An Assessment of Potential Economic Gain from Weather Forecast Based Irrigation Scheduling for Marginal Farmers in Karnataka, Southern State in India

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Abstract

This study is aimed to assess the usefulness of weather forecasts for irrigation scheduling in crops to economize water use. The short-term gains for the farmers come from reducing costs of irrigation with the help of advisory for when not to irrigate because rain is predicted (risk-free because the wrong forecast only delays irrigation within tolerance). Here, a quantitative assessment of saving (indirect income) if irrigation is avoided as rain is imminent (as per forecast), using a five-year archived forecast data over Karnataka state at hobli (a cluster of small villages) level is presented. Estimates showed that the economic benefits to the farmers from such advisories were significant. The potential gain in annual income from such forecast-based irrigation scheduling was of the order of 10% - 15%. Our analysis also indicated that the use of advisory by a small percentage of more than 10 million marginal farmers (landholding < 3 acres) in Karnataka could lead to huge cumulative savings of the order of many crores.

Keywords

Agro-Advisories, Economic Assessment, Environmental Benefits, Irrigation Scheduling, Weather Forecast Models, Weather Informatics

1. Introduction

The potential of accurate and applicable forecasts to aid precision agriculture has been recognized for a long time. A major challenge in implementation, however, is combining immediate gains for the end users with minimal risk; further, such practices must also be sustainable, and acceptable to the end users. Even simple weather forecast based agro-advisory to avoid unnecessary irrigation can have multiple and realizable benefits [1]. Multi-disciplinary approaches combining remote sensing, modeling, and deep learning techniques can help in improving agricultural practices and thereby increasing crop production [2]. The economic benefit to the farmers can be significant, especially for the marginal farmers, as each irrigation episode involves expenditure such as the hiring of pump set, cost of fuel, etc. Recent research has emphasized the potential use of weather informatics in improving the efficiency of the agricultural sector [3].

The international scientific community needs to democratize access to state of the art technologies which include high-resolution weather forecast models and customize them to suit the smallholders who comprise the majority of farmers worldwide and commit to creating data-driven agronomy that is accessible to all [4]. One of the major challenges in designing best practices is immediate and tangible benefits for the end users, with long term benefits and sustainability. Further, in addition to immediate benefit, such best practices must be risk-free for acceptability by the end users at an individual level. The long-term benefits may be intangible and unquantifiable in many cases, but should be at least clear at conceptual and logical level, with proper relevance to issues like economic advantages to the farmers and environmental health. The long-term benefits can be also realized in terms of policy inputs so that direct intervention in shorter-term issues can lead to longer-term benefits [5].

In agriculture, there are competing demands in terms of short-term and long-term benefits. Use of irrigation, pesticides, and fertilizers can enhance production (and hence increase farmer's income and food production); however, these short-term benefits may be offset in the long term by increased water usage and inefficient use and environmental load of pesticides and fertilizers [6]. Thus a major challenge in adopting best practices in agriculture is to design and implement processes and technologies that will enhance farmers' income, optimize water and energy efficiency while decreasing the load of pesticides and fertilizers on the environment [7]. The irrigation water is going to be increasingly constrained by growth in other sectors; other challenges, including falling groundwater tables and can further constrain water availability for irrigation [8]. In this scenario of limited primary resources, there is urgent need and great potential for improving water use efficiency in agriculture [9].

An emerging technology that can provide an integrated best practice is state of the art weather-forecast models based weather informatics. For example, rainfall forecasts at relevant spatial scales can aid agriculture in a number of ways, from crop choice to sowing schedule to irrigation. However, for effective real-time applications, such forecasts must be at relevant spatial scales, validated systematically against high quality observations. While the potential applications of rainfall forecasts in agriculture have been recognized, two major challenges in weather-based agricultural planning are the reliability of the forecasts and their usefulness. As discussed above, such forecasts must have immediate and tangible benefits with minimal risk, with long-term benefits and sustainability (and hence acceptable to policy makers).

