

Water balance studies of bunded rice fields in the Chhattisgarh region of Central India and some strategies to improve the low land rainfed rice productivity

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Abstract The Chhattisgarh region in Central India, (annual rainfall 1200–1600 mm) is known as the “rice bowl” of Central India. With a humid to dry sub-humid climate, this region records the lowest productivity of rice (about 1.0 t ha⁻¹) with most grown under rainfed conditions. The rice fields are bunded (diked) up to 1–1.5 m high and farmers impound as much water as possible. To sustain this water-logging they grow tall rice genotypes which are of longer duration. While the southwest monsoon in this area ends by mid-September, these varieties flower by mid-October and mature by mid-November and terminal drought for rice is a recurring problem in this region. For understanding the pattern of different water balance parameters, the field water balance for bunded rice fields has been computed using the concept of Thornthwaite’s book-keeping procedure with some modifications. In this region, there is a lot of soil variability ranging from lateritic to clayey soils. The water balance studies have been conducted for all the three soil types of the region, *viz*: sandy-loam, clay-loam and clayey soils. Based on the water balance, the storage indices have been worked out for excess, normal and deficit rainfall years to examine the water harvesting potential of excess, normal and deficit rainfall patterns. Based on the results of water balance studies, suggestions for improving the productivity of the rice crop under rainfed conditions have been made.

Estudios del balance hídrico de los arrozales con diques de contención en la región de Chhattisgarh en India Central y algunas estrategias para mejorar la productividad del arroz en tierras bajas

Resumen La región de Chhattisgarh en India central, con una precipitación anual que fluctúa entre 1200 y 1600 mm, es la principal productora de arroz de India central. Con un clima húmedo a seco sub-húmedo, la región registra la más baja productividad de arroz (~1.0 t ha⁻¹) bajo condiciones iluviosas. Los arrozales tienen diques de contención de hasta 1 o 1.5 m de altura y los campesinos retienen tanta agua como les es posible. Con objeto de conservar este anegamiento del terreno utilizan genotipos locales de arroz alto que son de mayor duración. Mientras que el monzón del sudoeste se retira a mediados de septiembre en la zona, estas variedades florecen a mitad de octubre y maduran a mitad de noviembre, por lo que la sequía terminal para el arroz constituye un fenómeno recurrente en la región. Para comprender el patrón de los diferentes parámetros del balance hídrico, se ha computado el balance hídrico de los arrozales dotados de diques de contención utilizando el concepto del procedimiento contable de Thornthwaite con la suposiciones y modificaciones necesarias. Existe en la región una gran variabilidad de suelos que va de arenoso a arcilloso. Los estudios de balance hídrico han sido llevados a cabo para los tres tipos de suelos de la región: limo arenoso, limo arcilloso y arcilloso. Sobre la base

del balance hídrico, se han estimado los índices de almacenaje para años de precipitación excesiva, normal y deficitaria a fin de examinar el potencial de captación de agua de lluvia bajo diferentes patrones de precipitación excesiva, normal y deficitaria. En base a los resultados de los balances hídricos, se presentan sugerencias para mejorar la productividad de las planaciones de arroz bajo condiciones de secano.

INTRODUCTION

In the sub-humid tropics of the world in general, and in India in particular, the rainfall received is too high to grow dryland crops which may suffer from water-logging, and it is too small to grow a rice crop because intermittent and terminal droughts result in low productivity.

In the Chhattisgarh region of Central India (Fig. 1), with an average annual rainfall of about 1400 mm, 90% of which is received during the monsoon months of June–September, rice is the major crop grown during the wet season in 3.8×10^6 ha; most is grown under rainfed conditions. Out of the three agroclimatic zones in the Chhattisgarh region, rice occupies about 80% of the net sown area in the Chhattisgarh Plains. In the Bastar plateau and in the northern hills, rice occupies 69 and 60% of the net sown area, respectively.

The southwest monsoon starts in mid-June and withdraws by mid-September whereas the rice crop flowers in mid-October and matures by mid-November. As a

