Water Balance Study of a Watershed of Rengma River in Golaghat District

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***Abstract*—*Water balances are vital for making judicious decisions concerning water availability, water conservation, and water management. This paper aims to identify and estimate the surplus and deficit of naturally available water during various period of the year. The volume of different hydrological variables like rainfall, runoff, evapotranspiration etc. were computed and the volume of surplus and deficit water for various periods of the year was observed. The analysis revealed that a major component of the inflow was lost as runoff, which contributes to about 64% of the total outflow, followed by evapotranspiration loss. The results highlight the necessity of efficient water management strategies in order to cater to the ever increasing demand of water among multiple users.*

Keywords*—*Hydrological variable, Water balance, Linear programming, Optimal cropping pattern.

I. INTRODUCTION

A major challenge in agricultural water resource management lies in understanding and refining water management without bargaining on the quantity and quality of produce from the agricultural fields. The estimation of water balance and its components is immensely necessary for such management. Water balance is a valuable tool in thoughtful evaluation of the hydrologic behaviour of a study area. There is a growing demand for water among agricultural, industrial, municipal, and domestic uses. As there is an ever-increasing interdependency among uses and users, significant efforts are being employed on improving integrated management of water resources. This project tries to assess the water potential of the area of about 46sq.km located between Rengma River and Tinisukia-Guwahati N.F. railway line in Sarupathar and Barpathar region under Golaghat district. The area has been an important sector of agricultural use and so timely and controlled water supply to the area would prove beneficial as the rainfall has been very scanty especially during the period of November-March. Thus the aim of water balance study is to predict the optimum combination of irrigated area (sq.km), storage capacity and variability in available water that is required to meet the various water demands. As a large consumer of water is irrigation, it has intense impacts on basin-wide water use and availability. Basins worldwide are facing water scarcity due to surge in water demands from all sectors.

II. MATERIALS AND METHODS

2.1 SITE DESCRIPTION

The following study has been carried out in the command area of the Rengma river irrigation project located at Golaghat district of Assam. Golaghat is a part of the vast alluvial plain of Assam and covers an area of 3,502 sq. km. The district is bounded on the North by the Brahmaputra River, on the South by the Nagaland state, on the East by Jorhat and in the West by Karbi-Anglong and Nagaon districts. The district enjoys sub-tropical humid climatic condition. Annual average rainfall in the district is 2185 mm. About 60% to 70% of the total annual precipitation is available during south-west monsoon ranging from May to September. The rainfall pattern varies in the district, from south to north, the intensity of rainfall increases and the maximum rainfall is received by the north eastern parts of the district. Annual average temperature of the district during winter period varies from 6°C to 14°C whereas during summer, it varies from 29°C to 36°C .The relative humidity varies from 93% to 95% during morning hours and during afternoon hours it varies from 53% to 75%.

The catchment area of about 46 sq. km is located in a region defined by latitude range 26˚5′ to 26˚12′ and longitude range 93˚51 ′ to 93˚58′, lying between Rengma River and Tinisukia-Guwahati N.F. railway line in Sarupathar and Barpathar region under Golaghat district. The population of the area is concentrated in village area and mainly depends upon agriculture as the prime source of income. The density of population seems to be higher than that of the district average. The area is approachable from Golaghat town via Barpathar and Sarupathar both by roads and railways.

2.2 LINEAR PROGRAMMING APPROACH FOR MAXIMIZING TOTAL NET INCOME

As a majority of population of the present study area depend on agriculture for their living and are usually much poorer than people employed in other sectors of the economy, it is essentially important to increase area under cultivation and/or upsurge production per unit area to meet the increasing demand of food for the ever increasing population. As the efficiency of irrigated agriculture is more than 2-3 times the efficiency of rainfed agriculture it is imperative to bring more area under irrigation. The want of increasing production per unit area need more scientific utilization of the available resources and their optimal allocation to attain maximum benefits with optimal investment. Also, the prevailing cropping pattern remains same for many years. Random introduction of new crops by the farmers in the command might not utilize the available land and water resources to achieve maximum returns. This emphasizes diversification of the prevailing cropping pattern such that it could maximize the net returns from the available land and water resources.

Most of the methods suggested for optimal allocation of these resources are complex and tedious for their wide scale use. These comprises of linear programming, non-linear programming, evolutionary algorithms etc. Linear programming technique has been found to be having widespread application for optimum allocation of land and water resources in the command area of irrigation schemes due to its ease in formulation and implementation. In the present study which targets at developing the optimal cropping pattern for maximization of net benefit from agriculture at minor level of command area, the linear programming technique has been used.

