MODELLING OF IRRIGATION RESERVOIR OPERATION FOR EFFICIENT WATER MANAGEMENT WITH A FOCUS ON WATER AND FOOD SECURITY

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DECLARATION

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Modelling of irrigation reservoir operation for efficient water management with a focus on water and food security

Abstract

Agriculture uses more water when compared with other water users. Insufficient water resources in a country would create additional issues of governance due to poor food security for its people and lack of water for the sustenance of the environment. Water shortages especially for agriculture are most felt in the dry zone in Sri Lanka and most of the farmers are failing to cultivate full extent in both Maha and Yala season. Irrigation Department Guideline (ID 1984) which is the base for reservoir operation, planning and management in Sri Lanka, has the need to improve its methods by identifying suitable parameters and operational options suited for field applications. There are only limited studies of reservoir operation practice in Sri Lanka. Twenty years (1997-2016) of reservoir operation data of Namal Oya reservoir at Ampara District, Sri Lanka were analyzed at a weekly time scale to compare the practice and the guideline to critically evaluate the requirements for better water management with a view of achieving water security and thereby reaching food security. This work is an evaluation of irrigation reservoir water management practice to make recommendation for efficient water management in order to achieve water and food security for farming communities in the dry zone of Sri Lanka. A weekly water balance model according to the Irrigation Department guideline was developed for the reservoir system while including the behavior of the catchment area and the practice of cultivation in the command area. The model development was carried out using spreadsheets. A weekly crop water requirement was also developed to check observed water release which were compared with the crop water model estimations to verify the adherence to the guidelines. These results were then compared with the actual water releases to evaluate the variations, influence of parameters and the field level cultivation practices. Inflow model was also developed based on Irrigation department guideline and a monthly 2 Parameters model and were later compared with observed storage. The comparison of model developed with ID guideline and the water use plans of the Namal Oya Irrigation department office revealed the average annual difference of observed and calculated water release is 1091 Ha.m where 392 Ha.m in Maha season and 699 in Yala season and observed annual water release is 2098 Ha.m where 705 Ha.m in Maha and 1391 Ha.m in Yala which indicating the Namal oya Irrigation reservoir are releasing 50% more water than the observed values in a water year. The model results and the actual practice demonstrated that the overall efficiency of the irrigation scheme is estimated based on trial and error method and the value is 55%. The most sensitive parameters in the water balance inflow, sluice release and seepage. The study indicated that if the efficiency level can be increased by 70%, the annual water demand will be reduced from 2654.82 Ha.m to 2055 Ha.m which enables to served nearly 496 Ha more command area each water year. The key parameters that need attention are inflow andsluice discharges. Consideration of practical advantages and the need for water security leads to recommending to incorporate the present practice with an update of ID guideline.

KEY WORDS: Evaluation, irrigation, water security, Sri Lanka

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1 INTRODUCTION

1.1 General

Water and food are playing an important role for human existence as well as human development. Access to water and food with their sustainable management of associate resources are the basis for sustainable development. Perceiving that efficient utilization of these limited or declining resources is basic to sustainability, the global community has directed its concentration toward the idea of the food and water nexus. Demand of water is expanding, driven by rising worldwide population with the fast environmental change, urbanization, changing food habits and points of economic development. Agriculture is the biggest consumer of the world's freshwater, and more than one-fourth of the energy utilized globally is expended on food production (UN Water, 2017). Water is a critical element of socio-economic development. Lack of water resources and lack of equitable distribution of water resources in a country would create additional issues of governance and peace. In order to achieve economic development there is also a great need for water for production. (Daily Mirror, 2015)

Water is vital to the world's development challenges. In the case of food and nutrition security, reduction of poverty, economic development, energy creation or human wellbeing, water is the nexus. Water is a key factor in the accomplishment of the Global Development Goals. Water for irrigation and food production constitutes one of the greatest pressures on freshwater resources. Agriculture accounts approximately ~70% of global freshwater withdrawals (up to 90% in some fast-growing economies). Therefore, food and water security are inseparably connected. Creating enough food for one individual for one day requires around 3,000 liters of water – or around 1 liter for every calorie. When contrasted with the 2–5 liters required for drinking, obviously water for food production is a basic issue as population and economic growth (Institution of Civil Engineers, 2009)Irrigation is only a modest part of agricultural needs, accounting for more than 40 per cent of world production on less than 20 per cent of cultivated land. Concerns about food insecurity are growing all over the world, and more water will be needed to meet growing food demands. (UNESCO, 2012).

South Asia is one of the most unique areas of the world as far as populace development, economic growth, urbanization, and industrialization. The geography and demographic conditions, growth, and ecological changes in South Asia have expanded the interest for natural resources and intensified their uses, which has critical implication for water and food security in this region.

Water and food security is a priority for any nation, given the current concerns over climate change, land use and the decline in the agricultural labor force (Daily News, 2017). Besides, water is one of the fundamental natural resources in Sri Lanka and it is the primary factor which contributes to the national economic development since the past. Sri Lanka being an agricultural country, the irrigation has had a unique contribution towards country`s agro-economy from history to this date (Ministry of Land and Land Development, 2014).

Sri Lanka depends heavily on agriculture, and both rain-fed and irrigated agriculture form are the backbone of rural livelihoods (Rajakaruna, 2014). There are a significant number of reservoirs in Sri Lanka, though these reservoirs served multiple purposes; irrigation has always played a major role in the economy Water shortages particularly for agriculture are most commonly felt in the dry zone, that is why the ancient people constructed a vast network of inland reservoirs over a period of 15 centuries to preserve and optimize the rainfall over a very short period of time. (Schokman, 2002). Scientists have indicated that Sri Lanka's total rainfall has decreased in many parts of the country (Rodrigo & Senaratne, 2013). The proven rainfall patterns have changed, and the distribution of rainfall across different parts of the country also seems to be undergoing changes. While droughts cause delays in planting seasons and are responsible for crop damage, floods have destroyed mature crops awaiting harvesting. (Rodrigo & Senaratne, 2013). The 2016/17 drought has been one of the major disasters in Sri Lanka over the last five years, causing around 227,000 households to become food insecurity in the affected areas so far. Food insecurity in drought-affected regions is widespread and is growing, with some areas having reached severely deteriorated levels of food consumption and over 16 percent of households becoming food insecure or borderline food insecure (WFP, 2017).

The total area cultivated in Sri Lanka is estimated at 1.86 million ha according to current statistics; where 632,000 ha. of is irrigated; the rest is rain-fed. Irrigated agriculture consists mainly of major irrigation schemes. There are also numerous smaller schemes, which can be categorized as semi-rain-fed systems. These include more than 15,000 village tanks spread across the country's dry zone. Irrigated agriculture in Sri Lanka has gained much attention from policy-makers over the past several decades, culminating in the accelerated Mahaweli Development Program of the mid-1980s. There have been many steps to rehabilitate and rebuild the ancient irrigation systems (Rodrigo & Senaratne, 2016).

In Sri Lanka, nearly 72% of paddy production, is grown during the wet season and in dry zones of the country where water resources are already stressed (Silva, Weatherhead, Knox and Diaz, 2007). Water demand in paddy cultivation is high compared to many other crops. Water is important for land preparation, crop planting and maintenance throughout the planting and harvesting process. Research has also indicated that the production of paddy in Sri Lanka would increase by 10% by 2025 and that additional amounts will be entirely based on irrigation (Rodrigo & Senaratne, 2016).

Out of 25 districts in Sri Lanka, Ampara District is known as the "rice bowl of the country" which produces 15% of the national paddy production. Ampara is predominantly an agricultural area in the dry zone. It has nearly 135,000 ha of potentially cultivable land of which around 70,000 ha under paddy cultivation. Paddy cultivation is the main livelihood of more than 45% of the working population of the District and a further 30% are indirectly involved in paddy cultivation and related activities. With the help of rain water, major irrigation facilities such as Senanayake Samudra reservoir and several other medium and minor tanks, Ampara farmers are able to cultivate paddy during both Maha and Yala seasons (Saleem, 2015). However, these appears only very limited study on the performance of irrigation reservoirs in Ampara district. Deshapriya & Wijesekera (2017) conducted a study on Rambakan Oya reservoir ampara district about the climate change effects on irrigation system. There are no major studies on irrigation reservoirs at Ampara district.

During the last two decades, irrigation sector has gone through many changes. Several government institutions (national and local) are involved in irrigation water management. The requirements of irrigation stakeholders including the farmers, irrigation system managers and policy makers, have changed. But there are not must study to know However, there are no studies to compare the gap between water availability and demand in irrigation reservoirs in Sri Lanka. One reason is the significant gaps data collection related to a quality, technology and coverage etc. Therefore, ensuring water security requires cooperation between different types of stakeholders and between those who share river basins and aquifers, within guidelines that allows critical habitats to be protected from contamination and other threats. Within the context of demographic growth, increased competition for water around the world, water resources should be equitably, effectively and integrate managed and developed.

Most of the large tanks in Sri Lanka have been restored in the recent years and put back into soperation; small tanks that are considered to be economically less efficient received orphan treatment (Rodrigo & Senaratne, 2013).

Appropriate reservoir operation and efficient water management are essential for increasing the overall performance of reservoir irrigation systems. The most important thing of a reservoir operation is to discharge right amount of water at the right time to command areas for achieving greater benefits. So, using the appropriate amount of water for irrigation purpose is the key factor and therefore efficient water management is very important for achieving food security.

The use of groundwater for irrigation has become popular among farmers for various reasons. Sri Lanka's use of groundwater for agriculture has historically been limited to the northern and eastern provinces that lack perennial surface water supplies. Due to constraints and limitations in the use of surface water, farmers have supplemented irrigation water from ground water by digging large, shallow wells known as agro-wells. Since then, agro-wells gained popularity as the farmer has high flexibility in the selection of crop and time of cultivation. Also, the farmer has full control over the irrigation, which allows him to irrigate on-demand basis. On the other hand, coastal sand belts with tremendous groundwater potential are threatened with water pollution resulting from excessive irrigation. However, the density of agro-wells, that is, the number of agro- wells per unit area, has increased creating a critical situation of over-exploitation of ground water.

The specific character of reservoir management and operations problems calls for investigation of every technology available to help bridge the gap between theory and practice.

1) Improvement of tank bunds and spillways,
2) Replacement of old sluices
3) Improvement of main and field channels, and
4) Provision of appropriate drainage systems, control structures, turn-out structures and measuring devices.

For promoting the efficiency of water resources utilization, management responsibilities and obligations should be clearly defined. The challenge facing national policy makers, irrigation officials and farmers is how best to maintain and raise rice yields and other food production while reducing the overall use of agricultural water. Irrigation can also be minimized by new techniques such as saturated soil agriculture, a method that relies on the development of field beds. Crops are grown on elevated beds, separated by furrows in which a shallow water depth is preserved. Rice grown with saturated soil cultivation in Australia used 32 per cent less irrigation water than traditional wet and dry season methods. Promotion of equipment efficiency, the suitability of various irrigation methods, i.e. surface, sprinkler or drip irrigation, depends largely on the following factors: natural conditions, crop size, technology type, previous irrigation experience, necessary labor inputs, costs and benefits (ACIAR, 2016).

The management of irrigation water should meet the perceived needs of the three key stakeholders, namely farmers, system operators and policy makers. The recent trend is the transition of irrigation system management from government agencies to farmer organization. Therefore, farmer's organizations should be strengthened by training and providing necessary legal, economic and social support to allow them to play an effective role in encouraging farmers to become partners rather than merely participants in irrigation water management.

Village-level officials from both governmental and non-governmental organizations engaged in advising farmers on irrigated agriculture should be regularly trained so that they can perform their position effectively leading to higher agricultural productivity. The training needs, mechanism for technology transfer and the adoption procedure of different management policies are to be re-identified, considering the current context of water sector at both local and global levels.

Finally, management of existing reservoir system require minimum infrastructure or practice change. It is also economic compare to other alternatives. In summary, this is an urgent need to efficiently manage dry zones irrigation system in Sri Lanka to ensure water and food security. However, there is lack of a critical research that highlight the management issues of irrigation reservoir by using system water balance approaches. Therefore, the main target of this study is to carry out a system analysis of Namal Oya reservoir, Ampara district in order to identify constrains for bettermanagement In order to manage the existing system, it is necessary to carry out a reservoir operation as part of the situation analysis for efficient water management of Namal Oya irrigation reservoir to fulfil water and food security.

Figure 1-1: Namal Oya reservoir, Ampara district, Sri Lanka

1.2 Overall and specific objective

1.2.1 Overall objective

The overall objective of the present work is to carry out a system analysis to an irrigation reservoir in order to evaluate the present status of water management to achieve water and food security for farming communities in the dry zone of Sri Lanka.

1.2.2 Specific objectives

a. Reviewing the current status of reservoir operation and irrigation management

b. To check in methods, tools and constraints of data collection of reservoir operation.

c. Carryout a system analysis for Namal Oya reservoir to identify the present situation.

d. Evaluate the results and identify critical alternatives for water management.

e. Make recommendations for efficient water management to achieve water and food security.

2 LITERATURE REVIEW

2.1 Typical models and practices

2.1.1 Importance of modeling

Today, planning, design and management of water resource systems ultimately requires the prediction of impact and this research modeling provides a way, perhaps the main way, to predict the actions or performance of the proposed system infrastructure in designing or developing management policies (Beek & Loucks, 2017). The modeling of water resource systems is a key component of the water resource planning process, as it provides a testing environment for assessing the system's behavior in any number of selected scenarios prior to actual experience (Nkwonta, Dzwairo , Otieno, & Adeyemo, 2017). Effective water resources management is very critical as it ensures that water resources are supplied and handled with the greatest efficiencies possible. Modeling helps to predict future events that are always uncertain, water demand and supply gaps in a given time and location, water resource management in a relatively organized and ordered manner, based on certain assumptions. Though models can not specify the best objectives or set of assumptions, they can help to identify the decisions that best meet any particular goal and assumptions.

2.1.2 Irrigation reservoir models

Management of reservoirs includes allocating available water to multiple uses and users, mitigating the risks of water shortages and floods and maximizing beneficial water usage (Jain, Goel, & Agarwal, 1998). Optimizing the economic advantages of water systems is a classic and persistent issue. Due to the large number of variables involved, the non-linearity of system dynamics, the stochastic existence of potential inflows, and other system uncertainties, the solution to this problem is difficult. Moreover, a range of mathematical programming techniques were developed to help derive optimal operating strategies for water resources system. Most optimization models are based on a certain form of mathematical programming methodology and usually belong to one of the three categories: linear programming (LP), dynamic programming (DP) and nonlinear programming (Bhadra, Bandyopadhyay, & Ragshuwanshi, 2015). The choice of these methods depends on the reservoir characteristics being considered, the availability of data, objectives and constraints. In addition, most of these methods work satisfactorily for the specific problems.

Sahoo, Loof, Abernethy, & Kazama (2001) used linear programming and the principal modeling tool in Thailand's irrigation system for enhancing crop and water planning decisions. The optimized solution of the model suggested a diversified crop pattern that would reduce water demand by 16.4 percent and increase net income by 39.9 percent per cubic meter of water.

Real-time model based on an integrated linear programming imgation model (LPIM) for a reservoir system meant hadbeen developed by Azamathulla, Ghani, Zakaria, & Kiat, (2009) for Chiller reservoir system at Madhya Pradesh, India in order to obtain maximum reservoir operating plan combining field level decisions in deciding the length and quantity of water to be released from the reservoir and this approach ensures maximum reservoir release over different periods of time.

Raman, Mohan, & Rangacharya, (1990) developed a LP Model which main objective was to find the optimal cropping pattern for maximization of area under cultivation, to take into account the effect of preparedness for drought and to obtain different drought conditions by using inflow data of Bhadra reservoir at Karnataka State, South India.

Tilmant, Vanclooster, Persoons, & Duckstein, (2002) compared reservoir operational policies derived from the Fuzzy Stochastic Dynamic Programming (FSDP) model and the classical Stochastic Dynamic Programming (SDP) model at the Mansour Eddahbi dam in Morocco and showed that both formulations produced identical system performance measurements, despite significant variations in mathematical representation of operating priorities, restrictions, etc.

Stedinger, Sule, & Louck (1984) in their work paper developed a Stochastic Dynamic Programming Model dam at Aswan in the Nile River Basin that uses the best forecast of the current period to identify the strategy for the release of reservoirs and measure the benefits of future operations. The use of the best inflow forecast as a hydrological state vector, rather than the inflow of the previous period, the simulated reservoir operations with associated stationary reservoir operating policies had resulted in significant improvements.

A Nonlinear Optimization Model by Reddy & Kuma (2007) for reservoir operation of Malaprabha Reservoir system, Krishna Basin, Karnataka State, India by integrating the water supply dynamics at reservoir level with the application of crop water requirements at field level, They have found that if the seasonal forecast is available in early, then the cropping pattern can be calculated by taking into account the total availability of water. Then, the developed model of operation of the reservoir with economic benefits enables the determination of appropriate decisions on the allocation of crop water to maximize the benefits of the water resources available.

Bhadra, Bandyopadhyay, & Ragshuwanshi,(2015) developed an easy-to-use generalized simulation model for reservoir management based on conservation-of-mass approach. This study develops and tests a water balance model for reservoir management for Kangsabati Reservoir, West Bengal, India. Two rule curves for determining the irrigation water available from the reservoir were created by taking on a daily basis for a 16-year period the average and minimum stage values (1988–2003). Maintaining a minimum stage of 120.4 m throughout the year acted as a further guideline for deciding on the release of irrigation water. From those reservoir specific rule curves created for irrigation purposes, the minimum permissible stage of the reservoir corresponding to a given date of the year can then be calculated. The maximum permissible water release / outflow from the test reservoir for irrigation was taken as the volume of water available above the minimum permissible stage corresponding to the chosen rule curve.

A tank water balance study, carried out at Paindikulama tank, (Anuradhapura) by Dharmasena (1989) during 1984 to1988, the extent of land cultivated was always below 60% of the available command area and cultivations were delayed in all observed seasons. According to observations, the farmer practice in relation to water management in this field is described as described as wasteful. More than half the storage in each season was lost without direct utilization for crops.

S Wijesekera (2001) a monthly water balance model to check the performance of Lunugamwehera reservoir, recorded output of the reservoir under different parameter scenarios. This work recommended a seepage coefficient analysis using measurements of soil moisture parameters to accurately estimate and classify pan evaporation values from the reservoir to enhance water management.

Meegassagama tank, Anuradhapura was studied by De Silva (2003) with The monthly water balance for the typical 1997 and 1998 years indicated that more than 50 per cent of the water left the reservoir as seepage losses.

2.1.3 Irrigation Model in Sri Lanka

In Sri Lanka, Irrigation department are using conservation of mass balance equation for reservoir operation for long times (Ponarajah, 1984). Water balance modelling could easily identify differences in the measurements and raise issues pertaining to the assumptions in reservoir operation. This will provide opportunities for a manager to closely monitor the system performance, data collection, data extraction and data recording. It also helps to identify which part of reservoir component are not working properly. Water balance models seem to offer significant benefits in terms of precision, versatility and ease of use compared to other approaches (Dharmasena,1989).

2.2 Parameters for efficient water management

2.2.1 Irrigation scheduling

Wickramaarachchi, Wijesekera, & Gamage (2002) studied water scheduling in paddy cultivation at Mahawali system H of Sri Lanka, using irrigation department guidelines (Ponarajah, 1984) and filed observations. In this work authors had noted that paddy yield in the study area was 5 metric ton/Ha while the regional average was6.42 metric ton/Ha. Field work revealed that water issue canals were overloaded, and farmers modified rotation intervals during cultivations. Considering the varieties of paddy and their sensitivity to water shortages at different plant growth stages, a modified schedule had been proposed by authors to overcome various farmer practices that had resulted significant deviations from the guideline recommended schedule. They concluded that 2% of total supply increase through the proposed scheduling could result a yield increase of about 25%.

Najim, Haque, & Lee,(2004) developed an A schedule for irrigation water delivery to improve irrigation output for a large-scale rice irrigation project in Malaysia. They concentrated on modeling the rice-based project's irrigation water supply schedules during the main season and off season. The approach of water balance was used where rainfall was considered a stochastic variable. Computed irrigation schedules could save 19% and 11% of irrigation water in the main season and off season, respectively, compared to traditional irrigation schedules.

Hadad & Bakr (2013) carried out a study at Iraq on irrigation schedulingwith filed trials on an area of NahrdSa’d irrigation project revealed a water saving of 36 and 56 MCM for two different seasons under the assumption of minimum drainage water from the system.The study reported that water scheduling could be used as a water saving tool if cropping pattern is chosen carefully. Literature on irrigation scheduling reflects that suitable field monitoring of soil moisture and other components corresponding water budget leads substantial water savings.

Irrigation scheduling is required to use water effectively and profitably for irrigating agricultural crops. Irrigation schedule depends on the nature, maintenance and operation of the irrigation system and water availability. It helps the farmer to schedule rotations of water between different fields to mitigate crop water stress and optimize yield. Systematic scheduling reduce farmers water and labor costs by reducing irrigation and optimizing the use of soil moisture storage.

2.2.2 Crop water requirement

The crop water requirement for crop evapotranspiration needs (ET crop) is specified as the depth of water needed by evapotranspiration to meet water loss. It is the amount of water that the various crops need for optimum growth (FAO, 1977).

Research on irrigation water demand forecasting by Khan, Islam and Hafeez (2011) has quoted FAO (1994) and work of Smith (2000) to indicate that on average, approximately 45% of water is used by crop, 15% is lost during conveyance, 15% is lost in supply channel within the farms and the remaining 25% is lost due to inefficient water management practices. Coding of a program by Ali (2013) to determine crop water requirement using local meteorological and research data of Sudan reflects the use of same values quoted by (Adnan & Khan, 2011).Field based evaluations by Wickramaarachchi et al.(2000) mentioned that the initial phase and flowering stages of a crop are highly sensitive and hence a deficiency in the water requirement would result in decreased crop yield.

Crop water requirements are highly dependent on the temperature, and water availability. Chowdhury (2016) working inan arid agriculture region of Saudi Arabia and comparing four scenarios for the period from 2011 to 2012 and using CROPWAT model had identified a 5.3%-9.6% increase of crop water requirement for a 6% an overall increase.. This work also indicated that a temperature increase by one degree centigrade would increase the crop water requirement by 2.9%.

From the above discussion, Crop water requirement depends primarily on three factors and they are

- The climate,
- Crop type,
- Growth stage of crop.

2.2.3 Land preparation

Land preparation is important to ensure that the crop field is ready for planting. The goal of land preparation is to provide the appropriate soil conditions to enhance the successful plantation of crops in field. According to Irrigation Department of Sri Lanka guidelines (Ponarajah, 1984) clayey soil or heavy soils in low land, generally requires two water applications for land preparation. One is 4” water requirement in 5 days for land soaking and 3” water requirement in 10 days for land tillage. In total, the recommendation is 15 days with 7” of total water depth for land preparation.

Loeve, Somaratne, Ariyaratne, & Markandu (2004) had studied about the reduction of land preparation delay in North Central Province of Sri Lanka where LB canal of Rajangana system was sampled from the starting time of land preparation to the collection of yield. Majority of farmers had taken the 11-25 days for the land preparation work in Rajangana. Approximately 72% of farmers had completed their land preparation in less than 21 days. Reason of the delay in land preparation was attributed to mismanagement of water and socio-political factors. Farmers whose land preparation was delayed had a, 8% decrease in paddy yield when compared with those who completed in time.

2.2.4 Conveyance loss and irrigation methods

Raju (2008) evaluated the progression of rice crop acreage in Orissa state of India using remote sensing data and identified that the water supply adequacy was only about 88%. An oversupply of approximately 45 MCM which was nearly 15% of total during the initial part of the season and a deficit of approximately 20% in the peak development stage which had shown that proper water scheduling could have facilitated high crop productivity. Naderi et al. (2013) studied the irrigation application efficiency of 12 wheat farms of Semnan province in Iran and found out that the average deep percolation was 54.9%, runoff was 7% and the average application efficiency was 30.6%. Field experiments performed at the Hsueh Chia Experimental Station in Taiwan from 1993 to 2001 revealed that deep percolation in the first rice crop and second rice crop were 295 mm and 296 mm respectively. Percentage of percolation in the single rice cropping fields is around 30.7% compared to 26% in the double rice cropping area (Kuo, Ho, & Liu, 2005).

The loss from seepage, percolation and evaporation is conveying the water from the sluice to the farm is provided in the conveyance efficiency of the distribution systems. The conveyance efficiency (e_c) of irrigation scheme depends primarily on the length of the canal, the amount of soil or the permeability of the canel banks and the canal conditions. Water is lost more in large irrigation schemes than in small schemes due to a long network of their canals. Canals lose more water in sandy soils than canals in heavy clay soils. Table 2.1 shows Displays conveyance efficiency predictive values for properly managed channels. The productivity of field applications depends primarily on the method of irrigation and the level of farm discipline. Several indicative values of the mean efficiency of field applications are given in Table 2.2. Dharmasena (1989) explained that in Sri Lanka most village tanks are not capable of feeding their entire command area , due to one or more of the following constraints: a) limitation of the catchment area; b) high tank water losses c) initial delay in cultivation; d) failure to make the best use of effective rainfall; and e) incorrect water management practices. This work presents a comprehensive discussion on the definitions of various efficiencies and measures related to irrigation.

Table 2-1 Indicative values of the conveyance efficiency (Ec) for adequately maintained canals (FAO,2012)

Earthen canals				**Lined canals**
Soil type	**Sand**	**Loam**	**Clay**	
Canal length				
Long (> 2000m)	60%	70%	80%	95%
Medium (200-2000m)	70%	75%	85%	95%
Short (< 200m)	80%	85%	90%	95%

Table 2-2 Indicative values of the field application efficiency (FAO,2012)

Irrigation methods	**Field application efficiency**
Surface irrigation (border, furrow, basin)	60%
Sprinkler irrigation	75%
Drip irrigation	90%

2.2.5 Effective rainfall

As per Ponarajah (1984) Effective rainfall is the part of the total monthly rainfall that is effective in meeting complete or partial land preparation requirements, crop water requirements, and farm losses. Irrigation department guidelines recommend 75% probability rainfall for the calculation of effective rainfall. Demonstrating the importance of correctly identified effective rainfall for crop water computation, Rahaman, Islam, & Hasanuzzaman (2008) in a study of different climatic zones in southern part Bangladesh concluded that effective rainfall in Kharif season varies from 13.94% to 100 % while in Rabi season almost 100% of rainfall is proportional to that to the consumptive use and conversely proportional to the amount of rainfall and its intensity. Adnan & Khan(2011) studying effective rainfall with 58 meteorological station data of different climatic zones and irrigated plains in Pakistan concluded that Efficient rainfall in the Rabi season varies widely from 13.03% in northeastern Punjab to 100% in several stations across Pakistan. Effective percentage of rainfall during the Kharif season varies widely from 21.31 percent in northeastern Punjab to 100 percent at most stations in this country. During irrigation water schedule preparation, it is important to identify the rainfall values that are used to compute the effective rainfall. FAO Report No 24 (Doorenbos and Pruitt, 1977) recommends the use of 75% for probable rainfall for the effective rainfall calculation.

2.3 Present irrigation, cultivation and guidelines practices.

2.3.1 Sri Lankan perspective

Irrigation systems in Sri Lanka under gravity irrigation may be classified according to size of water source and management. Major irrigation system is defined as one that has more than 1000 ha. command area and medium schemes ranges from 80 and 1000 ha. Small tanks or small irrigation systems are those with 80 ha or less of irrigated command area (Sivayoganathan & Mowjood, 2003). In major irrigation systems field level irrigation management is done with all relevant stakeholders specially irrigation engineers, technical assistants, work supervisors and irrigation laborers. A technical assistant is responsible for about 2000 ha of land, while work supervisors and irrigation laborer are responsible for 1000 ha and 200 ha land respectively. Water distribution and allocation is determined by the main stakeholders, the farmers at the seasonal (kanna) farmer meeting which is scheduled prior to every cultivation season. At this meeting officers and farmers collectively take decisions on water distribution and cultivations of a particular year. In Irrigation Management Division (IMD) schemes management of field channels are given to farmer organizations to operate. They are allowed to collect operation and maintenance (O&M) taxes and carry out maintenance themselves (Gamage, 2000). In Sri Lanka, Irrigation Guidelines (1984) is widely used for irrigation reservoir operation.

2.3.2 Other parts of the world

In the half century from the late 1950s to 2010 South Asia's population nearly tripled, from 588 million to 1621 million. With a high population growth and industrial development, agricultural land per capita has declined sharply over the years. Between 1980 and 2010, per capita arable land fell from 0.11 to 0.05 ha in Bangladesh, 0.23 to 0.13 ha in India, 0.15 to 0.08 ha in Nepal and 0.24 to 0.12 ha in Pakistan (Kumar, Karunagoda, & Haque, 2012). While total food production is growing due to additional areas under irrigation, the rate of growth in food production has slowed in many parts of South Asia and food consumption per capita has remained stagnant, given the impressive growth in per capita incomes in recent years. About 39% of the cropland in South Asia is irrigated, and irrigated agriculture accounts for 60-80% of food production (World Bank, 2017) Agriculture consumes about 90% of the water and about 20% of the energy used in South Asia. While the main source of irrigation in the early 1960s was surface water, groundwater inputs have been gradually growing and have now overtaken surface-water irrigation in some countries. At present groundwater’s contribution in agriculture is 79% in Bangladesh, 63% in India, 19% in Nepal, and 21% in Pakistan (Frenken, 2012).

In India, there are no unique guidelines for Irrigation reservoir like Sri Lanka ID guidelines because of size of the country and topographic condition. There are guidelines for overall reservoir operation which combinely focused on flood control, hydropower, river valley projects and in some cases irrigation as well. Those guidelines described the fixing the capacity of reservoirs, dead storage, live storage, flood storage, methods to determines evaporation, sedimentations in reservoirs, operational guidelines, determination the volume of water and level, design of drainages in irrigation project, quality of irrigation water, Code for construction and maintenance of surface farm drainage systems etc. (Indian Standards IS, 1986) In Nepal, there is guideline named” Design Manual for Small Scale Irrigation Scheme” revised in 2014 also described about different types of irrigation system, water requirement assessment, diversion works and intakes, canal design, control structures. (DoLIDAR, 2014) In Pakistan also, there are guidelines for multipurpose reservoirs not like Sri Lanka ID guidelines and focused on Flood control, Hydropower, canal network for irrigation purposes. (PWD, 1943)

2.3.3 Comparison of Regional guidelines and ID Sri Lanka Guidelines for Reservoir Operation

According to Indian Standards IS 7223 (1994), An adequate plan for collection and analysis of hydrological data should be developed and adopted in order to ensure efficient operation of reservoirs, particularly during the monsoon period. An adequate number of river gauging stations should be set at key locations according to relevant Indian Standards to provide satisfactory information on current river stages/flows upstream and an index to the total inflow to the reservoir. In case of flood control reservoirs, a sufficient number of river gauging stations should be set up below the dam to provide data at the locations to be protected. All stream gauging stations should also be equipped with instruments for measuring rainfall. Manual and/or automatic reservoir gauges should be installed for obtaining current reservoir levels. Reservoir levels should be recorded at regular intervals, say every 24 hours or as required. During flood times, reservoir gauges should be observed at closer intervals, say once in 3 hours or even more frequently. A complete schedule of releases in the form of a chart may be developed that will allow the outflow to be regulated on the basis of the current inflow and storage space available by making a series of computations with various assume values of inflows and amount of storage available. On the other hand according to ID Sri Lanka guidelines, for calculating inflow into the reservoir, iso-yield curve is used, along with seasonal rainfall which converted to volume of rainfall in Ha.m over the catchment (Ponarajah, 1984). For calculating reservoir inflow in Nepal, rational method (Q=0.278CIA) is widely used for small sized basins (DoLIDAR, 2014). According to Punjan Irrigation Department guidelines (1943), Inglis formula is used for the calculation of inflow into a reservoir from its catchment.

In case of evaporation, most of the guidelines are discussed about Pan Evaporation method. Evaporation mostly depends on the temperature and surface area of the reservoir. In Sri Lanka, evaporation value obtained by averaging over long periods of observation of the pan evaporation and adjusting using a pan coefficient of 0.8.

Indian Standards IS 6939 (1992) covers the methods for the determination of evaporation from reservoirs. It also provides certain empirical formulae for use in the absence of actual measurements. The main factors affecting the rate of evaporation are: a) vapor pressure differential between the water surface and the air layer just above, b) water and air temperature, c) Quality of water, d) Radiation e) Atmospheric pressure, f) Wind, g) Size of evaporation surface, and h) Heat storage in the water body. The depth of the water evaporated from the surface of the reservoir can vary from about 400 mm in cool and humid climate to over 2500 mm in warm and arid regions.

For the calculation of volume of reservoir, ID guidelines of Sri Lanka recommended to use Depth Area Capacity Curve method where Indian Standards IS 15840 (2009) disscused about the several mehtods for the calculation of the volume of reservoirs including conventional surveying method (water level, cross-section of reservoir, contours,volume), topographic survey (3D survey,bathymetric plan) and modern surveying methods which includeselectromagnetic distance measurement (EDM) and computer software facilities in surveying, together with the global positioning system (GPS), has virtually revolutionized land surveying.

