Climate information contributes to better water management of irrigated cropping systems in southern India

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Abstract

Irrigated crop production systems in Southern India are exposed to high year-to-year rainfall variability. Most of the rainfall is received during the summer (June-September; 33%) and winter (October–December, 47%) monsoon seasons, respectively. Over the last five decades, cropping patterns on small farms in this region have undergone substantial change – from less-intensive millets to semi-intensive cereals (rice, maize) and commercial crops (cotton and sugarcane) with high water requirements. Farmers exploit scarce groundwater resources to manage production uncertainties to improve household food and financial security. As a result, water tables have fallen by up to 25-30 meters in one decade. This alarming over-exploitation of groundwater has reduced the resilience of the production systems and increased the vulnerability of the farming population. The water table depth in the study region varies with seasonal rainfall. Analysis showed that the ground water table is responsive to interannual rainfall variations that are also influenced moderately by El Ni?o-Southern Oscillation related phenomenon. Our calculations show that irrigation requirements for a 120-day summer monsoon maize crop increase as the season progresses, particularly during an El Nino. An associated reduction of groundwater recharge during the season might limit the area under irrigated maize. The ability to anticipate groundwater recharge based on ENSO phases, has implications for crop selection and irrigation decisions in the dry (February-May) season and subsequent summer monsoon (June – September) following the winter monsoon. In El Ni?o years, increased water deficit during the summer monsoon increases the benefits of supplemental irrigation. Stakeholder meetings communicated the potential application of climate information for risk management to farmers and community workers. Our preliminary work describes a framework to use climate information for risk management in irrigated cropping systems in a highly vulnerable area. Additional research work is needed to find out the interaction between rainfall and ground water recharge conditioned by El Ni?o-Southern Oscillation.

Media summary

Using El Ni?o-Southern Oscillation (ENSO) based climate information can reduce climatic risk, increase on-farm water use efficiency and improve the resilience of irrigated cropping systems in southern India.

Key Words

Climate information, ENSO, irrigated cropping systems, Maize, Southern India

Introduction

Groundwater, the most assured widely available source of irrigation water, influences India's industrial and agricultural growth (Rao et al. 1996). About 12.5% of India's annual precipitation percolates into the groundwater (about 420 million ML per annum), where it is protected from evapotranspiration and regenerates flow into rivers. Demand for water by the agricultural, domestic and industrial sectors has increased tremendously over the years, resulting in excessive exploitation of groundwater resources. The number of wells has increased from 7.78 to 9.98 M (dug out), 2.13 to 4.77 M (shallow tube) and 33.3 to

49.1 M (deep tube) over the last 10 years. Continuous cropping reduces potential recharge by reducing downward flux of rainfall (O'Connell et al. 1995). Although vast, India's groundwater resources are not inexhaustible, as evidenced by continuous decline in groundwater levels in regions such as the Coimbatore District in western Tamil Nadu.

Efforts to ensure effective utilization and augmentation of water resources have not achieved the intended benefit. In many years, farmers lose their investment in production inputs and are forced to abandon their crop due to lack of water mid-season. Hence, it is important to devise suitable techniques to manage climatic risk and optimize the use of scarce groundwater resources. The aim of the study is to assess the impact of ENSO-related climate variability on rainfall, groundwater resources and irrigation requirements, and to explore applications of this information to irrigated crop production systems in the semi-arid western agro-climatic zone of Tamil Nadu.

Material and Methods

Description of the study area

The region selected for the study is the Coimbatore district (10?12'to11?24' N, 76?39'to 77?30' E) of Tamil Nadu State in Southern Peninsular India. Of the district's 746,800 hectares, 43% is cultivated. The region's climate is classified as hot semi-arid. The dominant soils are red (Alfisols) and black (Vertisols). Lack of irrigation water results in 20% of arable land left fallow in any year. The major agricultural crops in this region are sorghum, maize, rice, pulses, sugarcane, peanut and cotton. Tanks, canals and wells are major sources of irrigation water. The district has 77 small to medium tanks, most of which are poorly maintained. Groundwater from 94,271 open wells is the dominant source of irrigation. Bore wells are often dug to depths of more than 300 meters. Significant ground water recharge is taking place during winter monsoon season due to water storage in the check dams, tanks and percolation ponds at watershed scale. Rainfall received during south west monsoon is also a factor influencing water table depths, but not substantial compared to winter monsoon.

