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Assessing Water Resources Status for Crop Planning – A Study in Coastal Paddy Ecosystem of Odisha

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Assessment of the water resources was made in a coastal paddy ecosystem in Pattamundai block in Kendrapara district of Odisha for productive crop planning. Two-parameter Gamma distribution model at 30 per cent probability level was found best rainfall predicted model for the study area. It is observed that there is vulnerability of occurrence of dry spell to the tune of 17-55 per cent during monsoon period, when modeled through Markov chain probability model. Based on water budget technique on weekly basis, gross excess water availability of 1182 mm is reported occurring mostly during monsoon period. When computed through USDA SCS CN procedure, extreme peak runoff event of 358 mm/day generating from 370 mm/day rainfall amount emphasized for adequate provision of surface drainage network in the study area to drain out the excess runoff water. Provision of supplemental irrigation with rescheduling of canal water supply is envisaged for catering the contingent need of monsoon crop during dry spell and post monsoon crops to bring sustainable production.

*(**Key Words :** Water resources, Gamma distribution model, Markov chain model, USDA SCS CN model, Water budget, Crop plan)*

As an agrarian economy that employs around 73 per cent of its population in farming and related activities, agriculture contributes around 30 per cent to the net state domestic product in Odisha. But a major portion of the agricultural land is rainfed. The soils are variable characteristics with the colour ranging from light gray and pale yellow to deep gray; and the textures ranging from coarse sand to silty-clay to clay. The Bay of Bengal remains the centre of low pressures causing heavy rains and cyclones during monsoon season in the coastal Odisha. Thus, within 10 km proximity of the sea, the soils are saline and waterlogged to various degrees. Rice is grown by the farmers in waterlogged soils for general amelioration of chemical fertility, preferential accumulation of organic matter and improved availability of micronutrients, which facilitates the long-term maintenance of soil fertility and sustainability of wetland rice systems (Sahrawat, 2008).

Perpetual waterlogging condition due to saucer shaped land and frequent floods occurring through active south-west monsoon every year remain victim for low productivity in coastal districts of Odisha. As a result, a large area remains mono cropped. According to the Food and Agriculture Organization (FAO), the overall water use efficiency for irrigated agriculture in developing countries averages to 38 per cent (Tropp, 2006). But even if the coastal paddy ecosystem in Odisha has 42 per cent irrigated area, poor delivery mechanism and ill maintenance limits the cultivation during rabi season. The problem of equity, timeliness and reliability and the low efficiency in regards to conveyance, distribution and application of irrigation are considered as a main cause for the low productivity, where there is sufficient scope of improvement (Singh, 1999). For instance, 10 per cent improvement in water use efficiency (WUE) will add 14 million ha of additional irrigation in India (Saleth, 1996).

Apart from waterlogging condition, there is wide spread salinity problem in the area also. Bringing these problematic areas under cultivation would be of immense help to improve agricultural scenario in the coastal area. Quantification of the available water resources, which is basic database for crop planning, is of paramount importance to bring sustainable agriculture in the area. Thus, an attempt is made in the present paper to investigate temporal rainfall and runoff status using two - parameter Gamma distribution function and USDA SCS CN procedure, respectively; prevalence of dry spell and wet spell conditions using Markov chain model, status on seasonal excess - deficit water condition using water budgeting procedure in a coastal paddy ecosystem in Pattamundai block in

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Kendrapara district of Odisha, which further can help in compiling strategic crop planning.

MATERIALS AND METHODS

Two parameter Gamma distribution function

The Probability Distribution Function (PDF) and Cumulative Distribution Function (CDF) of two parameter Gamma distribution function, which are used in the present study (based on best fitted χ^2 values), are described in Eqn. (1 and 2).

Two - parameter Gamma distribution

$$\text{PDF} = f(x) = \frac{x^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)}\exp(-x/\beta) \quad (1)$$

$$\text{CDF} = F(x) = \frac{\Gamma_{x/\beta}(\alpha)}{\Gamma(\alpha)} \quad (2)$$

Where, α = constant shape parameter (α>0), β = constant scale parameter (β>0), Γ and $\Gamma_{x/\beta}$ are the Gamma and incomplete Gamma functions.