For the crop water requirements (ET_c) according to ID Sri Lanka guidelines calculated a three steps procedure that includes reference crop evapo- transpiration ET_0, Crop factor, K_C and factors affecting ET_c under prevailing local conditions. In Nepal also, crop water requirements (ET_c) calculated based on the following factors a) Cropping pattern, b) Calculating reference crop evapotranspiration c) use crop coefficient, d) calculate evapotranspiration from ETcrop e) Land preparation loss, L_p f) Deep percolation loss, d_p g) Evaporation from land preparation, h) total crop water requirement, i) Calculate effective rainfall and j) Calculate net crop water requirements (Department of Irrigation, Nepal, 1990)

3 Methodology

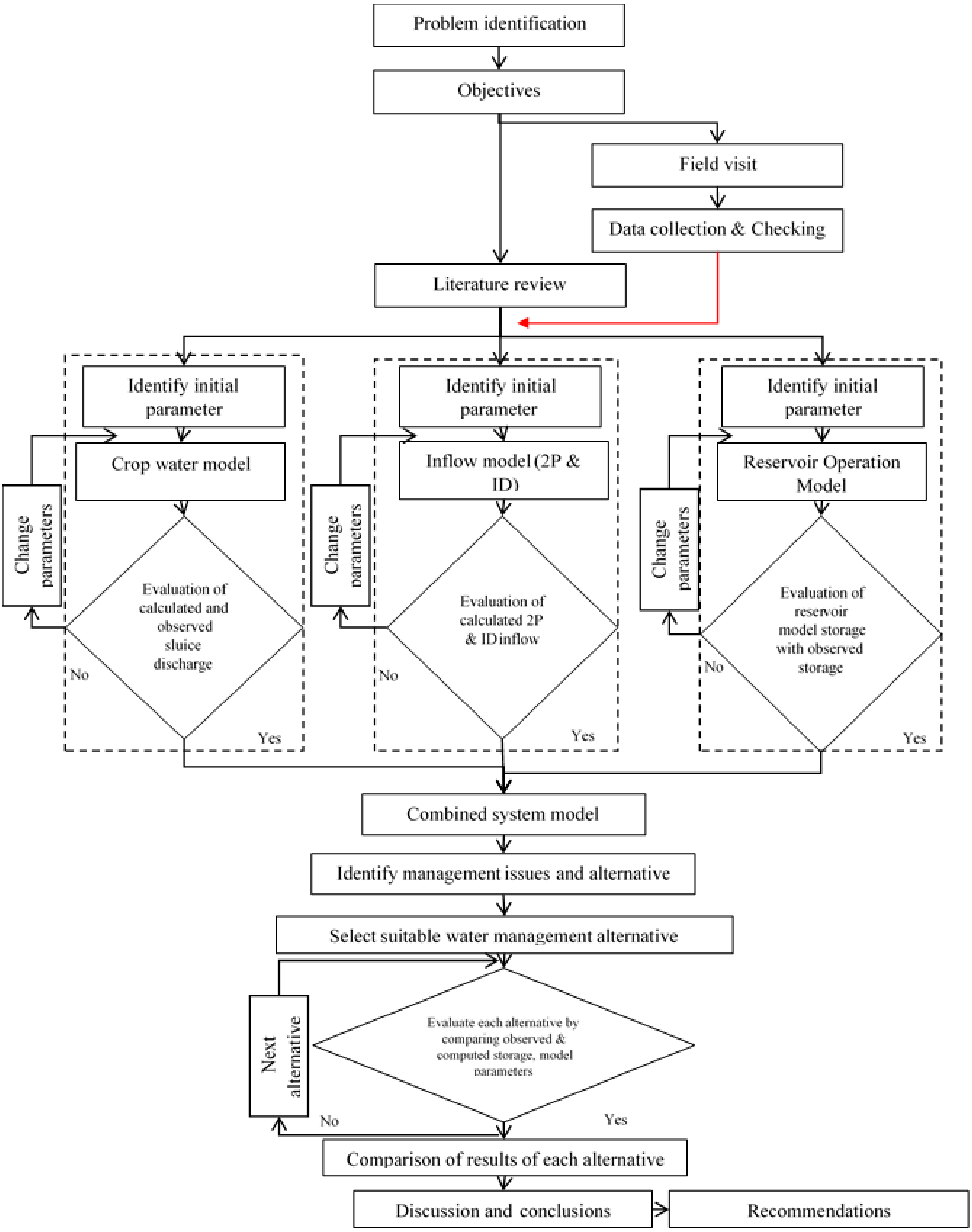


Figure 3-1 Methodology flow chart of the present work

Methodology adopted for the study is shown by the flow chart in Figure 3.1.

The present work commenced with a study of prevailing water resources situation especially in Sri Lanka then with the identification of the research problem and objectives. Namal Oya irrigation reservoir was selected as the study area. At the beginning of the study an extensive literature on irrigation practice in Sri Lanka an and around the world reviewed. By the consultation with Irrigation department, a reservoir (Namal Oya) were idenfied which have 20 years of operation data and only fed by rainfall. Institutional visits and field visits were undertaken to the project area for data collection followed by data checking and incorporating suitable assumptions for computations. Field surveys were undertaken for both data collection and gap filling of institutional data. Crop Water Model, Inflow Model and Reservoir Operation Model were developed based on Irrigation Department Guidelines. Later Model calculated value compared with observed value from the field. A combine system model was developed to identify the management issues of irrigation reservoir and alternative options. Critical evaluation of the results is then discussed and concluded for appropriate water management recommendations.

4 DATA COLLECTION AND CHECKING

4.1 Study area

Namal Oya reservoir is situated in Ampara district of Sri Lanka. The latitude and longitude of Namal Oya reservoir $7^{0}17'42''$N and $81^{0}30'43.2''$E. The reservoir (MSL 289m) is maintained by Irrigation Department of Sri Lanka. The catchment area of this reservoir is 56.43 Sq.km and Maximum capacity is 5171 Ha.m. The reservoir bund height is approximately 12m. The command area of Namal Oya reservoir is approximately 1498 Ha. Average yield of paddy in the command area is 52 Metric ton/Ha (ID). The spillway length of Namal Oya is 75m and height in 289m from MSL.

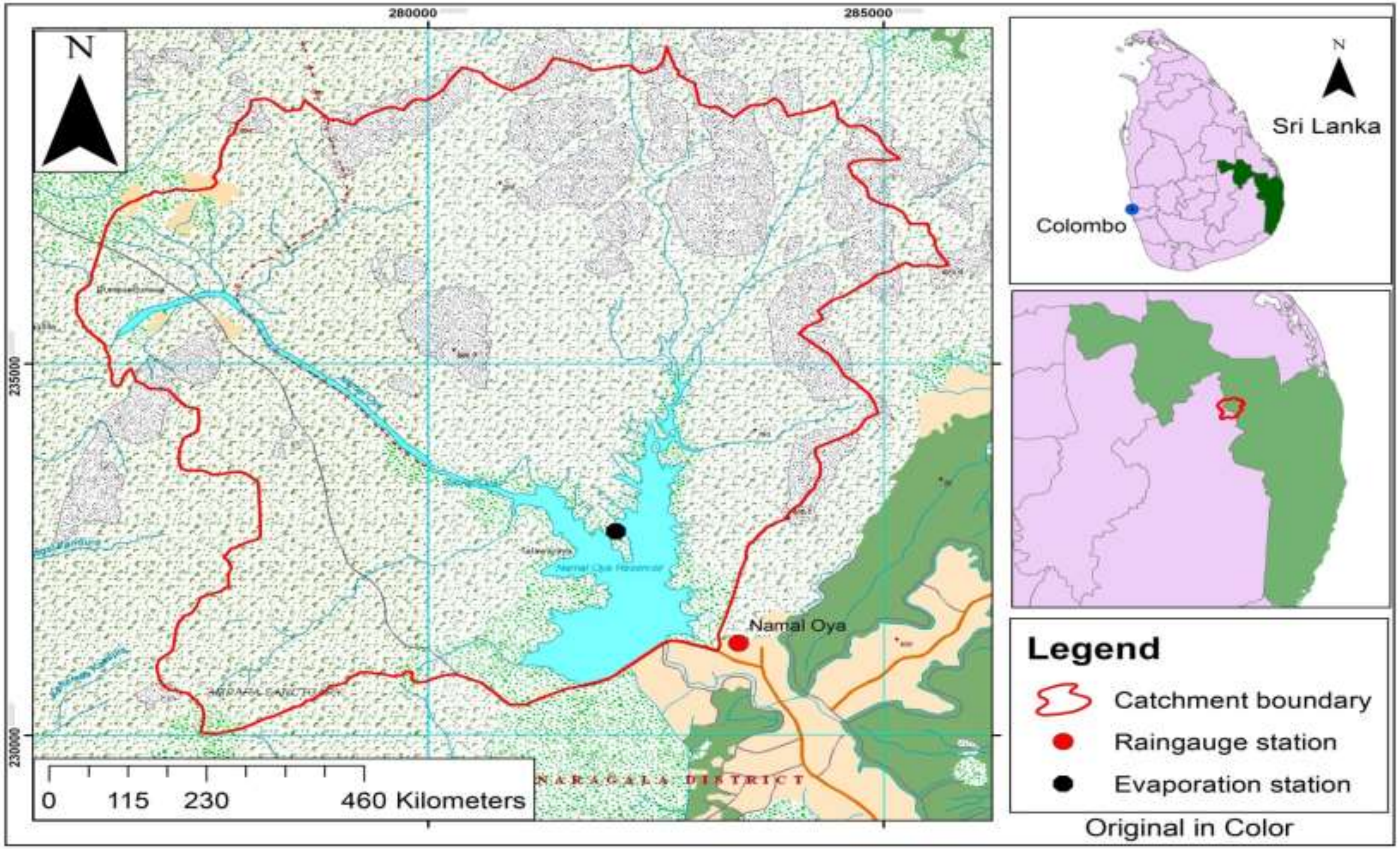


Figure 4-1 Catchment map of Namal Oya Reservoir

4.2 Collection of Data and Information

At the onset of the study, the data collection methods and temporal resolutions suitable for the study were evaluated. Water year from October of a given year to September of next year was taken as the "data-year" for computations. The water year is considerate here as Irrigation Department Guidelines are followed for all the reservoirs in Sri Lanka. All the data computation of reservoir operation in this study done on weekly, because Irrigation Department of Sri Lanka operated the reservoir on weekly basis. . A twenty water-year study period from 1997-98 to 2016-17 was selected by evaluating spatial and temporal data of the Namal Oya Irrigation System study area were categorized as institutional and farmer based, physical (Site visit) and operational etc.

4.2.1 Data Summary

Table 4-1 Data type, sources and resolution of Namal Oya reservoir

Data Types	Spatial Resolution	Source
Rainfall	Daily	Department of Irrigation
Sluice discharge, Water Issues, Reservoir Level	Daily	Department of Irrigation
Evaporation data	Daily	Department of Metrology
Topo Map, Contours	1: 50,000 Map	Department of Survey
Irrigation performance	Seasonal	Department of Irrigation

4.3 Field visit data

4.4 Reservoir operation data

Reservoir operation data such as rainfall, water level, sluice discharge, spillage, are collected from irrigation department for Namal Oya Reservoir and plotted on a weekly basis.

4.5 Rainfall

Namal Oya rainfall recorded in the irrigation department gauging station were plotted. On the average, Namal Oya catchment area receives an average rainfall of 1822mm/year which is almost double of monthly 75% probability rainfall (915mm) of that agro-ecological zone (DL2). Weekly and monthly rainfall values were plotted to identify similarity between rainfall and storage of the reservoir and shown Figure 4.2 and 4.3. The rainfall in the year 2014-15 had been about 46% more than the average and rainfall in the year of 2003-04 is 37% less than the average in the period 1997-2017. The monthly rainfall data in value are shown in Table 4.2 and 4.3. Monthly and seasonal pattern shows that the peak time of rainfall in the Maha season (average 1422 mm) and moderately less rainfall in Yala season (average 460mm)

4.6 Reservoir water release

Water release data plotted weekly and monthly for each year in the periods from 1997-2017 (Figures 4.4) shows significantly sudden rises and falls. The demand fluctuations do not show uniformity in the pattern, but it clearly shows peak of two main seasons Maha and Yala. The average water release curve shows that Yala season water demand is higher than Maha season. The water release in the year 2011-12 had been about 69% more than the average and water release in the year of 2008-09 is 57% less than the average in the period 1997-2017.

Monthly water releases show a vast variation in the pattern and also in the magnitude of releases during each month (Table 5.4). The monthly water release variation shows two minimum releases, with one during March and the other during September, showing the boundary of the Maha & Yala seasons. On the average the Maha (Oct-Mar) season and Yala (Apr-Sep) season water releases 699 Ha.m and 1380 Ha.m respectively.

4.7 Spillage from Reservoir

Over a period a 20 years from 1997-98 to 2016-17, 8 years spillage took places in Namal Oya Reservoir, 294 days with a total discharge of 17800 Ha.m. In the year of 2004-05, total 7 days spillage with a total discharge 297 H.ma. In the year 2010-11, total 65 days spillage happened in the Namal Oya with a total discharge 4885 Ha.m. Weekly Spillage data plotted in Figure 4.4.

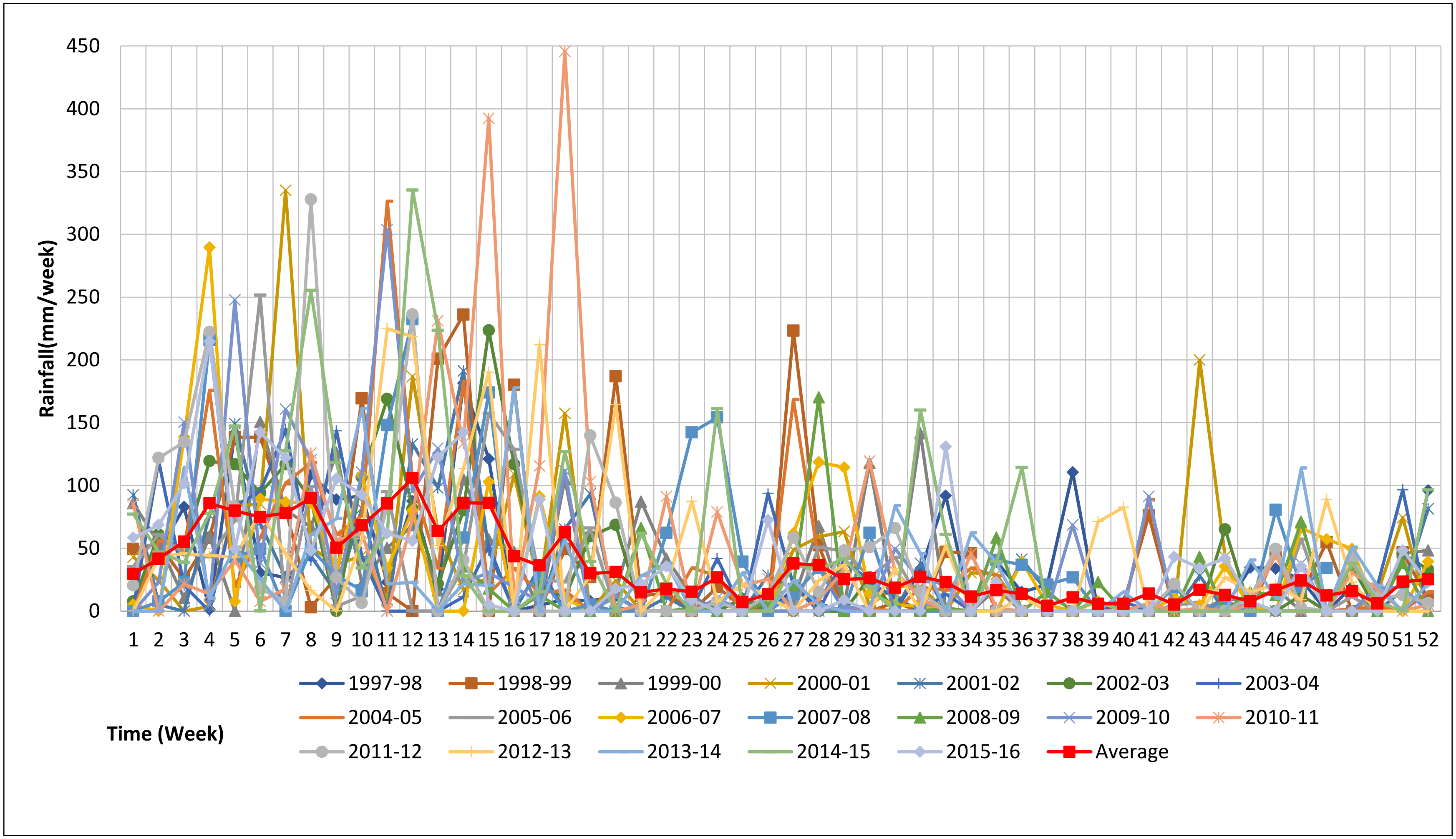


Figure 4-2 Weekly rainfall variation from 1997-2017

Table 4-2 Monthly rainfall in mm

Month	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09
Oct	139	266	209	71	313	328	142	288	185	441	246	
Nov	317	298	356	557	157	325	507	353	426	265	142	
Dec	291	405	225	340	344	378	43	704	107	252	425	
Jan	316	407	236	325	215	441	98	80	369	204	267	66
Feb	20	284	220	24	172	139	0	17	66	0	67	66
Mar	0	27	29	0	28	10	137	62	0	0	336	10
Apr	23	276	198	179	90	27	95	211	126	309	110	191
May	124	100	163	66	38	0	13	98	50	9	41	61
Jun	186	0	0	29	56	0	0	0	0	52	85	38
Jul	0	90	0	243	28	0	8	89	11	51	27	43
Aug	97	77	35	0	0	78	0	0	64	126	134	99
Sep	115	97	94	88	98	114	116	20	17	89		38
Total	1628	2326	1766	1923	1540	1839	1161	1921	1421	1797	1879	612

Table 4-3 Monthly Rainfall in mm

Month	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	**Average**
Oct	246	161	552	170	124	322	456	104	251
Nov	499	208	409	147	165	567	419	262	336
Dec	653	384	326	553	264	683	396	349	375
Jan	156	742	41	516	264	23	208	401	269
Feb	47	462	226	192	66	242	75	97	124
Mar	10	199	20	148	30	161	81	77	68
Apr	6	161	239	79	29	131	9	112	130
May	95	90	15	67	230	221	154	25	83
Jun	69	0	0	83	0	163	0	64	41
Jul	91	9	22	83	15	0	119	118	52
Aug	38	50	64	72	165	0	43	206	67
Sep	37	53	71	112	93	142	71	165	86
Total	1947	2519	1986	2221	1446	2655	2032	1980	1882

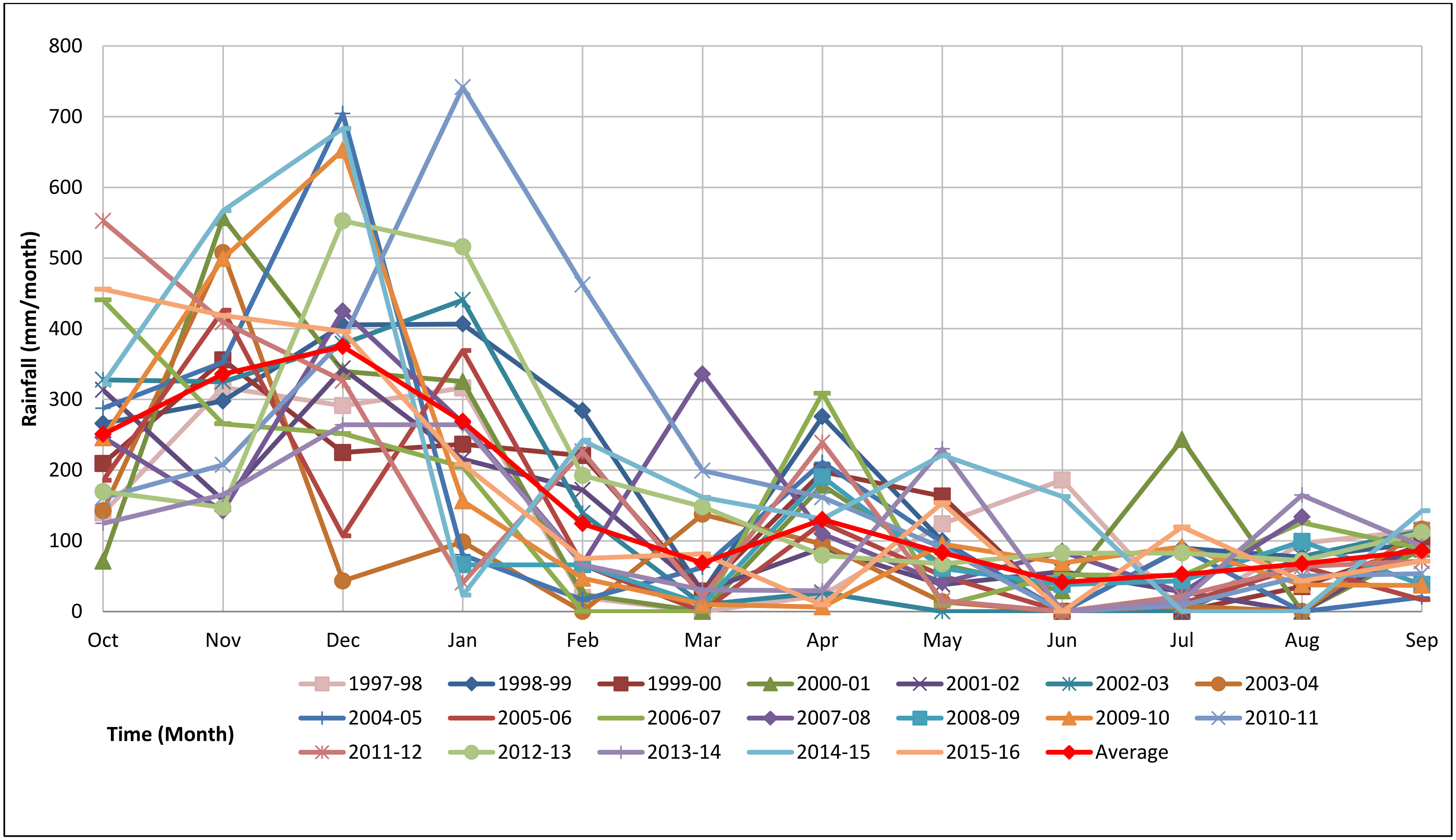


Figure 4-3 Monthly rainfall in mm from 1997-98 to 2016-17

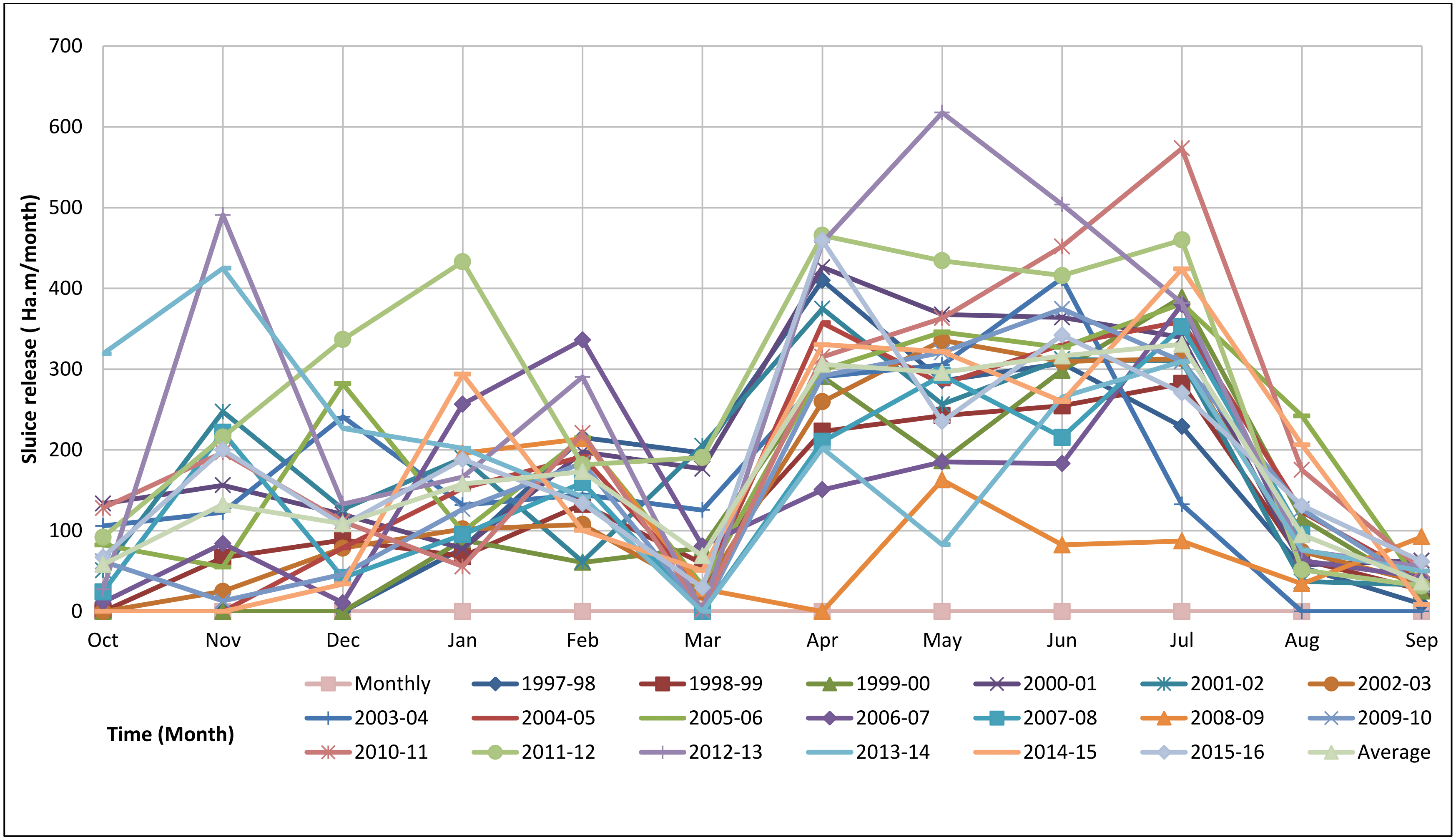


Figure 4-4 Monthly sluice release in Ha.m from 1997-98 to 2016-17

Table 4-4 Monthly sluice discharge in Ha.m

Monthly	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09
Oct	0	0	0	133	51	0	106	0	82	11	24	
Nov	0	66	0	156	247	25	123	0	55	84	222	
Dec	0	89	0	120	127	78	241	79	282	11	42	
Jan	78	68	88	78	190	102	132	152	99	257	95	196
Feb	215	133	61	197	62	108	145	192	215	336	159	214
Mar	196	59	79	177	205	24	126	27	33	81	0	28
Apr	410	223	291	426	375	260	291	357	299	151	210	0
May	286	242	186	368	257	335	305	281	346	185	292	163
Jun	307	254	299	364	312	309	413	330	327	183	216	82
Jul	229	282	389	339	310	313	132	359	381	380	352	87
Aug	55	64	115	58	37	74	0	123	242	63	96	34
Sep	9	27	25	63	33	35	0	40	31	42		92
Total	1785	1508	1533	2479	2205	1664	2012	1942	2391	1784	1709	897

Table 4-5 Monthly sluice discharge in Ha.m

Monthly	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	Average
Oct	62	128	92	27	319	0	67	58
Nov	13	197	216	491	425	0	200	133
Dec	46	111	337	133	227	34	107	109
Jan	127	56	433	166	202	294	188	158
Feb	184	221	181	290	142	100	134	173
Mar	0	2	191	0	0	51	29	69
Apr	292	315	466	457	202	330	459	306
May	321	363	434	618	82	322	235	296
Jun	375	452	416	504	266	260	342	316
Jul	309	573	460	382	309	424	270	331
Aug	126	175	51	75	76	206	131	95
Sep	32	52	31	55	50	9	62	36
Total	1886	2645	3308	3199	2300	2030	2225	2079

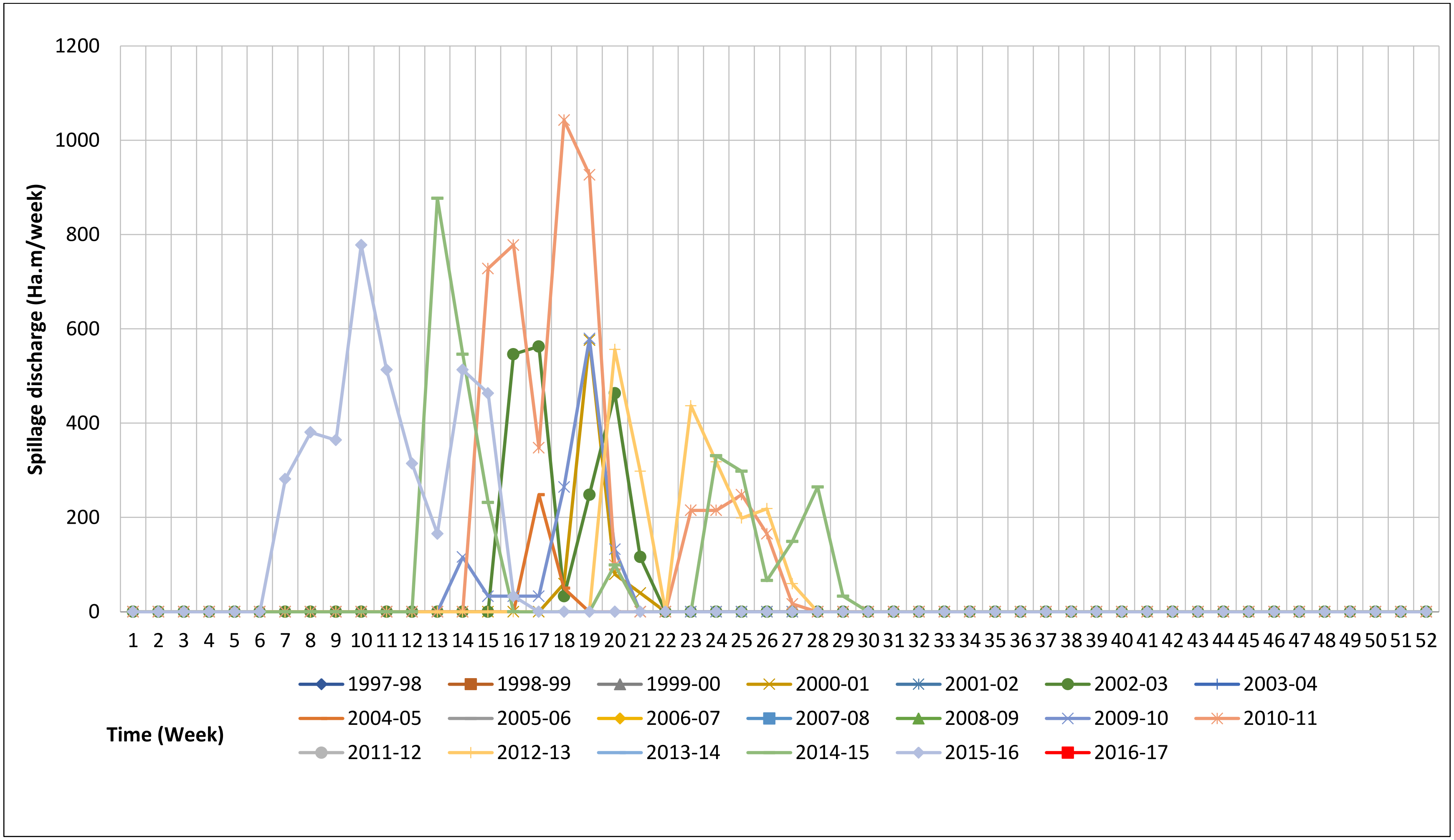


Figure 4-5 Weekly Spillage discharge in Ha.m from 1997-98 to 2016-17

4.8 Reservoir storage

Daily reservoir storage is recorded as reservoir water level and also as a storage value in the Irrigation Department Reservoir Operation data sheets. These two values were checked using the elevation area capacity curve of the reservoir and a discrepancy in the figures were found among storage and area of the reservoir.

From the Figure 4.5, is it shown that in the year January 2011, the reservoir capacity was highest 5487 Ha.m. The rainfall of the month of January, 2011 is also 742 mm which is the highest monthly rainfall in the period of 1997-2017. A weekly variation of storage in the Namal Oya reservoir is shown in Figure 4.5. Reservoir storage has fallen to very low levels at 732.43 Ha.m in the years 2003-04 and this has a direct link to the low rainfall experienced in that particular years when annual rainfall was 1152mm.