ENSO response analysis

Water level records (1997-2002) from control bore wells installed at 47 locations throughout the Coimbatore district were used to map the spatio-temporal variability of groundwater levels. ENSO phases were categorized based on 5-month running means of spatially-averaged SST anomalies in the NINO3.4 region of the tropical Pacific (Sittel 1994). A year was considered as 'warm' (El Ni?o) if SST anomalies were > 0.5?C, and 'cold' (La Ni?a) if < -0.5?C for at least six months, including October-December (Trenberth 1997). Monthly rainfall and potential evapotranspiration (calculated using the Penman-Monteith method) associated with each ENSO phase were compared. Influence of ENSO phases on calculated water balance components for an irrigated maize crop was evaluated in a similar manner.

Results and discussion

Spatio-temporal variability in water table levels

Considerable variation in water level (metres) from the ground surface was observed. In about 40% of the total 746,800 hectares, the water table was more than 15 meters below the surface. The water table is deeper during the March-May pre-monsoon period, due to a lack of recharge and exploitation of groundwater for irrigation purposes during the dry season. The water table becomes shallower during the winter (December-January) due to recharge during rainy months, in spite of substantial irrigation withdrawals.

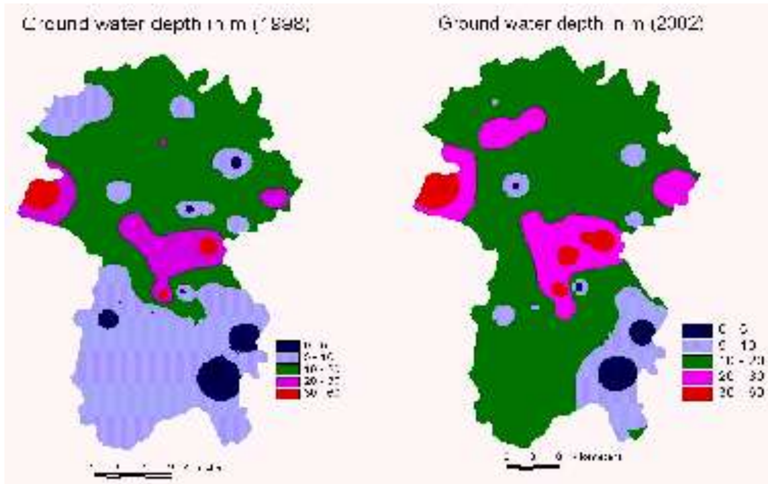

Figure 1. Spatial variation in groundwater table depth (m below the surface) in December during an illustrative high (1998) and low (2002) rainfall year, Coimbatore district, Tamil Nadu, India.

The observed groundwater table depth across the district is associated with inter-annual rainfall variability. Figure 1 illustrates the spatial pattern of water table depths in the Coimbatore district in two contrasting years. The December water table was substantially shallower in 1998 due to high rainfall compared to 2002. The total rainfall received during summer and winter monsoon seasons of 1998 was 567 mm compared to 385 mm in 2002.

ENSO, Rainfall and Water Requirement

Average rainfall in the study region is associated with ENSO phases. On average, summer monsoon (June-September) rainfall was 18% lower during warm than during cold ENSO years (Table 1). Conversely, mean winter monsoon (October-December) rainfall was 40% greater during warm than during cold ENSO years, leading to greater groundwater recharge (Figure 2). In seasons of low summer monsoon rainfall during warm ENSO years, potential evapotranspiration is increased by 0.8 mm/day, indicating higher irrigation requirement. Calculated October-December potential evapotranspiration did not vary significantly among the ENSO phases.

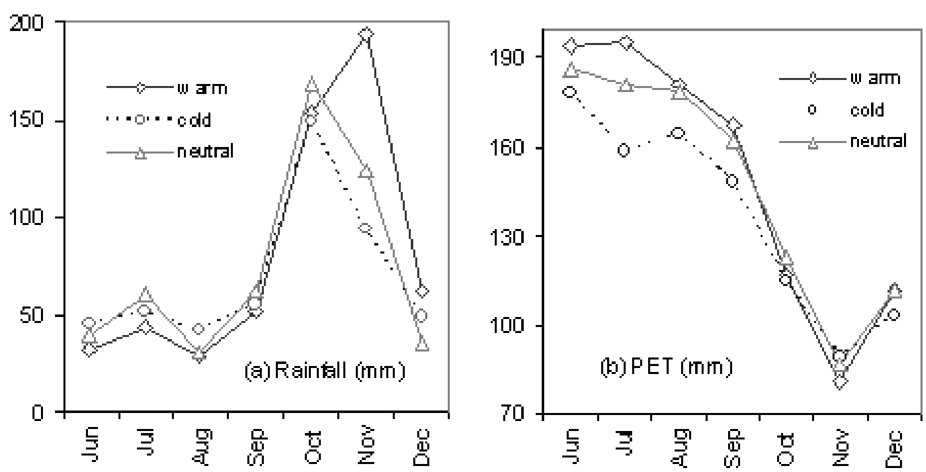

Figure 2. Average monthly rainfall at Coimbatore and potential evapotranspiration (PET) in different ENSO phases.