Chi-square test for goodness of fit

The chi-square test, which is widely applicable to problems of significance of hydro-meteorological nature is used in the present study to test the significance level of data set. The test statistic is as follows.

$$\chi^2 = \sum_{i=1}^{k}\frac{(O_i - E_i)^2}{E_i} \quad (3)$$

Where, Oi is the observed frequency for ith observation, and Ei is the expected frequency

Markov chain probability model for dry and wet spell analysis

The dry and wet spell analysis was carried out using Markov chain probability model as described by Reddy *et al.*, (2008), which helped to establish drought frequencies on weekly basis. Initial and transitional probabilities using this model are computed as follows:

Initial probability

Probability of dry week = P(d) = F(d)/N; and Probability of wet week = P(w) = F(w)/N Where, F(d) = frequency of dry weeks; F(w) = Frequency of wet weeks and N = Total no. of years of data used.

Conditional probability

Probability of a dry week preceded by a dry week = P(dd) = F(dd)/F(d); Probability of a wet week preceded by a wet week = P(ww) = F(ww)/F(w); Probability of a dry week preceded by a wet week = P(dw) = 1- P(ww); Probability of a wet week preceded by a dry week = P(wd) = 1- P(dd)

Where, F(dd) = Frequency of dry week preceded by another dry week, F(ww) = Frequency of wet week preceded by another wet week.

Consecutive dry and wet week probability

Probability of two consecutive weeks are dry = P(2d) = P(dw_1) * P(ddw_2); Probability of two consecutive weeks are wet = P(2w) = P(ww_1) *P(www_2).

Where, P(dw_1) = Probability of first week being dry, P(ddw_2) = Probability of second consecutive week being dry given the preceding week dry, P(ww_1) = Probability of first week being wet, P(www_2) = Probability of second consecutive week being wet given the preceding week wet.

Estimation of surface runoff using USDA SCS-CN procedure

An attempt is made to estimate event based surface runoff using USDA SCS-CN method. The value of the parameter CN was considered as 95 for monsoon paddy crop as reported by USAID (1991). Rainfall and irrigation contribution, if any from the canal were considered together while computing daily runoff depth. Daily estimation of runoff from total event based rainfall in a 24-hour period was computed by reducing AMC (II) (Antecedent Moisture Condition II), curve number value by 5 units as suggested by Rao (1995) and Krishna Rao (2001). The value of curve numbers for AMC (I) and AMC (III) conditions were further modified based on 5-days antecedent moisture conditions as suggested by Chow *et al.*, (1988).

Direct runoff can be computed based on the following equation;

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}, \text{ when } P > 0.2S$$

Q = 0, when P < 0.2S

Where, Q = direct runoff, mm; P = storm rainfall and irrigation, mm and S = maximum potential difference between rainfall and runoff, mm

The initial abstraction, I_a = 0.2S was considered. For convenience in evaluating antecedent rainfall, soil conditions, land use and conservation practices, USDA-SCS (1972) defined

$$S = \frac{25400}{CN} - 254$$

Where, CN = Curve Number varying between 0 to 100.

Study area

The study area (Fig. 1) comprising of 837 ha situated in Pattamundai block of Kendrapara district of Odisha comes under Mahanadi-Chitrotpala-Luna-Birupa drainage sector and East & South Eastern Coastal plain zone. It lies between 86° 14′ - 87° 3′ East longitude and 20° 21′ - 20o 47′ North latitude. The climate is generally hot (maximum 42°C) with high relative humidity (90 per cent) during April and May and cold (minimum 14°C) during December and January. Pattamundai main canal and Gobari extension canal passes close proximity to the study area. Field drains executed by Command Area Development (CAD), Department of Water Resources, Govt. of Odisha in the study area have varied success in improving the waterlogged condition in the crop fields.

Data base

Twenty years of daily rainfall data (1990-2009), ten years of daily canal water release data (2001-2010) and five years of daily evaporation data (2004-2008) were collected from Office of the DAO, Kendrapara (Odisha); Office of S.D.O., Department of Water Resources, Pattamundai (Odisha) and CRRI, Cuttack (Odisha), respectively and analysed for assessing the temporal availability of water resources for crop production.