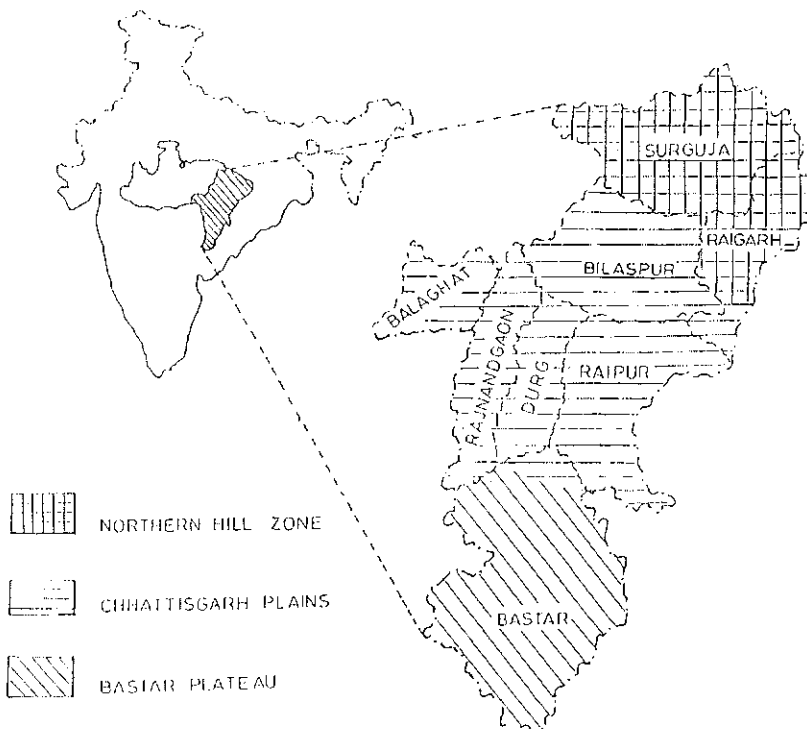


Fig. 1 Location map of the Chhattisgarh region of Central India.

water management practice, farmers construct 1.0–1.5 m high bunds (dikes) in rice fields. They accumulate water up to 30–40 cm high in these fields. To sustain such water accumulation they grow tall varieties and use the method of rice cultivation called the broadcast “biasi” method. In this method rice seeds are broadcast in pre-ploughed fields immediately after the onset of the southwest monsoon in mid-June. After 30–40 days, when sufficient water has accumulated, the fields are again ploughed which is known as “biasi”. The main purpose of a “biasi” is (a) to reduce the rice plant population which becomes high due to use of the broadcasting method; (b) to reduce the weed population that grows and competes with rice until the “biasi” operation; and (c) to create semi-puddled conditions to reduce the percolation losses.

With such typical rice growing systems and water management practices, an analysis of the water balance of the banded rice fields has been worked out. In this area, there is great soil variability ranging from lateritic to clayey soils through sandy-loam and clay-loam (Fig. 2). All these soils are found in almost every village. Rice is grown mostly in all soils except in lateritic soils. Water balance computations have been carried out for all the three types of soils where rice is grown.

METHODOLOGY

The method adopted for water balance computations is the book-keeping procedure of Thornthwaite & Mather (1955) which others have applied to different conditions (Subramanyam & Subramanian, 1964; Sastri *et al.*, 1981; Sastri & Patel, 1984). In

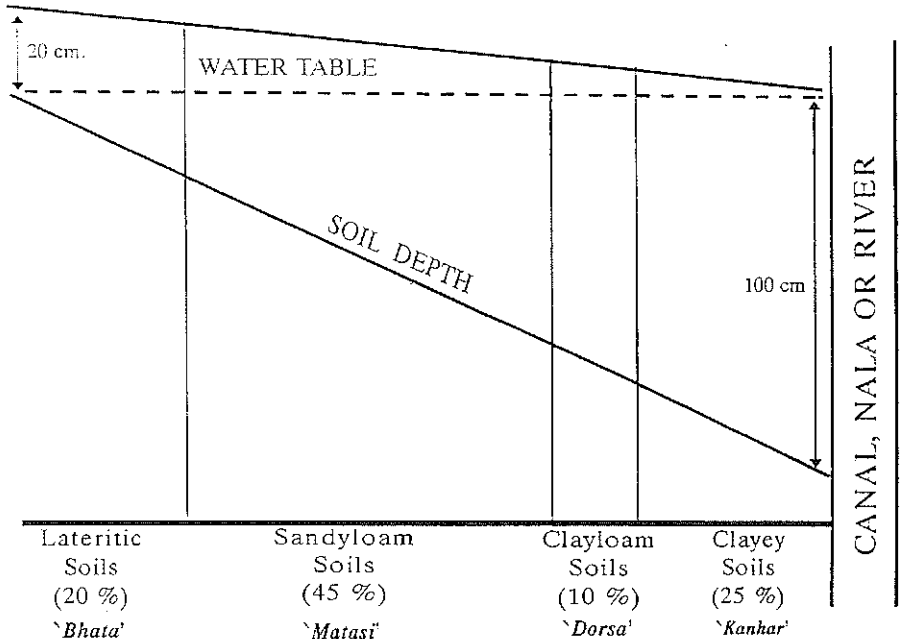


Fig. 2 Soil topography, soil depth and water table during the peak monsoon in Chhattisgarh region of Central India.

