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Validation and Application of Extended Range Rainfall Forecast for Crop Planning in Sub-Humid and Wet Temperate Climatic Conditions of Himachal Pradesh

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ABSTRACT

Seasonal rainfall forecast have the ability to sustain planning decisions and provide advanced weather information to the farmers to reduce the impact of prediodic weather variability. Assessing the reliability of seasonal forecasts is indispensable for monitoring the accuracy of forecasting system which will further lead to improvement in the forecasting techniques and increases its value to the end users. The extended range weather forecast providing forecast with lead time of 30-46 days will be more useful than medium range weather forecast (MRWF) for developing countries like India which are more vulnerable to climate change at the seasonal scale. The food production in such countries mainly relies on rainfed cropping systems and any changes in seasonal rainfall pattern can threaten the livelihood of local communities. Keeping these points in view, IMD and Indian Institute of Technology (IIT), New Delhi in collaboration started preparing extended range forecast (ERF) on real time basis for nine centers on pilot scale. On the basis of seasonal forecasts received from IMD, agro-advisories were prepared and disseminated to the farmers of two districts (Kangra and Kullu) of Himachal Pradesh. The reliability of forecasts was further assessed for seasonal rainfall. The ERF verification revealed that one month advance forecast was more reliable in the prediction of rainfall for south west monsoon season. The forecast received for individual months was more accurate than the seasonal forecast. The verification of south west monsoon revealed a positive trend with varying magnitude in percent deviation leading some values to negative while winter rainfall forecast showed higher forecast values than the observed rainfall except in February, 2011. However, the agro-advisories issued on the basis of forecast received proved more beneficial to the farmers.

1. Introduction

Weather plays a major role in determining the success of agricultural pursuits. It manifests itself through its effects on every phase of plant growth and development. Occasionally, adverse weather conditions can cause production losses, especially if experienced during critical stages of crop growth. Nearly three fourth of the annual loss in farm production both directly and indirectly occur due to weather (Liliane and Charles 2020). The crop losses can be reduced substantially by timely and accurate weather forecasts. The relevant forecast is not only useful for efficient management of farm inputs but also leads to precise impact assessment. Weather forecast for agriculture can be grouped into short range (upto 48 hours), medium range (3-10 days) and long range forecast (one week to entire season). Each forecast plays an important role in farm operations and planning of agricultural activities.

Till date, Medium Range Weather Forecast (MRWF) is being used by Agro Meteorological Advisory Services which is being provided by India Meteorological Department (IMD), Ministry of Earth Sciences (MoES) thereby helping the farmers to improve agricultural production through efficient use of natural resources.

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But, it becomes more and more important to provide climatological information blended with extended range and seasonal weather forecast before the start as well as during the cropping season in order to adapt the agricultural system to increased weather variability (Chattopadyay et al. 2018). Seasonal weather forecasts greatly influence the farmer's decision-making capacity in the selection of crops grown in relation to water availability. Crop yields may vary in response to the variable timing of the commencement and conclusion of the rainy season and prolonged dry spells within the rainy season. In other words, agricultural drought under rainfed conditions is putting the livelihood of farmers at risk by influencing water availability, agricultural production, food security and rural livelihood. In the drought year of 2009, many dry spells of monsoon and some transition phases of monsoon from weak phases to active phases and vice versa were observed. However, various climate research centers in India as well as abroad using statistical and dynamical models could not predict the extent of seasonal monsoon rainfall deficiency during June to September in 2009. Therefore, in the same year a proper real time monitoring of intra-seasonal fluctuation of rainfall during SW monsoon season by IMD was used to assess the amount and severity of drought situation in the country (Tyagi and Pattanaik 2010). For this reason an attempt was made by IMD and Indian Institute of Technology (IIT), New Delhi to develop multi-model dynamical statistical approach for seasonal rainfall forecast at regional scale (meteorological subdivisions) over India for four prominent seasons which are winter , pre-monsoon , summer monsoon, and post-monsoon. This prediction approach is referred to as extended range forecast system (ERFS(Mohantay et al. 2019).

Climate risk management through extended range forecasts would be more appropriate for climate vulnerable areas of the country like the Indian Himalayas,which is facing many challenges in terms of coping with the adverse effects of climate change in terms of physical and societal perspectives (Chaudhary and Bawa 2011).

Himachal Pradesh is one of the north Indian states situated in the North Western Himalayas. Agriculture and its allied sectors are the primary sectors of the economy contributing 10 per cent to the total regional income of the inhabitants in the state (Anonymous 2018). Variability of rainfall and temperature are the most important climatic factors that influence agricultural management practices like sowing time, plant spacing, seed rate, selection of variety, irrigation and fertilizer application etc. The three-fourth of rainfall received during south west monsoon largely determines the success or failure of *kharif* crops even though post monsoon and winter rains are also crucial for *rabi* crops. The temperature and rainfall play a decisive role in deciding the yields of crops as it affects flowering, fruiting/grain development stages and disease management activities which are highly climate driven activities causing a huge loss or profit to the farmer. The pre and post-harvest operations are also influenced by climatic conditions as it requires specific climate before crop is marketed. Therefore, one to two months advance climate information can help the majority of farmers in the hill state to reorient the entire management plan from cultivation to marketing. Most farmers in hill states are small and marginal and are thus more vulnerable to climate variability. They also lack access to relevant weather information that might enable them to respond to seasonal conditions. Therefore, the present study was planned with 25-30 days lead time to minimize the losses due to erratic weather by following appropriate corrective measures for climate risk management in agriculture. An attempt has been made in this investigationto validate the extended range forecast and to assess its applicability at farmer's field in different agro climatic regions of the state.