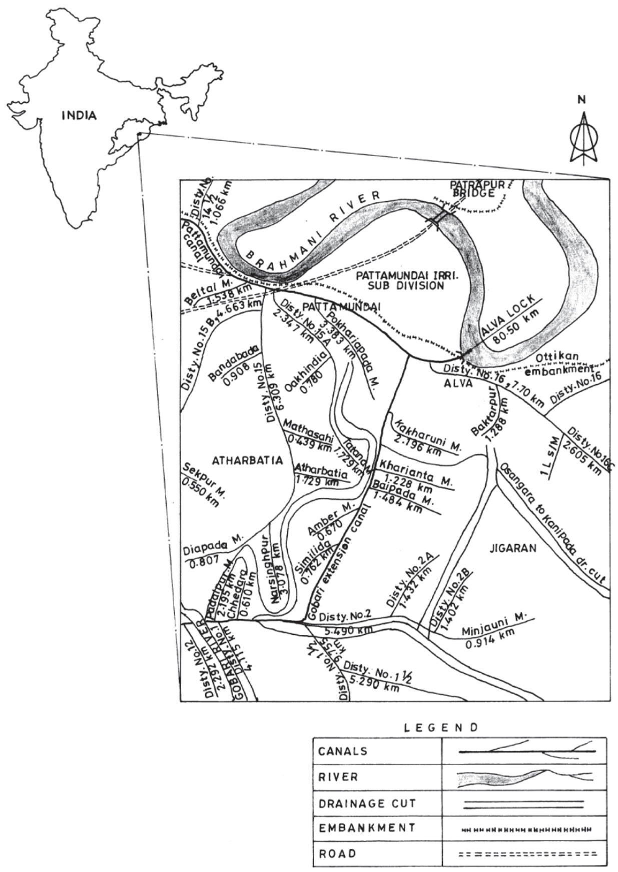

Fig. 1. Study area

RESULTS AND DISCUSSION

Present canal and surface drainage system and their functioning

A wide network of canal and field drainage system is being operated in the study area with varied degrees of functioning. The total length of primary, secondary and link drains comprising of 113, 452 and 342 km are working in Mahanadi-Chitrotpala-Luna-Birupa drainage sector. As to canal system, Pattamundai canal off takes from Kendrapara canal near Jagatpur, Cuttack (Odisha) with carrying capacity of 24 cumec and Kendrapara canal off takes from left side of Mahanadi barrage near Jagatpur, Cuttack (Odisha). After running 80 km distance, Pattamundai canal joins Gobari extension canal at its tail end near Alva (Fig. 1). The minors running in the study area are Kakharuni, Khadianta, Baipada and Amber and have lengths, CCA and design discharges varying between 0.7 - 2.2 km, 10.8 - 194.7 ha and 0.01 to 0.1 cumec, respectively. But practically, it is observed that much less flow is occurring in the minors due to either serious siltation or poor maintenance. Kakharuni Pani Panchayat is being operational since 2006 in the study area. Naladholia – Jigaran field drainage system having length of 3.5 km length helps in draining excess water from 837 ha area. As a result, total 745 nos. of farmers are being benefited from the drainage system. However, in spite of the active functioning of the Pani Panchayat, there have been many unauthorized outlets and farmers' are in practice of putting cross bunds across the minors for either catching fish or illegally diverting water to their crop fields, which is aggravating in reduction of the carrying capacity of the minors.

Table 1. *Socio-economic condition*

Category	Caste			Economic condition	
	General	OBC	SC	BPL	APL
Marginal (<2.5 acres)	18.6	3.4	20.3	42.4	–
Small (2.5-5 acres)	27.1	10.2	10.2	27.1	20.3
Medium (5-25 acres)	8.5	1.7	–	5.1	5.1
Total	54.2	15.3	30.5	74.6	25.4

Present land use pattern and socio-economic conditions

Out of the geographical area of 2.24 lakh ha of the study district, total problematic area is 1.68 lakh ha, respectively. As to total cultivated area, low, medium and up lands constitute to 49029, 71890 and 31081 ha, respectively. The district has mainly two varieties of soils viz. alluvial soil in the south-east and northern parts and normal strip of saline soil in the north-east along the coastal belt (District statistical handbook, 2007). Pattamundai block is predominant with low-lying and medium cultivated areas (76 per cent as against of total cultivated area of 15076 ha) and out of 11620 ha paddy area, lowland and medium land paddy area covers 83 per cent. Clay loam soil predominates 46.3 per cent area over total cultivated area, which remains for poor drainage situations during monsoon season. Total ninety per cent farmers are in marginal (< 2.5 acres) and small (2.5-5.0 acres) categories. Total 75 per cent farmers are under BPL category (DWM Annual Report, 2009-10). Due to lack of adequate in-situ water harvesting measures, there have been only 37 and 19 per cent coverage under crop during Rabi and Summer season, respectively.