Crop evapotranspiration (ETc) and irrigation requirement were calculated for a maize crop grown during the summer monsoon (June-September; *kharif*) in the study region. The calculations were based on a 120-day maize cultivar grown under irrigated conditions, in a medium-deep soil with available water holding capacity of 140 mm. The cropping season starts during first week of June and ends during the last week of September. Average climatic parameters from warm, cold and neutral ENSO years were used for calculating irrigation requirement. Consistent with typical practices, an irrigation event fixed at 50 mm was simulated whenever the available soil moisture reaches 50% of capacity.

The warm phase increased calculated crop evapotranspiration by an average of 14% resulting in a need for increased irrigation (Table 1). Reduced rainfall combined with increased evapotranspiration is likely to reduce or even prevent ground water recharge. The ground water recharge is not happening only due to direct rainfall, but the water storage in local water harvesting structures like tanks, percolation ponds also influences indirectly through giving enhanced opportunity time for infiltration.

Table 1. Water balance components for irrigated maize (June-September) under ENSO composites.

Particulars	Warm	Cold	Neutral
Effective rainfall (mm)	161	196	198
ETcrop (mm)	640	562	615
Total gross irrigation requirement (mm)	600	450	500
Irrigation efficiency (%)	77	83	82

Decadal (10 days) irrigation requirement calculations for a 120-day maize crop showed increasing water requirement throughout the season in warm ENSO years (Figure 3). The corresponding irrigation requirement was also higher. Insufficient groundwater recharge might limit the area under irrigated maize in warm ENSO years. Information about ENSO influence on water requirements and potential groundwater recharge could prove very useful for improving crop selection and irrigation management decisions during the dry season (February-May) following the winter monsoon. Advance knowledge of likely shortfalls in water available would enable farmers to save their substantial investment in irrigated crops. In the summer monsoon, preparing for supplemental irrigation could reduce the risk of crop failure in warm ENSO years. Modification of agronomic practices based on anticipated climate conditions offers some scope for risk reduction and increasing groundwater recharge (Jolly et al. 1989) in semi-arid environments.

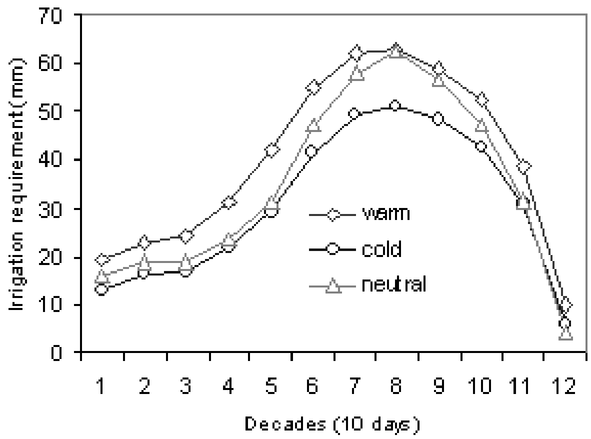

Figure 3. Decadal water requirement of irrigated maize (120 days duration) under various ENSO phases.

Conclusions

Our results demonstrate that there is an opportunity to manage irrigated crop production systems, if the rainfall and groundwater recharge relationships are adequately explained. Further, it is required to strengthen the predictability of seasonal rainfall and ground water recharge with sufficient lag prediction skill. We address some of the forecasting skill issues through dynamic downscaling techniques. Still there is an opportunity to use the prediction of SSTs well before on-set of the season through ensemble SST forecasting. Interannual rainfall variability exerts considerable influence on water resources. Since the irrigated crop production systems in the semi-arid tropics of the southern India are vulnerable to high frequency rainfall variability, the water resources are being exploited to support the seasonal water need of the crops. Exploitation of groundwater for irrigation in the semi-arid tropics of the southern India has been an effective means of coping with the region’s highly variable climate, but might already have reached unsustainable levels. Opportunities exist to better manage water resources through appropriate use of climate information, resulting in improved economic performance within a more sustainable production system. Regional and village-level stakeholder meetings are an effective vehicle for extending and coordinating the application of climate information for sustainable water management. There is a need to further advance the methods for using climate information, and develop effective extension programs to support this type of application.

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