2.2.1 Model development

The linear programming model comprising of three foremost components: an objective function for maximization of net benefit from agriculture, a set of linear constraints and non-negativity constraint was developed. The model was expressed to allocate land among the different crops, in order to maximize the net return from the command area.

2.2.1.1 The objective function

The areas to be distributed under different crops are the decision variables. The objective function is maximization of the total net benefits and is given by equation:

$$Max\ Z = \sum_{n=1}^{N} B_n A_n$$

Where Z=total net benefits, Rs

A_n = area to be irrigated under n^{th} crop, ha.

B_n = net benefit estimated from irrigation of n^{th} crop, Rs/Qtl

N = total number of crops

n = crop subscript

2.2.1.2 Kharif land availability constraint

$$\sum_{n=1}^{N} A_n \leq A_{t,k}$$

Where $A_{t,k}$=Total land available for cultivation during the Kharif season

2.2.1.3 Rabi land availability constraint

$$\sum_{n=1}^{N} A_n \leq A_{t,r}$$

Where $A_{t,r}$ = Total land available for cultivation during the Rabi season

2.2.1.4 Fertilizer availability constraint

$$\sum_{n=1}^{N} F_n A_n \leq F_t$$

Where F_n = cost of fertilizers for n^{th} crop, Rs/ha

F_t = Total capital available for fertilizers, Rs

2.2.1.5 Non negative constraint

$$A_n \geq 0$$

2.3 ESTIMATION OF WATER BALANCE COMPONENTS

The concept of the water balance has been successfully used to estimate the present and future water availability in and for water resources management. The term “water balance” is defined here as an accounting of the inflow to, outflow from, and storage in, a hydrologic unit. Simply put it can be expressed as:

Inflows – Outflows = Change in Storage

or $I - O = \frac{ds}{dt}$

Where I is the input into the watershed in the form of precipitation (P) and O is the output of the watershed in the form of runo (Q) and evapotranspiration (ET). S denotes the storage of water in the watershed. Thus the equation may be further expressed as:

$$P - Q - ET = S$$

2.3.1 RAINFALL

The volume of rainfall received by the area is expressed by the following equation:

$$V_{prec} = 10 \times A \times P$$

Where P = monthly rainfall (mm),

A= surface area of the watershed (ha) and

$1mm = 10\ m^3\ ha^{-1}$

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2.3.2 EVAPORATION LOSS

The volume of water lost by evaporation from the non – agricultural areas of the catchment for any given day was computed as a product of the rate of evaporation with the surface area of the catchment. This is expressed in the following equation:

$$V_{ev} = 10 \times A_{r2} \times E_{pan}$$

Where A_{r2} = area under non-agricultural use (ha)

E_{pan} = monthly average pan evaporation (mm)

2.3.3 RUNOFF

The peak discharge for the small catchment area was computed using the rational formula, where the maximum flood flow is assumed to be produced by a certain intensity of rainfall which lasts for a time equal to or greater than the period of concentration time (t_c).The peak value of runoff is given by the equation:

$$Q_p = \frac{C \times i \times A}{3.6}$$

Q_p = Discharge in cumecs

A= Catchment area in km^2

i=Intensity of rainfall in mm/hour

2.3.4 AGRICULTURAL WATER ESTIMATION

The staple food for the entire state of Assam is rice and the people of this area are no exception to this. The command area produces paddy in large quantities as it is considered as a major crop. In addition to this oil seed and pulses are also grown in the area. The agricultural land within the area mainly rely on natural rainfall to cater to the agricultural demands.Thenetvolumeof crop water requirement(CWR)wasestimatedusingthereferenceeva po-transpiration(ET_o)obtainedfrompanevaporationdataan dthecropcoefficients(k_c)obtainedfromFAOguidelinesfo r cropwaterrequirements, accordingtothefol-lowingequation:

$$CWR_n = \sum_{n=1}^{N} \{10 \times (ET_O \times k_{c,n} \times A_n)\}$$

Where A_n = surface area of each crop (ha)

2.3.5 DOMESTIC USES

Domestic water is used for various purposes, such as drinking, food preparation, flushing toilets, etc. In the guidelines for Drinking Water Quality, WHO defines domestic water as being "water used for all usual domestic purposes including consumption, bathing and food preparation". Domestic water use standards differ with environments, technology and economy. According to I.S. 1172: 1993, "code of basic requirements for water supply, drainage and sanitation", a minimum of 70 to 100 litres per head per day is considered adequate for domestic needs, apart from non-domestic needs as flushing requirements.