Temporal rainfall distribution modeled through probability functions

Rainfall analysis for the period 1990-2009 revealed that average weekly rainfall varied between 6.5 - 102.3 mm, maximum of 102.3 mm occurring during 31st week (July 29 - August 4) followed by 89.6 mm during 32nd week (August 5 – August 11). Rainfall variability less than 100 per cent is observed during 25th - 27th, 33rd and 37th weeks implying uniform wetness period (Fig. 2). As to annual variations, there have been wide differences among the years with minimum, maximum and average rainfall of 461 mm (during 2002), 3271 mm (during 1997) and 1452 mm, respectively.

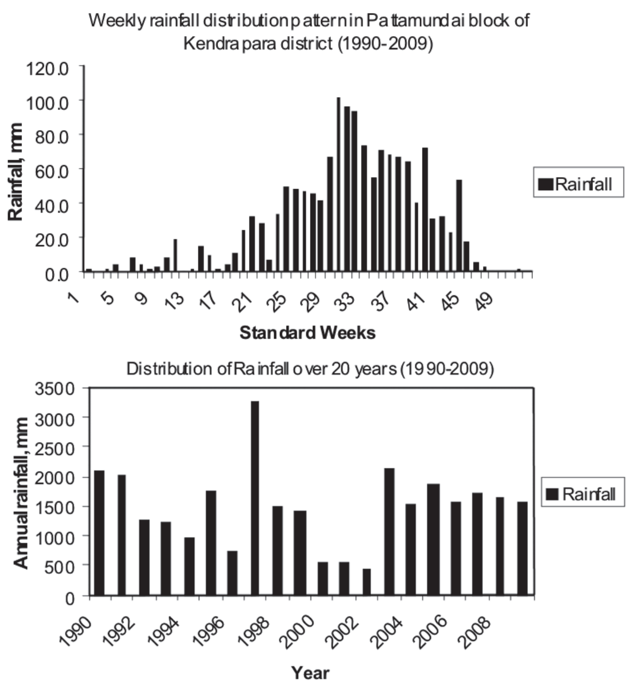

Fig. 2. Rainfall distribution pattern

Two-parameter Gamma, Normal, Log Pearson and Log Normal probability distribution functions were tested for modeling the rainfall distribution pattern. Among the distribution functions, when modeled through two-parameter Gamma distribution at 30 per cent probability level, there was no significant difference established between the observed and predicted weekly rainfall for the period (24th – 41st weeks) inferring the best fit distribution (Table 2 and Fig. 3). Both the data series were found no significant difference at $\alpha = 0.05$ level when tested through paired t-test. Same observations were also reported by Subash and Das (2004), while attempting to fit two – parameter Gamma distribution in standard weekly probability analysis of rainfall for Patna and was found best fit

Table 2. *Observed and predicted weekly rainfall at various probability levels using two - parameter Gamma distribution model*

Weeks	Observed data	Predicted data at different probability levels				
		30%	40%	50%	60%	70%
24	47.1	59.3	43.9	32.2	22.9	15.3
25	44.4	58.5	45.9	35.8	27.5	20.1
26	44.6	57.8	47.0	38.3	30.7	23.8
27	50.1	55.5	44.2	35.2	27.5	20.7
28	39.5	46.9	31.7	20.9	13.0	7.3
29	76.9	76.4	54.4	38.2	25.8	16.0
30	81.1	112.3	75.9	50.1	31.4	17.7
31	102.3	106.9	72.4	47.9	30.2	17.1
32	89.6	97.9	62.7	38.9	22.6	11.5
33	69.1	89.9	70.6	55.3	42.4	31.2
34	61.4	64.7	46.6	33.1	22.6	14.3
35	61.9	83.8	60.8	43.6	30.2	19.4
36	76.8	81.3	60.9	45.4	32.8	22.4
37	66.6	81.7	63.8	49.6	37.8	27.5
38	61.1	63.3	37.2	20.8	10.6	4.6
39	45.8	48.2	37.2	28.7	21.6	15.5
40	72.0	68.7	40.6	22.9	11.8	5.2
41	30.6	26.8	14.7	7.6	3.5	1.3

to the rainfall data series. Similarly, Sarkar (1994) found Gamma distribution as best fit to weekly rainfall, while estimating assured weekly rainfall at 30, 40, 50, 60, and 70 per cent probability levels for crop planning in the low water holding capacity soils of eastern Ganga plains of West Bengal. During the period, maximum, minimum, average and total rainfall were predicted as, 112.3 mm (31st week), 26.8 mm (41st week), 71.1 mm and 1280 mm as against of observed values of 102.3 mm, 30.6 mm, 62.3 mm and 1121 mm, respectively (Panda *et al.*, 2011).

