REVIEW ARTICLE

REDUCING HYDROLOGIC RISK IN *KHARIF* RICE FROM CARRYOVER EFFECT OF RAINFALL: A REVIEW

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Abstract: In agriculture, the primary production systems face the risk of failure. Therefore, a more in depth analysis is needed by incorporating useful plant and soil properties in for reducing water stress in *kharif* rice. The approach to determine effective rainfall in watershed could be more focused on the inter-relationship amongst plant, soil and climatic factors, considering the sensitivity of different plants to varying levels of water availability due to water transfer within watershed. Similarly, the assessment of water availability *vis-a-vis* growth risks could be done more realistically through water balance study. The best recommendation is suggested to reducing hydrological risk.

Keywords: Hydrologic risk, Rainfall, Water balance studies, Effective rainfall

INTRODUCTION

Rain or precipitation is the primary source of water, but it comes usually in short duration spells within a year, while the plants, need water throughout their life cycle. It is the soil which, during moisture stress periods, provides the supply of moisture of plants, provided sufficient moisture is stored in it. Thus, soil, plant and water are the primary factors which are involved in hydrologic risk analysis (Das, 1988).

Hydrologic risks to agriculture are mainly due to inadequate or erratic rainfall resulting in deficit water stress to crop plants. The susceptibility of agriculture production system to such risk can be accessed from the characteristics of rainfall, soil and plants being to be grown in given area. Besides direct availability of rainfall, a part of it is carried forward in time acting as cushion against water stress in absence of rainfall. This carry over moisture is viewed as the water shift within the watershed on time. There is another shift through the intervention of conservation practices which are adopted in the watershed to improve soil and water conservation and management. The moisture shift due to adopted water conservation measures takes place over space. The total of these moisture or water shifts help watershed enhance water retention, which is available to meet the plant water demand. Various hydrologic risk factors include rainfall, effective rainfall, carryover rainfall, runoff, water balance etc.

Research works carried out at different places are reviewed on hydrological risks assessment including rainfall, effective rainfall; carry over moisture/rainfall, water balance and their impact on crop and water resources on watershed basis. The prominent reviews are presented in subsequent sections.

Rainfall

Rainfall is the ultimate source of water and has great bearing on water resources management in watershed and the performance of crop has a direct relation with the availability of rainwater, particularly in rainfed areas. Generally probability analysis is made to assess the expected rainwater availability at certain probability of exceedence. Consequent probabilistic dry and wet spell also play an important role in crop planning. It is also necessary to study the variability of rainfall availability for effective crop and water resource planning. A lot of studies have been conducted on rainfall variability and its probabilistic aspect.

Subramniam and Srimannarayana (1991) carried out rainfall analysis in Madhya Pradesh. It was found that the coefficient of variation of annual rainfall was less than 20% for the eastern and south-western district of east Madhya Pradesh. In west Madhya Pradesh, the coefficient of variation of annual rainfall ranged from 25% over Seoni district in the east to nearly 40% in Morena district in the extreme north-west. Further, they concluded that the coefficient of variation of rainfall was very high in winter, hot weather and post-monsoon season over the state.

Ghadekar and Thakare (1991) studied characteristics of rainfall of Nagpur region for crop production and cropping patterns. They concluded that the mean rainfall of the *Kharif* season was 831.5 mm (CV 20.8%) with 52.3(CV 17.3%) rainy days. Further, it was found that cropping seasons of 13 weeks (25^{th} to 36^{th} SMW) with dependable rainfall at 75, 80, 85 and 95% probability levels were most assured and risk free.

Upendra Shankar *et al.* (1993) analyzed rainfall for Jabalpur region of M.P. for a period of 1951-89 with reference to length and date to south-west monsoon, total annual rainfall and optimum sowing dates for long, medium and short duration crops and accordingly cropping plans were suggested.

Subramaniam (1994) used the rainfall data of 90 years period from 1901-1990 to examine the possibilities of various meteorological sub-divisions to recover its

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June-July deficiency during the later half of the south-west monsoon period. The study revealed that east Madhya Pradesh recovers its June-July rainfall deficiency in September with a relatively high percentage (21%) whereas; in the Madhya Pradesh the deficiency worsens further in September (7%).

