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Water balance studies and strategies for combating water deficit in Upper Kolab catchment of Orissa

S. SUDHISHRI, A. DASS & N. K. PAIKARAY
Central Soil and Water Conservation Research and Training Institute, Research Center, PB No. 12, Sunabeda-2, Koraput (Orissa)

Abstract *Analysis of water balance for Upper Kolab catchment was done according to Thornthwaite book keeping technique for six stations located within the catchment and for the entire catchment for the normal climatic year. On annual basis the catchment has a water need, rainfall, actual evapotranspiration, water surplus and water deficit of 1703.7mm, 1479.82 mm, 1003.13 mm, 476.69 mm and 700.56 mm respectively. There is a water surplus from July to October and water deficit from November to May. The surplus months of June and part of July contribute to recharge the soil moisture deficit. The study shows the entire kharif season is deficit free and during rabi season the deficit amount is 455.88 mm. This deficit can be mitigated through low cost water harvesting structures, diversion of Jhola water, in-situ moisture conservation measures coupled with suitable agronomic practices. Though on an average the whole catchment is under water deficit (700.56 mm), the agro climatic situation of the region is slightly moist (MI = –13.14 %).*

Keywords: *Upper Kolab catchment; water balance; water deficit; strategies.*

INTRODUCTION

To any form of water, rainfall is the primary source and it is stochastic in nature. The annual rainfall of the country varies greatly and is not uniformly distributed. Moreover, the areas with high annual rainfall (>1125 mm) and seasonal dry spells experience floods and erosion hazards in agricultural lands, which is of prime concern to soil and water conservation scientists and its programme planners. It has been estimated that 50-60 percent of rainfall goes as flood, washing away 16 t/ha of topsoil annually (Reddy *et. al.*, 2001) in India and 45 t/ha/year in this region (Anonymous, 1988). This results in acute water deficits on one hand and siltation of reservoirs on the other. So there is a great importance to find out water deficit and water surplus of an area, which is possible through water balance study.

The term 'water balance' expresses overall mass conservation for all rain falling in any given period. With increasing population and decreasing per capita availability of water, optimum utilization and conservation of water has become a problem of vital importance in which water balance plays a crucial role. From hydrologic point of view, the precipitation constitutes almost the entire water supply to any region. However, the water potential can never be assessed from precipitation alone. To assess such potentiality, it is essential to have reliable information on the balance between inflows and outflows of water for each situation. Such information specifies the availability of water in time and space, extents of surplus and deficit for a given region and is therefore important to hydrologists, water conservationists and agriculturists in planning for water harvesting structures, artificial ground water recharge methods and adjusting agricultural operations in such a way to bring about maximum synchronization between availability of water and critical stages of crop growth. One of the approaches to study water balance of any region, as enunciated by Thornthwaite (1948), is the climatic water balance approach, and later modified by Thornthwaite and Mather (1955). This approach of computing water balance was carried out by Subramanyam (1982) for Godavari river basin. A similar study was taken up for Nale and Correia for weekly water balance of Udaipur by employing Thornthwaite's book keeping technique (Subramanyam, 1982).

The present study was undertaken in Upper Kolab catchment with the following objectives:

(a) Water balance study for the entire Upper Kolab catchment

(b) Agro climatic analysis of the region,

(c) Highlighting the strategies for combating water deficit in the region.

Upper Kolab Catchment

The Upper Kolab catchment (Figure 1) is situated in the Koraput district of Orissa. Looking into its delicate ecology and tribal socio-economy, Koraput is one of the most vulnerable districts of the country. The topography of the region is hilly, undulating and rolling. The degraded soils with exposed rocks resulted from severe erosion is the common landscape. The socio economic development in this district has remained sluggish due to hilly topography, lack of proper communication facilities and distance from the administrative headquarters.