this book-keeping method, the precipitation and potential evapotranspiration (PET) are given as input. Any excess rainfall above the value of PET goes to the soil as storage. The excess rainfall, after the soil attains field capacity, is considered to be surplus water and is lost either by runoff or by percolation. Detailed procedures and tables for computation of the water balance were also given by Thornthwaite & Mather (1957). For computing the weekly water balance in this paper, PET values were estimated using the Penman (1948) equation.

This water balance by book-keeping procedure has been modified slightly for the banded rice fields. Farmers, as mentioned earlier, accumulate water in the rice fields up to 30–40 cm. Therefore, the surplus water, after the soil reaches field capacity, is retained in the field. The weekly PET values and percolation at 7 mm day^{-1} or 50 mm week^{-1} , are deducted from this surplus water and rainfall during that week is added to the surplus water. The weekly water balance computations are made for three different soils *viz*: sandy-loam, clay-loam and clayey soils. The field capacity of these three soils is taken as 150, 200 and 250 mm per metre of root zone, respectively. The water balance computations have been done for four stations, *viz*: Raipur, Bilaspur, Durg and Rajnandgaon districts, of the Chhattisgarh Plains agroclimatic zone (ACZ). Also, water balance computations have been made for normal, excess and deficit rainfall years, each averaged for the period 1941–1990.

RESULTS AND DISCUSSIONS

Water balance of banded and unbanded fields

The pattern of weekly water balance diagrams for a normal rainfall year for unbanded soils, as per the original procedure, and for banded rice fields as per the modified procedure, are shown in Figs 3 and 4 respectively. In the water balance computations for unbanded fields, the weekly surplus water is divided as one third as percolation and two thirds as runoff. The amount of percolation in unbanded fields is 391.9 mm while in banded rice fields the percolation losses are 512.9 mm. The rainfall of a normal year during the period 23rd–45th standard meteorological weeks (SMW, 4 June–5 November) is 1135.3 mm and corresponding potential evapotranspiration values are 737.9 mm. It can be seen from the diagrams that the duration of percolation and runoff (*i.e.* the surplus water) is from the 27th SMW (2–8 July) to the 39th SMW (24–30 September) with a break during the 36th and 38th SMWs. One interesting point that has been observed is that in banded rice fields of sandy-loam soils, the runoff is practically none while in unbanded soils the ratio of total runoff to total rainfall during the crop growing season is 34.5%. The percolation in unbanded soils is only 38.1% of that of the banded rice fields. Thus the water balance components change completely in the banded rice fields as compared to unbanded fields.

Water balance of banded rice fields under different rainfall situations

The three important components of the water balance, that is, rainfall, percolation and runoff losses, during excess, normal and deficit rainfall years in the three

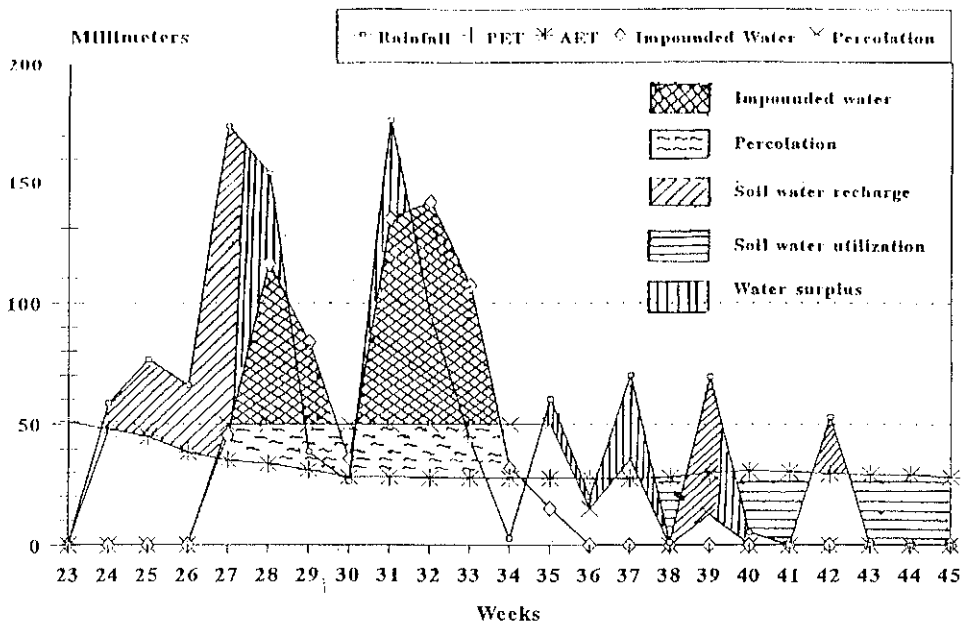


Fig. 3 Water balance of banded rice fields.