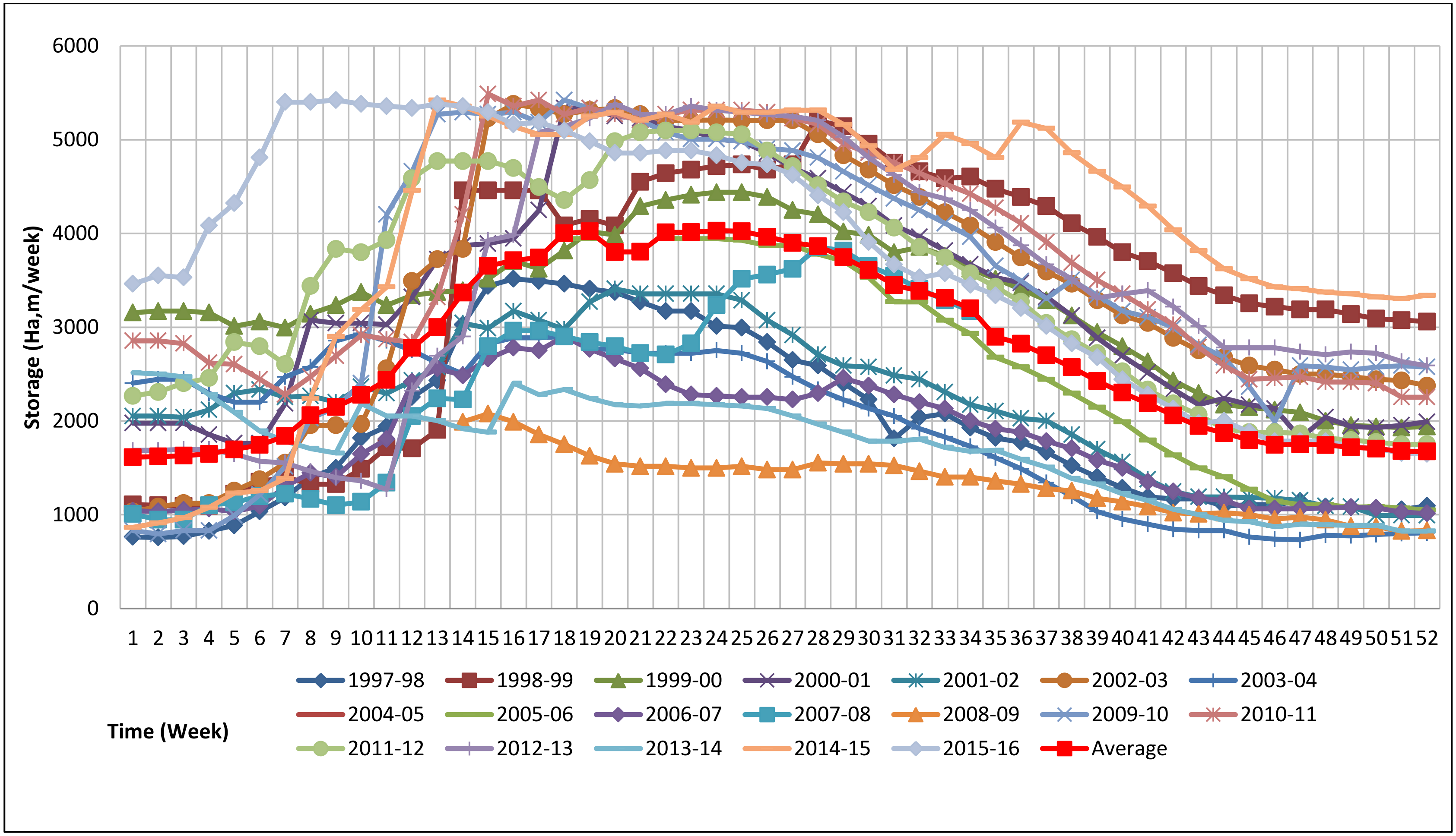
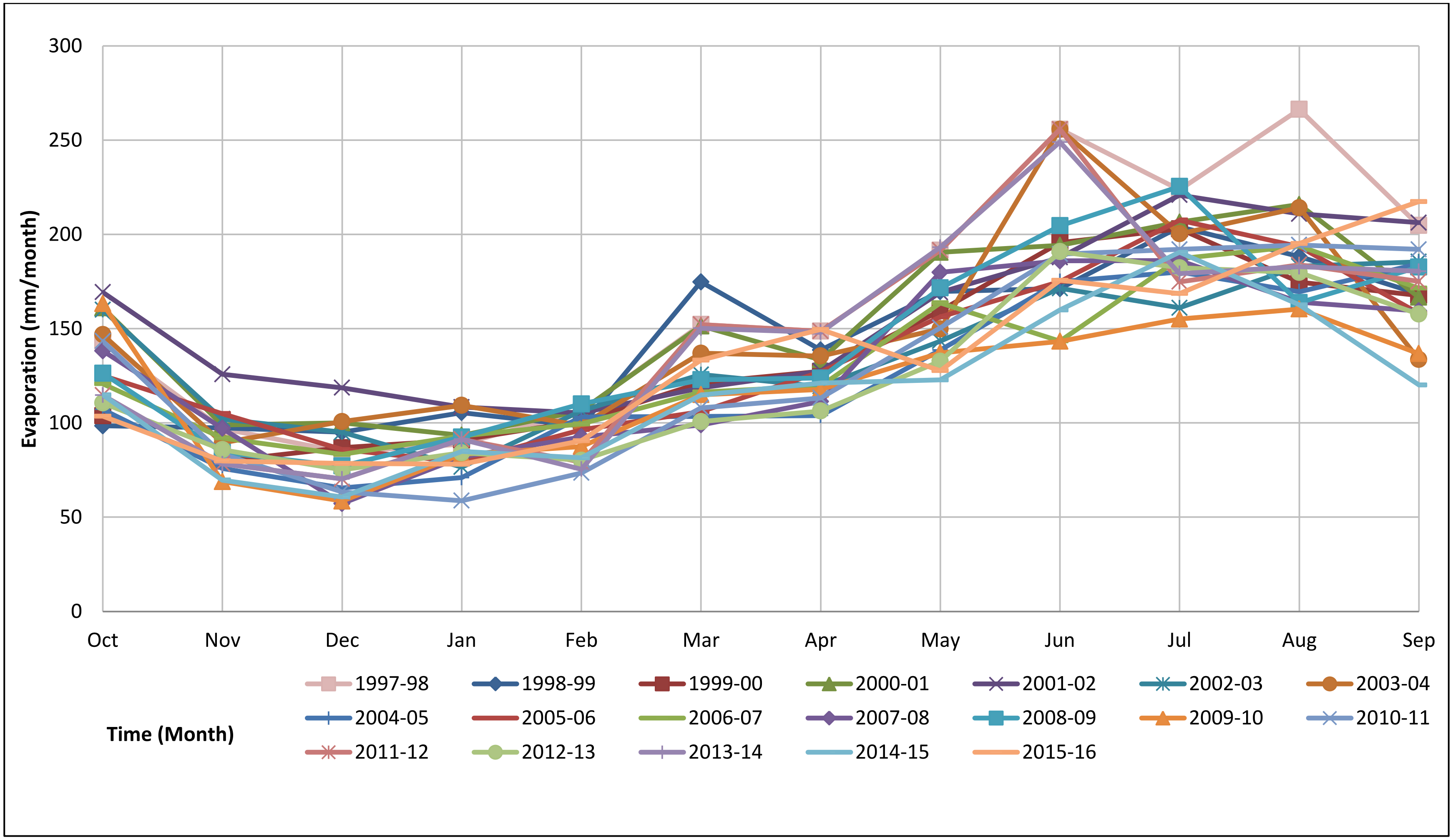


Figure 4-6 Weekly variations of storage in the Namal Oya reservoir in Ha.


300
250
200
150
100
50
0
Evaporation (mm/month)
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Time (Month)
1997-98
1998-99
1999-00
2000-01
2001-02
2002-03
2003-04
2004-05
2005-06
2006-07
2007-08
2008-09
2009-10
2010-11
2011-12
2012-13
2013-14
2014-15
2015-16

5 ANALYSIS AND RESULTS

5.1 Description of model and model development

5.1.1 Reservoir operation model

Reservoir water levels were computed using weekly water balance computations according to the ID Guidelines method without design safety considerations, using observed daily rainfall, observed spillage information and observed daily water releases from the sluice. A weekly spreadsheet model was developed and checked with manual computations for development accuracy as per computation is in annex 1. Model inputs were further checked by comparing the water release timing with respect to cropping calendars identified from stakeholder consultation and, relationship of rainfall with spillage and water issues. Weekly evaporation values corresponding to Aralaganvila station was used for computing reservoir operation model which shown in Annex 3.

5.1.2 Inflow model

The irrigation department guideline recommendation is to obtain the monthly yield from the seasonal yield maps and then carryout an apportioning based on the pattern of rainfall. Weekly yield from the ID guideline was computed using the observed rainfall pattern of the study period. Since there are no mathematical models developed for the Namal Oya watershed, a monthly stream flow estimation model was developed. Due to the simplicity in the model structure, appropriateness of temporal resolution for planning work, and with the consideration that there are already several applications Sri Lankan watersheds (Khandu, 2017) the two-parameter monthly water balance model of and was selected and later c and SC value optimized based on observed reservoir storage. Since the ID recommends a monthly analysis, the 2P model provides a monthly output that can be used for the computations in a manner similar to the recommendations in the ID guideline. Namal Oya reservoir inflow measuring gauge is not available. Hence the reservoir operation model outputs were used to evaluate the selection of the C and Sc parameters.

5.1.3 Irrigation water demand model:

In order to evaluate the water issues practices in the Namal Oya reservoir, a weekly spreadsheet models were developed and checked with manual computations. Water

Demand model development followed ID guidelines recommendations and the actual crop types and cultivation extents identified from the field for each year and each season. An overall project efficiency of 70% was assumed for water requirement from the reservoir sluice. Crop water requirement on different growth stage, requirement for land preparation, evapotranspiration and effective rainfall are calculated based on ID guidelines (1984). A sample computation is shown in Annex 1.

5.2 Assumption and parameters used in model development

5.2.1 Irrigation water requirement

In this study, one of the objectives is to compare guideline-based water demand in the Namal Oya reservoir irrigation scheme with the actual water use. The guideline presently used by the irrigation water managers is that technical guidelines of Ponrajah (1988). Hence in order to fulfill the objectives; an analysis according to the Technical Guidelines was carried out for the study period. This analysis looks at the computation of irrigation requirement according the guideline recommendations in which the weekly effective rainfall values calculated from observed rainfall and the evapotranspiration values were taken from the Tables in Ponrajah (1988). This was used to make a comparison with the water release from Namal Oya reservoir. In this analysis, 100% command area (1498 Ha.) in both Maha and Yala season, crop types, season commencement dates of a given year are the corresponding values used for computations. Finally, a comparison is also made between the guideline recommendations and the actual water issues. For this guideline-based computation, the actual evaporation and rainfall in the project area and the actual crop type, pattern, extents and dates are used.

5.2.2 Crop evapotranspiration (ETc)

In this study reference evapotranspiration (ET0) for the study area was obtained from ID guidelines (1984) Table 2.9.1. These values are

Table 5-1 Evapo-transpiration of reference crop

Month	ET_0 in mm	Month	ET_0 in mm
January	199.38	July	190.51
February	127	August	193.04
March	157.48	September	190.5
April	149.86	October	157.48
May	162.56	November	109.22
June	175.26	December	114.3

In case of crop factors (Kc), values in the Technical guideline of Irrigation Department (Table 5-16) and those extracted from FAO No-24 report were used (Table 5-17). It is important to note that the growth periods and crop coefficient values for crops differ from each other. Sri Lanka has two seasons of crop production, one is Maha and another is Yala. In Maha season (October to March), farmers usually cultivate paddy in the entire area while in Yala season (April to September), where rainfall is less the crop types are varied to match water availability. On average during the Maha and Yala season an area of 100 % (1498 Ha) is cultivated with rice. Farmers and Irrigation department officials during field visits mentioned that the preferred paddy variety is the shorter duration which takes a period of 105 days both in Maha and Yala. According to ID guideline (1984) Table 2.9.2. the Crop coefficients for paddy are 1.00, 1.15, 1.20 and 0.90 for the initial stage of 20 days, Crop Development stage of 30 days, Mid-Season period of 30 days, and the 25 days late stage respectively were also assumed in this study.

5.2.3 Selection of stagger

Practice in many irrigation schemes is to utilize a stagger to optimize the canal capacities and manage the machine power requirements for farming. This has been mentioned in the ID guidelines as, "For management of the overloading condition of the canal and to manage of machines and draft power, stagger is recommended for equal or unequal stagger of total extent of cultivation" (Ponrajah, 1984). However, the present practice of Namal Oya irrigation scheme does not incorporate a stagger. The sufficiency of water and carrying capacity in canals to cater the entire system at once are the reasons cited for the lack of a stagger. Therefore, computations in the present research did not use a stagger when computing the irrigation requirement.

5.2.4 Land preparation water requirement

According to the Irrigation Department, information for land preparation work given in the ID guidelines are generally used for the irrigation system planning and design in Sri Lanka. Based on Irrigation Department Guidelines (Ponrajah 1984), water depth of 7 inch (178 mm) for land preparation and a duration of 15 days were adopted for weekly water requirement computations in the case of lowland paddy cultivation. At Namal Oya irrigation scheme, rainfall is a major factor for land preparation work in Maha season. During Discussions, the staff of Namal Oya, ID indicated that the field practices demonstrated a usual land preparation which varies 15 to 28 days based on available water in reservoir and rainfall).

5.2.5 Effective rainfall

Effective rainfall computations were carried out using the Irrigation department guideline recommended empirical equations. In this research, computations were carried out at a weekly temporal resolution. ID guideline recommended monthly empirical equation was proportionately converted to compute weekly effective rainfall values. To compare actual water issue with the guideline recommendation, effective rainfall values for each year were computed using actual values of rainfall recorded at Namal Oya reservoir for the period 1997- 2017.

5.2.6 Canal efficiency

Irrigation demand values at the headwork were computed with the application of canal conveyance efficiency to canals on the field irrigation requirement. In the present work, computations were carried out with an overall canal conveyance efficiency of 70% (covering the network of primary, secondary and tertiary canals) as recommended by Irrigation Department guidelines.

5.2.7 Seepage losses

In addition to the loss of evaporation, more losses from a reservoir are caused mainly by seepage through the bed and flanks, the loss of seepage depends on the permeability of the bed and flanks of the reservoir, and is mostly a loss due to deep percolation. The calculation of such losses may be calculated by calculating the permeability of the soil in the reservoir bed of typical regions. According to ID guidelines, the monthly loss of seepage can be estimated to be 0.5% of the volume of water contained in the reservoir. ID guideline recommended monthly seepage loss was proportionately converted to compute weekly effective seepage losses.

5.3 Reservoir Model computations

5.3.1 Reservoir Inflow

The irrigation department guideline recommendation is to obtain the monthly yield from the seasonal yield maps and then carryout an apportioning based on the pattern of rainfall. Weekly yield from the ID guideline was computed using the observed rainfall pattern of the study period. Since there are no mathematical models developed for the Namal Oya watershed, a monthly stream flow estimation model was developed. Two Parameter (2P) monthly water balance model (Xiaong & Guo, 1999) were selected to the simplicity in the model structure, appropriateness of temporal resolution for planning work, and with the consideration that there are already several applications Sri Lankan watersheds. Since the ID recommends a monthly analysis, the 2P model provides a monthly output that can be used for the computations in a manner similar to the recommendations in the ID guideline. Namal Oya reservoir inflow measuring gauge is not available. Hence the reservoir operation model outputs were used to evaluate the selection of the C and Sc parameters. Computed inflows from the 2P model and the ID model comparisons are in Figure 5.1. These outputs together with the rainfall showed that ID model inflow are much higher than 2P model inflow for the 20 years period. ID model only consider only rainfall and catchment area while 2P model consider rainfall, catchment area, evaporation, initial soil moisture content. In the absence of rainfall of a particular month, ID model doesn’t give inflow estimates while 2P model provides inflow estimations. From the weekly plot of inflow model of 2P and ID, it is visible that ID model is responding proportionally to the rainfall where 2P model behavior is different. This is probably due to physical characteristics of the catchment which are not incorporated in the 2P model.

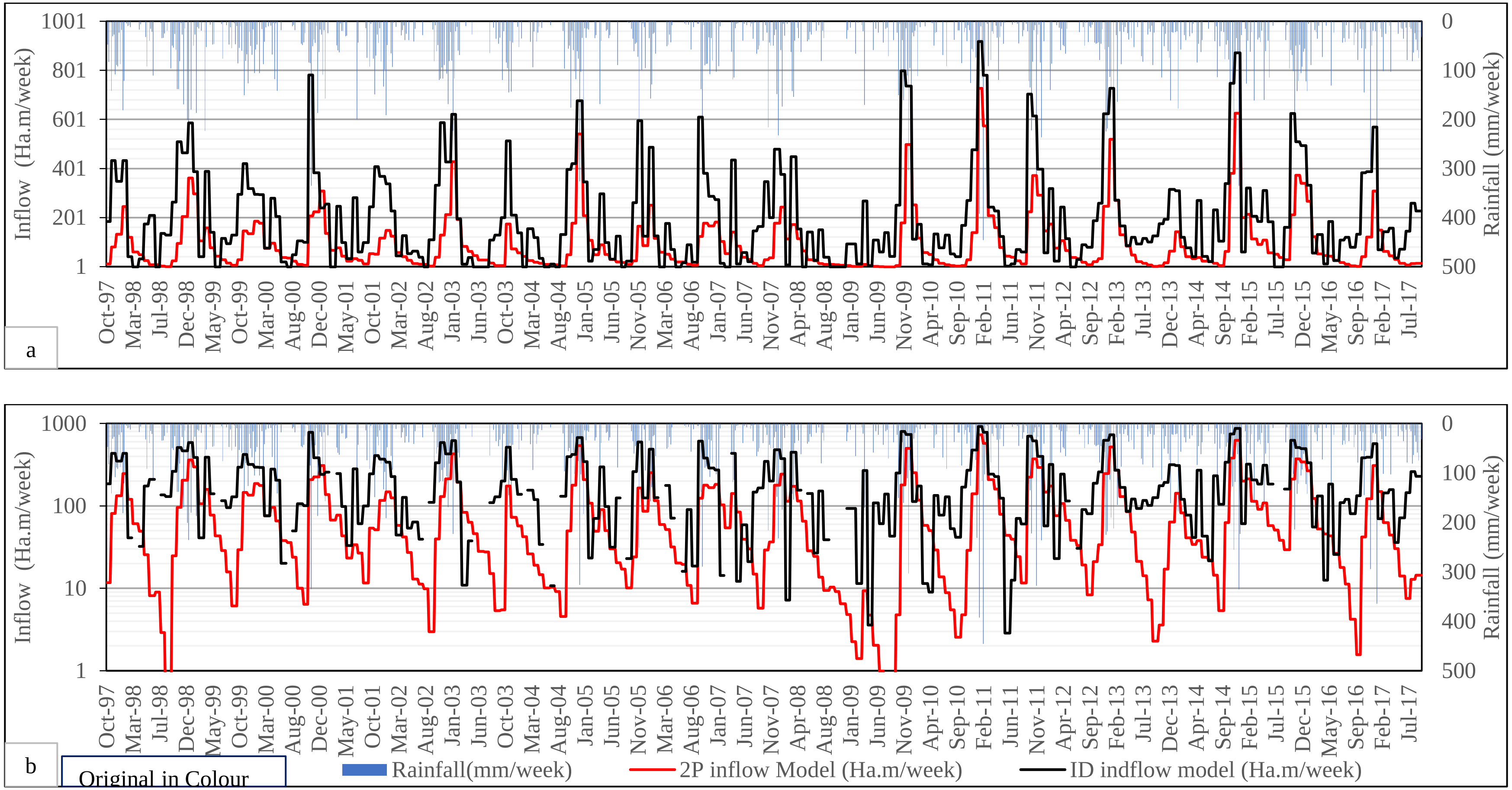


Figure 5-1 Weekly inflow comparison of 2P and ID model corresponding to rainfall.

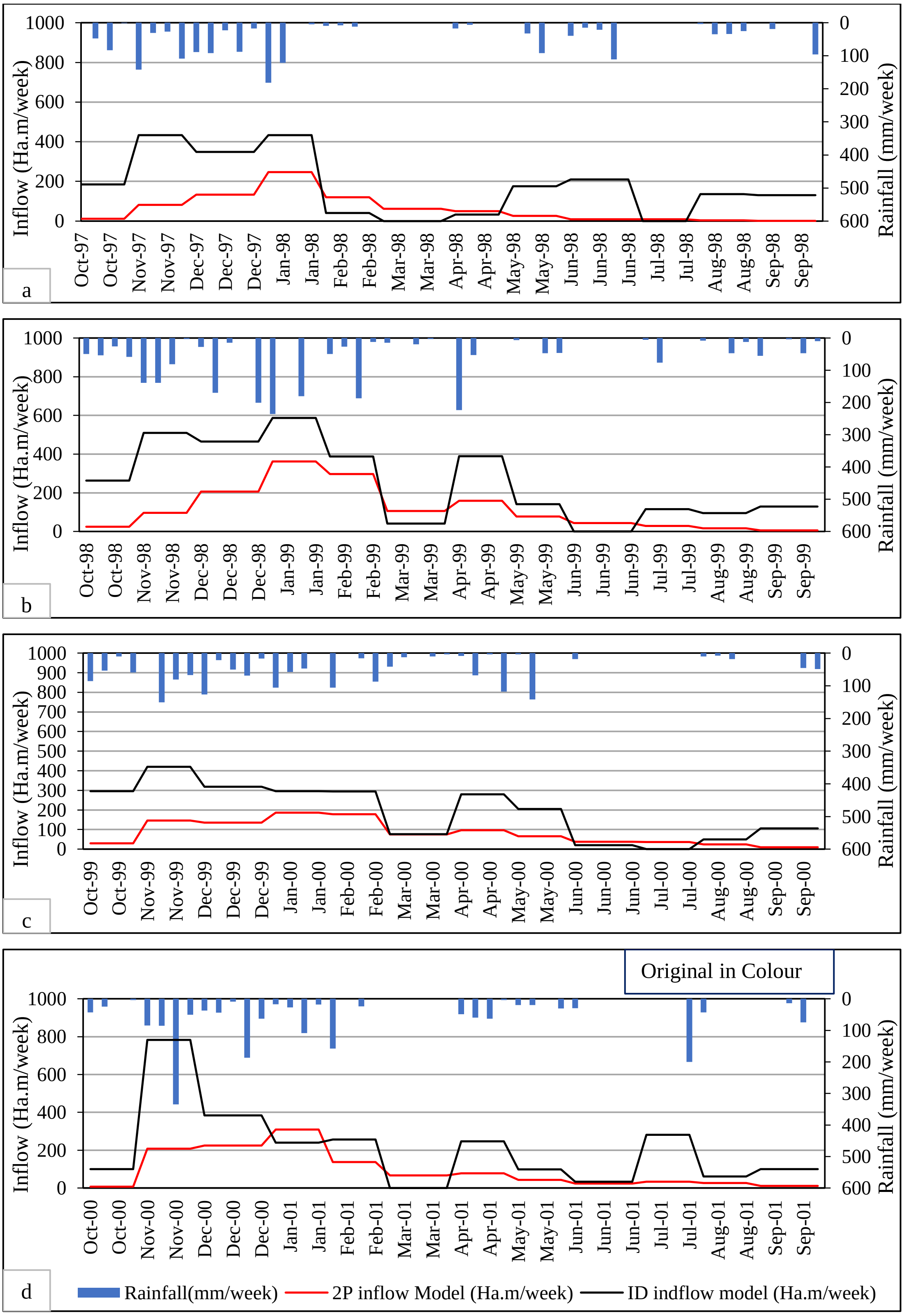


Figure 5-2 (a, b, c, d) Rainfall and inflow estimation comparison from two model (1997/98-2000/01)

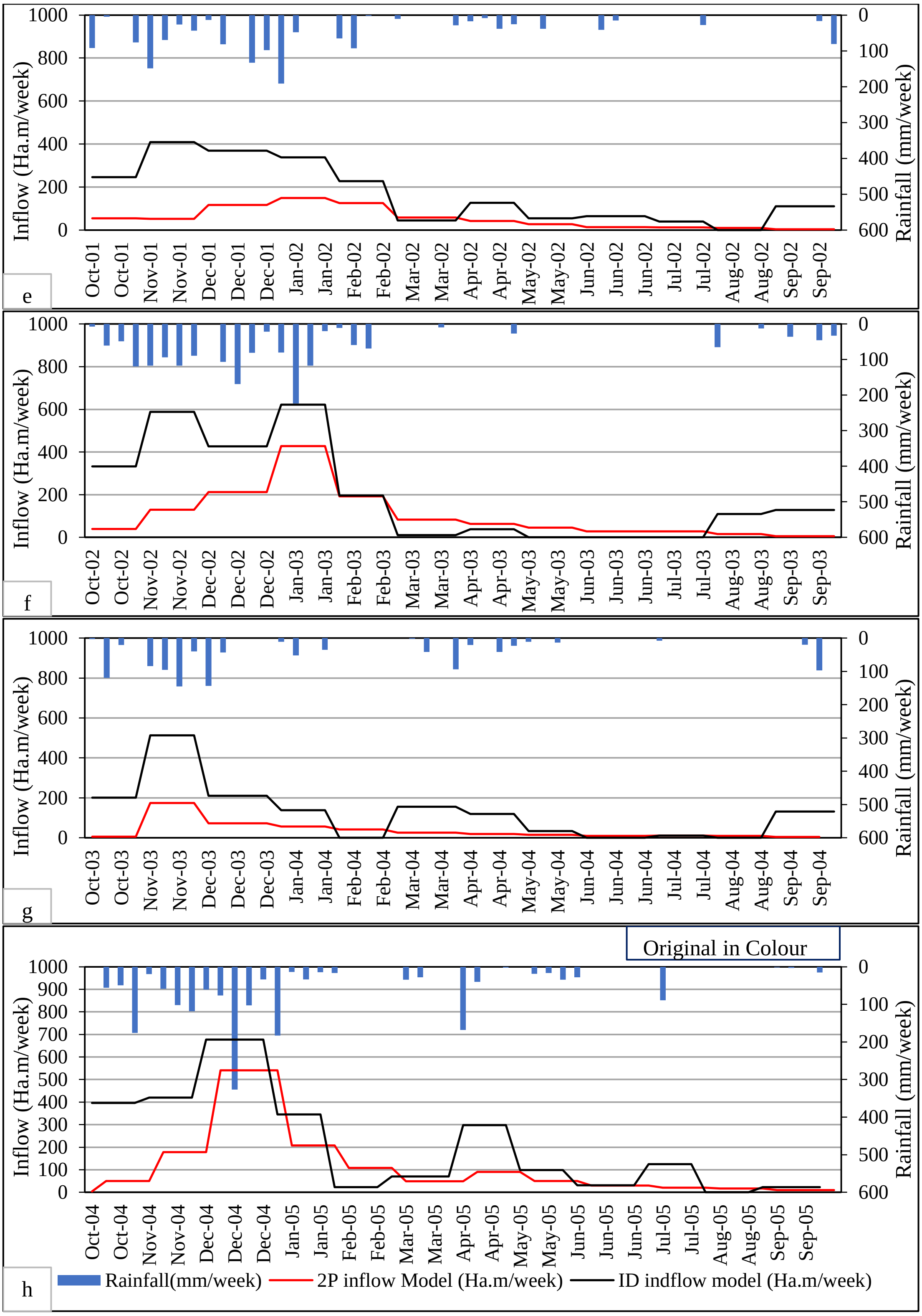


Figure 5-3 (e, f, g, h) Rainfall and inflow estimation comparison from two model (2001/02-2004/05)

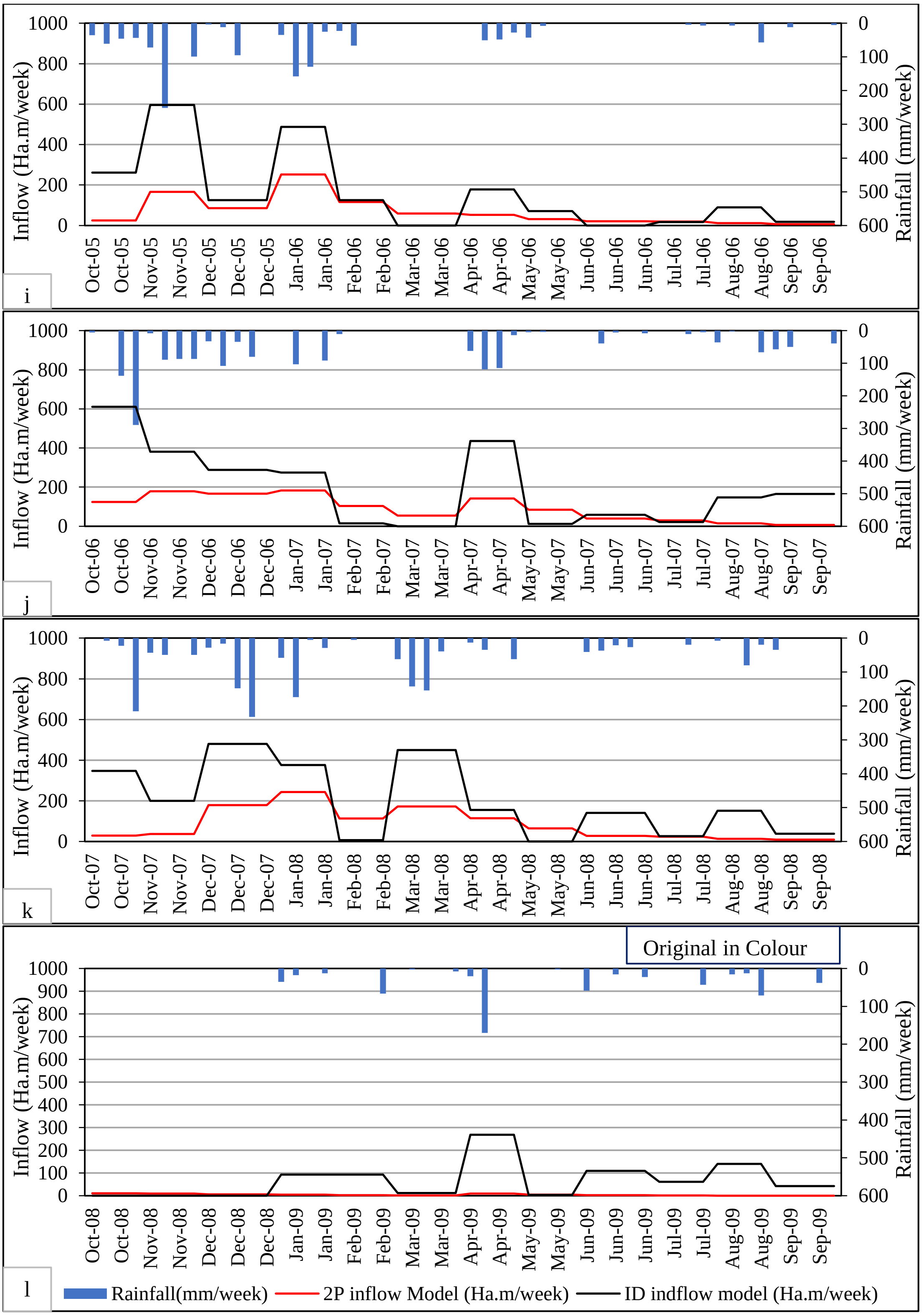


Figure 5-4 (I, j, k, l) Rainfall and infow estimation comparison from two model (2005/06-2008/09)

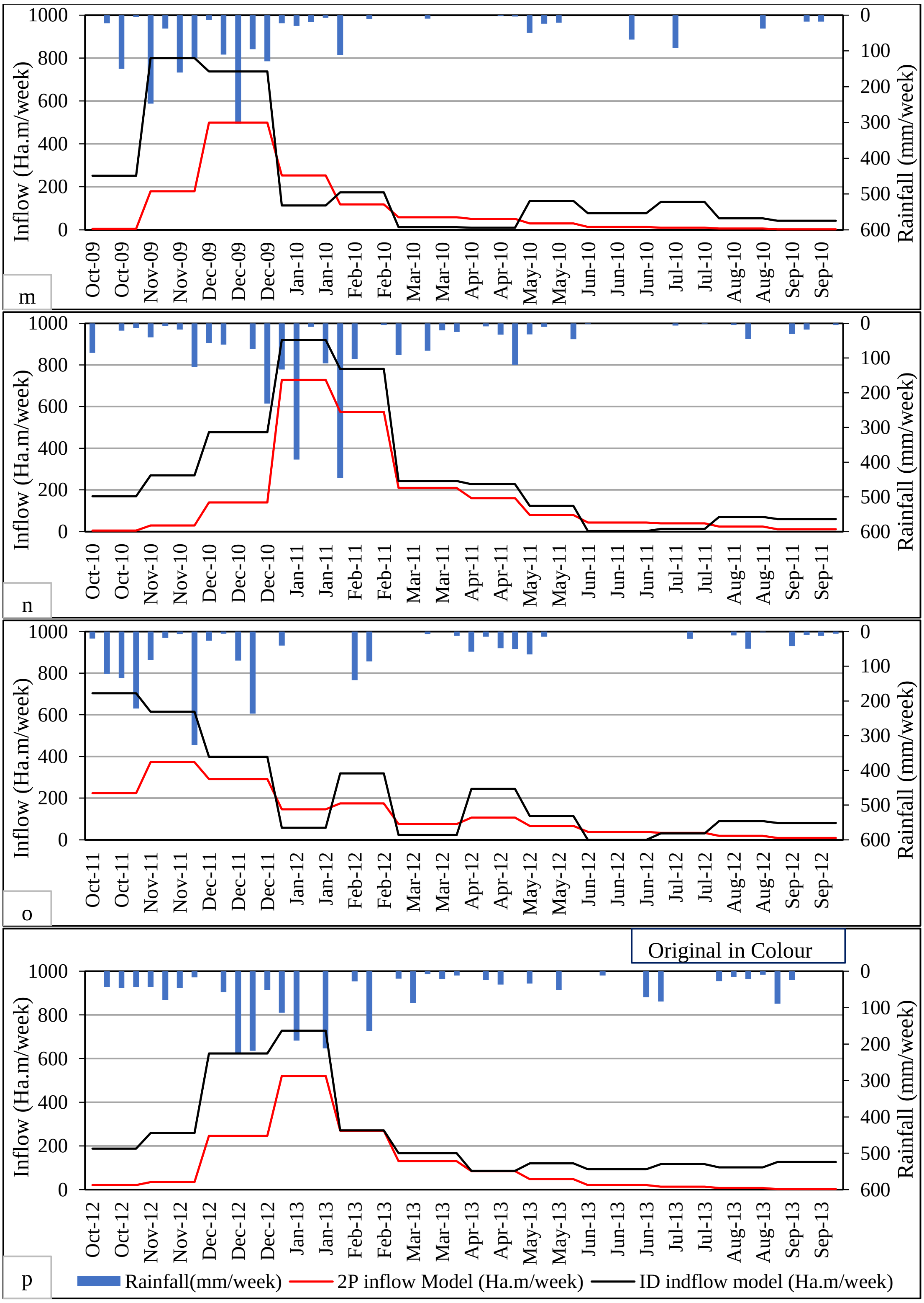


Figure 5-5 (m, n, o, p) Rainfall and inflow estimation comparison from two model (2005/06-2008/09)

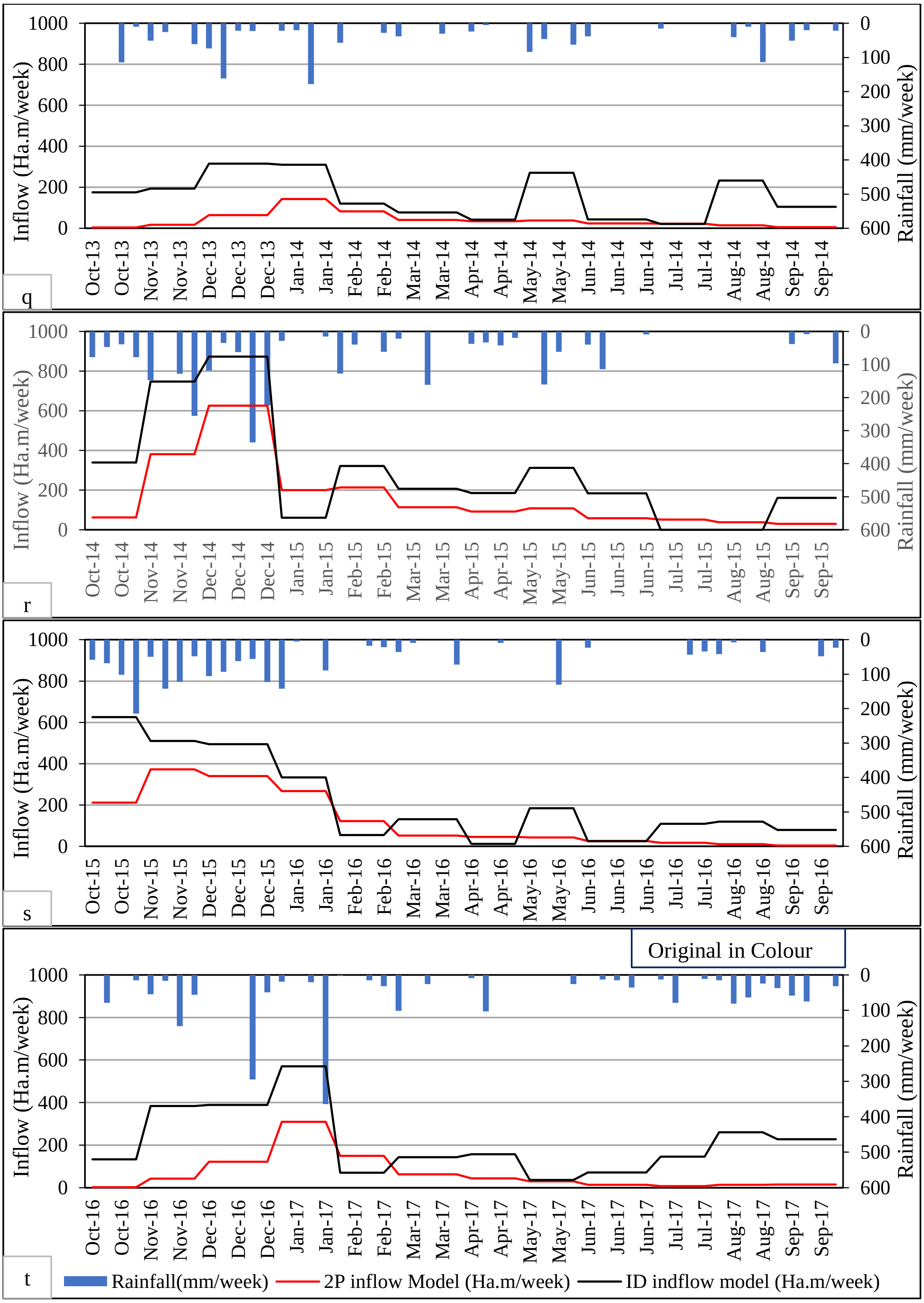


Figure 5-6 (q, r, s, t) Rainfall and inflow estimation comparison from two model (2005/06-2008/09)

5.3.2 Irrigation water demand:

Computed water demand and the observed water releases from the reservoir are in the Figure 5.7. Observed sluice discharge shows considerable sudden rises and falls. (Figure 5.8) The demand fluctuations do not show uniformity in the pattern, however, it clearly shows peaks of two main seasons Maha and Yala. The average water release is 2079 and average water release curve shows that Yala season water demand is higher than Maha season. The water release in the year 2011-12 had been about 69% more than the average and water release in the year of 2008-09 is 57% less than the average in the period 1997-2017 (Table 5.2, 5.3) Monthly water releases show a vast variation in the pattern and also in the magnitude of releases during each month. The monthly water release variation also shows two minimum releases, one during March and the other during September, this shows boundary of Maha & Yala seasons. On average, the Maha (Oct-Mar) season and Yala (Apr-Sep) season water releases 699 Ha.m and 1380 Ha.m respectively. (Table 5.2, 5.3)

Calculated demand from the reservoir show two peaks during both Maha and Yala seasons. Start of each season shows the highest value of a water year. This is because actual water demand was calculated based on irrigation department guidelines where land preparation, crop growth factor, crop water requirement was assumed as fixed. There are many disparities in the water releases and this could be due to measurement errors in the actual observations or due to the errors in the model parameters such water issue commencement dates, crop factors, crop development periods, water transfer efficiency, effective rainfall incorporation and use in practice, land preparation water estimates and use in practice. Critical evaluation conducted to identify the gap between observed and calculated demand in section 5.4.