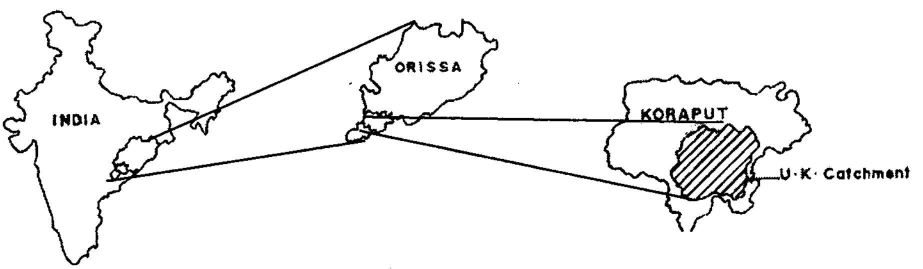

Figure 1. Location map

The river Kolab, known as "Sabari " in its lower reaches, forms a tributary of river Godavari. The river originates from the Eastern Ghats in Koraput district at an altitude of RL 1200 m and descends to RL 810 m at the dam site near village Karanga after traversing about 78 km with average bed slope of 6.25 m/km (Anonymous, 1988). The catchment area intercepted at the dam site is 1630 sq.km. This is bounded by latitude 18^0 23' and 18^0 47' N and longitude 82^0 32' 30" and

83^0 2' 30" E. Catchment characteristics (Table 1) show that the catchment is of compact and square shaped with dendritic type of drainage pattern (Figure 2). The area is situated on the Koraput – Pottangi plateau at an elevation of 850 –900 m. This plateau is characterized by deeply gullied undulating tablelands profusely scattered with hundreds of hillocks of remarkable similarity in look. The process of denudation and resultant degradation has advanced too far and hillocks are left mostly with low scrub disfigured with bare patches of shifting (Podu) cultivation. The catchment is mostly devoid of vegetation, as a result of which too much of silt flows with run-off in the river. The muddy river water carrying heavy silt load flows into the dam (reservoir) constructed near Karanga village thereby silting it up and jeopardizing its storage capacity. The average soil type of the catchment area is mostly red and texture is sandy loam to sandy clay loam.

Table 1. Geomorphological characteristics of Upper Kolab catchment

Characteristics	Values	
Area	1630 sq.km	
Perimeter	194.97 km	
Maximum flow length	73.48 km	
Stream order	No.	Length (km)
1^{st}	66	263.52
2^{nd}	20	131.76
3^{rd}	3	104.65
4^{th}	1	24.58
Total	92	524.51
Average slope	0.281	
Form factor	0.648	
Circulatory ratio	0.752	
Elongation ratio	0.844	
Drainage density (km/sq. km)	0.321	
Stream density/sq km	0.0552	
Compactness coefficient	1.362	
Basin shape factor	1.767	
Bifurcation ratio		
1st	3.30	
2^{nd}	6.67	
3^{rd}	3.00	

Climate

The catchment receives fairly good rainfall during the monsoon. Most of the rainfall comes down during cyclonic storms, resulting in flashy flows in the river. Such cyclonic storms are very common during late September, October or even in November. Summer showers are common during April- May. During rainy season, drizzle continues in the catchment for a number of days continuously though the runoff during this period is nominal. The weighted average rainfall for the catchment is 1420 mm and average annual runoff is 1704 M.cum. (Anonymous, 1988). The climate is warm and humid with mean maximum and minimum temperature of 31^{0}C and 17^{0}C respectively. The mean annual maximum and minimum relative humidity values are 52% and 27% respectively (Anonymous, 2001).