Mishra *et al*. (1996) analyzed rainfall data for Chotanagpur Platau of Bihar using the rainfall record from 1967-92. The range, mean, standard deviation and coefficient of variation for weekly, monthly, seasonal and annual rainfall were calculated. The variation in monthly rainfall was October > June > September > August > July. During June to September, at least 826 mm rainfall was predicted at 80 percent confidence level. The analysis also revealed that sowing of paddy varieties with a maturity period of 80-95 days should be completed in June, while shorter (70-85 days) varieties can be sown later.

Kalaiselvan *et al*. (1996) suggested cropping system for early, normal and late rain condition by analyzing rainfall data for a period of 15 years (1973-88) of Viddhachalam taluka of Tamilnadu.

Chaudhary and Tomar (1999) determined the rainfall pattern over 12 Stations of Baster districts in erstwhile Chhattisgarh region of Madhya Pradesh by analyzing 40 years of rainfall data (1957-86) and relationship between rainfall and rice yields were worked out. Weekly mean rainfall of 50 mm for lowland and 75 mm for upland with coefficient of variation less than 100% was considered as stable rainfall period.

Jadav *et al*. (1999) analyzed the rainfall probability for crop planning in scarcity zone of Maharashtra. The rainfall data of 30 years (1966-1995) was analyzed for rainfall amount at various probability levels (30, 60, 70 and 90%) for weekly, monthly, seasonal and annual trends at Solapur. They found that on an average, annual rainfall of Solapur region was 723.4 mm received in 43 rainy days. The mean monthly rainfall of Solapur was 113.3, 127.7, 140.3 and 172.3 mm in the months of June, July, August and September, respectively with the total monsoon rainfall of 553.8 mm. The seasonal rainfall for these months accounted for 76% of the annual rainfall. The monthly coefficient of variations ranged between 55-226%.

Janendra *et al*. (1999) analyzed rainfall data for 27 years of Kotagarh, Orrisa. The average rainfall at Kotagarh was estimated to be 1387 mm and average rainy days were found as 67 out of the total rainfall 81% of the annual rainfall received during June-September. Selection of crop cultivar with growing seasons in June-September was recommended.

Hundal and Kaur (2002) examined annual and seasonal climatic variability at different locations of Punjab state. The rainfall variabilities were analyzed from historical daily meteorological data for Amritsar (1970-98), Patiala (1970-98), Ludhiana (1970-99) and Bathinda (1977-98). It was found that the annual as well as seasonal rainfall exhibited high standard deviation and coefficient of variations indicating large variations in rainfall at all stations. The five yearly moving average trends in rainfall showed an overall increase of about 120 mm at Amritsar, 150 mm at Ludhiana, 150 mm at Patiala, and 140 mm at Batinda.

Singh and Lal (2005) investigated rainfall as one of the most important weather factors that control the crop productions in rainfed areas. The daily rainfall data for 28 years (1972-99) as recorded at agromet observatory Sabour, Bhagalpur were analyzed for annual, seasonal, monthly and weekly periods. The probability of 10, 20, and 40 mm rainfall per week exceeded 60% between 19^{th} and 41^{st}, 24^{th} and 40^{th} and 26^{th} and 39^{th} standard meteorological weeks, respectively. The overall mean annual rainfall was computed as 1185.3 mm, of which 954.0 mm, 105.2 mm and 126.2 mm were received in *Kharif*, summer and *Rabi* seasons, respectively. The highest rainfall (320.5 mm) was recorded in July and the lowest (7.52 mm) in December. About 87% of the total annual rainfall was observed between 22^{nd} to 41^{st} weeks. Months from July to August are regarded suitable for transplanting of paddy. In the upland situation, where three crop sequences are followed, the third crop should, however, be sown before the end of October.

Bhakar *et al.* (2006) carried out rainfall analysis for drought estimation of Udaipur region. He stated that in regions, where rainfall is erratic and frequent, temporary drought conditions are expected within the monsoon season also. Therefore, rainfall analysis for drought estimation is helpful in crop planning accordingly. In the study, normal, abnormal and drought months were determined for the period of 1981-2005 for Udaipur region. Out of the rainfall record from 1981-2005, a total number 12 months were observed as drought months during the rainy season. Probability of occurrence of 6 drought months in a year was 96% and for 10 months, it was 4%.