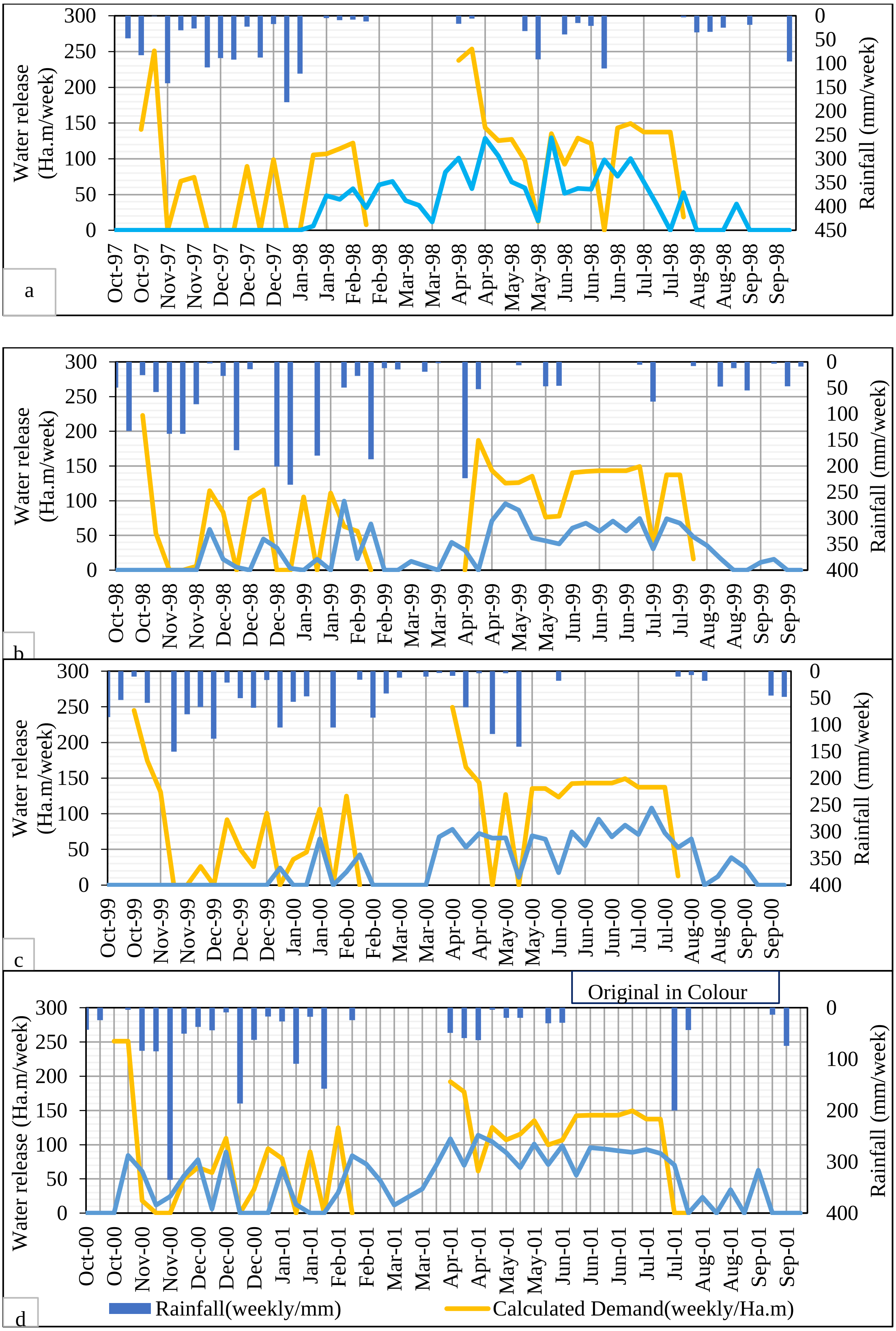


Figure 5-7 (a, b, c, d) weekly calculated and observed demand in Ha.m

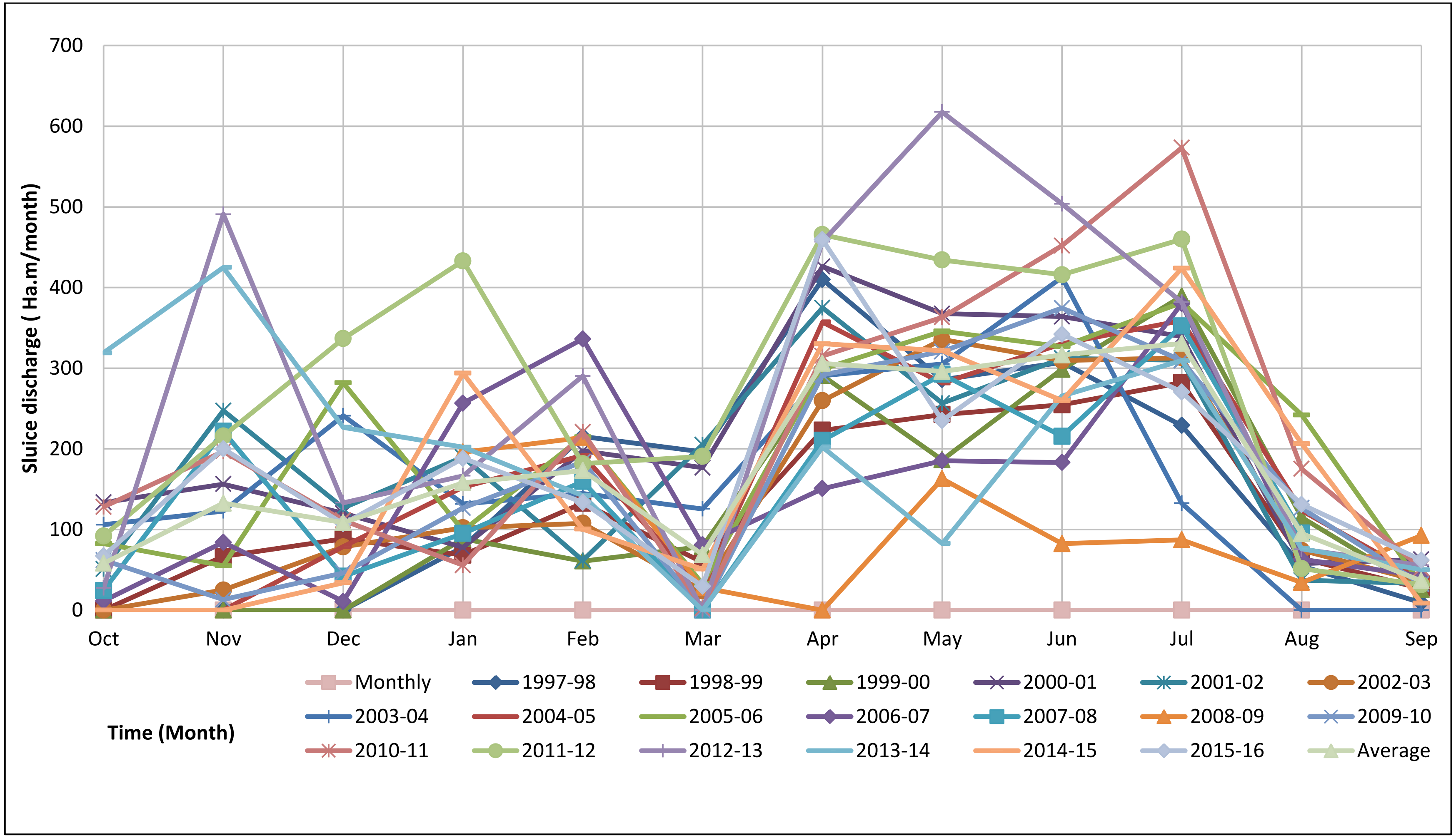


Figure 5-8 Observed sluice discharge Ha.m/monthly from 1997/98 to 2015/16

Table 5-2 Monthly sluice discharge in Ha.m from 1997/98 to 2008/09

Monthly	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09
Oct	0	0	0	133	51	0	106	0	82	11	24	
Nov	0	66	0	156	247	25	123	0	55	84	222	
Dec	0	89	0	120	127	78	241	79	282	11	42	
Jan	78	68	88	78	190	102	132	152	99	257	95	196
Feb	215	133	61	197	62	108	145	192	215	336	159	214
Mar	196	59	79	177	205	24	126	27	33	81	0	28
Apr	410	223	291	426	375	260	291	357	299	151	210	0
May	286	242	186	368	257	335	305	281	346	185	292	163
Jun	307	254	299	364	312	309	413	330	327	183	216	82
Jul	229	282	389	339	310	313	132	359	381	380	352	87
Aug	55	64	115	58	37	74	0	123	242	63	96	34
Sep	9	27	25	63	33	35	0	40	31	42		92
Total	1785	1508	1533	2479	2205	1664	2012	1942	2391	1784	1709	897

Table 5-3 Monthly sluice discharge in Ha.m from 2009/10 to 2015/16

Monthly	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	Average	Maha Average	Yala Average
Oct	62	128	92	27	319	0	67	58		
Nov	13	197	216	491	425	0	200	133		
Dec	46	111	337	133	227	34	107	109	1380	
Jan	127	56	433	166	202	294	188	158		
Feb	184	221	181	290	142	100	134	173		
Mar	0	2	191	0	0	51	29	69		
Apr	292	315	466	457	202	330	459	306		
May	321	363	434	618	82	322	235	296		
Jun	375	452	416	504	266	260	342	316		
Jul	309	573	460	382	309	424	270	331		699
Aug	126	175	51	75	76	206	131	95		
Sep	32	52	31	55	50	9	62	36		
Total	1886	2645	3308	3199	2300	2030	2225	2079		

5.3.3 Reservoir operation

Comparison of measured storage values with the inflow from the ID model and 2P model are in Figure 5.2 to Figure 5.7. The 2P model outputs were calibrated by varying C and Sc parameter values. Matching of observed and computed reservoir water storage values showed that the best fit C and SC parameters are 1.5 and 2000 respectively. In this computation, observed water releases were considerate as correct and were kept constant. Model output shows that the ID model over estimates the inflows during entire 20 year period. In summary the inflow model provided a clear indication that the ID model estimations without 7.5% and 35% constraints and using actual rainfall patterns are significantly higher that the estimates from the 2P model. The final inflow comparison with the calibrated parameters shows that there is a significant disparity between the computed and observed reservoir storage (Figure 5.9). The maximum difference ID inflow model storage and 2P model storage with observed storage are 3172 Ha.m and 3323 Ha.m respectively. This could be either due to the known issues in the inflow, the errors in observed sluice water releases or due to both and hence requires investigation. 2P, ID and observed storage comparison are shown in Figure (5.9, 5.10, and 5.11). Evaluation of results over the 20-year period showed that the observed reservoir levels do not match with the computed values. This could be due to issues with inflow computation, storage, spillage and sluice release measurement errors. Also, the disparities may be because of inaccurate Area capacity curves, evaporation values and seepage coefficients. After comparing many area capacity information which were available in data tables, and maps, it was identified that the Area capacity curve computed with contours and elevation provide the most acceptable curve for computations. Order of magnitude of the evaporation and seepage indicated that the values are significantly smaller when compared with the sluice release values and inflows. The reservoir water level data were checked for any errors in units, reporting, recording etc. Due to the order of magnitude of the system components, priority was given to investigate the compatibility of water demand data and inflow data used in the reservoir operation model.

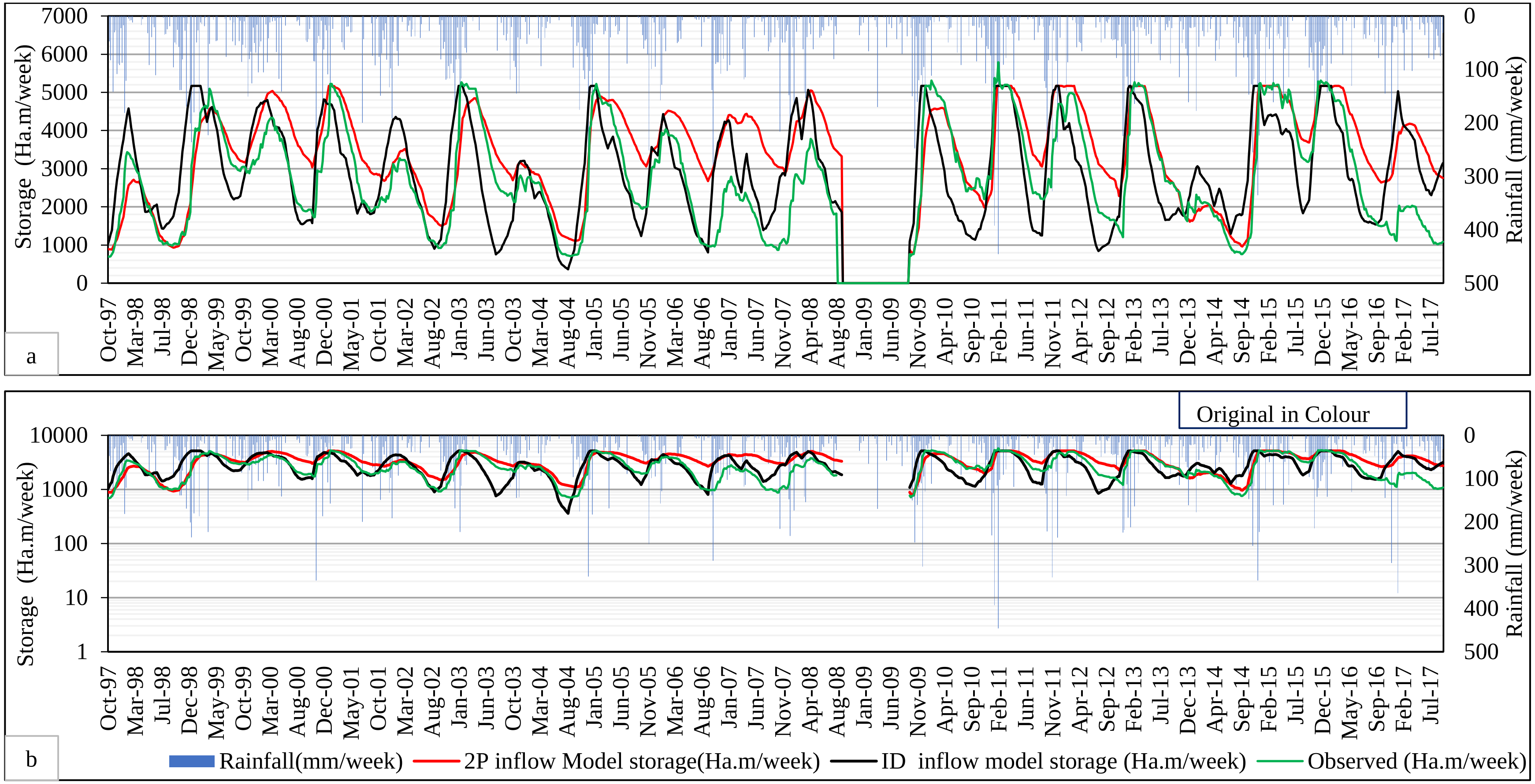


Figure 5-9 Comparison of rainfall, reservoir storage with observed storage

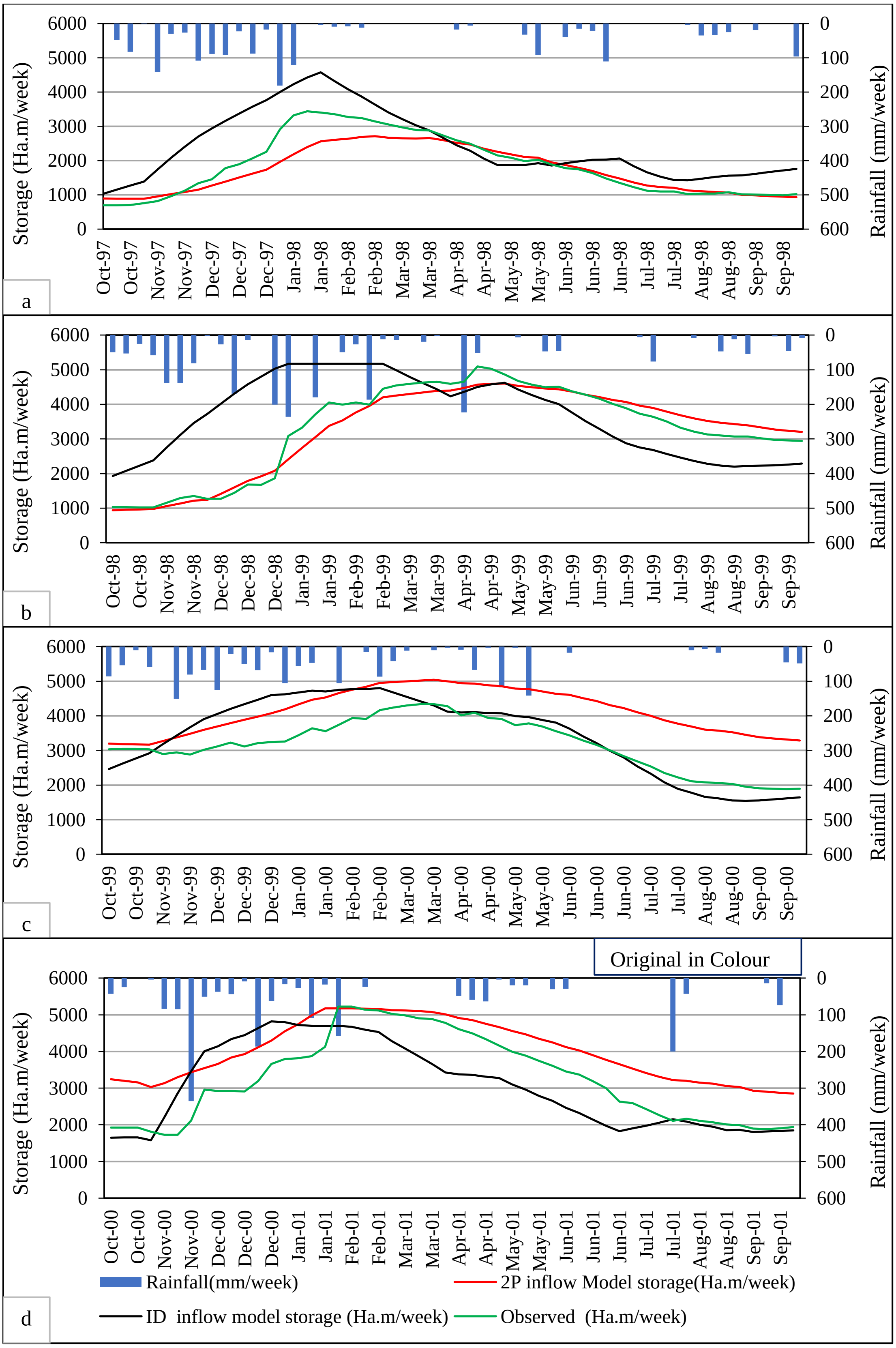


Figure 5-10 (a,b, c, d) Comparison of rainfall, model storage and observed storage (1997/98-2000/01)

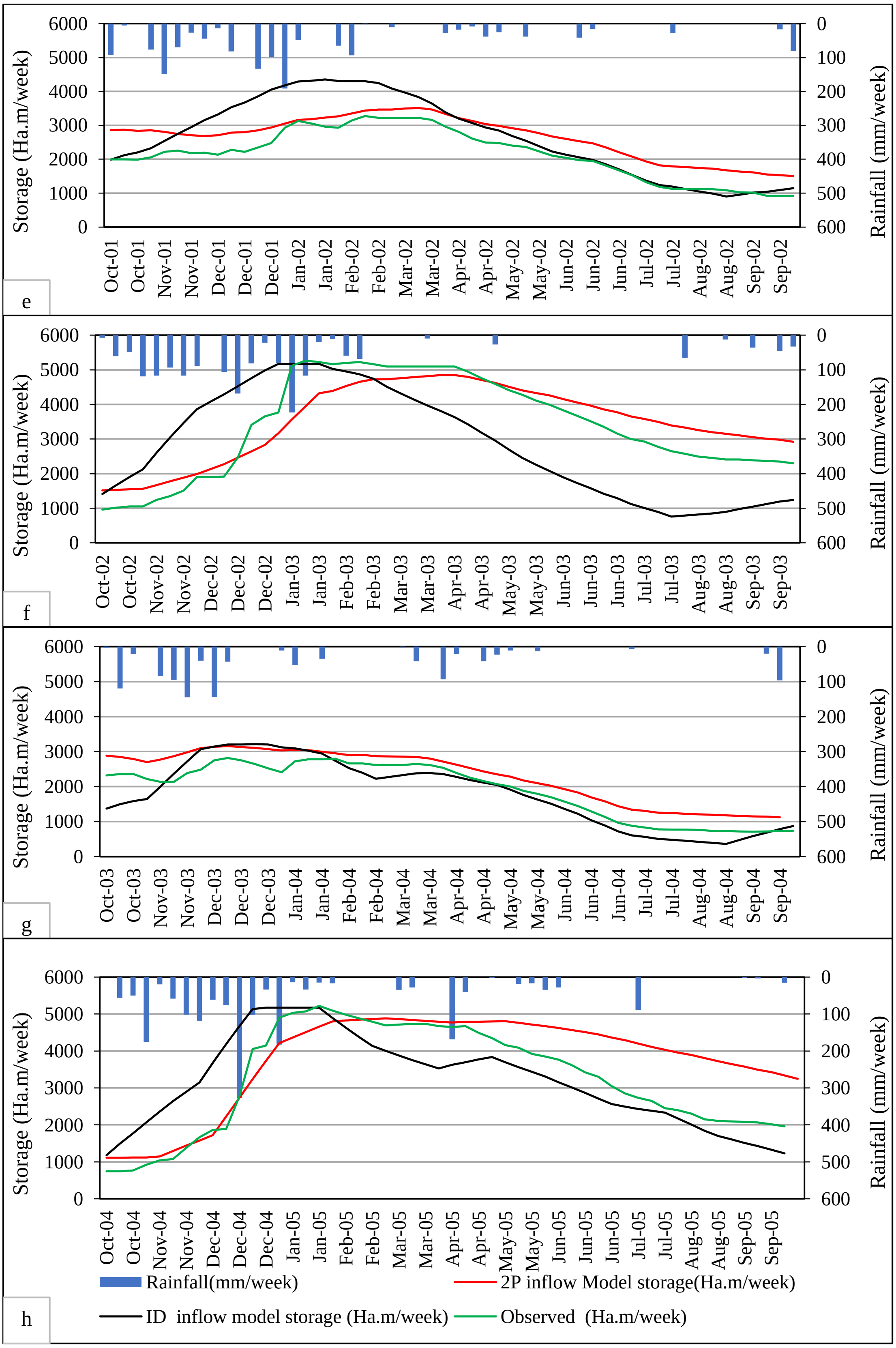


Figure 5-11 (e, f, g, h) Comparison of rainfall, model storage and observed storage (2001/02-2003/04)

5.4 Combined system performance:

Combine system is the combination of watershed inflows, reservoir storage and water release functioning at weekly temporal scale. Inflow options and water demand options were used as the inputs for the combined system model to evaluate the performance. Two main cases were considered for inflow model, first one is Irrigation Department guideline model and second one is the most realistic 2P inflow model. Three Sluice release cases were incorporateed identify critical components of irrigation reservoir.

5.4.1 Inflow model options

Case 1: Inflow from 2P model: 2P monthly model with c and SC as 1.5 and 2000 respectively was used. Difference with observed storage on occasions increased to a value approximately equal to 3300 Ha.m. The maximum average monthly difference is 907 Ha.m. In this case, canal efficiency was taken as 70%. And entire command area was cultivated of both Maha and Yala season. .

Case 2: Irrigation Department guidelines model: Computed values for the period from 1997-98 to 2016-07 are shown in Figure 1. Results over the study period indicated an accumulation of reservoir storage gap between the observed and ID calculations.. The gap on some occasions increased to an approximate value of 3071 Ha.m. Maximum average monthly storage variation is 1203 Ha.m. Efficiency was assumed as 70%. Entire command area(1498 Ha) was cultivated of both Maha and Yala seasons. .

5.4.2 Reservoir water releases

Various trials were carried out to match the observed water release data with the computed irrigation demand values. The details are as described below Parameters for the best fit water releases for each year were identified. Behavior of commencement dates in Maha and Yala seasons, water issue period for land preparation, water issue duration comparison for each season, impact of water quantities with respect to different growth stages were varied by trial and error approaches and the best watching graph are shown in the figures 6.14. In order to identify the most critical factors, an increase in the water for land preparation from 15-28 days, a decline of project efficiency due to lack of maintenance (70%-50%)

,changes of crop type and inefficient use of effective rainfall etc. were incorporate Water releases were compared with of on Irrigation department guidelines. The disparity indicates that either errors in water release measurements could be the reason. the influence of other factors that may have not been accounted for the model computations. Water release values we computed from the sluice opening and the water head at the sluice gate. In this case, if the water levels were not recorded properly, then also errors can occur in the flow records. Therefore, the above mentioned factors question the accuracy of water level measurements. Considering the above cases can be taken as critical consideration for water management.

Case 1: Irrigation demand values were calculated using irrigation department guidelines. Therefore, In this case, crop water requirement, evapotranspiration, crop factor on different growth storage, requirement for the land preparation, effective rainfall farm losses, irrigation efficiency were selected from ID (1984) guidelines. Effective rainfall is a key factor for irrigation requirement. In this case, as indicated in the guidelines, effective rainfall calculated for each week. This calculation doesn't considering any effect of rainfall that occurred in the previous week. . Under this consideration, on some occasions, irrigation requirements are more than the actual observed. To minimize this, a part of effective rainfall used for the previous week was considered using trial and error. Though water shortage is a problem ,water consumption is very high during land preparation in most of the years between the period of from (1997-98 to 2016-17) Though, water requirement for 15 days land preparation is 178 mm according to ID guidelines, the analysis showed that land preparation had used 190-230 mm and consumed more than 15 days. To evaluate this, a 178 mm water requirement for a 15,21, and 28 days period was incorporated to incorporated to observe the variations of sluice discharge. During filed visits it was revelaed that during the Maha season, it is usual for farmers to avoid the use of reservoir water for land preparation. During Maha season, the dependence is mostly on rain. Therefor in case 1, water release only for Yala season was considered.

Case 2: Based on irrigation department guidelines, the overall efficiency of the irrigation was assumed as 70% for initial computations. During the field investigation, it could be seen that canal maintenances poor. Irrigation Department official also confirmed this opinion. Therefore, a trial and with overall efficiency values of considerate 65% , 60%, 55%, 50% was considered to capture the best fit computed reservoir storage.

Case 3: Though Namal Oya irrigation scheme was planned to serve the entire command area during both seasons. This was noted as inconsistent rainfall. Due to rainfall deficiencies, the seasonal command area utilization has changed but there was a data deficiency. In order to capture an average utilization, the percentage command ara was varied 95%-30% in steps of 5. In case 3, this attempt was used to watch the observed and computed water demands.

5.5 Management-Option evaluation

For each case mentioned above compared with observed and computed storage levels, then find out what should be done to best manage the situation. In each case, summaries of the computed and actual water release on monthly, seasonal and annual basis. Management alternative are the combination of two cases (Reservoir inflow model and Sluice releases) that mentioned above. Those combinations had done to know the actual scenario of the current reservoir water management and recommend best alternative reservoir operation for future.

5.5.1 Management alternative 1: combination of Inflow case 1 (2P) and sluice discharge case 1

The storage variation of alternative 1 with the observed storage is shown in Figure 5.12(a, b). and Figure 5.13 For land preparation, it is assumed 177.8 m water required for land soaking and land tillage for a 15 days period. But in the irrigation scheme it varies from each season. In some seasons land preparation are totally based on rainfall and rainfall isn't sufficient than only water release from the reservoir. So, land preparation varies from 15 days to 28 days based on rainfall and available water in the reservoir. In the calculated water demand, it is assuming land preparation starts between 1st week of October to 1st week of November for Maha season, and for Yala season it is assumed from mid-March to mid-April. This is why harvesting period of both are also varied in the observed water demand compare to calculated water demand. On the average the Maha (Oct-Mar) season and Yala (Apr-Sep) season water releases 699 Ha.m and 1380 Ha.m respectively and calculated water demand for Maha (Oct-Mar) season and Yala (Apr-Sep) season 663 Ha.m and 1981 Ha.m respectively. The highest water calculated demand is 3237 Ha.m in the year of 2003-04 which year the rainfall was 1161 mm which representing minimum rainfall over 20 years of period. Weekly calculated water demand for the Maha and Yala are shown in Figure 5.14.Overall efficiency of the irrigation scheme considerate as 70% and farmers of Namal oya reservoir are cultivating 105 days paddy for both Maha and Yala season.The annual average evaporation is 804 Ha.m. Seepage factor estimated as 3.5% based on trial and error method and annual average seepage is 721 Ha.m. The maximum difference between observed and calculated storage 2360 Ha.m.