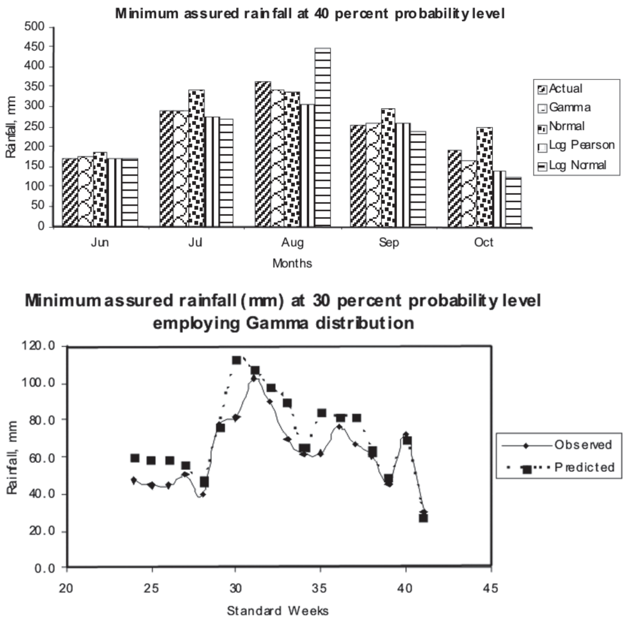

Fig. 3. Rainfall modeled through probability functions

Weekly dry and wet spell conditions

Initial and transitional probabilities were computed using Markov chain model (Fig. 4). Results revealed that the probability of occurrence of dry week is higher during 1st - 22nd, and 41st - 52nd weeks. The range of probability of occurrence of dry week in these weeks varies from 60 - 100 percent. The probability of dry week preceded by another dry week is higher during 1st - 23nd and 42nd - 52nd weeks, ranging between 69.2 - 95 percent. Probability of occurrence of dry week proceeded by wet week is 100 per cent during 1st - 14th, 16th - 18th and 47th - 52nd weeks. Probability of occurrence of wet week and the transitional probability of wet week preceded by wet week is higher during 23rd – 41st weeks with the range of probability varying between 40 - 90 percent. Probability of wet week preceded by dry week is higher in weeks 24th – 41st with the range varying between 45.4 - 83.3 per cent, implying vulnerability of dry spell of 17 - 55 per cent during the monsoon period. Consecutive probability of two wet weeks is varying from 31.8 - 75 per cent during 23rd – 40th weeks. The result infers that apart from the usual phenomena of prevalence of dry spell or wet spell during post monsoon and monsoon seasons, respectively, there is probability of occurrence of dry spell to the tune of up to 55 per cent during monsoon season. Thus it necessitates contingent plan through in-situ conservation measures for meeting the eventualities for crop sustenance.