Singh and Kaur (2007) analyzed daily rainfall data of 36 years for Kulu and Solan districts of Himachal Pradesh and weekly, monthly, yearly and seasonal rainfall were worked out for all the years of the record. The analysis revealed that solan received average annual rainfall as 1315.6 mm and Kulu as 948.5mm. As per the seasonal distribution of the rainfall, 17,8%, 66%, 2.6% and 13.5%, of the annual rainfall were received in Solan, whereas in Kulu, 29.9%, 41,8%, 5.7% and 22.6% of the annual rainfall were received in summer, south-west, north-east and winter season, respectively. During the study, more than the normal rainfall was received in 7 years and less than normal in 24 years in Solan, whereas Kulu received more than normal in 4 years and normal or less than normal in 27 years. At both of the places, July was found most wet and November was most dry month. Solan had 50% month normal, 39%, abnormal and 11% dry, where as in Kulu, it was 62, 30, 8%, respectively, In solan, out of total abnormal months, 66% of the time observed during Oct-May and at Kulu it was observed 65% during Sept-Jan. The probability of rainfall in one week (10, 20, 75mm) was observed in Solan during 25-30 weeks, whereas in Kulu, it was maximum in 26-36 week. During this period the rainfall water can be stored in ponds so that it can be used for irrigation.

Chand *et. al.* (2011) analyzed rainfall data for the period of 34 years (1975-2008) for Jhansi in Bundelkhand agro-climatic zone of U.P. and weekly, monthly, seasonal and annual probabilities at different levels of rainfall were worked out for suitable crop planning. It was found that 90.3% of the total annual rainfall is received during SW monsoon months (June-September) with high intensity causing moderate to severe erosion. Post monsoon or winter months (October to February) accounted 7.1 %, while pre-monsoon or summer months (March-May) accounted 2.6 % of total yearly rainfall. Analysis also showed that the frequency of drought has increased since the year 2000 onwards in the zone. The maximum amount of rainfall was received during August (286.0mm) and minimum in April (3.1mm) month. Occurrence of 70 % of initial probability of a dry week from 1 to 24th week and the conditional probability of wet week preceded by a wet week was also high from 26th to 37th week. The *Kharif* season crops and their varieties may be chosen with the growing period to avoid moisture stress and in-situ moisture conservation practices like mulching, use of anti-transparent, control of weeds, adequate plant stands should be adopted and to mitigate the effect of dry spell during critical crop growth stages, life-saving or supplemental irrigation through use of sprinkler system should be provided. The sowing of rainfed crops in *rabi* season may be completed between 40th to 41st standard weeks because subsequent week has rare chance to get rains. It was also indicated that the pulses and oilseeds, whose average water requirements are 300 mm, could successfully be cultivated during *rabi* season.

Gowda *et. al.* (2011) analyzed monthly and annual rainfall data of 17 stations located in 3 districts of Karnataka falling under the Bhadra Command Area (BCA) for a period 1975-2005. In the study, statistical parameters like mean, standard deviation, coefficient of variation and coefficient of skewness for monthly and yearly rainfall data were determined. The average depth of rainfall over the command area was computed by arithmetic mean, Thiessen Polygon and Isohyetal methods. The coefficient of variation (CV) of annual rainfall was found to vary from 14% to 83%. The co-efficient of variation (CV) and coefficient of skewness (CS) of annual rainfall were found to be non-symmetrically distributed at all stations. The average depths of annual rainfall over the study field calculated from different methods were found to be 769.5 mm, 612.20 mm and 686.54 mm, respectively. It was found that the monsoon (June–September) rainfall contributed about 55% of the mean annual rainfall**.** But the results of 3 yearly and 5 yearly moving average curves also showed increase in rainfall trend over the study area.

Effective rainfall

The effective rainfall is that portion of the total rainfall amount that is used by crop plant for its growth and development. Many workers have studied the effective rainfall and its impact on crop performance and water resource management.

Tsai et *al.* (2005) carried out a study on effective rainfall for paddy fields in Taiwan based on the practical model of planned effective rainfall. In this study, a method was developed for paddy crop to predict the planned effective rainfall based on gate operation management system used in the Taoyuan Irrigation Association, Taiwan. The practical model for rotational irrigation developed in this study considered the effective height of the border ridge of farm parcels in the irrigation plans. To estimate the planned monthly effective rainfall, the best-fit distribution of monthly effective rainfall was first determined; then the value of the 75 % of the probability of occurrence was used for the analysis. The calculated monthly effective rainfall was found as 113 % of the value used by the gate operation management. The study concluded that the high limit of effective rainfall depth can be increased from 30 mm to 42 mm to raise the planned effective rainfall.