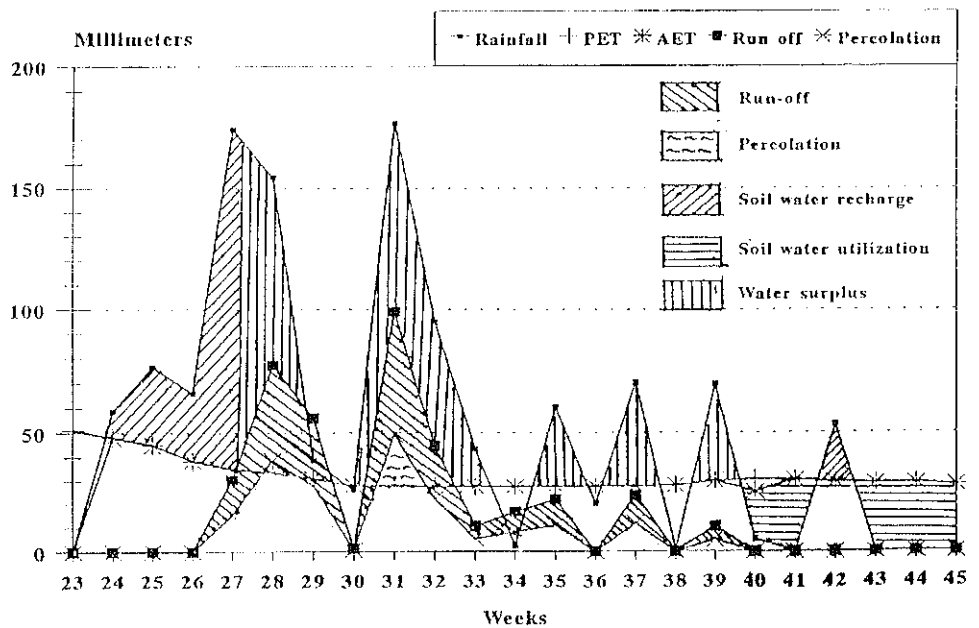


Fig. 4 Water balance of unbanded rice fields.

different soils of the four districts are shown in Table 1. It can be seen that there are no runoff losses during deficit rainfall years in all the situations, and in normal rainfall years runoff is nil in sandy-loam soils in all the districts and in the clay-loam soils of Raipur and Durg districts.

Table 1 Water balance of different districts.

District	Parameter (mm)	Sandy loam (Matasi)			Clay loam (Dorsa)			Clayey soils (Kanhar)		
		Excess	Normal	Deficit	Excess	Normal	Deficit	Excess	Normal	Deficit
Raipur	Rainfall	813.5	1142.2	763.2	813.5	1142.2	763.2	813.2	1142.2	763.2
	Percolation	032.6	434.9	137.1	730.8	389.6	76.1	220.2	312.6	26.3
	Runoff	85.1	0.0	0.0	262.9	0.0	0.0	398.3	27.2	0.0
Rajnand-Gaon	Rainfall	002.3	1232.2	682.4	002.3	1232.2	682.4	002.3	1232.2	682.4
	Percolation	958.0	535.8	59.2	850.7	475.8	8.3	621.6	405.7	0.0
	Runoff	75.2	0.0	0.0	323.1	10.0	0.0	724.1	29.7	0.0
Durg	Rainfall	736.5	1136.7	862.7	736.7	1136.7	862.7	736.9	1136.7	862.7
	Percolation	981.2	450.5	244.8	390.5	390.5	193.8	580.5	314.8	137.6
	Runoff	0.0	0.0	0.0	0.0	0.0	0.0	375.7	24.8	6.2
Bilaspur	Rainfall	475.6	1201.0	804.3	475.6	1201.0	804.3	475.6	1201.0	804.3
	Percolation	970.9	462.1	153.2	499.4	390.1	103.2	399.4	348.3	52.7
	Runoff	18.5	0.0	0.0	143.8	22.0	0.0	244.4	13.9	0.0

In clayey soils, with lower percolation rates (3 mm day⁻¹), there is considerable runoff during excess rainfall years in all the four districts. Farmers usually drain off the impounded water above 30 cm and hence in clay-loam and clayey soils under excess rainfall years the runoff amount is quite high as compared to sandy-loam soils.