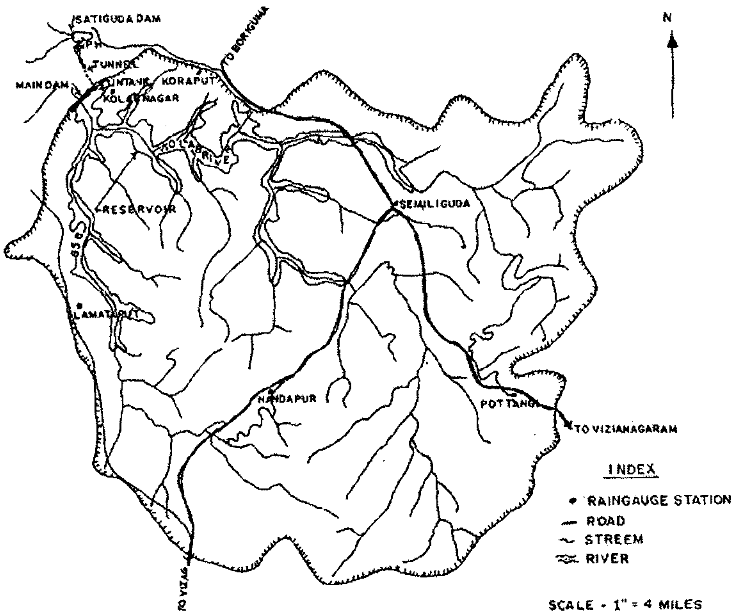

Figure 2. Map of Upper Kolab catchment

MATERIALS AND METHODS

Data Source

Monthly rainfall data were collected from CSWCRTI, Research Station, Collectorate office, Koraput and Head Works division, Kolab project for the period 1967 to 2002. The daily maximum and minimum temperature data of 32 years (1970-2001) were obtained from Agricultural Meteorological Observatory, Mixed Farm, Govt. of Orissa and Central Soil and Water Conservation Research and Training Institute, Research Center, Semiliguda in the district of Koraput (Orissa). Out of the data collected, computation was made for monthly and yearly total and average rainfall, maximum and minimum temperature.

Water Balance Study

In Thornthwaite's approach, rainfall is treated as income and Potential Evapotranspiration (PE) as committed expenditure. According to Thornthwaite's method (Rao and Subramanyam, 1961), the three parameters required to compute water balance of any place are precipitation (P), potential evapotranspiration (PE), and available moisture holding capacity or field capacity of soil (FC).

Determination of PE

PE was calculated by Hargreave's method (Hargreaves *et. al,* 1985 and Hargreaves, 1994) that requires only temperature data for all the six-raingauge stations.

$$PE = 0.0022*RA*(Tc+17.8)*TD^{0.5} \quad (1)$$

where, RA= extra terrestrial radiation, mm/day, Tc = mean temperature. ^0C, TD = Difference between maximum and minimum temperature, ^0C

Determination of F.C.

At four representative sites covering the whole catchment, soil samples were collected for estimation of field capacity from three different depths, viz. 0-15 cm, 15-30 cm and 30-45 cm in varied topo-positions, viz. hilly upland, medium land and low land. At the sampling sites, soil depth was determined by the help of a screw auger. For determining the average profile soil moisture storage (FC) in the whole catchment, areas under different topo-positions were taken into account. In the catchment area under low land (Jhola), medium land, upland, forest area and rocky area is 11, 22, 13, 51 and 2 percent, respectively (Senapati and Sahu, 1966; Anonymous, 1997 a). A weighted average was found out taking F.C., percentage area and depth of soil of different topo positions into account as follows:

$$\text{Weighted F.C.} = \Sigma\,(F.C.* A * D)/100 \quad (2)$$

where, F.C. = Field capacity, cm/m, A = Area in percentage, D = depth of soil, m

Computation of water balance

The water balance was computed by using above three parameters. The resultant parameters obtained by these analyses are changes in soil moisture storage (ΔSt), actual evapotranspiration (AE), water deficit (WD), and water surplus (WS).

Subtraction of monthly values of PE from P results in a series of positive and negative differences, which represent potential additions or losses to or from the soil. The negative value indicate a potential loss of water from the soil which has to be converted into values of actual change in soil moisture storage due to the fact that as the soil dries out, water is lost from the soil at a rate less than the potential rate. Soil moisture storage at the end of each month was computed by

$$St = FC*e^{-APWL/FC} \quad (3)$$

where, St = moisture remaining in the soil as storage and APWL = accumulated potential water loss, which is equal to accumulated (P-PE).