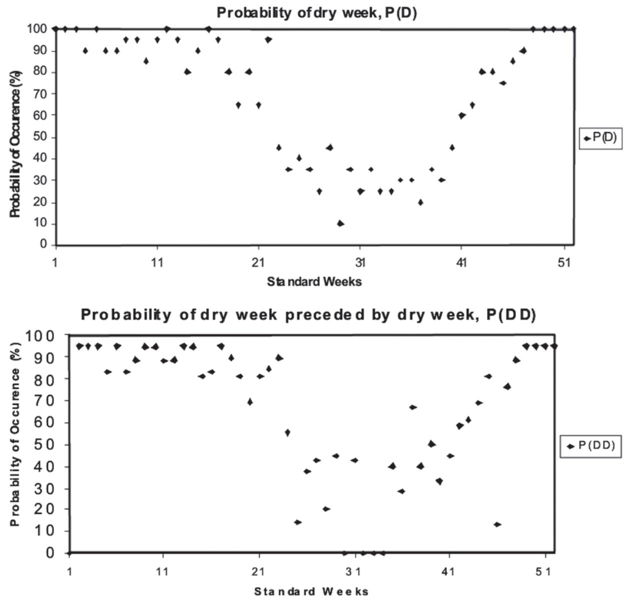

Fig. 4. Dry spell analysis using Markov chain model

Water budgeting

An attempt was made to budget the water for the study area. While budgeting through rainfall, irrigation and evaporation on weekly basis were used. When analyzing the canal irrigation water supply, as usual practices were noticed as prevalent in many other canal systems in the country elsewhere. Present canal water supply schedule (2006-2009) operated through the Department of Water Resources, Govt. of Odisha revealed that the supply of canal water continued from 2nd week of July - 3rd week of November, when almost 70 per cent of monsoon rain occurs; where as a short supply continued during 2nd week of January - 1st week of February during rabi season, when there is no rainfall (Fig. 5). There has been mismatch in occurrence of rainfall and canal water supply in the area. Water budget procedure revealed that total excess water of 1575 mm is available during 23th – 47th weeks (1519 mm) and 4th – 7th weeks (56 mm) with total deficit water amounting to 393 mm

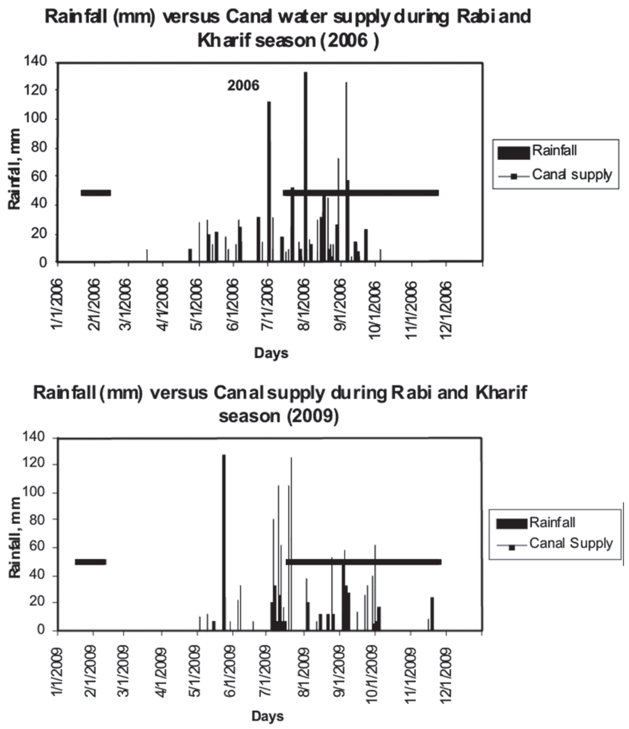

Fig. 5. Canal operational schedule of two representative years

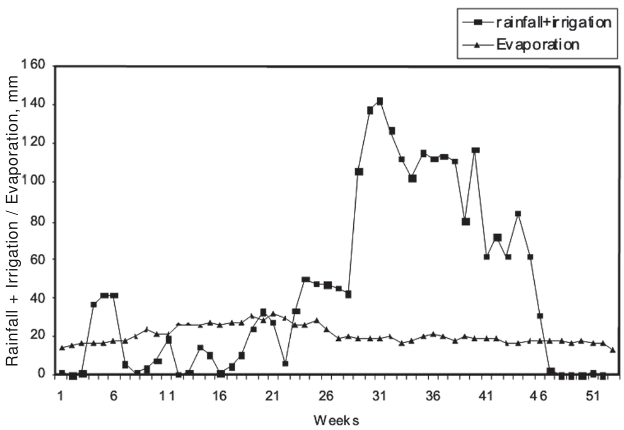

Fig. 6. Weekly water budgeting

occurring during 7th -23rd weeks (235 mm) and 47th – 3rd weeks (158 mm). Thus, there is gross excess water availability of 1182 mm occurring mostly during monsoon season (Fig. 6).

Predicted surface runoff

Event based runoff was estimated using USDA SCS CN procedure during period 1990 -2009. The result revealed that as against of maximum daily rainfall of 370 mm occurring during 1997, a runoff event of 358 mm is estimated. This emphasized for creation of adequate surface drainage provision in the study area for evacuating unprecedented runoff events.