2.3.6 WATER REQUIRED FOR LIVESTOCK

The livestock in the region includes cattle, buffaloes, goat and pigs. The total livestock data for the whole district of Golaghat has been collected from "Agriculture Contingency Plan for District: Golaghat". The density of livestock presence was computed using the total area of the district and the number of livestock for the whole district. The computed density was used to evaluate the number of livestock for the watershed.

III. RESULTS

a. CROPPING PATTERN OPTIMISED USING LINEAR PROGRAMMING

The proposed cropping pattern has been computed using linear programming in M.S. Excel. The net cropping intensity was computed to be 170.1% of which 82.09%, 8.49%, 9.43%, 9.57%, 15.66%, 18.57%, 14.29%, 5.71%, 3.43%, 2.86% are for Winter rice, Sugarcane, Summer rice, Autumn rice, Rapeseed & Mustard, Pulses, Potato, Wheat, Maize and Rabi groundnut respectively.

b. RAINFALL AND RUNOFF

The total volume of rainfall and runoff was observed to be maximum in the month of July followed by June and May respectively. The runoff coefficient for agricultural and non-agricultural fields were considered to be 0.7 and 0.4 respectively.

c. EVAPORATION FROM NON-AGRICULTURAL FIELDS

The average daily rates of evaporation ranged from 2.4 to 3.16 mm/day in the dry seasons and 3.4 to 4.82 mm/day in the rainy seasons. The evaporation rates were at its peak during May followed by April and June respectively.

d. LIVESTOCK REQUIREMENT

The water requirement of the livestock assumed for the area was obtained by considering an average value of consumption of water by the livestock. The total volume of water required was found out to be about 275 litres per day.

e. CROP WATER REQUIREMENT

The crop water requirement of the proposed crops were computed by considering the reference crop evapotranspiration and crop coefficient value. The area for all the proposed crops were optimised using simplex linear programming for various constraints. The values of area thus obtained was used to calculate the volume of evapotranspiration and consequently the volume of crop water requirement.

f. DOMESTIC USE

According to Economic survey, Assam 2013-2014 the population density of Golaghat per sq. km is 305 persons.

The area used in the study = 4600ha

= 46 sq.km

Thus population of the area = 305 × 46
= 14030 persons

Considering an average of 85 litres per head per day for a population of about 14030 persons,

The volume of water required = 14030 × 85
=1192550 litres per day.

g. TOTAL WATER AVAILABLE AND WATER REQUIREMENT OF THE AREA

The total volume of water available for the watershed was 101MCM whereas the total volume of water required for a water year was 107MCM with the volume of inflow and outflow peaking in July. But as observed, the surplus water was available in May as compared to any other month of the year. Hence efficient water resource management is necessary.

Table 1: Proposed cropping pattern and their respectively

Proposed crops	Proposed area (ha)
Autumn rice	335
Maize	120
Potato	500
Pulses	650
Rapeseed & Mustard	548
Rabi groundnut	100
Sugarcane	297
Summer rice	330
Wheat	200
Winter rice	2873

Table 2: Rainfall and runoff volume

Month	Total volume of rainfall (10^6 m^3)	Total volume of runoff (10^6 m^3)
January	0.81	0.52
February	1.63	1.04
March	4.16	2.64
April	7.31	4.64
May	15.53	9.86
June	18.11	11.5
July	18.73	11.89
August	15.49	9.83
September	11.36	7.21
October	5.94	3.77
November	1.02	0.65
December	0.46	0.29

Table 3: Monthly volume of evaporation

Month	Evaporation (mm/day)	Volume of evaporation, V_{ev} (m^3)
January	2.55	790500
February	3.16	884800
March	4.13	1280300
April	4.7	1410000
May	4.82	1494200
June	4.58	1374000
July	4.38	1357800
August	4.29	1329900
September	3.9	1170000
October	3.44	1066400
November	2.91	873000
December	2.4	744000

Table 4: Livestock water requirement

Livestock	Total (in number, 10^3)	Volume of water required (m^3)
Non descriptive Cattle (local low yielding)	480288	220.81
Crossbred cattle	2684	2.29
Non descriptive Buffaloes (local low yielding)	41569	30.03
Goat	238004	12.51
Pig	89138	5.85
Poultry	626873	2.88
Total water required per day		274.37