Conditions

(a) During any month if P>=PE, then AE=PE (4)

Any excess P of PE goes to recharge the soil till the soil is brought to FC; any further remainder is termed as water surplus.

(b) When P<PE, then AE= P+ ΔSt (5)

(c) The water deficit is the difference between PE and AE. Using these computations, the water balance was determined month-by-month using the following equation

$$P=AE + \Delta St + WS \quad (6)$$

Equation (6) is valid under the assumption that the ground water inflow and outflow of the watershed are equal.

Agro climatic condition of the region

To know the climatic condition, the method adopted by Krishnan and Singh (1972) was used and it was known on the basis of moisture index (MI), which is calculated as

$$MI= (P-PE)/PE*100 \quad (7)$$

where, P= Precipitation, mm, PE= Potential evapotranspiration, mm

RESULTS AND DISCUSSIONS

Water balance Component

As per the procedure described above field capacity for different topo- sequences were determined (Table 2) and using equation 2 weighted F.C was determined and found as 17.5 cm. Values of various parameter of annual water balance for six rain gauge stations are presented in Table 3. Following the same procedure, water balance of the entire basin was also worked out for each month & values of different parameters are presented in Table 4.

Table 2. Average field capacity of 1m-soil profile in U.K. catchment

Category of land	F.C. (cm/m)	% of Area	Depth of soil (m)
Jhola	46.525	11	1
Medium	35.015	22	1
Upland	25.545	13	0.5
Forest & Barren	20.0	51	0.3
Rocky	0	2	0

Table 3. Annual values of components of water balance (mm)

Station	PE	P	AE	WD	WS
Kolab	1703.04	1860.38	1013.21	689.83	847.17
Koraput	1702.85	1422.02	980.24	722.61	441.78
Lamataput	1704.28	1411.45	915.58	788.7	495.87
Nandapur	1704.07	1393	997.13	706.94	395.87
Pottangi	1704.07	1421.03	1100.65	603.42	320.38
Semiliguda	1702.75	1372.9	1013.51	690.22	359.37
Entire catchment	**1703.7**	**1479.82**	**1003.13**	**700.56**	**476.69**

Table 4. Water Balance study (mm) of U.K. catchment as a whole

Month	PE	P	AE	WD	WS	SMU	IMA
January	121.32	5.47	27.75	93.57	-	22.28	0.23
February	133.49	8.27	20.4	113.09	-	12.13	0.15
March	170.11	15.51	22.31	147.8	-	6.8	0.13
April	184.15	40.98	43.66	140.49	-	2.68	0.24
May	188.93	87.19	88.13	100.8	-	0.94	0.47
June	155.94	211.05	155.94	-	-	-	1
July	125.85	362.68	125.85	-	118.12	-	1
August	125.66	375.09	125.66	-	249.43	-	1
September	127.31	236.45	127.31	-	109.14	-	1
October	138.48	102.84	135.09	3.39	-	32.25	0.98
November	117.34	30.35	86.26	31.08	-	55.91	0.74
December	115.11	3.94	44.77	70.34	-	40.83	0.39
Annual	**1703.7**	**1479.82**	**1003.13**	**700.56**	**476.69**	**173.82**	

PE= Potential Evapotranspiration (mm), P= Precipitation (mm), AE= Actual Evapotranspiration (mm), WD= Water Deficit (mm), WS= Water Surplus (mm), SMU= Soil Moisture Used (mm) and IMA= Index of Moisture Adequacy (mm)

The annual values of rainfall, water surplus and water deficit of all six stations were used to plot the isohyets of annual rainfall (Figure .3), isolines of water surplus (Figure 4) and isolines of water deficit (Figure 5) over the basin. Figure 3