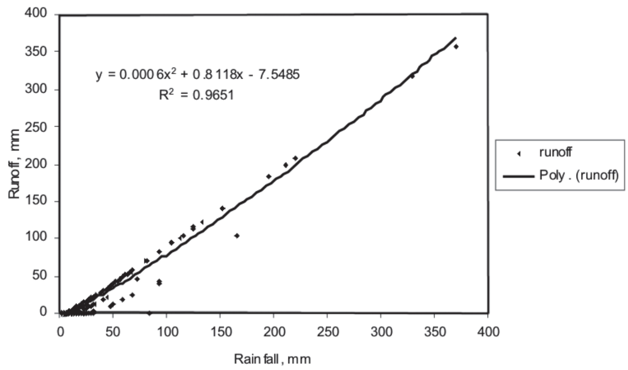

Fig. 7. Observed rainfall versus predicted runoff

An attempt was made to develop an empirical function for predicting the surface daily runoff through various best fit functional relationships without computing through the rigorous USDA SCS CN procedure. Total 255 data sets were randomly selected from the data series and among various functional relationships, 2nd order polynomial function i.e. Yrunoff = 0.0006Xrainfall^2 + 0.812 Xrainfall – 7.549, R^2 = 0.97, where, Xrainfall = daily observed rainfall, mm and Yrunoff = daily predicted runoff, mm (Fig. 7). This empirical relationship shall be useful in similar crop ecosystems in predicting daily runoff, which can help in planning and designing irrigation and drainage structures to accommodate the peak rainfall events.

CONCLUSION

Provision of creation of supplemental in-situ water harvesting devices for catering the need of monsoon crops at critical stages during dry spells and post monsoon crops, rescheduling of canal water supply with efficient delivery mechanism and adequate provision of surface drainage network are required in the study area to introduce diverse crop plan for higher productivity.

REFERENCES

Chow, V. T. (1988). *Handbook of applied hydrology*. McGraw Hill Book co., New York, U. S. A.

District Statistical Handbook (Kendrapara). (2007). Directorate of Economics and Statistics, Bhubaneswar, Orissa, p 107.

DWM Annual Report. (2009-10). Directorate of Water Management, Bhubaneswar, Orissa. pp 59-60.

Krishna Rao, B. (2001). Investigation on impact of rainfall distribution on runoff estimation using SCS CN method. *Unpublished M. Sc. Thesis,* IARI, Pusa, New Delhi.

Panda, R. K., Singh R., Kar, G. and Kumar Ashwani (2011). Resources appraisal of coastal paddy ecosystem of Orissa – A case study. In: Raychaudhuri *et al.*, (eds.) Souvenir, Seminar on *Water use in Agriculture; Challenges Ahead*, Indian Society of Water Management, Orissa Chapter, Directorate of Water Management, Indian Council of Agricultural Research, Bhubaneswar-751023, Odisha, India. p 10.

Rao, K. V. R. (1995). Runoff estimation from daily total rainfall using curve number method, *Unpublished M. Sc. Thesis*, IARI, Pusa, New Delhi.

Reddy, G. V. S., Bhaskar, S. R., Purohit, R. C. and Chittora, A. K. (2008). Markov chain model probability of dry, wet weeks and statistical analysis of weekly rainfall for agricultural planning at Bangalore, Karnataka. *Journal of Agricultural Sciences*, **21**(1): 12-16.

Sahrawat, K. L. (2008). Soil fertility advantages of submerged rice cropping systems. *Journal of Sustainable Agriculture* **31**(3): 5 – 23.

Sarkar, J. (1994). Crop planning on the basis of assured rainfall in low water holding capacity soils of eastern Ganga plains ecozone of West Bengal. *Mousam* 633 : 631.15 : 631.4 (541.2) : 194-195.

Singh, G. B. (1999). Natural resource management for sustainable agriculture in "Fifty years of natural resource management in India". ICAR, New Delhi.

Subash, N. and Das, P. K. (2004). Rainfall characteristics and probability analysis for crop planning under rice-wheat system in sub-humid (dry) climate. *Indian Journal of Soil Conservation* **32**(2): 124-128.

Saleth, R. M. (1996). Water institutions in India: Economics, law, policy, Common Wealth Publishers, New Delhi.

Tropp, H. (2006). Developing water governance capacities, Stockholm Water Front: *A Forum for Global Water Issues*, 2, Stockholm International Water Institute (SIWI), Stockholm, p 10.

USAID. (1991). *Drainage aspects of Eastern region and the Eastern coastal areas of India.* Technical Report No. 38, Louis Berger International, Inc. and WAPCOS (India) Ltd.