Rahman *et al.* (2008) carried out a study on effective rainfall for irrigated agriculture in south-eastern part of Bangladesh. In the study, four different methods were used for estimating effective rainfall in Bangladesh. Effective rainfalls were estimated for the 10 meteorological stations of Bangladesh, covering south-eastern part of the country. By using different climatological data, effective rainfall were estimated for two crop growing seasons i.e. *Kharif* (July to October) and *Rabi* (December to March). The study revealed that the value of effective rainfall percentage for *Kharif* season varies. It was also observed that as the distance from sea increases, the value of effective rainfall percentage also increases. While designing an irrigation project, optimum utilization of irrigation water can be achieved by using the effective rainfall values.

Adnan and Khan (2009) studied effective rainfall i.e. useful rainfall for irrigated agriculture plains of Pakistan**.** In agriculture, effective rainfall is that portion of the rainfall amount that directly satisfies crop water requirements. Four different methods were used to estimate effective rainfall using data from 58 meteorological stations covering irrigated plains of Pakistan. The effective rainfall was estimated for two crop growing seasons, i.e. *Rabi* (October to April) and *Kharif* (May to September). It was observed in the study that effective rainfall values for *Rabi* and *Kharif* season varied widely from 13.03% and 21.31% at humid zone of northeastern Punjab to 100% at several stations, by Renfro equation method, 43% and 30% at humid zone of northeastern Punjab, 99.86% to 100% at central Sindh by U.S Bureau of Reclamation method, 17.57% at humid zone of Northwestern Front Province (NWFP), 98.98% and 99.93% at arid zone of southwestern Sindh and Balochistan by Potential Evapotranspiration Precipitation Ratio method and 54.40% and 60% at arid zone of southern Balochistan to 100 % at several stations by U.S.D.A, SCS method respectively. Murree had the lowest amount of effective rainfall. It was also observed that the effective rainfall is directly proportional to consumptive use, water storage capacity and irrigation application. Renfro equation was not found suitable for short term planning.

Chen *et al.* (2013) studied the agricultural effective rainfall for irrigating rice using the optimal clustering model of rainfall station network. The optimal clustering model of effective rainfall comprised of self-organizing map (SOM), k-means (KM), and fuzzy c-means (FCM) clustering algorithm. The results showed that the SOM clustering with groups three was the optimal model for prediction of effective rainfall.

Naeini *et al.* (2013) estimated effective rainfall using ANNs, WNNs and PSONNs models. For this purpose, by applying the SCS method, effective rainfall of monthly statistics data of Tabriz meteorological station from 1982 to 2008 was computed. The data of the reference evapotranspiration, precipitation, maximum and minimum temperature, relative humidity and wind speed were used in models for various scenarios. 240 series of the monthly data were used for training and 84 series of the monthly data were used for testing models. It was found that PSONNs performed better in the forecast of the effective rainfall from aerologic data. Relative humidity in ANNs, wind speed in WNNs and precipitation in PSONNs were found the most effective aerologic parameters, which were not in SCS equation.

Carry over rainfall

Precipitation and rainfall is the primary source of water but rain generally comes during short spell within a year while the plants need water through their life cycle. In absence of rainfall during the period, soil which acts as store-house comes to aid plant during the rainless period by supplying moisture from 'carry over' effect of rainfall received in preceding days on the soil moisture retention in succeeding days. This soil hold water coming from preceding rain is called 'carry over' rainfall. Not many research works are found in literature of carry over rainfall.