Table 5: Crop water requirements of the proposed crops

Month	Winter rice (m^3)	Sugarcane (m^3)	Summer rice (m^3)	Autumn rice (m^3)	Rapeseed & mustard (m^3)	Pulses (m^3)	Potato (m^3)	Wheat (m^3)	Maize (m^3)	Rabi groundnut (m^3)	Crop water requirement (10^6 m^3)
January	0	0	0	0	0.32	0.27	0.38	0.1	0.09	0.07	1.23
February	0	0.14	0	0.29	0	0	0.23	0.16	0.1	0.06	0.98
March	0	0.24	0.4	0.51	0	0	0	0.18	0.07	0	1.4
April	0	0.3	0.53	0.61	0	0	0	0	0	0	1.44
May	0	0.36	0.64	0.48	0	0	0	0	0	0	1.48
June	3.85	0.37	0.54	0	0	0	0	0	0	0	4.76
July	4.65	0.4	0.4	0	0	0	0	0	0	0	5.45
August	4.71	0.4	0	0	0	0	0	0	0	0	5.11
September	3.28	0.32	0	0	0	0	0	0	0	0	3.6
October	0	0.26	0	0	0.1	0.31	0	0	0	0.02	0.69
November	0	0.19	0	0	0.24	0.53	0.19	0.03	0.04	0.04	1.26
December	0	0.12	0	0	0.32	0.47	0.36	0.06	0.08	0.05	1.46

