefore, agricultural land will face scarcity of water. Many techniques are used to save water and maximize its use but the loss of still water increases. Following are the conclusions from this study.

1. The extracted river surface area shows an average 110% & 90% increase in peak season (July – Sep) when compared with off season (Oct – Apr).
2. During Sep 2014 floods the surface area increased 21% when compared with average 3-year river surface area during peak season (July – Sep).
3. 10-year Average of maximum pan evaporation for four station nearby river is 6.8mm/day during (Apr – Jun). When extrapolated over river surface area the average day evaporation loss is 567 cusecs (16.05 m^3/sec) during peak season (July – Sep) due to increased flow.
4. River section Marala – Khanki showed maximum seepage loss 2.08mm/day in comparison to 1.27 & 1.42mm/day from Khanki-Qadirabad & Qadirabad-Trimmu, respectively. When extrapolated over total river surface area the average day seepage loss is 177 cusecs (5.01 m^3/sec).
5. River Chenab (Marala – Trimmu) average daily cumulative water loss (Evaporation + Seepage) during peak season (July – Sep) is (21.06 m^3/sec) (0.54 MAF/yr) and (4.67m^3/sec) (0.12 MAF/yr) during off peak season (Oct – Apr).

6. The difference between estimated and actual outflow reduces as when river sections daily inflow become consistent, reflecting that error maybe due to the presence of water already in system.
7. Considering large data variation in river gain/loss, it can be concluded a comprehensive river data monitoring is required for efficient distribution of water and making rivers a sustainable source.

5.2 Recommendations

Several suggestions and recommendations were presented by different stake-holders like planners, agencies, and organizations, but the main concern is the producing the viable plan which is practical and can be implemented easily practicality. The following possible solutions for accountability for river water is articulated below.

1. Empirical methods can also be explored in estimation of evaporation where data is available.
2. Other methods such as energy budget can also be compared with this study for open surface water mass balance.
3. A broad study is required for river water monitoring that includes identification of leakages, river flow modelling and modern data recording at various barrages.
4. This study can be applied to other rivers in the country to estimate total loss in the country water system.

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