Das (2009) worked on reduced hydrologic risks to plant growth from carryover effect of rainfall within a watershed. Using data from two watersheds of Sahibi catchment of Rajasthan, the effect of the time space transfer of carry over rainfall on removing water stress in some weeks and total utilization of such water for agricultural production system was studied for the watershed, namely Tatarpur and Pithalpur. It was observed the carry over rainfall in the succeeding weeks augmented the water availability for plants during rainless period. On an average over 12 years during crop growth period (22nd to 41st SMW) an amount of 217.83 mm for Tatarpur 215.80 mm for Pithalpur was worked out as carryover rainfall from previous wet spell. These amounts of carry over rainfall were found to be 43.5 % and 43% respectively of the total monsoon rainfall of the 500.20 mm. Though this augmentation of moisture supply to plants during rainless period was not uniform over all the weeks of growth period but it certainly helped the plants in critical growth stage. The method based on carryover rainfall and on land transfer of rainfall was used to plan watershed management interventions and to assess the impact of soil water conservation measures including water harvesting and recharge of groundwater.

Runoff and Soil Loss

Runoff is that portion of the rainfall which flows on the ground surface after satisfying losses in terms of interception, infiltration, depression and channel storages. It is therefore necessary to manage this runoff on watershed basis so that it can be used for the benefit to the agriculture, particularly in rainfed areas. Similarly, soil loss is caused by the runoff causing erosion if not managed properly. Several studies have been conducted at many places in India as well as abroad to quantify the runoff potential and soil loss due to erosion of the soil by flowing runoff.

Thakur (2004) used SCS Curve Number model in GIS environment to estimate runoff generated in Chhokranala watershed in Raipur district of Chhattisgarh state. Soil loss due to runoff was also estimated by applying modified universal soil loss equation (MUSLE) and based on the estimated runoff and soil loss, critical sub-watersheds were identified and prioritized for planning implementation of soil and water conservation and management plans. Critical sub watersheds were identified on the basis of average annual sediment yield. The remote sensing satellite data were interfaced with GIS software for extracting the information used in runoff and soil loss estimation. The study revealed that the SCS-CN model and MUSLE could successfully be used for identifying and prioritizing critical sub-watersheds.

Rahangdale (2005) estimated the soil loss and surface runoff and then applied to evaluate the performance of soil conservation structures of *Chhokra nala* Watershed in Chhattisgarh state. The value of curve number for *Chhokra nala* watershed was determined and CN method was validated. Adequately validated USLE was applied for estimating the soil loss. The performance evaluation of soil conservation structures was carried out on the basis of soil loss from watershed. Estimated value of soil loss for five events was compared with their counter parts results revealed that USLE was capable of estimating soil loss on event basis from the *Chhokra nala* Watershed Satisfactorily. Similarly CN Number method was also found acceptable for estimating surface runoff on event basis from *Chhokra nala* watershed and the value indicated that there was a good agreement between estimated and observed runoff values. Based on the resulting CN method soil and water conservation plans were suggested for the watershed.

Mishra *et al.* (2012**)** studied that assessment of design runoff curve number for a watershed. A simple approach was suggested for derivation of the design runoff CN for different durations, wetness conditions, and return periods for use in the SCS-CN methodology. The derived design CN values were tested for their validity using the design runoff estimated conventionally from the observed data. The match between the design CN (for dry condition)-generated runoff and the conventional design runoff was found to be satisfactory for all return periods and rain durations for the studied watershed.

Water Balance Studies

A water balance studies are used to describe the flow of water in and out of a hydrological system such as watershed, drainage basin. Water balance has wider application in crop and water resources management in a watershed. Water balance of the watershed provides information about periodic shortages or surpluses of water. In the last two decades, a number of studies have been conducted on water balance in the watersheds.

Chakraborti *et al.* (1990) conducted an agro-climatic study in Hoogly district of West Bengal by analyzing rainfall data for a period of 60 years (1920-85). A water balance approach was found quite effective to assess the water availability period for crop planning under rainfed condition.

Hassan and Bhutta (1996) evaluated various recharge component of a groundwater reservoir to estimate the long-term average seasonal groundwater recharge in Rechna doab, Pakistan. A regional lumped water balance model was developed and applied to estimate the long-term seasonal recharge to a groundwater reservoir. For comparison, recharge was also estimated by a specific yield method from observed groundwater levels. A water balance study was accomplished on seasonal basis (6 months) for a period of 31 years (1960-1990). The average value of groundwater recharge during *kharif* (April-September) season was found to be 60 mm. No recharge occurred during *rabi* (October – March), rather there was a depletion of the groundwater reservoir during the winter months. It was concluded that on regional basis, the groundwater reservoir was depleted and resulted in an average groundwater table fall of 2.3 m over the 1960-1990 period.