While there have been a number of studies on evaluation of rainfall prediction, relatively fewer studies have examined their economic and societal impacts, especially for marginal farmers. Our objective here is to present design and evaluation of such a strategy based on a combination of model optimization, forecast design, real-time dissemination and impact evaluation. The advanced Weather Research and Forecasting (WRF) model [10] forecasts at high resolution were evaluated for its usefulness in irrigation applications over Karnataka state. Rakesh *et al.*, [9] showed that such forecasts are useful in applications like irrigation despite errors in quantitative precipitation forecasts inherent with such numerical models. In this study, a quantitative assessment of potential gain in annual income for marginal (having < 3 acres of land) farmers over Karnataka from the implementation of such forecast based irrigation scheduling of crop lands. While we implement and evaluate the strategy for a given region, the principles and the methodology are applicable to any region.

2. Materials and Methods

Assessment Methodology

We have computed the percentage potential gain in annual income from forecast based irrigation scheduling for a farmer as follows:

$$EG_P\left(h\right)=\left[\frac{N_I\times CI}{AI}\right]*100 \tag{1}$$

where N_I is the number of occasions where forecasts saved avoidable irrigation cost, CI is the cost per irrigation episode (two hours of irrigation per day is considered as one irrigation episode) per land parcel and is estimated as Rs. 2600—this includes charges in hiring pumps, electricity cost, labor, etc. [11], AI is the annual income of a marginal farmer (Rs 120,000 per year is considered as annual income) [12].

Similarly, we have computed the maximum possible economic gain per taluk (in millions of rupees) by saving the avoidable irrigation as follows

$$EG_P\left(t\right)=N_P t\times N_I\times CI \tag{2}$$

where $EG_p(t)$ is the economic gain per taluk (in millions of rupees), $N_p t$ is the total number of agricultural land parcel in a taluk defined as $N_P t=\frac{A(t)}{A(p)}$, where $A(t)$ the total agricultural area of a taluk* in acres and $A(p)$ is the area of land parcel in hectares (3 acres of area is considered as a land parcel).

*Taluk wise agricultural area is obtained from Karnataka state government website http://raitamitra.kar.nic.in/landholdings.html.

3. Results and Discussion

We have evaluated the usefulness of rainfall forecast from numerical mesoscale model for Karnataka, a southern state in India (**Figure 1**). The major rainfall seasons over the state are the two prominent monsoon seasons such as the south-west (June-September) monsoon and the north-east (October-December) monsoon. Traditionally, being an agrarian economy with a large percentage of citizens engaged in agriculture (nearly 56% of the workforce engaged in agriculture), the failure of rains generally has adverse effect on the economy of the state. While 26.5% of sown area (30,900 km^2) is subjected to irrigation, the rest of the cultivated land is mostly dependent on rainfall. The forecast model used is the WRF Model customized for regional forecasting over Karnataka [more details about model configuration and forecast methodology is available in Rakesh *et al.*, [9]. Here, we have utilized the archived forecast data for a five year period 2011-2015 generated as part of the five year collaborative project between CSIR Fourth Paradigm Institute and Karnataka State Natural Disaster Monitoring Center (KSNDMC) for carrying out the assessment of usefulness of forecast in irrigation scheduling. The daily rainfall forecasts generated during the period 2011-2015 from domain 3 (**Figure 1**) having horizontal resolution of 4 kilometers are utilized for carrying out the analyses. The forecasts are verified against corresponding observations from TRG rain-gauge network are comparable in resolution [more details on observation datasets used for validation is available

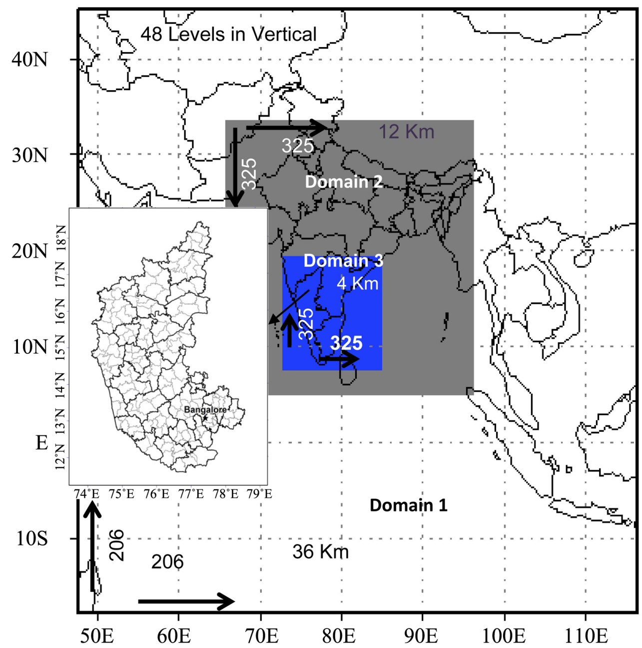


Figure 1. Model domains used for the numerical simulations. The horizontal resolutions of Domain 1 (Outermost largest domain shaded as white area), Domain 2 (inner domain shaded as gray), and Domain 3 (innermost domain shaded as blue) are 36, 12, and 4 Km respectively. The hobli division over Karnataka, for which the forecast is evaluated, is shown in the inset (Adopted from Rakesh *et al.* 2016).