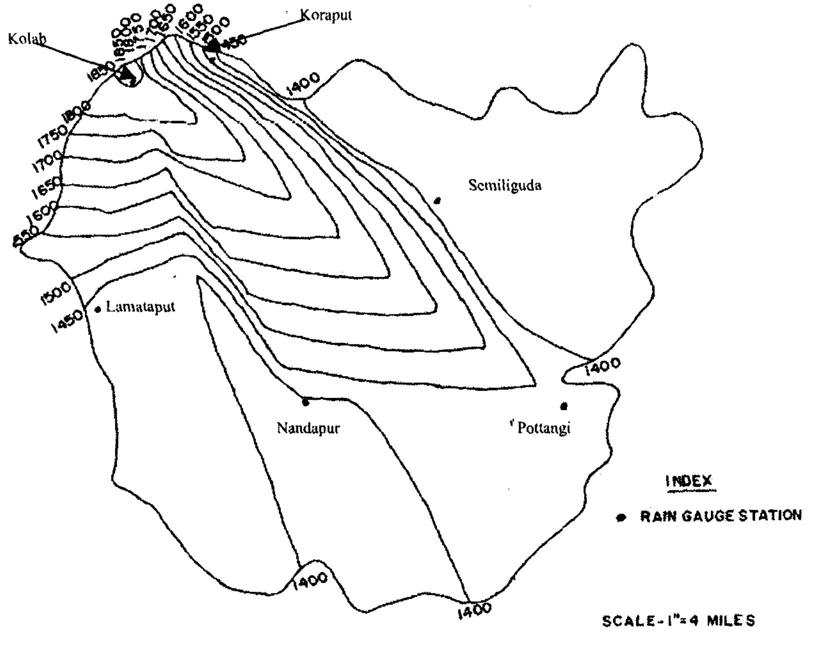

Figure 3. Isohyets of Annual Rainfall in Upper Kolab catchment

shows that the annual minimum and maximum rainfall values on the entire basin vary from 1400 to 1850mm. It has been observed from Figure 4 that the northwestern part of the catchment has maximum amount of water surplus, which is fed to the river system. The entire catchment provides a minimum of 300mm and maximum 850mm of water to the river. Figure 5 indicates that the minimum water deficit over the catchment is 600mm and maximum water deficit is 800mm. The water deficit is very low in southeast and central part of the catchment.