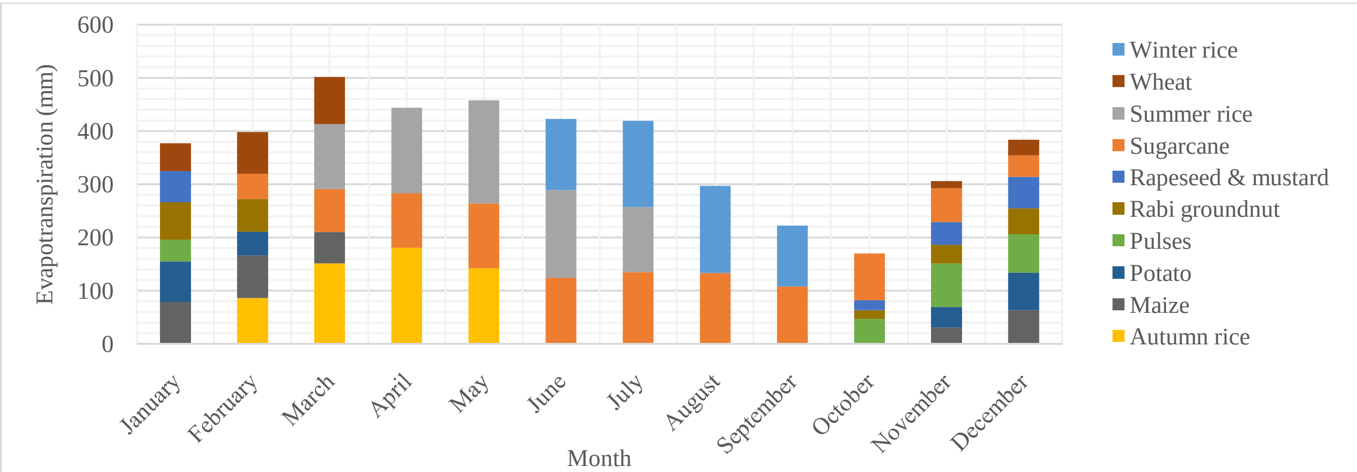

Fig.1: Evapotranspiration for different crops

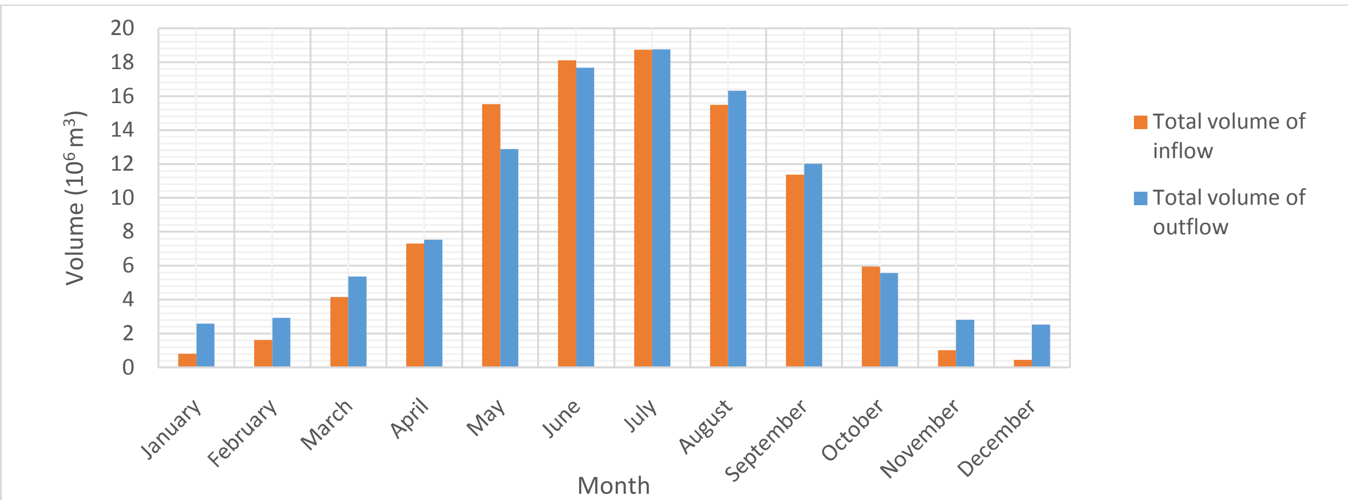

Fig 2: Supply and demand of water in the watershed

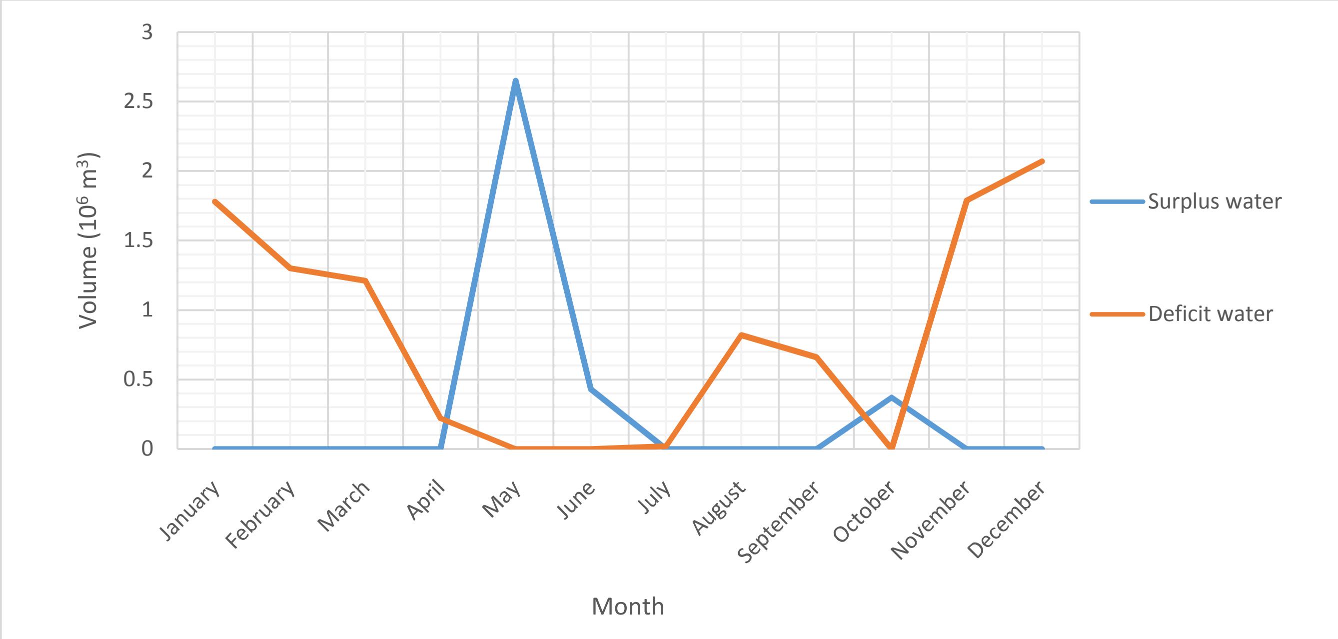

Fig.3: Water balance of the watershed

IV. CONCLUSION

The water resources of Golaghat is becoming scarce. Efficient water balance analysis plays a vital role for sustainable food production and agricultural development in the future as one of the major concerns is the decreasing trend of precipitation with lack of storage and efficient use. The intent of this paper is to provide water balance estimates using a linear programming based computer model which is valuable in finding the optimal cropping pattern under given situation of crop mix and net benefit.This approach helps in the maximization of profit, coupled with optimum resource allocations like land, capital, etc. subjected to the minimization of fertilizer use and the minimization of cost of production. The model can further be used to evaluate different scenarios of present and future policies in agriculture. The analysis shows that nearly 101MCM water is available from precipitation, of which 63.8 MCM of water is lost by runoff alone. The demand of water include 28.86 MCM for crop consumptive use,0.47MCM for domestic use and13.77MCM for evaporation loss. From the water balance study it is evident that the supply in agriculture falls short of 20 MCM than the demand. The analysis clearly represents that water is becoming increasingly scarce therefore, efficient water resource management is the need of the hour.

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