in Rakesh and Goswami [1]. We have used five-year archived dataset to give statistical robustness to our results. Our main focus in this study is to evaluate the potential of rainfall forecasts in irrigation scheduling over Karnataka using five years datasets.

Conventional way of evaluating rainfall forecast may not be suitable for assessing economic potential of forecast based irrigation scheduling because a farmer may not irrigate his farmland throughout the year. Instead, a farmer goes for irrigation when there is a continuous dry spell (no rainfall for many consecutive days) which results in significant reduction in soil moisture content and when the crops suffer moisture stress. A crucial parameter for quantifying the economic potential of weather forecast based irrigation scheduling is finding the number of critical irrigation episodes in a year for each of the land holdings. The number of days a crop can withstand without irrigation is related to moisture stress tolerance of the crop. Since, the main objective of this study being quantification of usefulness of forecast based irrigation schedule over the entire state for assessment, we have selected our criteria in general irrespective of soil and crop category. We have selected two criteria based on analysis of observed daily rainfall data namely 10 day dry spell and 7 day dry spell criteria. In the 10 day criterion, we have assessed the usefulness of forecast based on its skill in predicting rainfall successfully on the 11th day after an observed 10 day dry spell. Similarly, in the 7 data criterion, we assessed model skill in predicting rainfall on 8th day after a continuous 7 day dry spell. Such an evaluation is very important in assessing usefulness of weather forecast in irrigation scheduling because after a continuous dry spell of 7 or 10 days the farmer has no choice but to irrigate the land.

Firstly, we computed the number of 10 day and 7 day dry spell episodes from the four year daily observed rainfall datasets. The spatial distribution of number of 10 day continuous dry spell (no rain for 10 days continuously) episodes over Karnataka for each hobli (typically having area of the order of 10 square kilometer; such an area corresponds to a cluster of adjoining villages and corresponds to an administrative unit called a hobli in Karnataka) division during the period 2011-2015 is shown in **Figure 2**. It is clear that there are many dry spell episodes over the state except over the west coast (**Figure 2(a)**). There are 412 hoblis (out of 747 hoblis) where the 10 day continuous dry spell episodes are more than 10 with larger number of such episodes in south and central part of Karnataka (**Figure 2(a)**). The percentage of cases where model could successfully predict the rainfall occurred on 11th day after a continuous 10 day dry spell is shown in **Figure 2(b)**. It is clear that for a good number of hoblis the success percentage of rainfall forecast is above 40; over 229 hoblis model has a success rate of 40% - 60% and for 97 hoblis model success rate is above 60% (**Figure 2(b)**). It should be noted here that the rainfall prediction by models after a continuous dry spell is relatively harder when compared prediction during rainy conditions. Generally rainfall prediction skill of numerical models is relatively low during dry season when compared to rainy season [13].