In sandy-loam soils the percolation losses under excess rainfall conditions are very high ranging from 958 to 1033 mm in different districts. Thus, due to higher percolation losses in the bunded rice fields, dug wells work better for water conservation as compared to farm ponds.

Storage index

It is interesting to note that in this area there are numerous tanks used for both irrigation and domestic purposes. For example in Raipur district alone there are about 12 500 tanks while in Bilaspur district there are more than 14 500 tanks. Most of the tanks are situated just below the lateritic soils which are usually barren and are used as a catchment area for these tanks. The rainwater thus collected is used to irrigate the rice fields, especially those sandy-loam soils situated adjacent to these tanks. In order to assess the runoff potential during excess, normal and deficit rainfall years in the catchment area, a storage index has been developed as:

$$\text{Storage Index (SI)} = \frac{\text{Total surplus water (mm)}}{\text{Normal rainfall (mm)}} \times 100$$

The average rainfall is taken as the dividing factor in order to compare the runoff volumes during excess and deficit years with the normal years; if the denominator is changed for every situation, the values are not comparable. Using the book-keeping procedures of water balance for unbunded areas, that is, as per the original procedure of Thornthwaite & Mather (1955), the water balance of 21 stations in Raipur district has been computed for excess, normal and deficit rainfall years. The storage index in respect of all these stations for excess, normal and deficit rainfall years has also been computed and is shown in Table 2. It can be seen that during excess rainfall years the

Table 2 Storage indices in different stations of Raipur district during normal, excess and deficit years.

Block/rainfall station	Storage index			Normal (mm)
	Excess	Normal	Deficit	
Raipur	87.6	39.6	3.0	1149.4
Dhamtari	86.4	35.4	2.3	1388.4
Simga	63.5	27.6	2.5	1185.7
Balodabazar	74.9	33.8	3.5	1269.2
Gariyaband	83.0	40.2	6.6	1521.3
Arang	78.3	34.4	8.2	1342.6
Rajim	72.8	35.0	10.5	1351.8
Saraipali	75.5	35.7	0.0	1389.0
Mahasamund	89.3	38.4	5.5	1367.6
Deobhog	67.4	25.5	2.7	1345.2
Kurud	75.3	27.9	0.0	1276.0
Bindram	76.8	24.2	0.0	1353.1
Kusrangi	80.4	32.7	0.0	1327.4
Khairadatan	66.3	30.2	0.5	1376.5
Pithora	73.7	37.1	8.2	1532.6
Lakholi	78.8	27.4	0.0	1404.0
Rudri	68.5	32.8	0.0	1462.3
Murransilli	77.1	35.0	2.6	1550.1
Bhatagaon	75.0	34.4	11.4	1453.2
Kondapur	72.5	30.2	0.0	1422.1
Kanki	62.9	32.1	2.4	1394.1

SI varies from 62.9 to 89.3% of the normal rainfall of the respective stations. In deficit rainfall years, the value of the storage index varies from nil in some stations to 11.4% at Bhatagaon station, while in normal years the *SI* value varies from 24.2 to 40.2% of the normal rainfall of the respective stations.

The percentage probability of excess, normal and deficit rainfall years in the four districts considered is given in Table 3. Thus, the tanks that are traditionally constructed in the lower part of lateritic soils, have the potential to provide life saving irrigation for 80–90% of the years (both excess and normal years combined) and hence they are important to the life of the people in this region who are mostly either tribal or economically disadvantaged.

CONCLUSIONS

From the analysis, it has been observed that for the bunded rice fields area of sandy-loam, clay-loam and clay soils, the percolation losses are always greater than the

Table 3 Percentage probability of excess, normal and deficit rainfall years.

District	Percentage probability		
	Excess	Normal	Deficit
Raipur	15	70	15
Durg	17	61	22
Rajnandgaon	13	77	10
Bilaspur	8	71	21

runoff losses as the farmers impound water to at least 30 cm depth in the fields and let the water out over and above 30 cm depth. This happens mostly during excess rainfall years. The runoff amount in excess rainfall years is higher in clayey soils, due to lower percolation rates as compared to the other two soils.

In the lower of part of the lateritic soils, villagers traditionally construct tanks for both domestic and irrigation purposes. The lateritic soils, which are mostly barren, act as a catchment area. From the storage index analysis, it is observed that these tanks get runoff water of varying amounts in 80–90% of the years which are either excess or normal rainfall years.

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