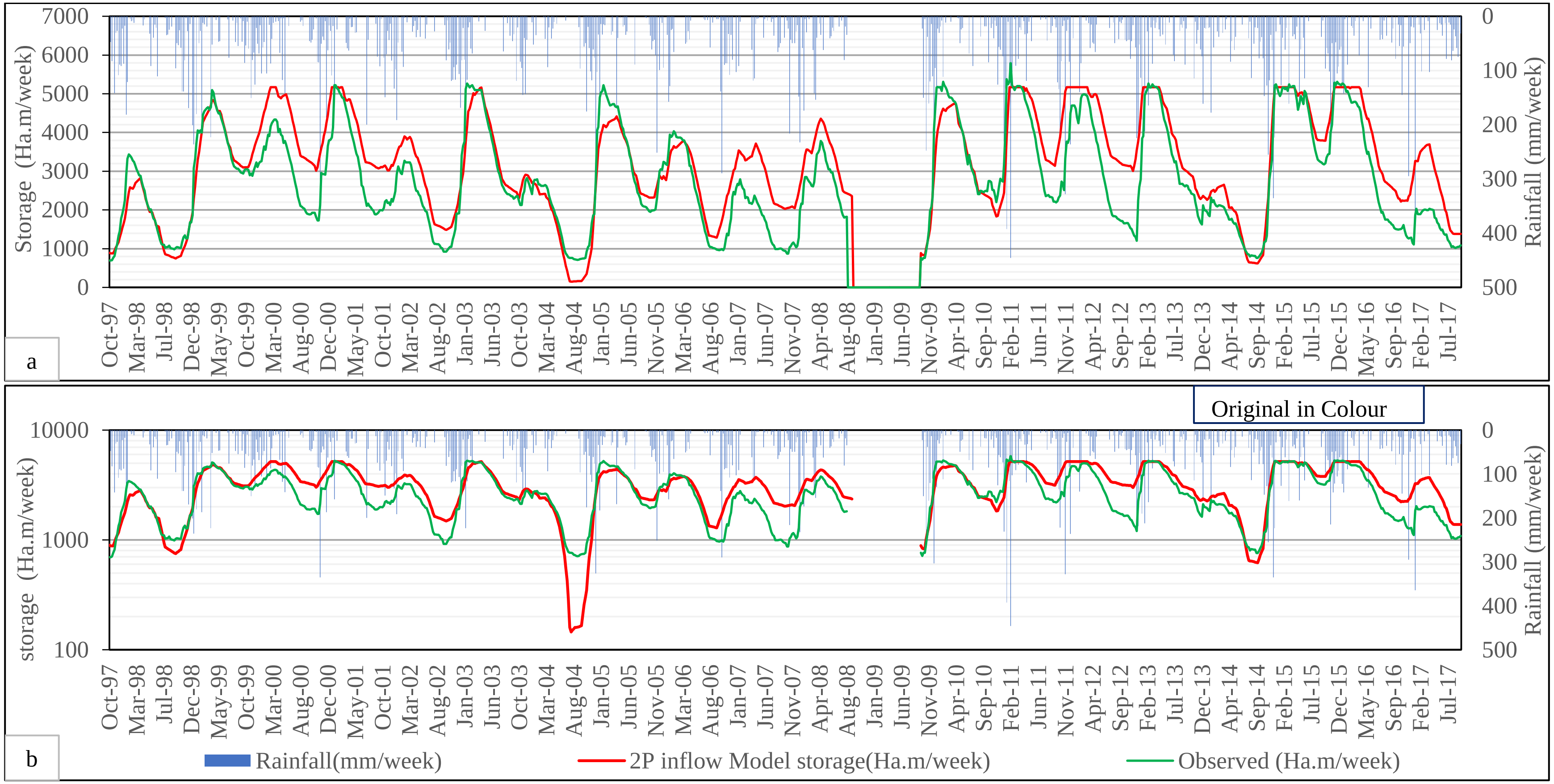
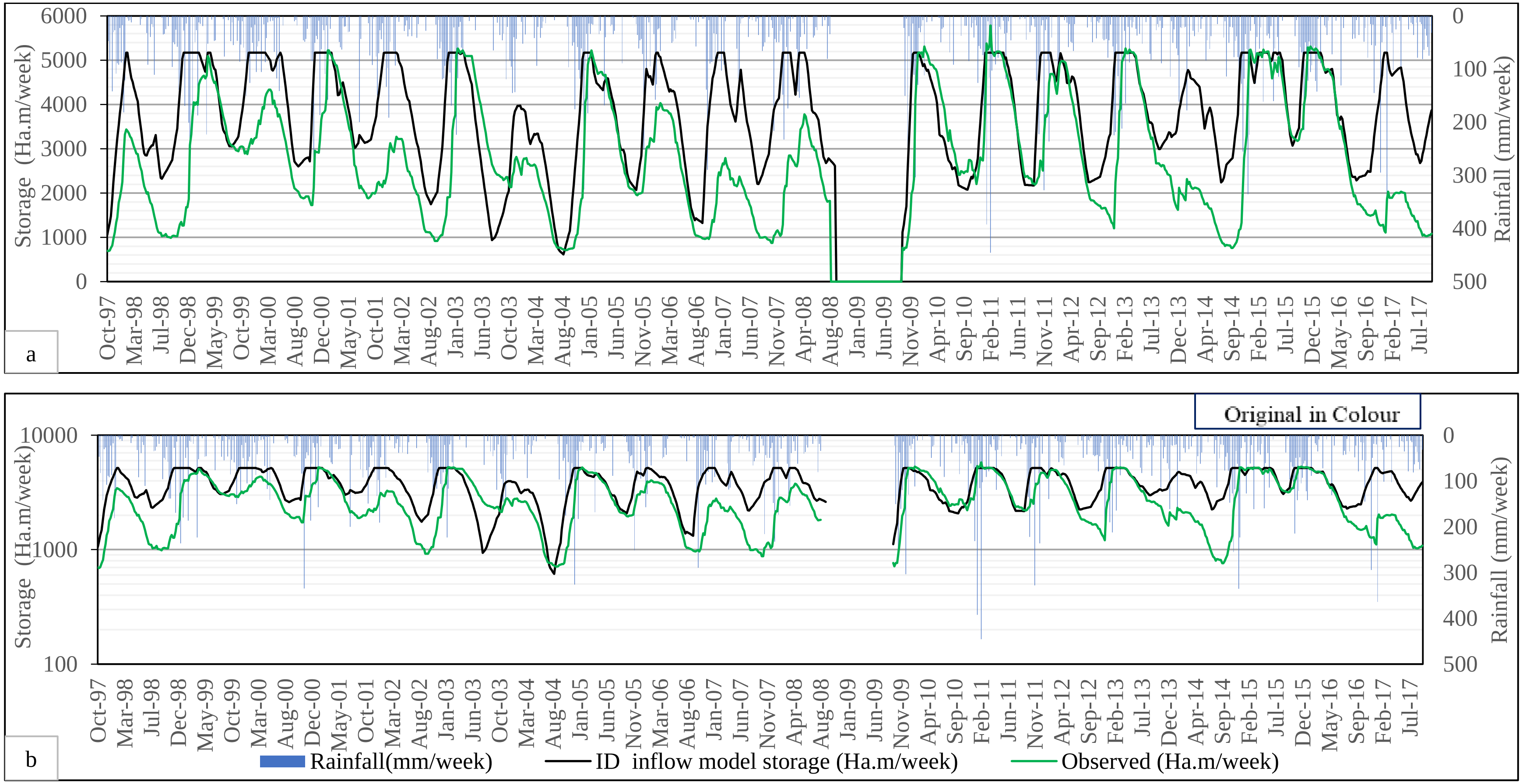


Figure 5-12 Weekly 2P and ID storage variation on Alternative 1



5-13 Weekly 2P and ID storage variation on Alternative 2

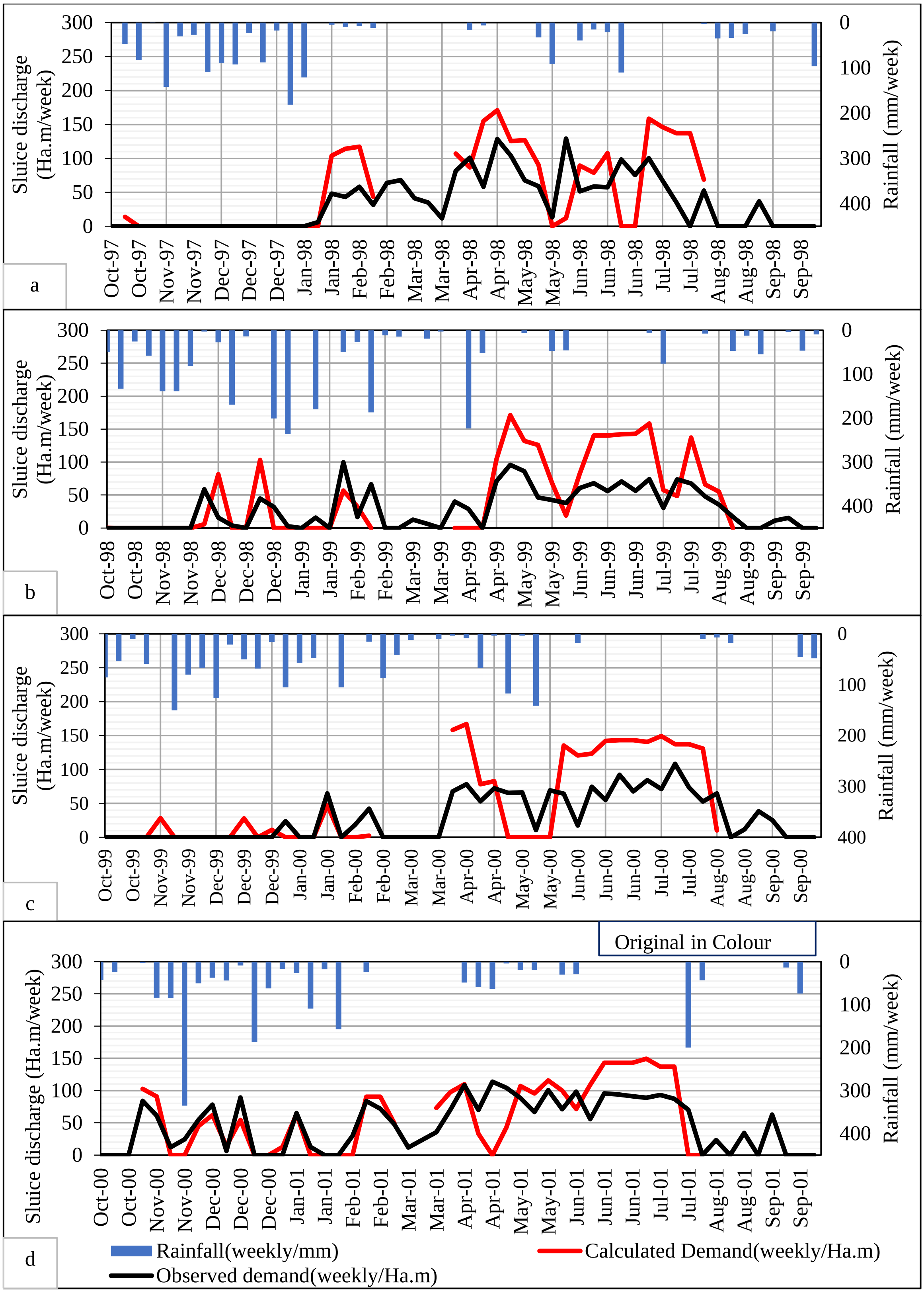


Figure 5-14 (a, b, c, d) Weekly observed and calculated demand in Alternative 1

5.5.2 Management alternative 2: inflow case 2 (ID) and sluice discharge case 1

The storage variation of management alternative 2 with the observed storage is shown in Figure 5.13(a, b). The difference between observed storage and calculated storage is higher than alternative 1 because of higher inflow than 2P model. The sluice discharge is this is similar to alternative 1. Overall efficiency of the irrigation scheme considerate as 70% and farmers of Namal oya reservoir are cultivating 105 days paddy for both Maha and Yala season for whole command area. The annual average evaporation is 811 Ha.m. and June are identified as highest evaporation month at a 121 Ha.m. Seepage factor estimated as 10 % based on trial and error method and annual average seepage is 4038 Ha.m. The maximum difference between observed and calculated storage 3760 Ha..m where Alternative 1 was 2362 Ha.m. This mismatch may be due to Irrigation demand calculation and command area %. Monthly reservoir storage of alternative 2 is shown in Table 6.18 and 6.19 and variation of storage in different years in shown on Figure 6.6. Storage variation of alternative 2 and observed storage also shown in Table 5.20 and 5.21.

5.5.3 Management alternative 3: inflow case 1(2P) and sluice discharge 2

The storage variation of alternative 3 with the observed storage is shown in Figure 5.17(a, b). On the average the Maha (Oct-Mar) season and Yala (Apr-Sep) season water releases 699 Ha.m and 1380 Ha.m respectively and calculated water demand in altenative 4 and for Maha (Oct-Mar) season and Yala (Apr-Sep) season 725 Ha.m and 2167 Ha.m respectively and annual average water demand in 2892. Weekly calculated water demand for the Maha and Yala are shown in Figure 5.14.. Based on irrigation department guidelines, the overall efficiency of the irrigation was assumed as 70%. During the field investigation, it has been seen that canal are not maintenance properly and irrigation department official also informed that. To solve this, here trial and error method were used to optimized sluice discharge value with observed value overall efficiency considerate 65% , 60%, 55%, 50%. Overall efficiency of the irrigation scheme estimated as 64% based on trial and error method seepage factor is 0.8%. and annual average seepage amount is 361 Ha.m. The annual average evaporation is 817 Ha.m. The maximum difference between observed and calculated storage 2627 Ha.m

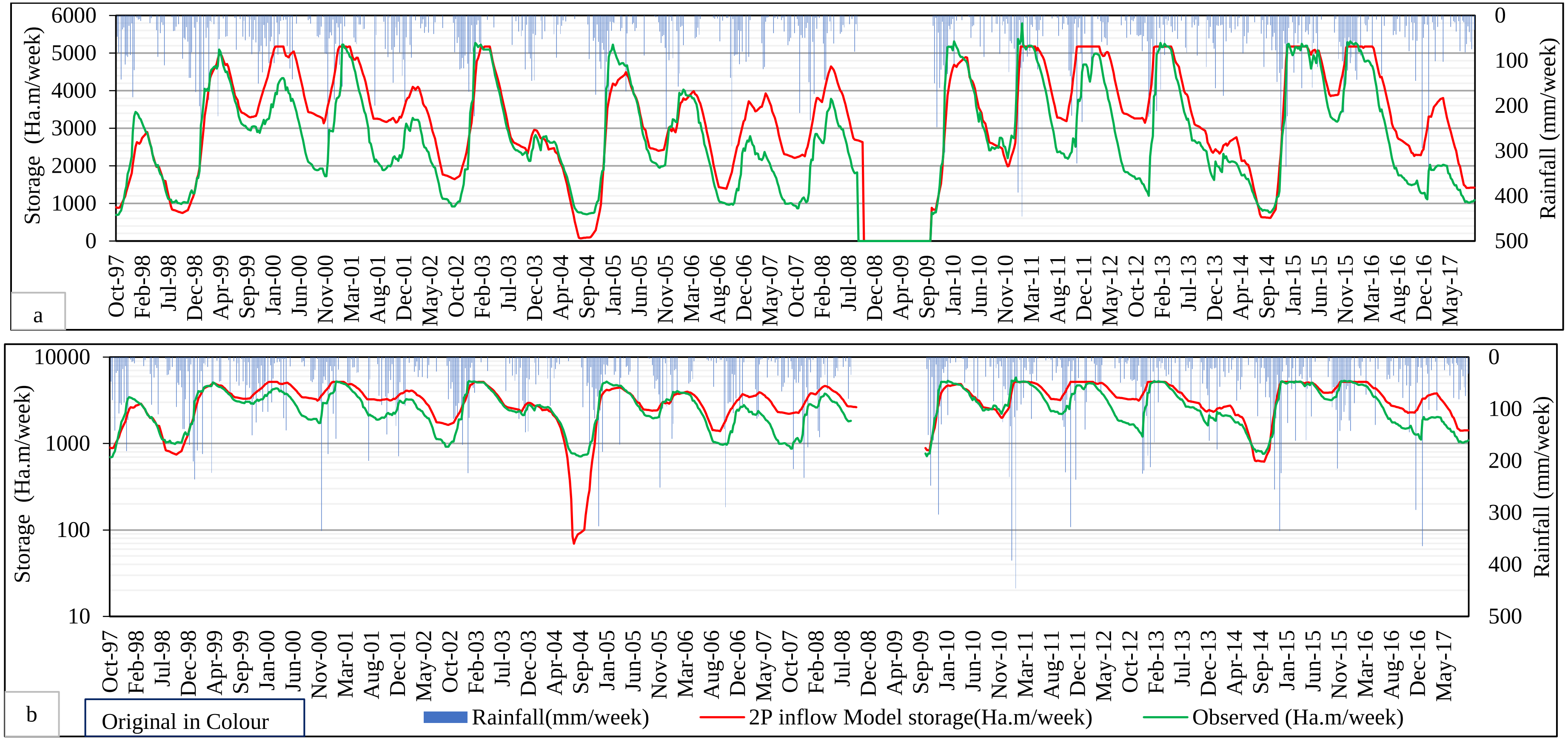


Figure 5-15 Weekly storage variation of alternative 3 with observed storage

5.5.4 Management alternative 4: inflow case 2(ID) and sluice discharge case 2

The storage variation of alternative 4 with the observed storage is shown in Figure 6.18(a, b). On the average the Maha (Oct-Mar) season and Yala (Apr-Sep) season water releases 699 Ha.m and 1380 Ha.m respectively and calculated water demand in altenative 4 and for Maha (Oct-Mar) season and Yala (Apr-Sep) season 725 Ha.m and 2167 Ha.m respectively and annual average water demand in 2892. Weekly calculated water demand for the Maha and Yala are shown in Figure 6.14. Overall efficiency of the irrigation scheme estimated as 64% based on trial and error method seepage factor is 10 %. and annual average seepage amount is 3945 Ha.m. The annual average evaporation is 863 Ha.m. The maximum difference between observed and calculated storage 3664 Ha.m. Monthly storage variation of 20 years shown in Annex 3.

5.5.5 Management alternative 5: inflow model (2P) case 1 and sluice discharge 3

As Namal Oya irrigation scheme was planned to server whole command area in both Maha and Yala season but in this case of alternative 95%, 90%, 85%, 80%, 75%, 60%, 55%, 50%, 45%, 40%, 35%, 30% of command area is considerate to optimize the calculated storage with respect to observed storage of the reservoir. The weekly storage comparison with the observed storage is given best fitted curve in this alternative compare to previous four alternative. The overall efficiency of Irrigation scheme is also optimized by using 65% , 60%, 55%, 50% and for 55% efficiency the model given more best fitted curve with observed storage. The maximum storage variation is 2168 Ha.m and in the month of January 2007. From the Figure 6.19 is clearly shown that during Yala season the observed storage is nearly similar with computed storage but during the Yala season there is gap. This is because of we calculated catchment inflow on monthly basis and later equally distributed it in every week of a month. But Irrigation reservoir reservoir receive water from its catchment based on daily rainfall. On the average the Maha (Oct-Mar) season and Yala (Apr-Sep) season observed water releases 705 Ha.m and 1391 Ha.m respectively and calculated water demand in altenative 5 and for Maha (Oct-Mar) season and Yala (Apr-Sep) season 815 Ha.m and 1840 Ha.m respectively and calculated annual average water demand in 2655 Ha.m. The command area of both Maha and Yala season are shown in Table 6.33. From the Table 6.33, Namal Oya was able to serve to its whole command 5 times, more than 80% is four times. During the year 2003-04 and 2005-06, Its failed to serve whole command area in Maha season. It is also revealed that there is error on sluice release measurement and the difference between calculated and observed sluice shown in Table 6.38 and 6.39.

Table 5-4 : % and of command area of Namal Oya reservoir

Year/season	Maha %	Maha (Ha)	Yala %	Yala(Ha)
1997-98	100	1498	90	1348.2
1998-99	100	1498	60	898.8
199-00	100	1498	100	1498
2000-01	100	1498	90	1348.2
2001-02	100	1498	50	749
2002-03	100	1498	55	823.9
2003-04	55	823.9	50	749
2004-05	100	1498	85	1273.3
2005-06	75	1123.5	65	973.7
2006-07	100	1498	100	1498
2009-10	100	1498	50	749
2010-11	100	1498	100	1498
2011-12	100	1498	100	1498
2012-13	100	1498	90	1348.2
2013-14	100	1498	40	599.2
2014-15	100	1498	85	1273.3
2015-16	100	1498	100	1498
2016-17	100	1498	50	749

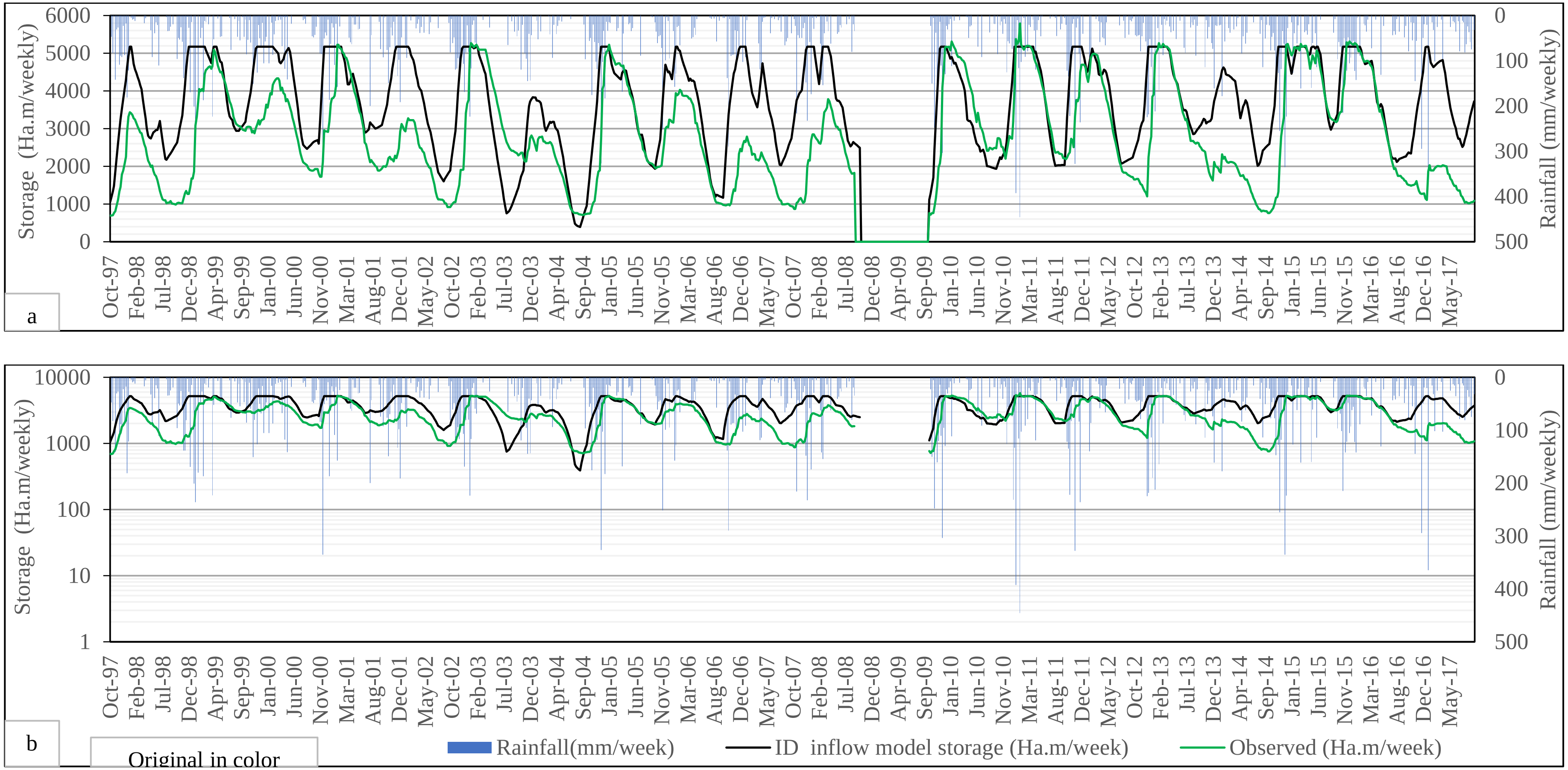


Figure 5-16 Weekly storage variation of alternative 4 and observed storage in Ha.m

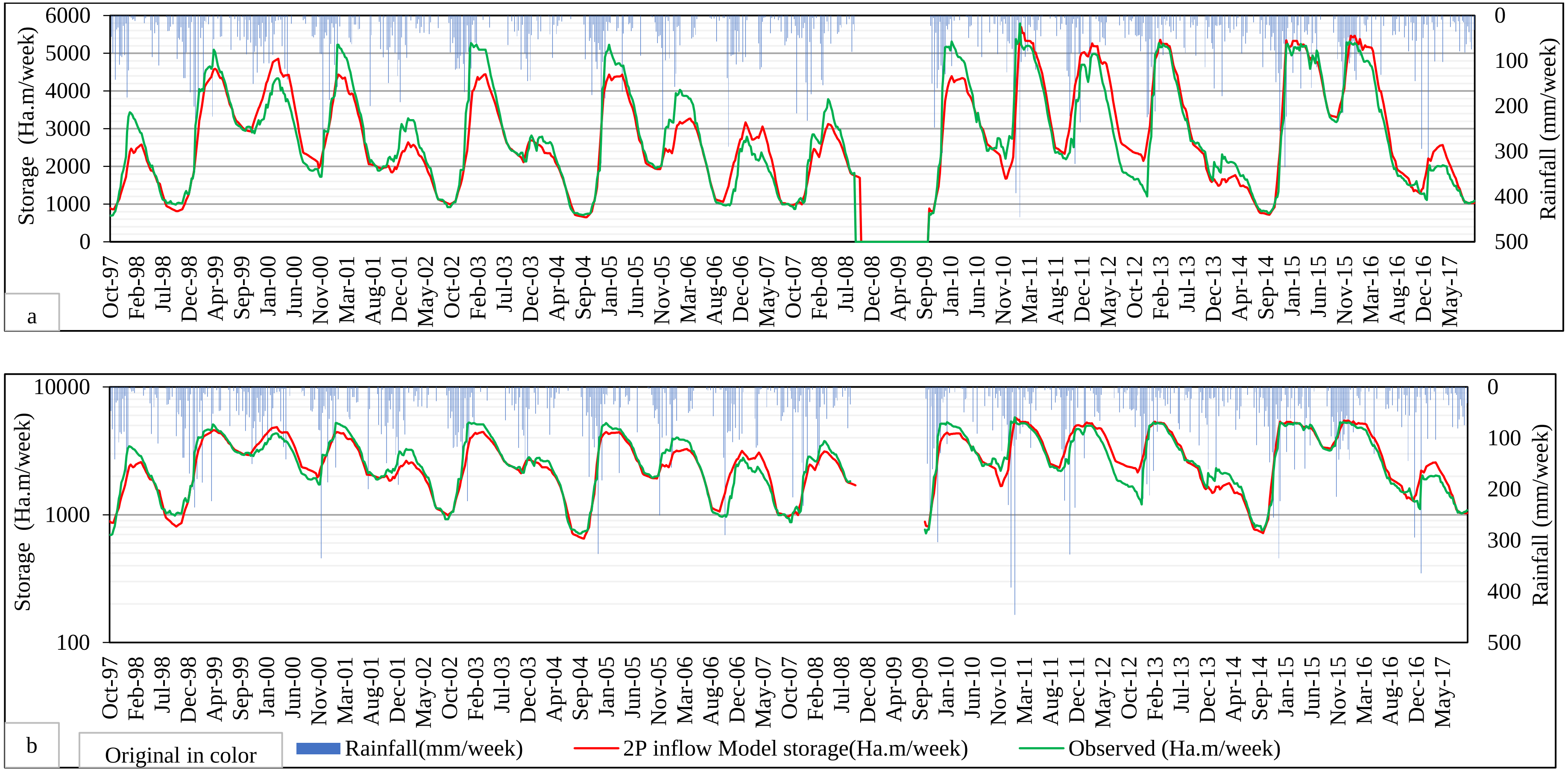


Figure 5-17 Weekly storage comparison of management alternative 5 with observed storage in Ha.m

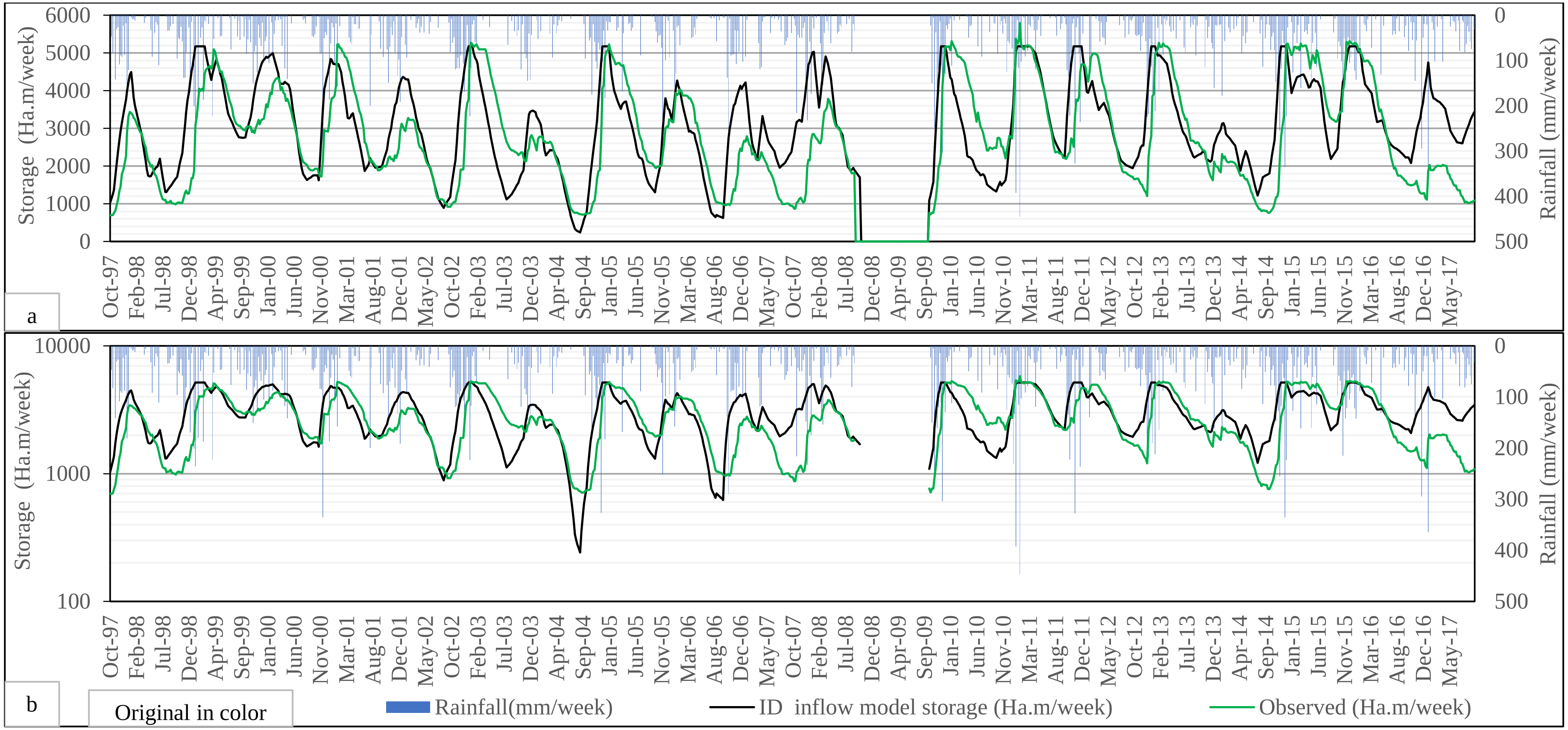


Figure 5-18 Weekly storage variation of management alternative 6 and observed storage in Ha.m

5.5.6 Management alternative 6: inflow model 2(ID) sluice release 3

As Namal Oya irrigation scheme was planned to server whole command area in both Maha and Yala season but in this case of alternative 6, 95%, 90%, 85%, 80%, 75%, 60%, 55%, 50%, 45%, 40%, 35%, 30% of command area is considerate to optimize the calculated storage with respect to observed storage of the reservoir.. The overall efficiency of Irrigation scheme is also optimized by using 65% , 60%, 55%, 50% and for 55% efficiency the model given more best fitted curve with observed storage. The maximum storage variation is 3064 Ha.m and in the month of December 1998. On the average the Maha (Oct-Mar) season and Yala (Apr-Sep) season observed water releases 705 Ha.m and 1391 Ha.m respectively and calculated water demand in altenative 5 and for Maha (Oct-Mar) season and Yala (Apr-Sep) season 787 Ha.m and 838 Ha.m respectively and calculated annual average water demand in 1626 Ha.m. The command area of both Maha and Yala season are shown in Table 6.3. From the Table 6.3, Namal Oya was able to serve to its whole command 5 times, during yala season it was able to serve nealrly 60 % in 6 times.

Table 5-5 % and command area in Ha. of Alternative 6

Year/season	Maha %	Maha (Ha)	Yala %	Yala(Ha)
1997-98	100	1498	50	749
1998-99	100	1498	40	599.2
199-00	100	1498	50	749
2000-01	100	1498	40	599.2
2001-02	100	1498	50	749
2002-03	100	1498	55	823.9
2003-04	55	823.9	40	599.2
2004-05	100	1498	40	599.2
2005-06	75	1123.5	50	749
2006-07	100	1498	100	1498
2009-10	100	1498	40	599.2
2010-11	100	1498	100	1498
2011-12	100	1498	100	1498
2012-13	100	1498	40	599.2
2013-14	100	1498	40	599.2
2014-15	100	1498	40	599.2
2015-16	100	1498	100	1498
2016-17	100	1498	100	1498

5.6 Evolution of combined system model

The crop water requirement and inflow from catchment were used as the inputs for the combined system model to evaluate the performance. There are two main cases considerate for inflow model, first one Irrigation Department guidelines models and second one is 2P inflow model. There are also three Sluice releases cases studied to identify critical components of irrigation reservoir. Irrigation demand was calculating based on irrigation department guidelines. In this case, crop water requirement, evapotranspiration, crop factor on different growth storage, requirement for the land preparation, effective rainfall farm losses, irrigation efficiency were calculated by following ID (1984) guidelines. Effective rainfall plays an important role and there are some limitations for calculating effective rainfall of a week, if we consider one week, according to Irrigation department guidelines, effective rainfall was calculated for that week only. This calculation isn't considering how much rainfall happened in the previous week. So sometimes because of this, irrigation requirements are showing more water than the actual one. To minimize this, trial and error method of effective rainfall used of the previous week is also added in a particular week's effective rainfall. Though water shortage is a problem in the irrigation reservoir, water consumption is very high during land preparation in most of the years from (1997-98 to 2016-17) of Namal Oya reservoir. The water requirement for land preparation is 178 mm according to ID guidelines for a 15 days period of time but it have been seen from the analysis that land preparation took much more water 190-230 mm and it takes more than 15 days. To optimized this, we used 178 mm water requirement for a 15, 21, and 28 days of period to see the variations of sluice discharge for each different land preparation days and for 28 days. Moreover, during the Maha season, usually farmers are not using reservoir water for land preparation. They are mostly depending on rainfall for land preparation during Maha season so here we are only considering reservoir water release for Yala season. Based on irrigation department guidelines, the overall efficiency of the irrigation was assumed as 70%. During the field investigation, it has been seen that canal are not maintenance properly and irrigation department official also informed that. To solve this, here trial and error method were used to optimized sluice discharge value with observed value overall efficiency considerate 65%, 60%, 55%, 50% and finally identified that the current overall efficiency of Namal Oya scheme is 55%. As Namal Oya irrigation scheme was planned to server whole command area in both Maha and Yala season but in this case of alternative 95%, 90%, 85%, 80%, 75%, 60%, 55%, 50%, 45%, 40%, 35%, 30% of command area is considerate to optimize the calculated storage with respect to observed storage of the reservoir. From the above management alternative of combined system model and, Alternative 3 and 5 considered as the most critical condition hence proposed management options provided for management alternative 3 and 5.