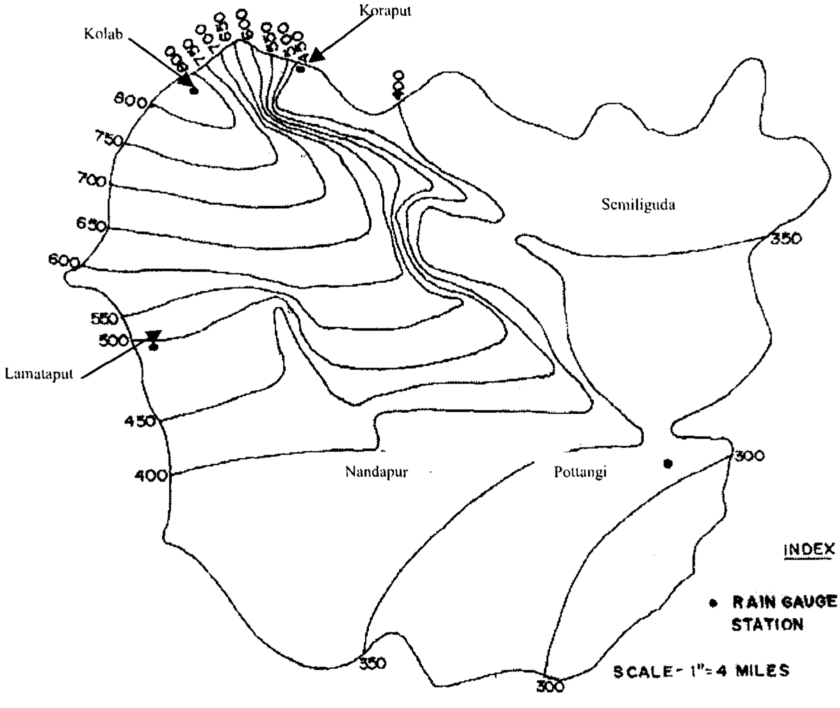

Figure 4. Isolines of water surplus in Upper Kolab catchmant

Water balance computed for the entire basin has been shown graphically in Figure 6. This graph is a comparison of P, PE and AE from which extent and epochs of water surplus, water deficit, soil moisture used and soil moisture recharge can be visualized. When P falls short of PE, water is drawn from soil for evapotranspiration. The negative change in soil moisture has been taken as soil moisture utilization. When P is greater than PE the positive change in soil moisture has been taken as soil moisture used till soil attains field capacity. It is seen from Table 4 that highest monthly rainfall is 375.09mm in the month of August and the water surplus in this month is 249.43mm, which is the highest water surplus in any month. From Figure 6 it is revealed that PE exceeds P for eight months & the total deficiency during this period is 700.56mm. For the rest of the period i.e. June to September the value of P exceeds PE (650.51mm). Out of this amount 479.69mm appears as water surplus and remaining 173.82mm adds to soil moisture as recharge. It has been observed that in three months (July to September) there is water surplus, and in eight months (October to May) there is water deficit. The water surplus during June & part of July goes to recharge the moisture deficit of the soil mass. On annual basis the catchment has a water need of 1703.7mm whereas the rainfall is 1479.82mm, still 476.69mm water appears as surplus on account of the relative marches of rainfall from June to September being in excess of water need by an amount of 650.51mm.

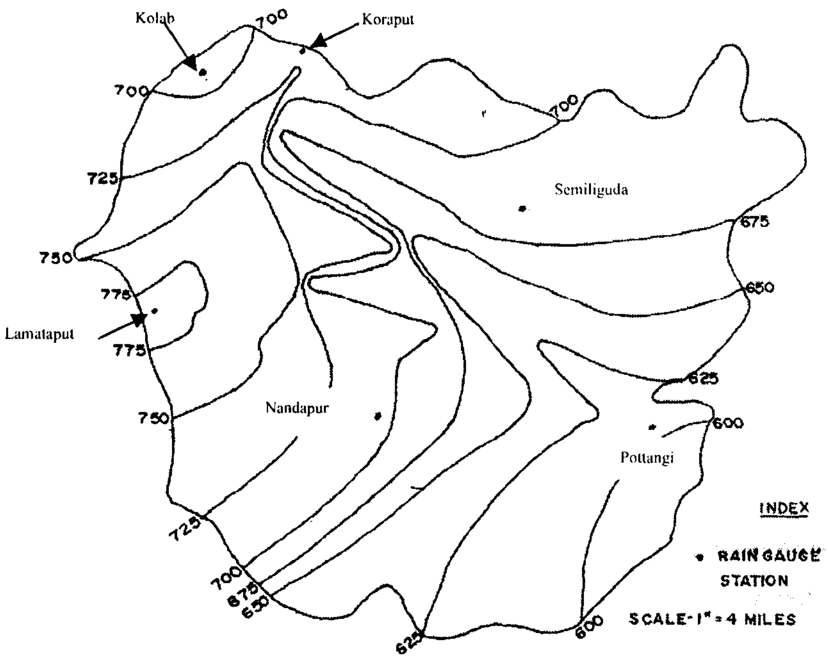

Figure 5. Isolines of water deficit in Upper Kolab Catchment

Index of Moisture Adequacy (Subramanyam, *et. al.*, 1964) indicates the rate at which moisture is available to the crop compared to its demand. IMA values in the range of 0.45 to 0.6 for millets and for groundnut in the range of 0.52 to 0.75 are considered favorable for efficient crop growth. Water balance study indicated that in an average year (Table 4), the period between May to November is drought free and favourable for such crops. Moisture Index determination (Table 5) reveals a positive value only for Kolab region, whereas all other parts showed a negative value. So for better rain use efficiency and to tide over inter-spell moisture deficiency, following strategies may be adopted in the area.