Ranade *et al.* (2003) had done water balance study of water harvesting tank located at Pipliyahana watershed at the boundary of College of Agriculture, Indore, Madhya Pradesh, India. It was found that the maximum utilization of harvested of water was for irrigating different crops during the stress period. Similarly evaporation from water surface of the tank was one of the main factors responsible for depletion of tank water storage. The data analysis reveled that approximately 1257.05 m^3 of water was lost through evaporation which could have otherwise been utilized for providing extra irrigation to cropped area. It was concluded that the present site is very much suitable for the water harvesting tank, as the seepage rate was found to be only 1/10 to that of total storage volume available.

Singh *et al.* (2004) assessed water balance of Nana Kosi watershed in Uttaranchal, India. The water balances were then used for computing seasonal and geographical pattern of water availability to facilitate better management of available water resources. The water balance using the Thornthwaite and Mather model with the help of remote sensing and GIS was worked out to determine the period of moisture deficit and moisture surplus for entire the basin. The study indicated that there was an annual deficit of 288.56 mm and an annual surplus of 307.76 mm in the study basin.

Kothari *et al.* (2007) computed water balance of Bhilwara district of Rajasthan using daily meteorological data of 45 years (1960-2004) by Thornthwaite book keeping technique. The studies revealed that on annual basis, the region require 1691.3 mm water, whereas the rainfall was 669.1 mm. The actual evaporation in the region was 476.6 mm and water deficit 1214.7 mm. The water surplus was 189.6 mm during 31st to 36th week and water deficit in remaining meteorological weeks. The entire *kharif* season was free from ware deficit during the normal years whereas in *rabi* season, water deficit was worked out to be 481.8 mm.

Kumambala *et al.* (2010) worked on sustainable water resources development of Malawi lake of Eastern Africa. They reported that a thorough assessment of the impact of climate change on the future water levels of Lake Malawi is necessary because Lake Malawi together with its out flowing Shire river water system is Malawi's most important water resource for hydropower generation, water supply for industrial and domestic use in the city of Blantyre and its surrounding urban areas together with irrigation water in the Lower Shire Valley (LSV). Any changes in the hydrological or ecological behavior of the lake will have far reaching consequences on the economy of Malawi. They also reviewed the literature on the water balance studies of Lake Malawi and introduced climate change modeling into the water balance model to assess the likely future behavior of the lake.

Singh *et.al.* (2010) carried water balance studies for crop planning in Ranchi, Jharkhand**.** They analyzed 35 years of rainfall data to quantify the rainfall efficiency for increased production for Ranchi region. It was found that no surplus water was recorded during driest year. In respect of coefficient of variation, the month of July registered the lowest coefficient of variation as 35% followed by August (38%) indicating lesser variability during this month. The threshold level of coefficient of variation ranged from 50 to100% in April to October and indicated the dependability of rainfall in these months as compared to other months. The maximum length of growing season as 28 weeks and minimum as 12 weeks was recorded. In normal conditions, the length of growing season was recorded as 18 weeks. Short duration paddy variety Birsa Gora-101, maize, *i.e*., Devki, Ganga-11, Suran and *kharif* pulses were found suitable for the region.

Wang (2012) studied annual water storage changes at 12 watersheds in Illinois based on the long-term soil moisture and groundwater level observations during 1981–2003. Storage change is usually ignored in mean annual and inter-annual water balance calculations. However, the inter-annual variability of storage change could be an important component in annual water balance during dry or wet years. Annual precipitation anomaly was partitioned into annual runoff anomaly, annual evaporation anomaly, and annual storage change. The estimated annual storage change ratios were found to vary from 60% to 40% at the study watersheds. The inter-annual variability of evaporation was not strongly correlated with the inter-annual variability of precipitation, but was correlated with the inter-annual variations of effective precipitation. As a response to the inter-annual variability of precipitation, the inter-annual variation of evaporation was found smaller than those of runoff and storage change.

All the reviews discussed here in focus on the importance of each of the criteria for efficient soil, crop and water management in a watershed.

CONCLUSION

Based on water balance analysis surplus and deficit of rainfall are find out and water resources conservation and management plans have been developed. Reviews highlight the importance of soil and water conservation and management based on different components of the water balance including rainfall, runoff, and carryover rainfall etc. for achieving highest reward from various crops under limited resources.

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