5.7 Recommended irrigation plan for management alternative 3 and 5

This is the recommended water plan that a water manager would prepare prior to a cultivation season. In other words, a good and efficient irrigation water manager would make attempts to issue more water when the actual rainfall is less than the 75% probable rainfall and vice versa. This method enables the understanding of whether such changes are significant; therefore, the recommended water release which is calculated with historical data, considers the field reality with the knowledge of actual Crop type, Cropping calendar, Extent of Cultivation, rainfall and Evaporation, a manager would have to estimate the evaporation and rainfall. Recommended water use for the study period considering rainfall experienced at the Namal Oya Irrigation Scheme and weekly values of rainfall and water release volume was calculated as and were plotted (Figure 5-18) Seasonal variations of total recommended water release are given in the Table 5-6. Irrigation water requirement per unit command area corresponding to the recommended water release are given in the Table 5-4 and Table 5-5.

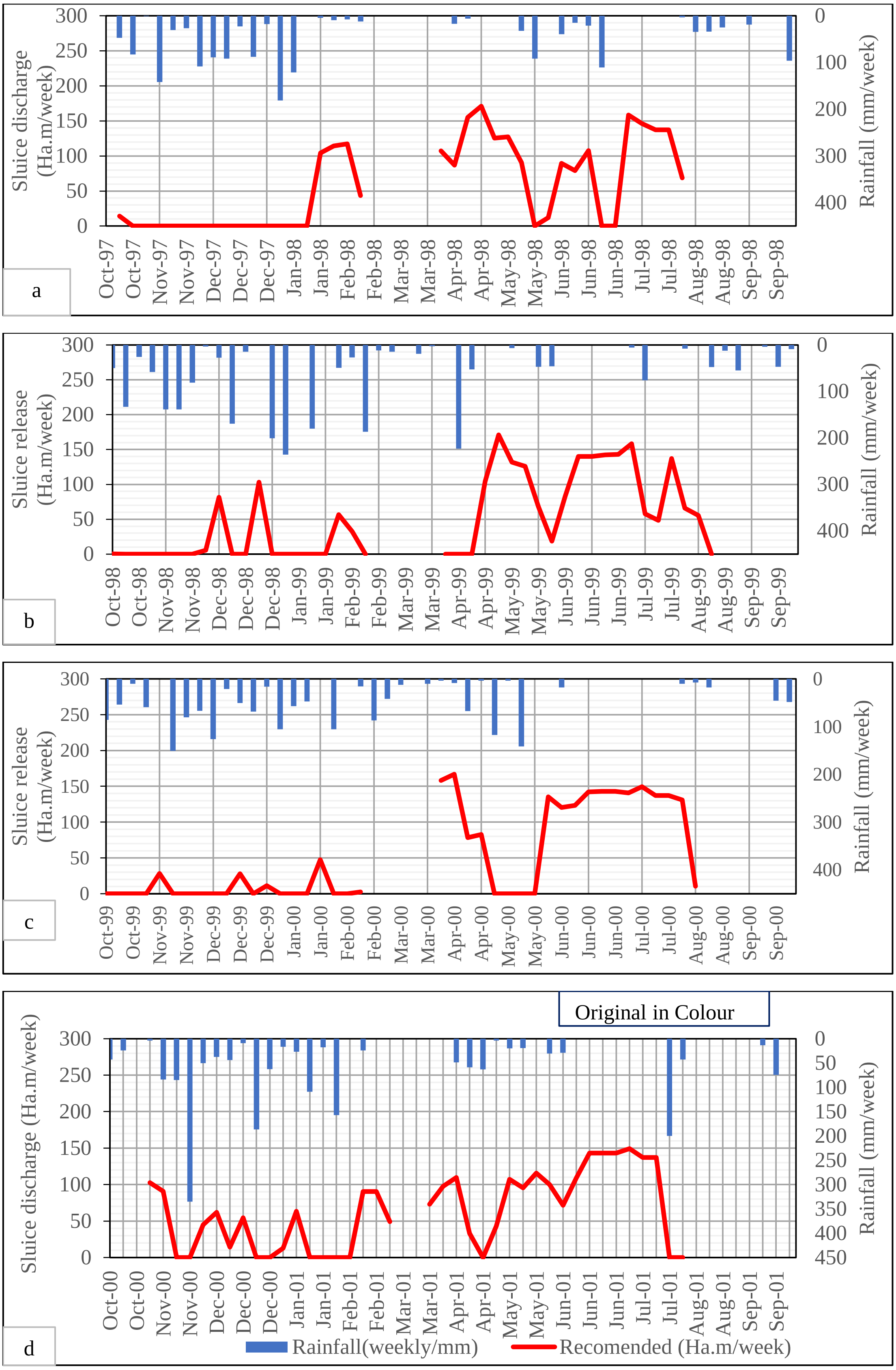


Figure 5-19 Recommended water release options for management alternative 3

Table 5-6 Recommended water release of management alternative 3 in Maha season (Ha.m)

Water year	Recommended water release of management alternative 3					
	October	November	December	January	February	March
1997-98	14.09	0.00	0.00	104.27	275.15	107.32
1998-99	0.32	5.66	184.69	0.00	89.18	0.00
1999-00	0.00	28.24	39.16	47.38	2.46	158.19
2000-01	102.53	135.48	130.63	76.14	90.42	170.59
2001-02	20.40	191.65	155.09	145.15	26.65	212.83
2002-03	0.00	0.00	47.53	3.52	116.34	0.00
2003-04	105.38	59.71	349.92	244.55	303.63	135.91
2004-05	1.71	9.11	88.69	108.13	217.65	0.00
2005-06	0.00	0.00	446.43	147.02	181.27	0.00
2006-07	0.00	0.00	76.42	108.77	349.68	17.12
2007-08	0.00	83.05	74.90	110.37	317.47	0.00
2009-10	38.56	0.00	91.03	188.88	225.27	0.00
2010-11	143.55	331.81	30.77	0.00	116.64	0.00
2011-12	350.00	350.00	350.00	350.00	350.00	350.00
2012-13	0.00	170.91	137.19	109.40	196.83	0.00
2013-14	262.97	262.48	265.73	254.20	171.61	0.00
2014-15	0.00	0.00	0.00	380.51	0.00	0.00
2015-16	44.99	188.65	56.26	218.80	116.64	0.00
2016-17	133.43	161.57	363.86	285.56	247.15	0.00

Table 5-7 Recommended water release of management alternative 3 in Yala season(Ha.m)

Water year	Recommended water release of management alternative 3					
	April	May	June	July	August	September
1997-98	538.47	192.16	276.41	579.16	68.77	0.00
1998-99	275.61	295.66	505.57	401.69	65.86	0.00
1999-00	327.65	255.77	529.07	564.37	131.01	0.00
2000-01	185.75	382.42	466.38	423.75	0.00	0.00
2001-02	404.34	453.44	440.52	529.26	0.00	0.00
2002-03	465.04	529.83	563.11	603.45	46.88	0.00
2003-04	305.65	517.17	568.71	555.85	18.82	0.00
2004-05	415.78	348.10	458.96	365.27	131.73	0.00
2005-06	220.09	469.80	561.11	623.24	130.27	0.00
2006-07	50.82	537.89	469.77	545.29	89.12	0.00
2007-08	178.35	490.02	304.50	523.07	129.18	0.00
2009-10	458.86	376.49	473.56	354.95	131.73	0.00
2010-11	266.60	376.49	473.56	354.95	131.73	0.00
2011-12	350.00	365.95	505.94	601.99	131.73	0.00
2012-13	374	432.68	568.71	515.79	18.82	0.00
2013-14	618.47	137.537	389.761	576.497	131.731	0.00
2014-15	305.92	137.54	389.76	576.50	131.73	0.00
2015-16	555.91	195.38	234.08	605.15	131.73	0.00
2016-17	349.82	378.26	514.31	455.59	39.23	0.00

Table 5-8 Seasonal Variation of Recommended Water release for management alternative 3 (Ha.m)

Water year	Recommended water release in Ha.m				
	Maha	Yala	Total	Difference	% Difference
1997-98	500.82	1654.97	2155.80	1154.15	53.54
1998-99	279.85	1544.39	1824.24	1264.54	69.32
1999-00	275.42	1807.88	2083.30	1532.46	73.56
2000-01	705.79	1458.30	2164.09	752.51	34.77
2001-02	751.75	1827.56	2579.31	1075.81	41.71
2002-03	167.39	2208.30	2375.69	2040.92	85.91
2003-04	1199.11	1966.20	3165.31	767.09	24.23
2004-05	425.29	1719.84	2145.13	1294.55	60.35
2005-06	774.72	2004.51	2779.23	1229.79	44.25
2006-07	551.98	1692.88	2244.86	1140.89	50.82
2007-08	585.79	1625.12	2210.91	1039.33	47.01
2009-10	543.74	1795.59	2339.33	1251.86	53.51
2010-11	622.77	1603.33	2226.10	980.56	44.05
2011-12	2100.00	1955.60	4055.60	144.40	3.56
2012-13	614.32	1910.00	2524.32	1295.68	51.33
2013-14	1216.99	1853.99	3070.99	637.00	20.74
2014-15	380.51	1541.45	1921.96	1160.94	60.40
2015-16	625.35	1722.26	2347.60	1096.91	46.72
2016-17	1191.56	1737.21	2928.77	545.65	18.63

Table 5-9 Recommended water release of management alternative 5 in Maha season (Ha.m)

Water year	Recommended water release of management alternative 5 in Maha(Ha.m)					
	October	November	December	January	February	March
1997-98	14.09	0.00	0.00	104.27	275.15	107.32
1998-99	0.32	5.66	184.69	0.00	89.18	0.00
1999-00	0.00	28.24	39.16	47.38	2.46	158.19
2000-01	102.53	135.48	130.63	76.14	90.42	170.59
2001-02	20.40	191.65	155.09	145.15	26.65	212.83
2002-03	0.00	0.00	47.53	3.52	116.34	0.00
2003-04	105.38	59.71	349.92	244.55	303.63	135.91
2004-05	1.71	9.11	88.69	108.13	217.65	0.00
2005-06	0.00	0.00	446.43	147.02	181.27	0.00
2006-07	0.00	0.00	76.42	108.77	349.68	17.12
2007-08	0.00	83.05	74.90	110.37	317.47	0.00
2009-10	38.56	0.00	91.03	188.88	225.27	0.00
2010-11	143.55	331.81	30.77	0.00	116.64	0.00
2011-12	350.00	350.00	350.00	350.00	350.00	350.00
2012-13	0.00	170.91	137.19	109.40	196.83	0.00
2013-14	262.97	262.48	265.73	254.20	171.61	0.00
2014-15	0.00	0.00	0.00	380.51	0.00	0.00
2015-16	44.99	188.65	56.26	218.80	116.64	0.00
2016-17	133.43	161.57	363.86	285.56	247.15	0.00

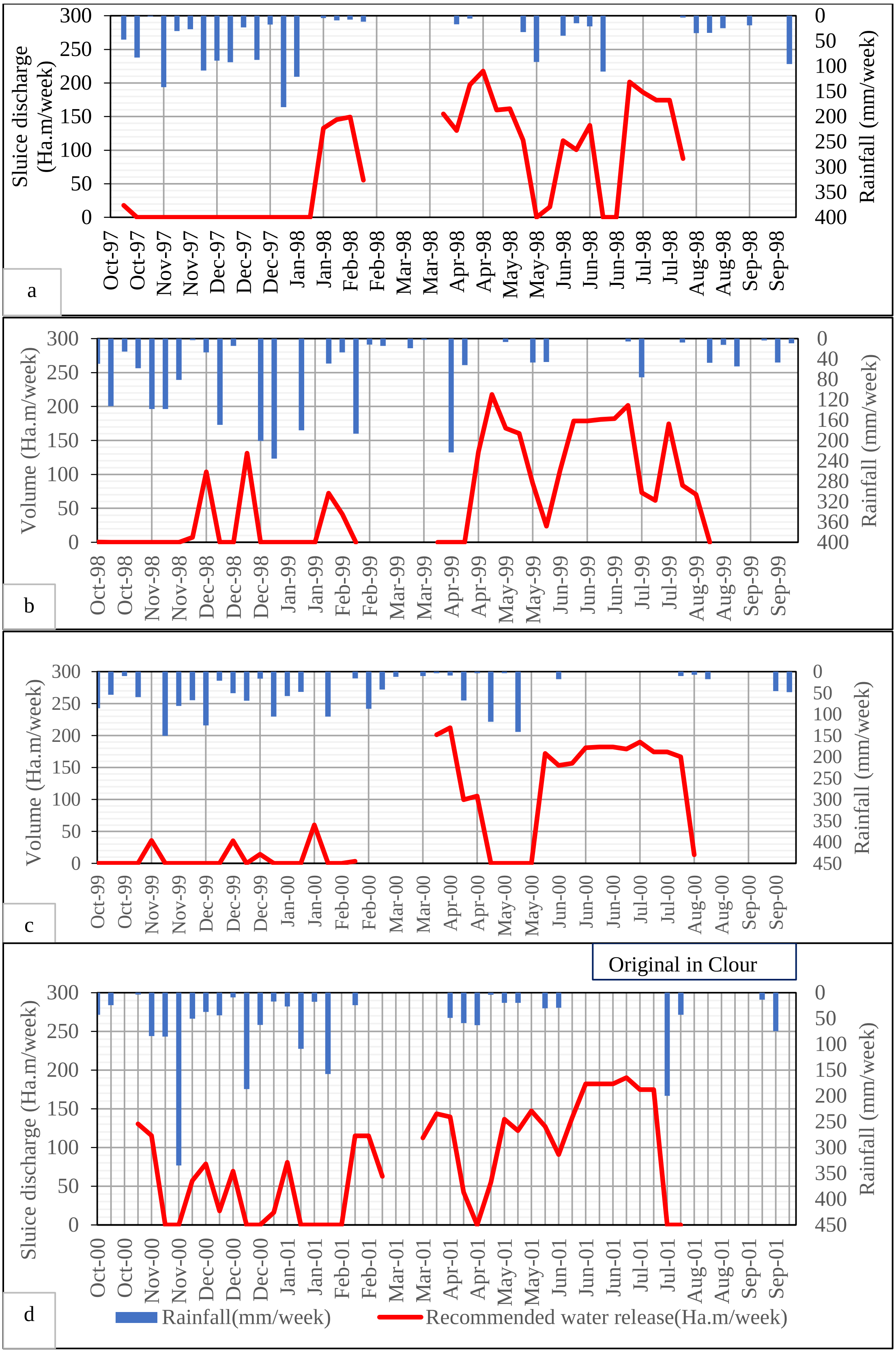


Figure 5-20 Recommended water release for management alternative 5 in Ha.m

Table 5-10 Recommended water release of management alternative 5 in Yala season (Ha.m)

Water year	Recommended water release of management alternative 5(Ha.m)					
	April	May	June	July	August	September
1997-98	538.47	192.16	276.41	579.16	68.77	0.00
1998-99	275.61	295.66	505.57	401.69	65.86	0.00
1999-00	327.65	255.77	529.07	564.37	131.01	0.00
2000-01	185.75	382.42	466.38	423.75	0.00	0.00
2001-02	404.34	453.44	440.52	529.26	0.00	0.00
2002-03	465.04	529.83	563.11	603.45	46.88	0.00
2003-04	305.65	517.17	568.71	555.85	18.82	0.00
2004-05	415.78	348.10	458.96	365.27	131.73	0.00
2005-06	220.09	469.80	561.11	623.24	130.27	0.00
2006-07	50.82	537.89	469.77	545.29	89.12	0.00
2007-08	178.35	490.02	304.50	523.07	129.18	0.00
2009-10	458.86	376.49	473.56	354.95	131.73	0.00
2010-11	266.60	376.49	473.56	354.95	131.73	0.00
2011-12	350.00	365.95	505.94	601.99	131.73	0.00
2012-13	374	432.68	568.71	515.79	18.82	0.00
2013-14	618.47	137.537	389.761	576.497	131.731	0.00
2014-15	305.92	137.54	389.76	576.50	131.73	0.00
2015-16	555.91	195.38	234.08	605.15	131.73	0.00
2016-17	349.82	378.26	514.31	455.59	39.23	0.00

Table 5-11 Seasonal Variation of Recommended Water release for management alternative 5 (Ha.m)

Water year	Recommended water release in Ha.m				
	Maha	Yala	Total	Difference	% Difference
1997-98	500.82	1654.97	2155.80	1154.15	53.54
1998-99	279.85	1544.39	1824.24	1264.54	69.32
1999-00	275.42	1807.88	2083.30	1532.46	73.56
2000-01	705.79	1458.30	2164.09	752.51	34.77
2001-02	751.75	1827.56	2579.31	1075.81	41.71
2002-03	167.39	2208.30	2375.69	2040.92	85.91
2003-04	1199.11	1966.20	3165.31	767.09	24.23
2004-05	425.29	1719.84	2145.13	1294.55	60.35
2005-06	774.72	2004.51	2779.23	1229.79	44.25
2006-07	551.98	1692.88	2244.86	1140.89	50.82
2007-08	585.79	1625.12	2210.91	1039.33	47.01
2009-10	543.74	1795.59	2339.33	1251.86	53.51
2010-11	622.77	1603.33	2226.10	980.56	44.05
2011-12	2100.00	1955.60	4055.60	144.40	3.56
2012-13	614.32	1910.00	2524.32	1295.68	51.33
2013-14	1216.99	1853.99	3070.99	637.00	20.74
2014-15	380.51	1541.45	1921.96	1160.94	60.40
2015-16	625.35	1722.26	2347.60	1096.91	46.72
2016-17	1191.56	1737.21	2928.77	545.65	18.63

5.8 Summary of results

The Namal Oya Irrigation reservoir was able to serve 100% command area (1498 Ha.) during Maha season in 17 years. In the year of 2003-04 and 2005-06, the reservoir failed to serve 100% command area due to less rainfall respective 1161 mm and 1421 mm where the average rainfall is 1822mm. During Yala seasons the reservoir able serve 100 % command area in five (5) years, more than 80% in five (5) years and 40-60% of the command area in rest of the years (Table 5.4, 4.2, 4.3)

Evaluation of the Namal Oya irrigation system over the twenty years study period revealed the Namal oya Irrigation reservoir are releasing 50% more water than the observed values in a water year (Table 5.9. 5.10, 5.11). The average annual difference of observed and calculated water release is 1091 Ha.m where 392 Ha.m in Maha season and 699 in Yala season and observed annual water release is 2098 Ha.m where 705 Ha.m in Maha and 1391 Ha.m in Yala.

According to Irrigation Guideline Recommended Water Plans, the average Maha and Yala season water consumption during the study period had been approximately 711 and 1770 Ha.m respectively. Comparison of Yala and Maha water requirements noted that on average, Yala requirement is 1073 Ha.m (47%) higher than the Maha Season. (Table 5.9. 5.10, 5.11)

It is revealed that Land preparation takes 15-28 days and applications of water for LP varies from 190-230 mm whether ID suggest 178mm for 15 days period. (Figure 5.19, Table 5.10)

The overall efficiency of the Namal Oya irrigation scheme was identified as 55% by a trial and error method. (Figure 5.6)

Monthly 2P inflow model giving more best fitted curve than Irrigation guidelines inflow model when compared to observed reservoir operation data (Figure 5.16).

6 DISSCUSSION

The Namal Oya Irrigation reservoir was able to serve 100% command area (1498 Ha.) during Maha season in 17 years . In the year of 2003-04 and 2005-06, the reservoir falied to served 100% command area due to less rainfall respective 1161 mm and 1421 mm where the average rainfall is 1822mm. During Yala seasons the reservoir able serve 100 % command area in five (5) years, more than 80% in five (5) years and 40-60% of the command area in rest of the years which mainly depends on rainfall over the study.

6.1 Methods of cultivation, water scheduling and water release

The present study identified that in the Namal Oya reservoir was designed to serve 100% of the command area (1498 Ha) in both Maha and Yala season by paddy. The varieties of paddy cultivated during the both seasons are short duration of 105-day variety. This is a deviation from the anticipated crop for Maha which recommended 135-day paddy variety (Ponrajah, 1984). During discussions with water experts and at field level stakeholder consultations, it was indicated that the reason for selection of 105-day paddy for Maha Season was the water availability. This contradicts the finding from the present study which revealed that there is a significant over issue of water when compared with that recommended in the ID Guidelines. Hence it is important to carry out a more focused investigation to understand the underlying reasons for the change. The study also identified that Namal Oya water planners had not considered a stagger in the water scheduling. Practice of a stagger could not be captured during the field work too. In the present study computation of weekly values, the timing of seasons, base data etc., were carefully checked and matched to avoid unrealistic situations. In reality, water demands are adjusted to suit field conditions and to farmer requests thereby leading to large differences.

It was recognized that there is a difference in the Namal Oya reservoir water release and the computed water issue recommendations computed in this study. Both works used the same ID guidelines and field data but carried out separately. This reveals that there is room to improve the clarity of ID guidelines together with an updating of the data used for these recommendations. The updating of ID Guideline has to be through structured research. As at present water manages and farmers had maintained only the water issue records at the one main sluice. This deprived a more detailed evaluation of water use efficiencies and other factors that could have led to a better understanding of water issue deviations from the ID guideline recommendations. Also, the lack of a detailed measuring and recording system for the canal system prevents the evaluation of spatial differences, issues and strengths that could show the way to better water use. Hence it is important to appreciate the order of magnitude of the results highlighted in the present research. Though the study recognized that the farmers and water managers adjust the water issue schedules to suit the availability of rains, there is a need to introduce, an appropriate number of gauges and dynamic management information systems to make necessary adjustments with short lead times and then to document such changes for periodic evaluations. Comparisons carried out by the present study pointed to the need to consider the actual rainfall for better accounting for water savings.

6.2 Irrigation water requirement model

Water release data plotted weekly and monthly for each year in the periods from 1997-2017 shows significantly sudden rises and falls (Figure 6.1) The demand fluctuations do not show a uniformity in the pattern, but it clearly shows peak of two main seasons Maha and Yala. The average water release curve shows that Yala season water demand is higher than Maha season. The water release in the year 2011-12 had been about 69% more than the average and water release in the year of 2008-09 is 57% less than the average in the period 1997-2017(Table 6.1 and 6.2). Monthly water releases show a vast variation in the pattern and also in the magnitude of releases during each month (Table 6.1). The monthly water release variation shows two minimum releases, with one during March and the other during September, showing the boundary of the Maha & Yala seasons. On the average the Maha (Oct-Mar) season and Yala (Apr-Sep) season water releases 699 Ha.m and 1380 Ha.m respectively.

Irrigation requirement model was developed based on Irrigation department guidelines. Crop water requirement, evapotranspiration, crop factor and growth factor, requirement for land preparation, overall efficiency, effective rainfall, command area evaluated to identify actual scenario of the irrigation reservoir. It is revealed that Land preparation takes 15-28 days and applications of water for LP varies from 190-230 mm whether ID suggest 178mm for 15 days period. The overall efficiency of the irrigation scheme was identified as 55% by a trial and error method. 70 %, 65%, 60%, 55%, 50% used to optimize calculated reservoir storage with observed reservoir storage. From the both observed and calculated, it is shown that during Crop growth stage Mid, water requirement is high both in Maha (February) and Yala(July) season. This is because of less rainfall on that particular time of period.

Results of modeling reflected the need to incorporate significant modifications to the sluice release which was found to be illogical. Comparisons both graphically and numerically are shown in Figure 6.1, 6.2 and Table 6.1 to 6.4 respectively. Figures and tables showed that significant deviations in the modeled and actual storage in the reservoir. These deviations in magnitude, reflected deficit storage values which represent much larger quantities than evaporation and seepage indicating the difficulty to obtain water balance through adjustments to evaporation and seepage in water balance computations. The average annual difference of annual observed and calculated water release is 1091 Ha.m where 392 Ha.m in Maha season and 699 in Yala season and observed annual water release is 2098 Ha.m where 705 Ha.m in Maha and 1391 Ha.m in Yala. That means, Namal oya Irrigation reservoir are releasing 50% more water than the observed values (Table 5.9. 5.10, 5.11).

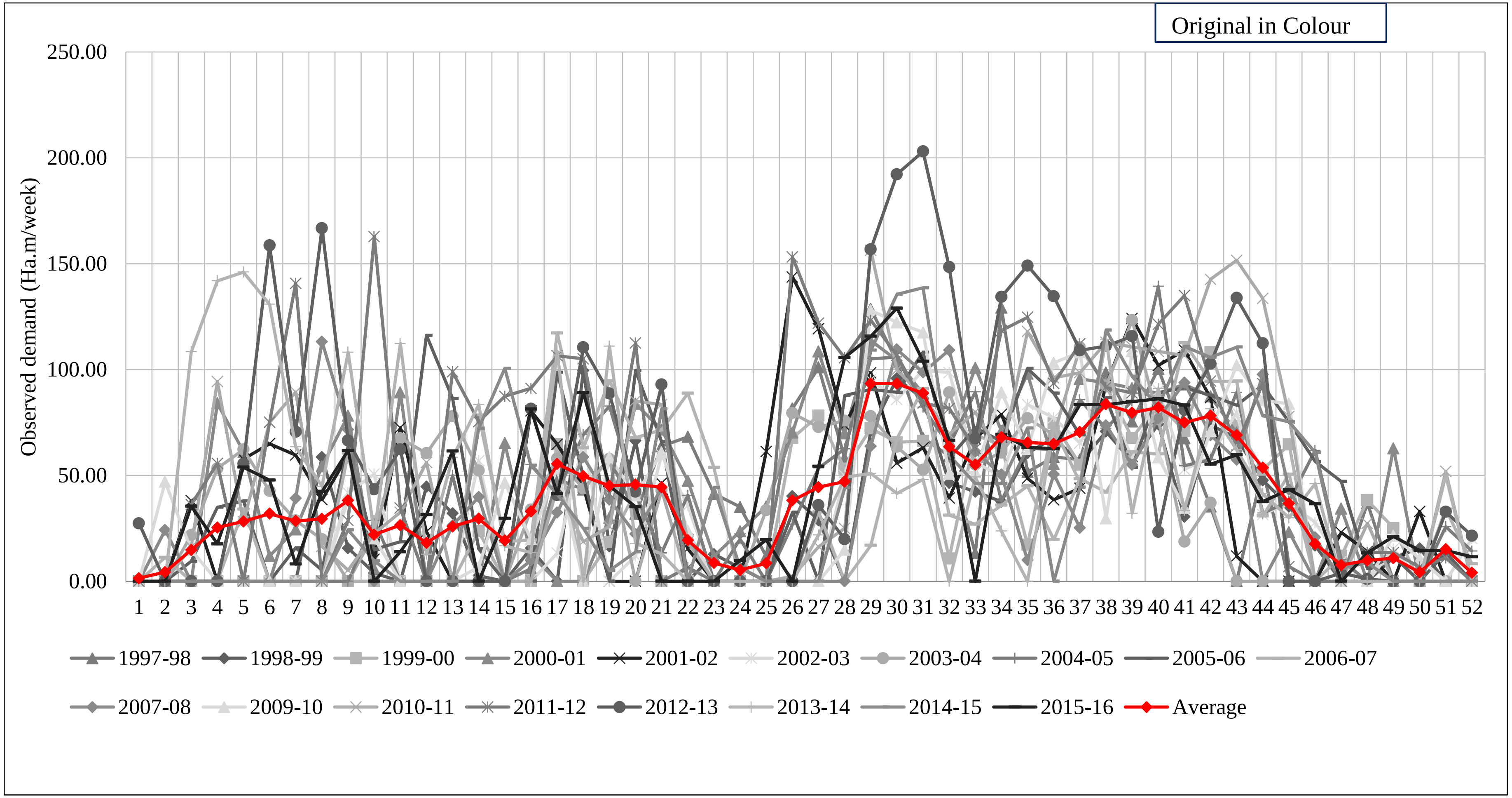


Figure 6-1 Weekly sluice discharge from Namal Oya reservoir (1997-2017)

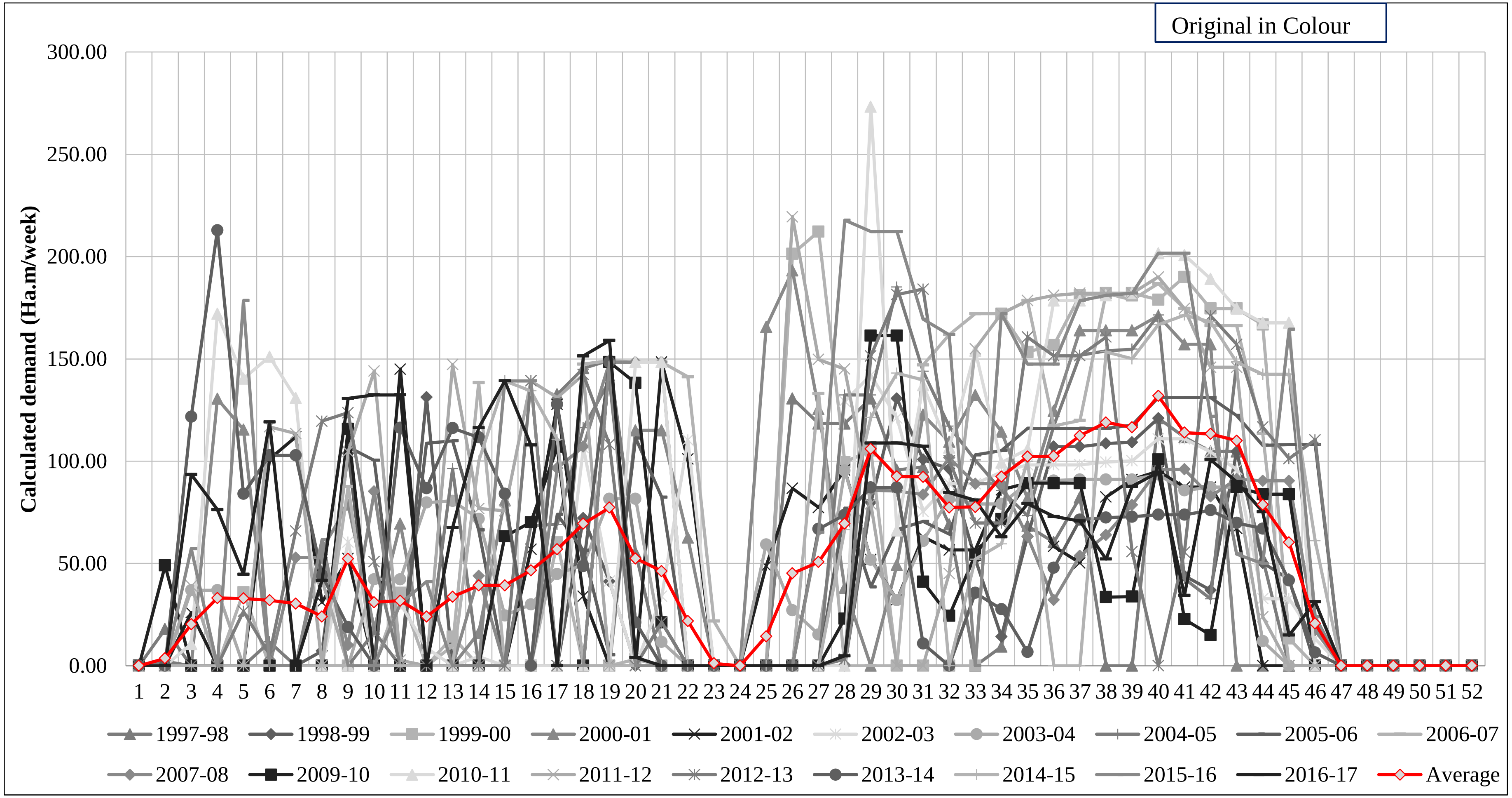

Original in Colour
Calculated demand (Ha.m/week)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
1997-98
1998-99
1999-00
2000-01
2001-02
2002-03
2003-04
2004-05
2005-06
2006-07
2007-08
2009-10
2010-11
2011-12
2012-13
2013-14
2014-15
2015-16
2016-17
Average

Table 6-1 Difference between calculated water release and observed water release in Ha.m

Month/year	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08
Oct	17.93	0.40	0.00	2.89	25.09	0.00	32.14	2.17	82.42	11.32	24.23
Nov	0.00	59.28	35.94	16.19	3.41	24.86	81.03	11.60	54.95	84.02	115.99
Dec	0.00	146.51	49.84	46.26	70.67	17.88	3.99	34.07	144.39	86.67	53.35
Jan	54.49	68.12	28.17	19.12	5.05	97.53	39.50	14.77	41.61	118.17	45.30
Feb	134.97	19.06	57.67	32.78	120.74	74.43	79.67	85.18	40.65	257.32	393.04
Mar	196.22	59.40	78.97	51.59	55.25	86.49	66.20	26.95	32.57	82.06	0.00
Apr	53.51	12.57	126.24	213.31	117.58	132.73	96.29	92.72	116.93	17.44	39.30
May	110.36	20.95	14.23	111.32	5.76	12.64	4.29	165.72	2.77	467.92	71.09
Jun	96.26	240.85	556.95	334.10	59.12	184.94	40.45	320.82	255.14	593.76	76.33
Jul	213.26	24.56	329.01	146.07	27.10	109.58	221.35	36.05	134.39	313.80	13.84
Aug	2.18	28.43	65.12	57.58	37.03	4.62	11.98	181.90	81.97	50.33	102.53
Sep	9.07	26.70	25.16	62.80	32.98	35.45	0.00	40.06	31.32	42.42	0.00
Total	888.26	706.83	1367.31	1094.01	559.79	781.16	676.89	1012.02	1019.12	2125.22	935.01

Table 6-2 Seasonal difference of calculated and observed water release in Ha.m

Season/year	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08
Yala	403.61	352.77	250.58	168.83	280.22	301.19	302.54	174.75	396.59	639.56	631.92
Maha	484.65	354.06	1116.72	925.18	279.57	479.97	374.35	837.27	622.53	1485.66	303.09

Table 6-3 Monthly Difference between calculated water release and observed water release in Ha.m

Month/year	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	Average
Oct	12.80	54.76	52.89	27.38	15.68	0.00	9.97	158.54	27.93
Nov	12.94	225.35	14.39	273.30	90.80	0.00	40.11	110.80	66.05
Dec	69.64	72.19	62.05	41.43	111.64	34.00	35.39	278.91	71.52
Jan	113.76	55.52	10.15	27.22	121.54	190.58	90.41	259.99	73.74
Feb	124.06	76.21	39.12	18.52	76.48	100.41	14.85	143.70	99.41
Mar	0.00	2.35	190.63	0.00	0.00	50.89	29.46	0.00	53.11
Apr	54.37	24.18	91.47	120.77	112.77	0.68	248.22	222.61	99.67
May	129.27	133.99	61.97	193.77	8.32	70.24	268.28	143.52	105.07
Jun	39.40	374.17	490.12	176.48	5.76	143.39	494.52	154.49	244.06
Jul	83.47	192.90	196.52	1.89	16.00	230.66	309.43	142.96	144.36
Aug	41.25	160.22	27.50	252.94	39.01	139.76	107.33	24.52	74.54
Sep	32.16	51.91	31.41	55.41	50.04	8.65	61.82	0.00	31.44
Total	888.26	706.83	1367.31	1094.01	559.79	781.16	676.89	1012.02	1019.12

Table 6-4 Seasonal difference of calculated and observed water release in Ha.m

Season/year	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	Average
Yala	333.19	486.38	369.21	387.86	416.15	375.88	220.19	951.94	391.76
Maha	379.92	937.37	898.98	801.26	231.91	593.39	1489.61	688.10	699.14

6.3 Reservoir operation model with ID and 2P inflow.

Keeping the water releases at the observed values given in the operation data sheets, water balance modeling was continued. The inflow calculated both using ID Guidelines and 2 Parameters monthly model. Results of modeling reflected the need to incorporate significant modifications to the ID guideline inflow which was found to be illogical. Comparisons both graphically and numerically are shown in Figure 6.1 and Table 6.1 to 6.4 respectively for 2P inflow and ID inflow model. Weekly storage variable of ID, 2P and observed storage also shown from Figure 6.2 to 6.6. ID yield model showed significant deviations compare to 2P inflow model with observed storage in the reservoir. These deviations in magnitude, reflected deficit storage values which represent much larger quantities than evaporation and seepage indicating the difficulty to obtain water balance through adjustments to evaporation and seepage coefficients. The average evaporation is 726 Ha.m where 266 Ha.m in Maha and 460 Ha.m is Yala season. The seepage factor estimate as 3.5 % by trial and error method and annual average seepage value 1083 Ha.m where 483Ha.m in Maha and 530 Ha.m in Yala.