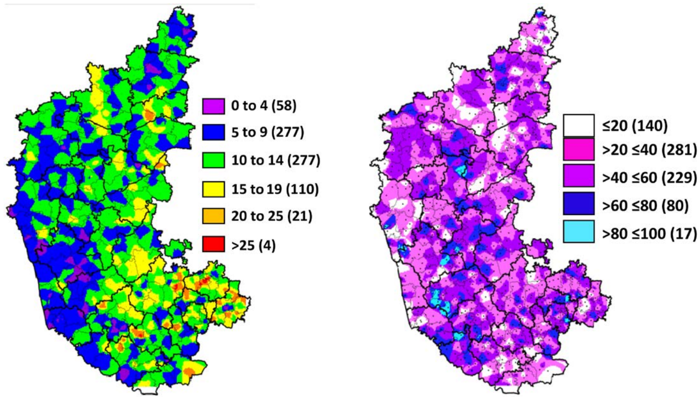
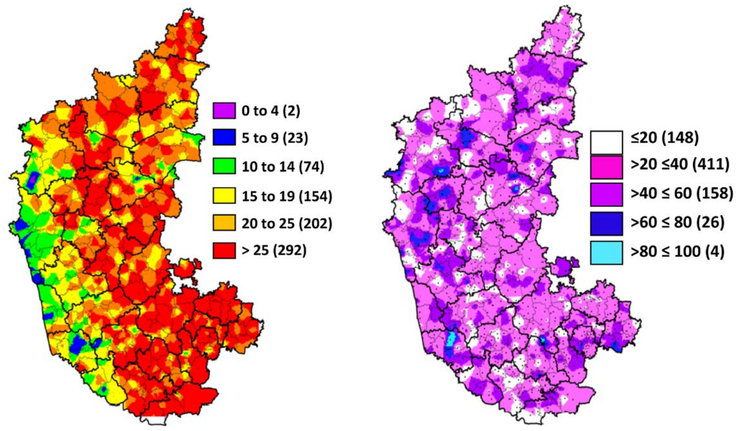


Figure 2. Assessment of impact of forecast-based irrigation scheduling; spatial distribution of (a) the number of observed 10 day continuous dry spell cumulative for the five years (2011-2015); (b) percentage of cases out of the total number of 10-day dry spells for which rain was successfully predicted for the 11th day (thus avoiding irrigation). The number in bracket shows the number of hoblis in each range.

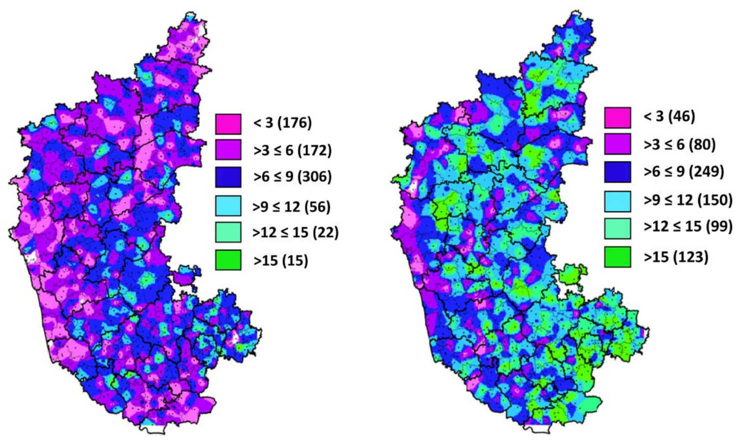
The spatial distribution of number of 7 day continuous dry spell (no rain for 7 days continuously) episodes over Karnataka for each hobli division is shown in **Figure 3**. As expected number of 7 day spell episodes over the Karnataka are much higher compared to 10 day dry spell criterion (**Figure 3(a)**). There are 648 hoblis (out of 747 hoblis) where the 7 day continuous dry spell episodes are more than 15 and whole Karnataka except the west coast has a large number of such episodes (**Figure 3(a)**). The percentage of cases where model could successfully predict the rainfall occurred on 8th day after a continuous 7 day dry spell is shown in **Figure 3(b)**. For majority of hoblis (411 out of 747) the model success rate is 20% - 40% and the model success rate is found to be not superior for 7 day criteria when compared to 10 day criteria (**Figure 3(b)**). Though the percentage success rate is slightly lower in the 7 day criterion compared to the 10 day criterion, the effective number of successful rainfall prediction episodes will be higher in the 7 day criterion because of the relatively larger number of 7 day dry spell episodes compared to 10 day dry spells.

Subsequently, we have computed (Equation (1)) the percentage potential gain in annual income (Rs 120,000 per year is considered as annual income) of marginal farmers who schedule irrigation based on rainfall forecast for 10 day and 7 day spell criteria. The percentage potential gain in annual income for the10 day dry spell criterion for those farmers who schedules irrigation based on rainfall forecasts over different parts of Karnataka cumulative for the years 2011-2015 is shown in **Figure 4**. While the potential gain in annual income for farmers over 91 hoblis is found to be above 10%, for 308 hoblis the gain in annual income is 5% - 10% (**Figure 4(a)**). The percentage potential gain in annual income from forecast based irrigation scheduling for 7 day criteria is much higher compared to 10 day criteria (**Figure 4(a)** & **Figure 4(b)**). It is found that the potential gain in annual income is more than 15% for farmers over 217 hoblis in Karnataka



(a) (b)

Figure 3. Assessment of impact of forecast-based irrigation scheduling; (a) Number of observed 7 day continuous dry spell cumulative for the five years (2011-2015); (b) percentage of cases out of the total number of 7-day dry spells for which rain was successfully predicted for the 8th day (thus avoiding irrigation). The number in bracket shows the number of hoblis in each range.