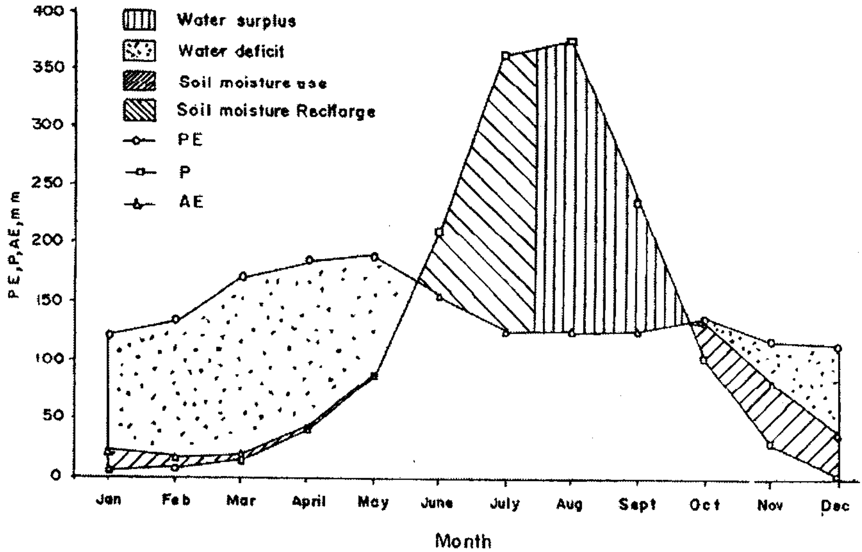

Figure 6. Water Balance in Upper Kolab catchment

Table 5. Agro climatic analysis of the region

Station	MI (%)	Climatic group
Kolab	9.24	Moist
Koraput	-16.49	Slightly moist
Lamataput	-17.18	Slightly moist
Nanadapur	-18.25	Slightly moist
Pottangi	-16.61	Slightly moist
Semiliguda	-19.37	Slightly moist
Entire catchment	-13.14	Slightly moist

Strategy Adopted for mitigating Water Deficit

(A) Water harvesting and recycling

1. It was found that water surplus in the catchment is 476.69 mm. Also this catchment is bestowed with many natural hill streams and farmers are diverting this stream water through earthen channels with very low conveyance efficiency (<30%). Therefore, harvesting of such water and conveying and distributing through under ground pipeline system or lined channel can irrigate 777 km^2 area out of 1630 km^2 catchment area, for supplemental irrigation to remunerative crops like vegetables. In Kokriguda watershed, a representative of Upper Kolab catchment, installation of under ground pipeline system increased potential area under irrigation for vegetables from 2.95 ha to 35 ha benefiting 45 families; conveyance efficiency also enhanced from 23 to 95 per cent (Sudhishri *et.al.*, 2004).

2. In the catchment, the water flow remains round the year in *jhola* (stabilized broad and terraced gully bed). *jhola* water can be harvested/ diverted for irrigating adjoining medium lands by constructing water holes of 3 m diameter and depth of 2 to 4 meter depth (location specific) at the side of *jhola* or field channels (Anonymous, 2004).

(B) *In-situ* moisture conservation

In this region 66 per cent area is under hill and uplands. Also uplands constitute a large portion of cultivable area, which are unbunded and thus generate huge amount of runoff. Constructing graded bunds, vegetative bunds, trench-cum-bund-cum vegetative barriers/hedgrows, terraces etc. may conserve this runoff water. In Kokriguda watershed due to construction of trench-cum-bund (planted with vetiver & sambuta grass and Assam shade & *Gliricidia* as hedge row on bunds); stone bunds with cut outlet structures, bunding and land leveling increased the crop yield by 15 per cent during the drought year 2002..In hill slopes due to different *in-situ* moisture conservation like tick ditch, micro catchment, trench, saucer shape soil working techniques and installation of pitcher in horticultural trees like mango and cashew increased the survival percentage even up to 88 to 95 per cent (Patnaik *et.al.*, 2004).