Table 6-5 % and quatity of command area of Namal Oya reservoir

Year/season	Maha %	Maha (Ha)	Yala %	Yala(Ha)
1997-98	100	1498	90	1348.2
1998-99	100	1498	60	898.8
199-00	100	1498	100	1498
2000-01	100	1498	90	1348.2
2001-02	100	1498	50	749
2002-03	100	1498	55	823.9
2003-04	55	823.9	50	749
2004-05	100	1498	85	1273.3
2005-06	75	1123.5	65	973.7
2006-07	100	1498	100	1498
2009-10	100	1498	50	749
2010-11	100	1498	100	1498
2011-12	100	1498	100	1498
2012-13	100	1498	90	1348.2
2013-14	100	1498	40	599.2
2014-15	100	1498	85	1273.3
2015-16	100	1498	100	1498
2016-17	100	1498	50	749

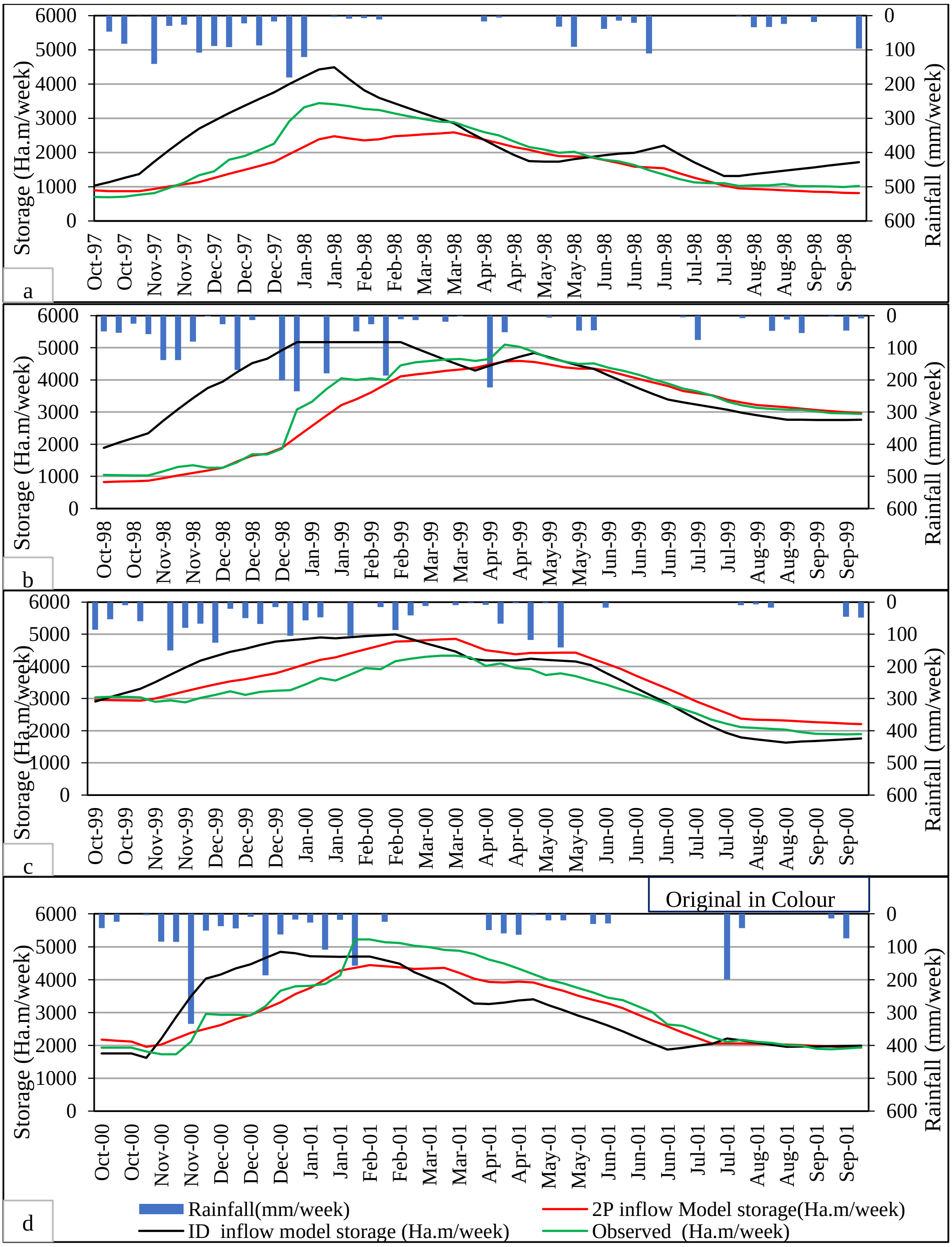


Figure 6-2 Weekly ID, 2P model and observed storage in Ha.m

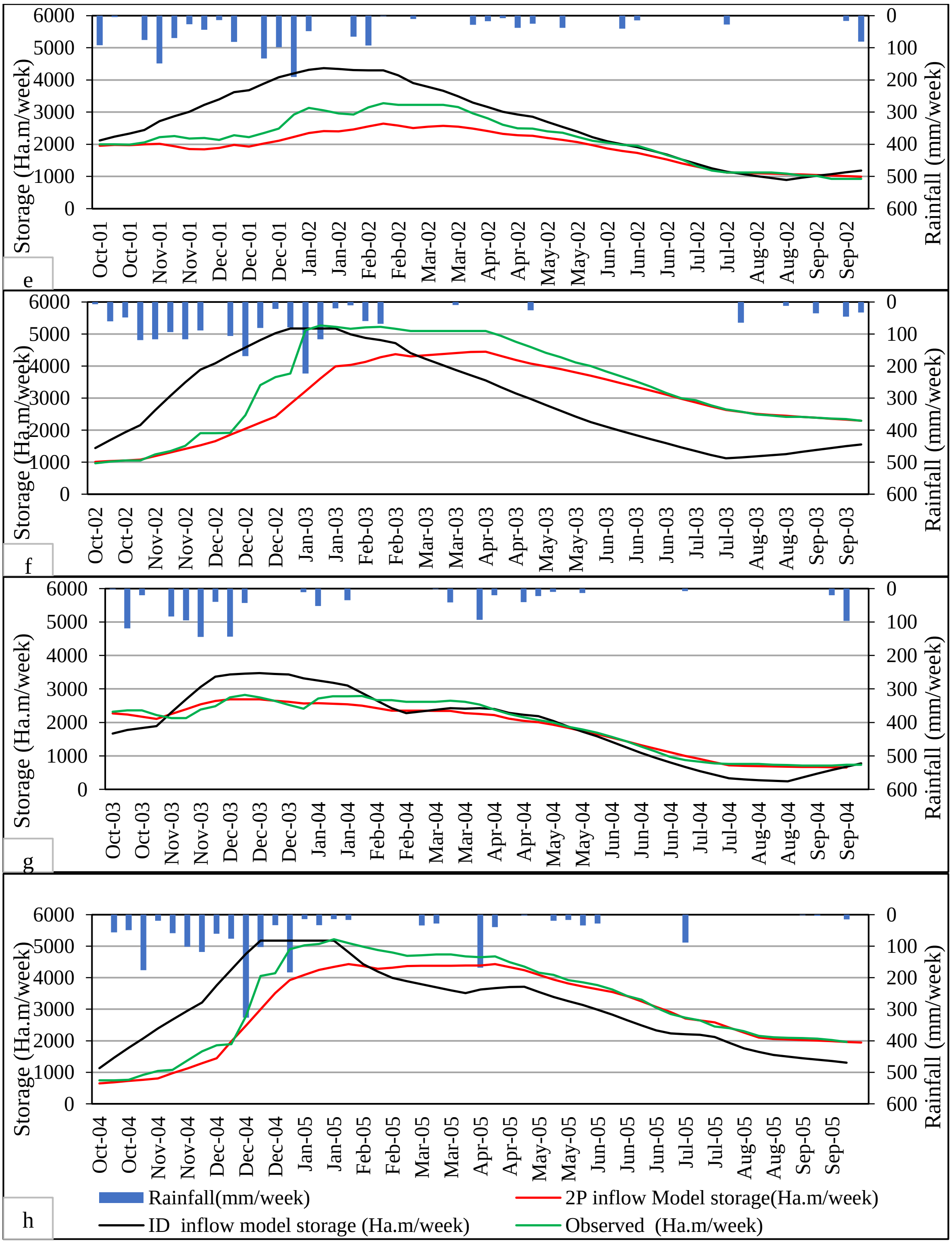


Figure 6-3 Weekly ID, 2P model and observed storage in Ha.m

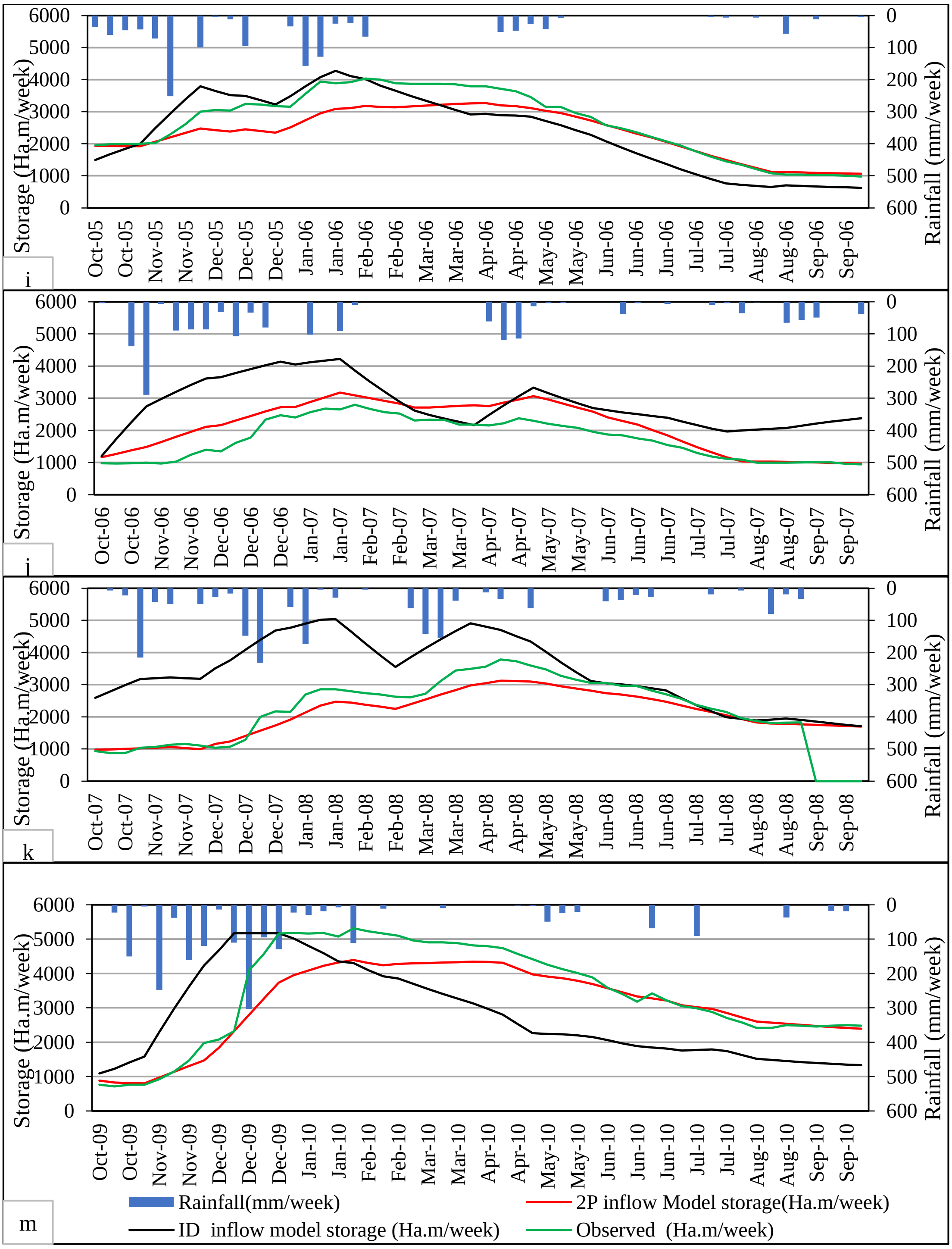


Figure 6-4 Weekly ID, 2P model and observed storage in Ha.m

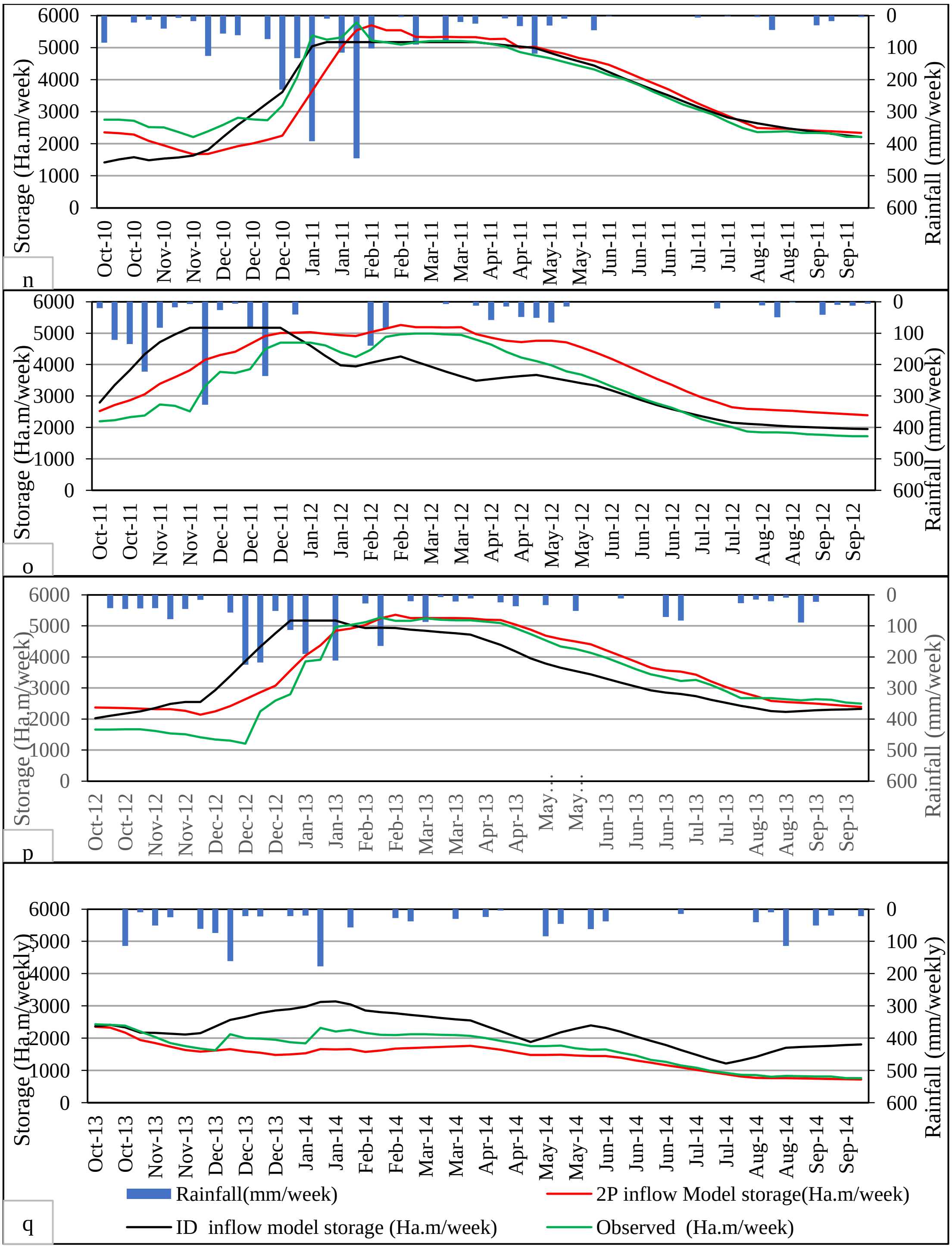


Figure 6-5Weekly ID, 2P model and observed storage in Ha.m

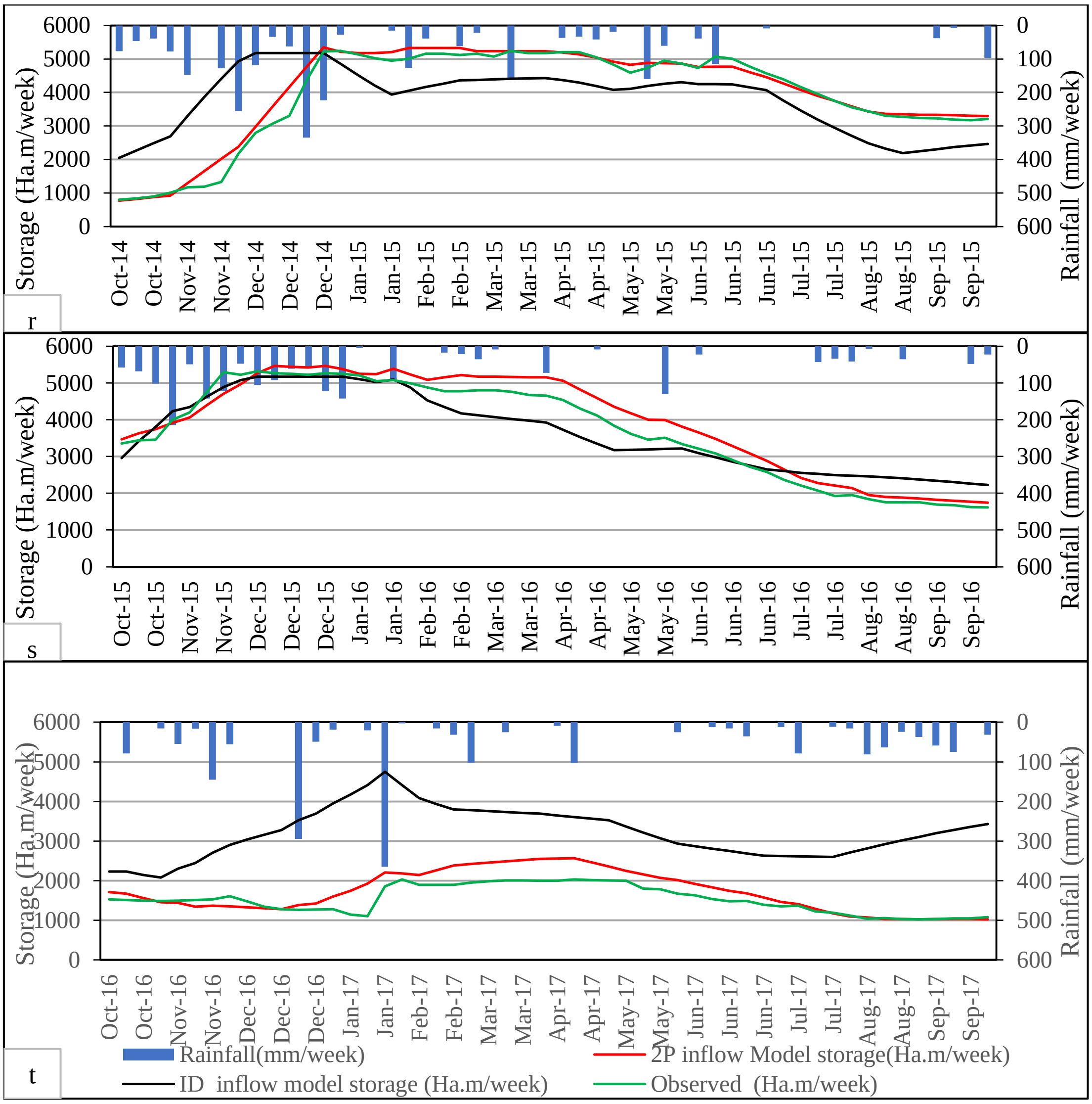


Figure 6-6 Weekly ID, 2P model and observed storage in Ha.m

7 CONCLUSION

1. The average annual difference of observed and model calculated water release is 1091 Ha.m where 392 Ha.m in Maha season and 699 in Yala season and observed annual water release is 2098 Ha.m where 705 Ha.m in Maha and 1391 Ha.m in Yala,
2. This study clearly indicates that there is room to improve the clarity of ID guidelines together with an updating of the data used for irrigation reservoir operating system.
3. The overall efficiency of the irrigation scheme is estimated based on trial and error method and the value is 55 %. If the efficiency level can be increased by 70%, the annual water demand will be reduced from 2654.82 Ha.m to 2055 Ha.m which enables to serve nearly 496 Ha more command area each water year.
4. The seepage factor is also estimated 3.5 % based on trial and error method and it is higher than 3% from ID guideline and the amount is 1013 Ha.m where ID seepage value is 267 Ha.m. The evaporation value does not affect that much in reservoir water balance

8. References

ACIAR. (2016, 01 18). *Growing more rice with less water.* Retrieved from Australian Centre for International Agricultural Research : http://aciar.gov.au/content/growing-more-rice-less-water

Adnan, S., & Khan, A. (2011). Effective Rainfall for Irrigated Agriculture Plains of Pakistan. *Pakistan Journal of Meteorology*, 61-72.

Azamathulla, M., Ghani, A., & Zakaria, N. (2009). Linear Programming Approach for Irrigation Scheduling – A case Study. *14th MANCID Annual Conference (MANCO).* Malaysian National Committee on Irrigation and Drainage.

Beek, E., & Loucks, D. (2017). Water Resource Systems Modeling:Its Role in Planning and Management. *Water Resource Systems Planning and Management*, 51-72.

Bhadra, A., Bandyopadhyay, A., & Ragshuwanshi, N. (2015). Development and application of a simulation model for reservoir management. *Lakes and Reservoirs: Research and Management, 20*, 216-228.

Chowdhury, S. (2016). Implication of climate change on crop water requirement in arid region: An example of Al-Jouf, Saudi-Arebi. *Engineering Science*, 21-31.

Daily News. (2017). *Importance of food security.* Colombo: Daily News.

Department of Irrigation, Nepal. (1990). *Design manual for Irrigation Projects in Nepal (M3-Hydrology and Agro-Meterology Manual).* Katmundo: MacDonalds Agriculture Service Ltd.

Deshapriya, V., & Wijesekera, S. (2017). Climate Scenario Identification and Evaluation of Irrigation Responses: Case Study Application of Rambakan Oya Reservoir Using Irrigation Department Guidelines. (pp. 15-19). Colombo: UMCSAWM Water Conference .

Dharmasena, P. (1989). Optimum utilization of the Storage. *Tropical Agriculturist, 145*, 1-11.

DoLIDAR. (2014). *Design Manual for Small Scale Irrigation Scheme.* Lalitpur: Minitry of Federal Affairs and Local Development.

Frenken, K. (2012). *Irrigation in Southern and Eastern Asia in figures.* Rome: FAO UN.

Gamage, H. (2000). *Land and water sector development in Sri Lanka.* Colombo: FAO.

Hadad, A., & Bakr, T. (2013). Journal of Engineering. *Irrigation scheduling effect on water requirements*, 96-145.

Indian Standards IS 15840. (2009). *Determination of Volume of Water an Water Level in Lakes and Reservoirs.* New Delli: Bareau of Indian Standards.

Indian Standards IS. (1986). *Public Safety Standards of the Republic of India.* New Delli: Indian Standards Institutes.

Indian Standards IS 6939. (1992). *Methods of Determination of Evapporation from Reservoirs.* New Delli: Bareau of Indian Standards.

Indian Standards IS 7223. (1994). *Operation of Reservoirs Guidelines.* New Delli: Bureau of Indian Standards.

Institution of Civil Engineers, R. A. (2009). *Global Water Security.* Stockholm: Global Water Partnership.

Jain, S., Goel, M., & Agarwal, P. (1998). Reservoir Operation Studiees of Sabamati System, India. *Journal of Water Resources Planning and Management, 124*(1), 31-37.

Kumar, K., Karunagoda, K., & Haque, E. (2012). *Addressing long-term challenges to food security and rural livelihoods in South Asia.* Chennai: Madras School of Economics.

Kuo, S., Ho, S., & Liu, C. (2005). Estimation of irrigation water requirements with derived crop coefficients for upland and paddy crop in ChiaNan Irrigation Association. *Agriculture water management*, 433-451.

Loeve, R., Somaratne, P., Ariyaratne, B., & Markandu, A. (2004). *Institutional changes to reduce land preparation delay in the North Central Province of Sri Lanka.* Colombo: International Water Management Institute.

Ministry of Land and Land Development. (2014). Land Secretariat. *National Policy on Protection and Conservation of Water Sources, their Catchments and Reservations in Sri Lanka*.

Najim, M., Haque, M., & Lee, T. (2004). Modeling Irrigation Water Delivery Schedule for Rice Cultivation in East Coast Malaysia.

Nariman Valizadeh, Shafie, A., & Mirzaei, M. (2014). Accuracy Enhancement for Forecasting Water Levels ofReservoirs and River Streams Using a Multiple-Input-PatternFuzzification Approach. *The Scientific World Journal*.

Nkwonta, O., Dzwairo , B., Otieno, F., & Adeyemo, J. (2017). A review on water resources yield model. *South African Journal of Chemical Engineering, 23*, 107-115.

Ponarajah, A. (1984). *Design of Irrigation Headworks for Small Catchment.* Colombo: Irrigation Department.

PWD. (1943). *Manual of Irrigation Practice.* Lahore: Public Works Department.

Rahaman, M., Islam, M., & Hasanuzzaman, M. (2008). Study of effective rainfall for irrigated agriculture in South Eastern part of Bangladesh. *World Journal of Agricultural Sciences*, 453-457.

Rajakaruna, R. (2014). New Approach for the Success of Yala cultivation in Dry zone under Drought Condition. *ENGINEER, XLVII*(4), 79-84.

Raju, P. (2008). In-season time series analysis of Resourcesat-1 AWiFS datafor estimating irrigation water requirement. *International Journal of Applied Earth Observationand Geoinformation*, 221-228.

Raman, H., Mohan, S., & N. C. V., R. (1990). Decison support for crop planning. (H. Raman, S. Mohan, & R. N. C. V., Eds.) *Journal of Irrigation and Drainage, 118*(2), 229-241.

Reddy , M., & Kuma, D. (2007). Optimal reservoir operation for irrigation of multiple crops using elitist-mutated particle swarm optimization. *Hydrological Sciences, 52*(4), 686-701.

Rodrigo, C., & Senaratne, A. (2013, 03 21). *Island.* Retrieved 10 17, 2017, from Island.lk: http://www.island.lk/index.php?page_cat=article-details&page=article-details&code_title=75212

Sahoo, G., Loof, R., Abernethy, C., & Kazama, S. (2001). RESERVOIR RELEASE POLICY FOR LARGE IRRIGATION SYSTEM. *Journal of Irrigation and Drainage Engineering, 127*(5), 301-310.

Saleem, M. (2015). *Ampara "the rice bowl of the country"*. Retrieved from Eastern Sri Lanka: https://easternsrilanka.natgeotourism.com/content/ampara-quot-the-rice-bowl-of-the-country-quot/sri2080526cf509b11c3

Schokman, D. (2002, 02 08). *Food Security and small tank systems in Sri Lanka.* Retrieved 10 17, 2017, from Daily News: http://archives.dailynews.lk/2002/02/08/fea15.html

Sivayoganathan, C., & Mowjood, M. (2003). Role of Extension in Irrigation Water Management in Sri Lanka. *Tropical Agriculture Research and Extension*.

Stedinger , J., Sule Bola F, & Loucks, D. (1984, November). Stochastic Dynamic Programming Models for Reservoir Operation Optimization. *Water Resouces Research*, *20*(11), 1499-1505N.

Tilmant, A., Vanclooster, M., Persoons, E., & Duckstein, L. (2002). Comparison of Fuzzy and Nonfuzzy Optimal Reservoir. *Journal of Water Resources Planning andManagement,, 128*(6), 390-398.

UN Water. (2017, 11 06). *Water, Food and Energy*. Retrieved from UN Water: http://www.unwater.org/water-facts/water-food-and-energy/

UNESCO. (2012). *Managing Water under Uncertainty and Risk-World Water Assessment Programme.* Paris: UNESCO.

WFP. (2017). *Sri Lanka-Joint Assessment of Drought Impact on Food Security and Livelihoods.* Colombo: United Nations World Food Programme.

Wickramaarachchi, T., Wijesekera, N., & Gamage, N. (2002). Water Scheduling for Better Yield in Paddy Cultivation – A study from Mahaweli System H in Sri Lanka. *Engineer*.

World Bank. (2017). Retrieved from World Bank South Asia water: Irrigation and drainage: http://web.worldbank.org/archive/website01062/WEB/0__CON-8.HTM

Ye, Z., Chen, Y., Shu, S., & Wu, Q. (2017). Analysis of water level variation of lakes and reservoirs in Xinjiang, China using ICESat laser altimetry data (2003–2009). *PLOS One*.

Annex 1

Steps of Spreadsheet model (Crop Water requirement, Inflow Model and Reservoir Operation model)

7.1 Steps of model development and evaluation of Spreadsheet

7.1.1 Crop water model

Irrigation water requirement of the current cropping pattern were calculated. Those steps are

i. To calculate ET_c a three-step procedure is recommended as per Poonrajah (1984). These are Evapotranspiration of Reference Crop(ET_O), Crop Factor (k_c) and Factors affecting ET_c under prevailing local conditions. Thus ET_c= ETO x k_c.

ii. Weekly Effective Rainfall were calculated based on empirical equation of ID guidelines and P_e =0.67*(R-0.23) for lowlands Where R is the weekly rainfall in inches.

iii. Water requirement for land preparation was taken 177.8 mm for paddy based on Irrigation department guidelines for 15 days of period.

iv. Farm loss also assumed 152 mm for 31 days period

v. Field water requirement, FWR = ETc + LP + FL

vi. Field irrigation requirement, FIR = FWR –P_e

vii. Irrigation Demand, ID = FIR/ 0.70 for overall efficiency 70% assumed in this study.

For calculating crop water requirement, effective rainfall is the most important factor. Usually during Yala season, reservoir water used for land preparation and duing Maha season, its fully depend on effective rainfall.

7.1.2 Inflow model

The irrigation department guideline recommendation is to obtain the monthly yield from the seasonal yield maps and then carryout an apportioning based on the pattern of rainfall. Weekly yield from the ID guideline was computed using the observed rainfall pattern of the study period. Since there are no mathematical models developed for the Namal Oya watershed, a monthly streamflow estimation model was developed. With a few trial and error calibration attempts with a matching of observed and computed reservoir water storage showed that the best fit inflow parameters would be 1.5 and 2000 for c and SC respectively. In this computation the observed water releases were taken as correct and were kept constant for both inputs.

Model output shows that the ID model over estimates the inflows during entire 20 years period (Figure 6.9-6.). In summary the inflow model provided a clear indication that the ID model estimations without 7.5% and 35% constraints and using actual rainfall patterns are significantly higher that the estimates from the 2P model.