(a) (b)

Figure 4. Assessment of economic impact of forecast based irrigation scheduling; (a) for 10 day and (b) 7 day continuous dry spell scenario; these figures show the percentage potential gain in annual income (Indian rupees, Rs 120,000 per year is considered as annual income) for a farmer over different parts of Karnataka cumulative for the five years (2011-2015). The number in bracket shows the number of hoblis in each range.

(Figure 4(b)). While farmers over 147 hoblis had a gain in annual income of the order of 10% - 15%, the potential gain is 5% - 10% for marginal farmers over 240 hoblis in Karnataka. In general, it is found that there is a significant gain annual income for the farmers over Karnataka who follow such forecast based irrigation scheduling. We computed (Equation (2)) the potential economic gain per taluk in crores cumulative for the five years (2011-2015) from forecast based irrigation scheduling by marginal farmers (Figure 5). The spatial distribution of economic gain over different taluks in Karnataka based on 10 fay dry spell criteria clearly shows the commercial importance of forecast based irrigation scheduling; for

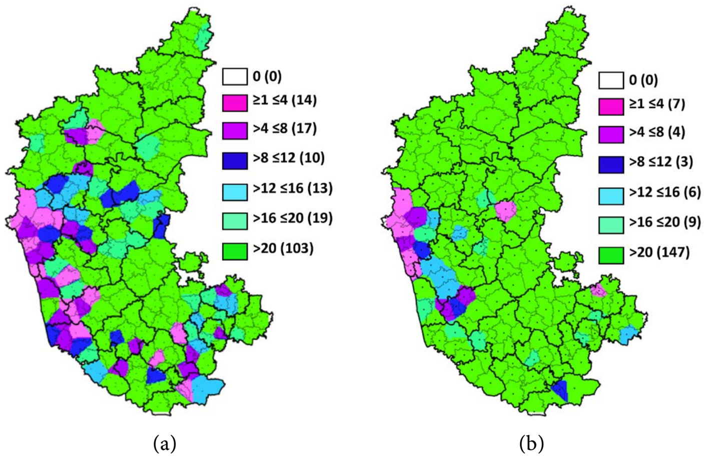


Figure 5. Assessment of economic impact of forecast based irrigation scheduling; (a) for 10 day and (b) 7 day continuous dry spell scenario; these figures show the potential economic gain per taluk in crores of Indian rupees cumulative for the five years (2011-2015). The number in bracket shows the number of taluks in each range.

majority of taluks the economic potential is more than Rs. 10 crores (**Figure 5(a)**). The economic potential of forecast based irrigation schedule is much higher for the 7 day criterion when compared to the 10 day criterion and for the majority of the taluks, the commercial gain is more than 20 crores (**Figure 5(b)**).

4. Conclusion

A quantitative assessment of saving (indirect income) that if irrigation avoided as rain is imminent (as per weather forecast) for a five-year period over Karnataka shows that the economic benefits to the farmers from such advisories can be significant. The economic impact of forecast based irrigation scheduling is assessed by computing the percentage potential gain in annual income (Rs 120,000 per year is considered as annual income) for a farmer over different parts of Karnataka. We have examined the economic gain for 10 days and 7 days continuous dry spell scenarios. Our estimates showed that the economic benefits to the farmers can be significant for both 10-day and 7-day scenarios; potential gain in annual income was found to be of the order of 5% - 10% for the 10-day scenario and 10% - 15% for the 7-day scenario for many hoblis. Results also showed that use of advisory by just 1% of more than 10 million marginal farmers (landholding < 3 acres) in Karnataka can lead to cumulative savings of the order of many crores per taluk. The methodology represents good practice, as long-term environmental benefits result from enhanced water and energy efficiency, and reduction of environmental loads of pesticides and fertilizers due to unwarranted irrigations.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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