(C) Agronomic practices

1. Seeds should be placed in the moist zone through line sowing to have uniform germination and better establishment of young seedlings. It was found that line sowing in ragi (the staple food) recorded highest grain yield of 21.94 q/ha and increased plant height, primary branches/plant and better germination compared to broadcast method (Anonymous, 2003).
2. Shallow hoeing/ one hand weeding at 25 days after sowing should be done to maintain moisture availability. It was observed that one hand weeding in horse gram increased seed yield by 12.2 per cent over no weeding, may be due to weeding operation maintained enough moisture and nutrients to horse gram crop (Patra and Nayak, 2000).
3. Intercropping of *kharif* crops like ragi and paddy with pigeon pea is the promising system in this region for mitigating ill-effects of water deficit. In an on-farm trial in this region, rice+ pigeon pea (6:2) produced 26 per cent higher rice equivalent yield than sole crop during drought year (2002). In other similar trial, ragi and pigeon pea inter cropping system gave higher net returns as compared to sole crop ragi (Anonymous, 2004).
4. Conservation of residual soil moisture and increase in the yield of rabi crops using locally available mulches like paddy/ragi straw, gliricidia leaves, lantana and local grass. It was observed that in this area lantana, local grasses and gliricidia mulches @ 8 t/ha were able to retain sufficient moisture to sustain rabi crops like wheat, gram and niger (Anonymous, 1997 b). In turmeric, highest moisture content (21.25 %) was observed

with paddy straw mulch (6, 8 and 10 t/ha) followed by grass and gliricidia mulch and minimum was under control treatment (Anonymous, 1996).

5. Use of organic/ bio-manures also enhances moisture retention. Application of vermi-compost @ 200 gram/plant in tomato and cabbage increased sufficiently the water holding capacity of soil, and increased the yield (Chaudhary *et.al.*, 2003)
6. Adopting following suitable crop sequence in this region under rain fed conditions to withstand water deficit

Upland	Ist crop	2nd crop
Unbunded	Ragi, maize, suan, groundnut, vegetables, beans, black gram, cowpea	Horse gram, niger,
Upland (terraced)	Early high yielding paddy (100 days)	Niger/mustard/mung/cowpea
Medium land:	Medium high yielding varieties (120 days)	Mustard, safflower/ gram/ lentil/ linseed.
Low land (Jhola)	Long duration paddy	Paddy, vegetables in partially dried portion.

CONCLUSION

Water balance of upper Kolab catchment shows the values of water need, rainfall, actual evapotranspiration, water surplus and water deficit of 1703.7mm, 1479.82mm, 1003.13mm, 476.69mm and 700.56mm, respectively. Under normal climatic condition, entire *kharif* season is deficit free. Deficit to the tune of 455.88 mm of water occurs in *rabi* season. Since the water surplus is excess of precipitation over the water needs of the atmosphere and the soil, it must find its way through rivers & streams. Thus determination of water surplus enables the estimation of yields from the catchment. Such information can be used in designing storage structure for use of water during deficit periods. In the same way water deficit is the shortage of precipitation for satisfying the full demands of evapotranspiration. On an average, the whole can be said to be under water deficit region, though climatic condition is slightly moist. Hence, the *rabi* crops are either avoided or taken up in extremely limited area reflecting under utilization of land and water resources. However, there exists scope for taking winter and rabi crops too in sequence even under rainfed conditions, provided that appropriate water harvesting measures, moisture conservation measures and agronomic practices are adopted in an integrated manner.

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