7.1.3 Reservoir operation model

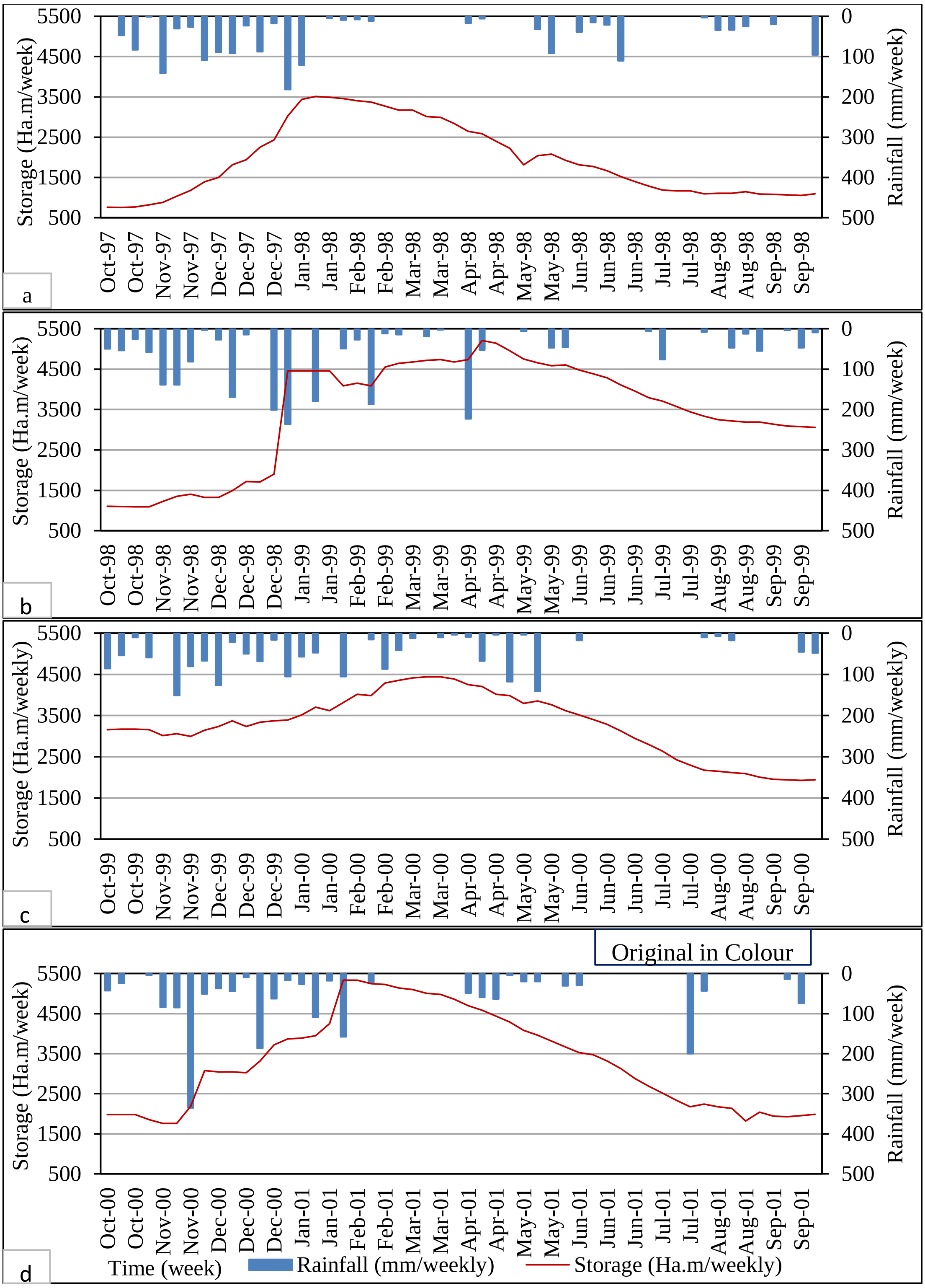
Steps carried out for Reservoir operation model are

i. Calculating catchment area, computed 56.43 Sq.km
ii. Identification of total command area both Maha and Yala season (1498 Ha)
iii. Computed inflow from ID and 2P model
iv. Assume Initial storage (Si) = Minimum operation level Capacity that
v. Calculating Evaporation (E) = Surface area *evaporation of a week
vi. Calculating Seepage (S) = 0.5% of the storage capacity on weekly basis
vii. Irrigation demand calculated form crop water requirement and observed water release.
viii. Applying Continuity Equation for the Reservoir, Inflow – Outflow = Change in Storage that is $I - (E - S - D) = S_{End} - S_{Beginning}$ where I is representing Catchment Inflow, E is Evaporation, S is seepage, D is Irrigation demand, S_{End} is the storage at the end and $S_{Beginning}$ is the storage at the beginning in weekly time resolution.

Order of magnitude of the evaporation, seepage indicated that the values are significantly smaller when compared with the sluice release values and inflows (comparative figure with RF, inflow, outflow evaporation, seepage, demand etc. from the model computations in a weekly format for 20 years shown on (Annex 1) The reservoir water level data were checked for any errors in units, reporting, recording etc. Due to the order of magnitude of the system components, priority was given to investigate the compatibility of water demand data and inflow data used in the reservoir operation model

Annex 2

Observed weekly rainfall and storage capacity (1996/97-2000/01)



7-1 (a, b, c, d) Comparison of observed weekly rainfall and storage capacity (1996/97-2000/01)

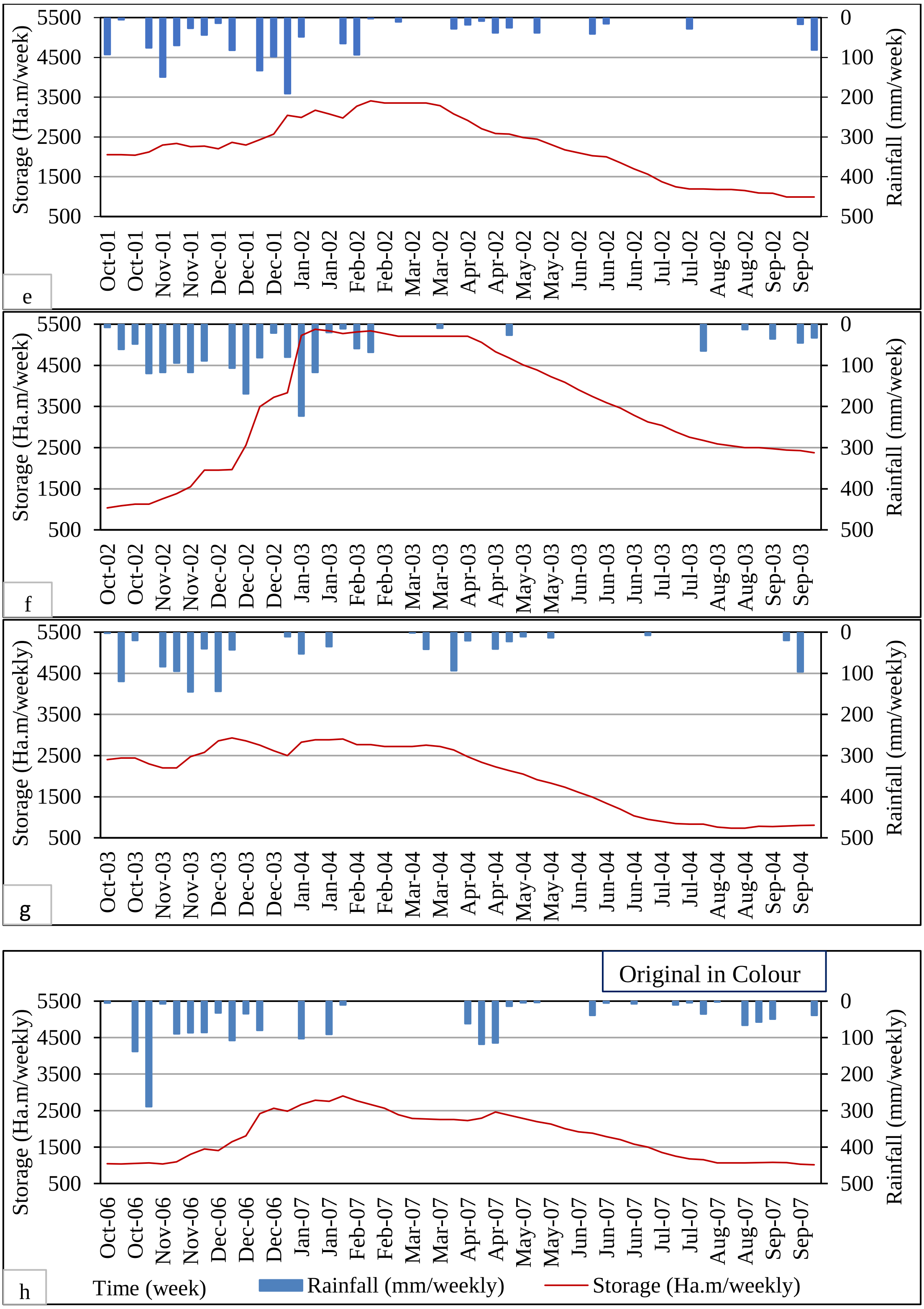


Figure 7-2(e, f, g, h) Comparison of observed weekly rainfall and storage capacity (2000/01-2006/07)

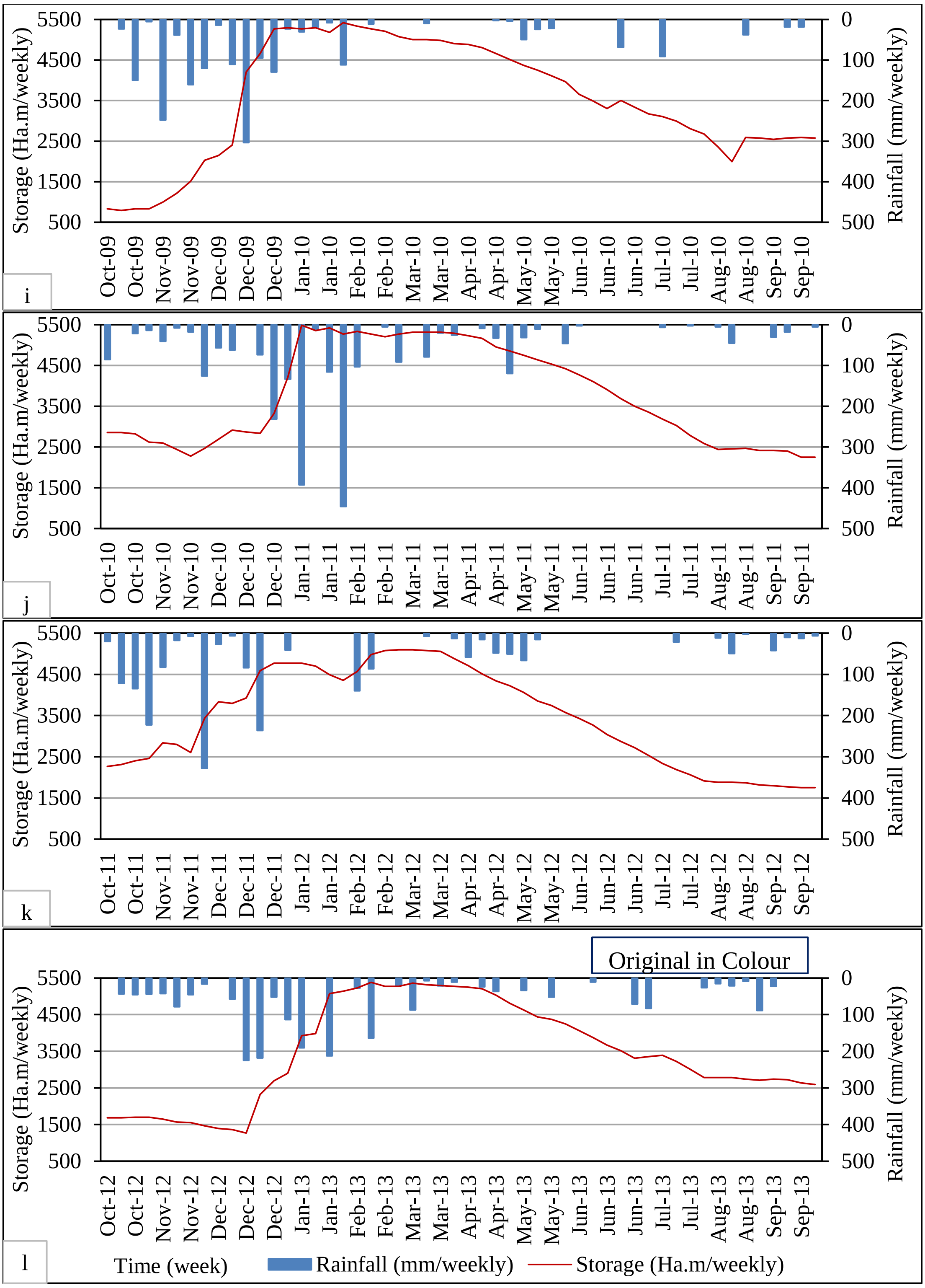


Figure 7-3(i, j, k, l) Comparison of observed weekly rainfall and storage capacity (2009/10-2012/13)

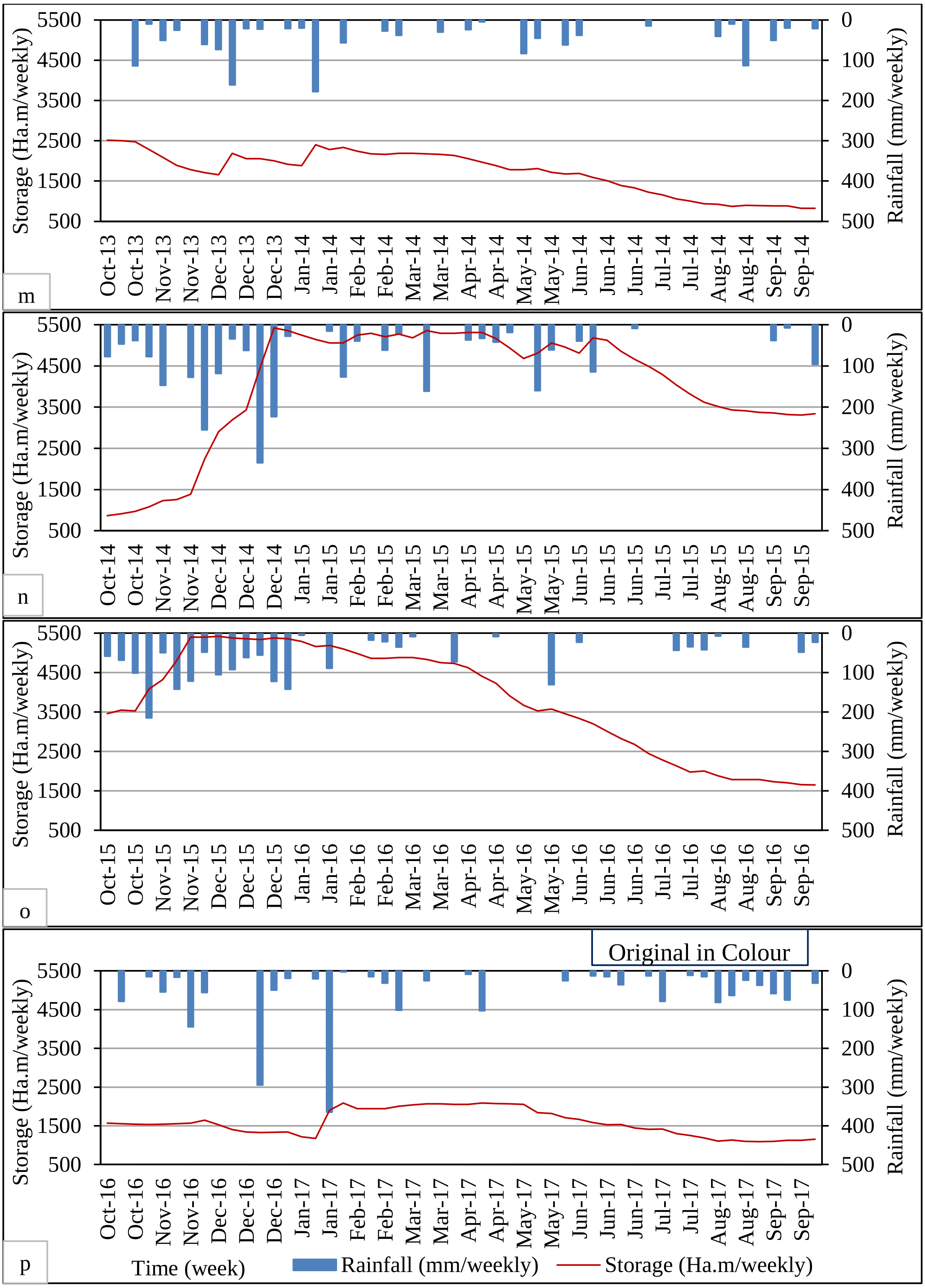


Figure 7-4 (m, n, o, p) Comparison of observed weekly rainfall and storage capacity (2013/14-2016/17)

Annex 3

Weekly evaporation values corresponding to Aralaganvila station from 1997/98 to 2016/17.

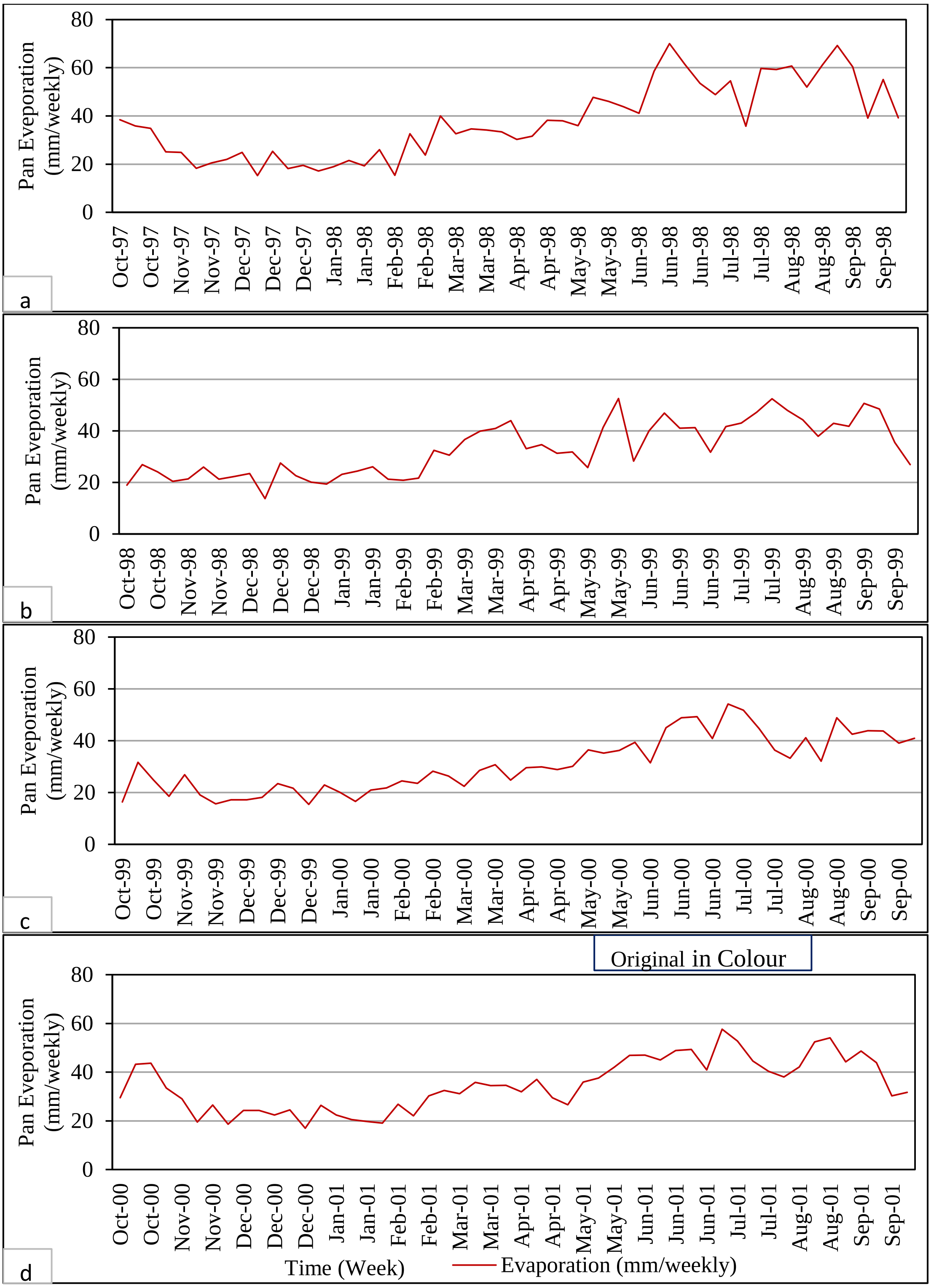


Figure 0-1 (a,b,c,d) Weekly evaporation values corresponding to Aralaganvila station from 1997-98 to 2000-01

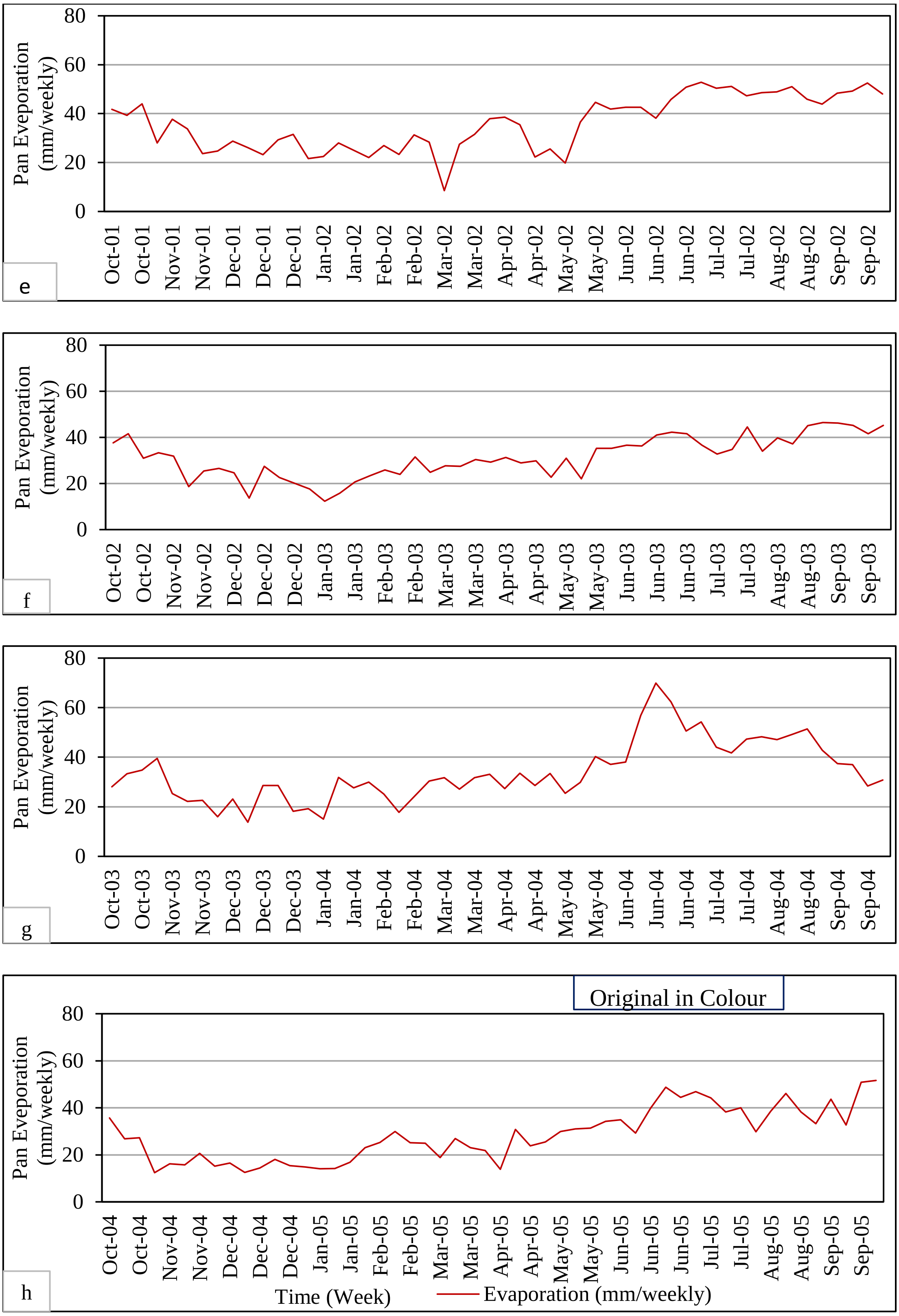


Figure 0-2 (e,f,g,h) Weekly evaporation values corresponding to Aralaganvila station from 2001/02 to 2004/05

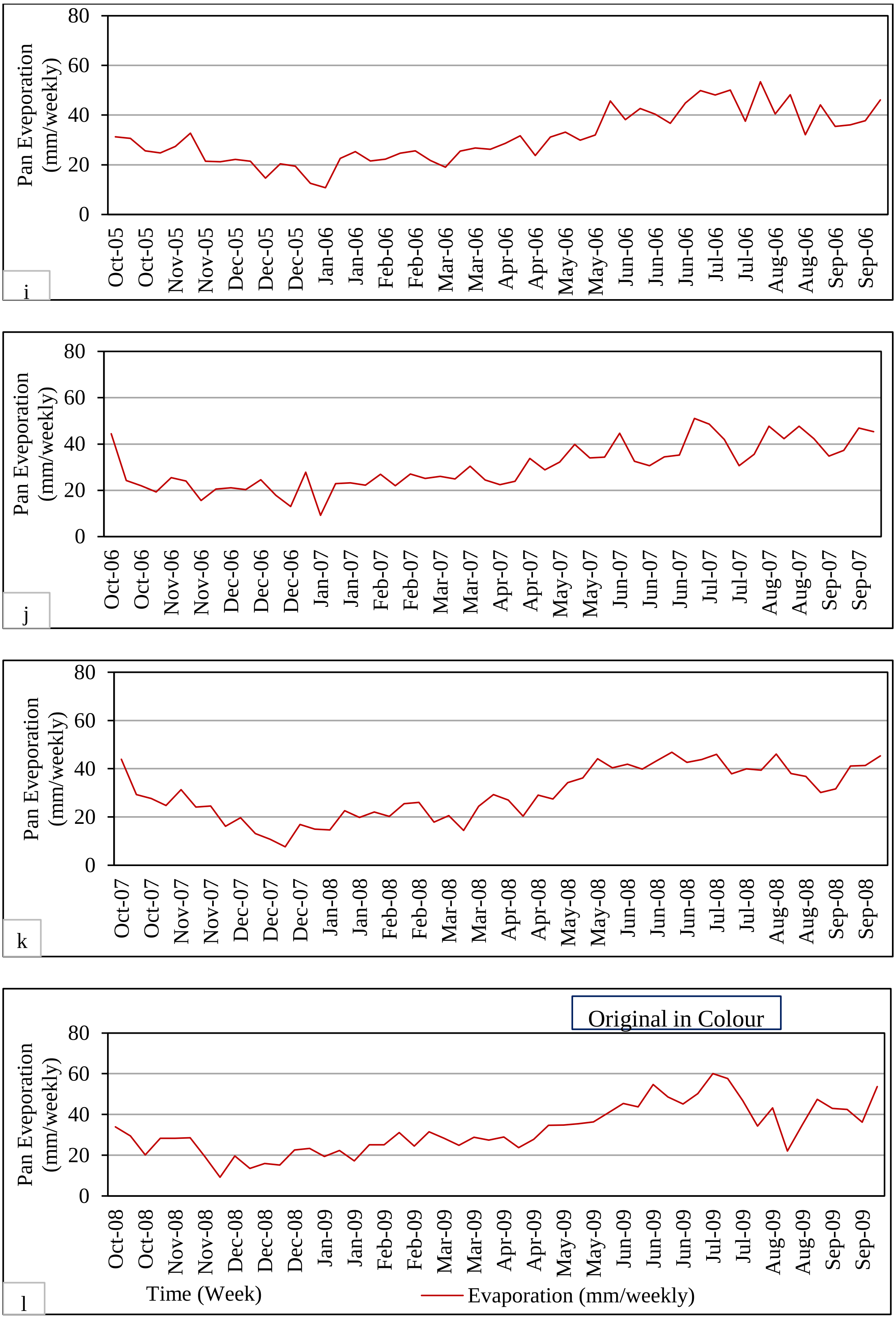


Figure 0-3 (i,j,k,l) Weekly evaporation values corresponding to Aralaganvila station from 2005/06 to 2008/09

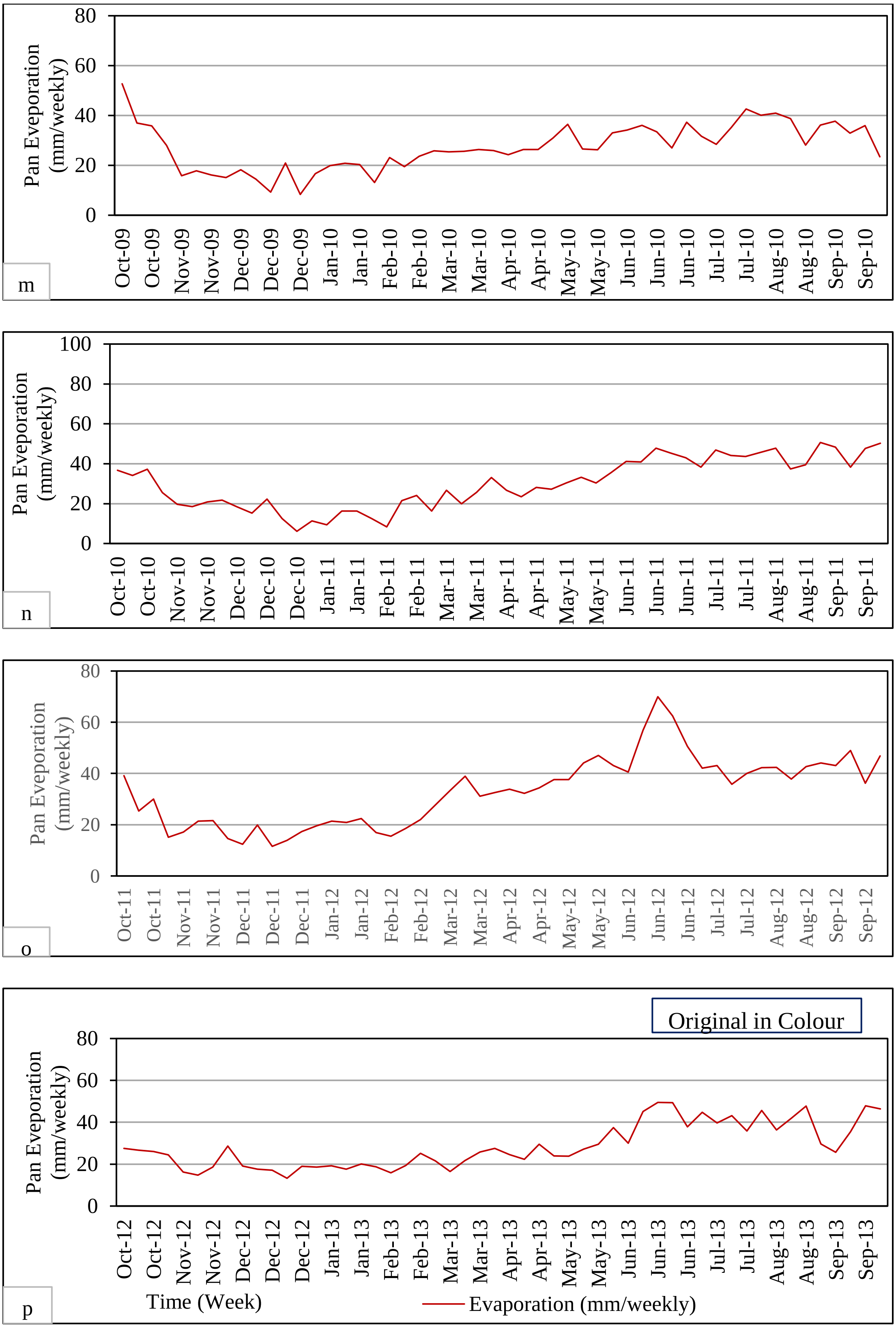


Figure 0-4 (m,n,o,p) Weekly evaporation values corresponding to Aralaganvila station from 2009/10 to 2012/13

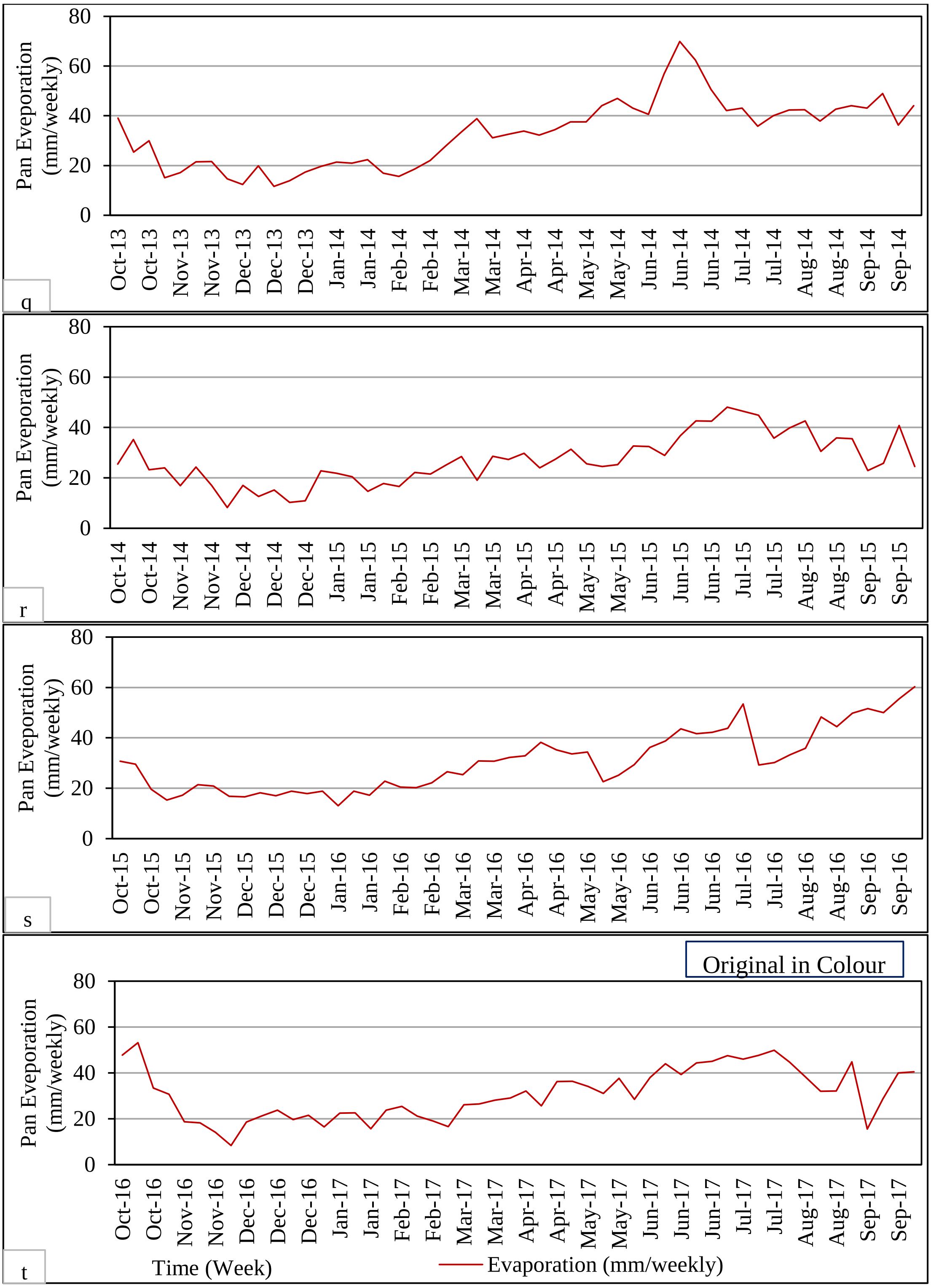


Figure 0-5 (q,r,s,t) Weekly evaporation values corresponding to Aralaganvila station from 2013/14 to 2016/17