2. Data and Methodology

The study area is confined to the state of Himachal Pradesh (HP), comprising a geographical area of 55,673 sq km in the northern part of India amidst the western Himalayas. The entire state has a hilly and rugged terrain, with altitude ranging from 350m to 7000m above sea level. Geographically, the study area extends from 30˚22' 40" to 33˚12' 40" North and from 75˚45' 55" to 79˚04' 20" East covering 12 districts. On the basis of the geologic formation, the state is broadly divided into three zones namely, the outer Himalayas (the districts of Bilaspur, Hamirpur, Kangra, Una and the lower parts of Mandi, Sirmaur and Solan) the lesser Himalayas (parts of Mandi, Kullu, Sirmaur and parts of Chamba, Kangra and Shimla) and the greater Himalayas or the alpines (include Kinnaur and parts of Lahaul and Spiti, Chamba districts). Elevation of areas of the state increases as we move from west to east and from south to north (Guhathakurta et al. 2020). The year is divided into four seasons: winter season (December to February), pre-monsoon or hot summer season (March to May), the monsoon season (June to September) and the post monsoon season (October and November). The climate of the state varies from place to place depending on the altitude. The average annual rainfall is around 1122 mm. Most of the rainfall occurs during the monsoon season (Anonymous 2010). This study was carried out in two districts of the state *viz.,* Kangra (Palam valley) and Kullu (Kullu Valley) which are depicted in Fig I. The characteristic features of the study area are given in Table I.

Forecast Methodologies

The different model's output was used for generating the monthly as well as seasonal forecast depending upon their skill for the corresponding season and month. The different methods like SVD Based Regression, Supervised Principal Component Regression and Canonical Correlation Analyses etc., were used to generate the deterministic rainfall forecast by IIT, New Delhi. All these above stated forecasts were combined using some statistical techniques and delivered to the pilot universities. The same forecast has been converted into a probabilistic forecast to see the chance of occurrence of a particular event. Probabilistic forecast is made in three categories *viz.* below normal, near normal and above normal. These categories are based on the previous year's observed data set (IMD's gridded data). The model and observed data sets were normalized to have zero mean and one standard deviation before subjecting to any analysis. As the mean was shifted to zero and standard deviation changed to unity, the boundaries for the categories became as follows.

Below Normal category: $-\infty$ to -0.43

Near Normal category: -0.43 to 0.43

Above Normal category: 0.43 to ∞ (Tippett et al. 2006)

Forecast verification

The quality of a forecast can only be assessed when it is compared or verified against a corresponding observation of what actually occurred. The main reason to verify the forecast is to monitor and improve the quality of the forecast and increase its value to the users. During the study period, two forecasts were received for SW monsoon *i.e.*, during the month of April; Two-month advance forecast for SW monsoon June, July, August, September (JJAS) and in the month of May; One month advance forecast for SW monsoon JJAS. On a monthly scale, the forecast was received one month before the start of next month *viz.,* May start June, June start July and so on. While for winter rains one month advance forecast was received *i.e.* in the month of September for October, November and December (OND) and in the month of December for January, February and March (JFM). The application of ERF has been started on pilot approach for two districts *viz.,* Kangra and Kullu of HP from 2009-2012, usability of seasonal forecast and its applications in two major crops (wheat and apple) of the state for agricultural planning was tested. From each district, two villages were selected and from each village 40 farmers were identified to study the impact of ERF. The ERF and agro advisories during the project period were provided to the farmers in Hindi as well as English language. Bulletins are regularly prepared and effectively communicated to the farmers based on ERF through personal contact/SMS/telephone etc., for climatic signals so that specific management strategies were followed in time by the farmers. While preparing the agro-advisories the preference was also given to pre and post-harvest management of the crops. The reliability of ERF was done using standard techniques. The outcomes were used to determine the extent of benefit derived from forecasts in the real time management of seasonal variability. Farmer and other stakeholders' interactions were also organized from time to time.

3. Results and Discussion

The data of actual and forecasted rainfall were analyzed separately for south west monsoon and winter seasons during the study period.

Verification of Forecast for South West Monsoon

The southwest monsoon season in HP is characterized by significant rainfall that contributes about 73% of the total annual rainfall. The southwest monsoon extends over the entire state by the last week of June. July and August are the rainiest months accounting individually 25% to the annual total rainfall. The maximum number of rainy days range from 37 to 42 for the entire south west monsoon season. The withdrawal of the southwest monsoon begins from the northern parts of the state in the middle of September and withdraws from the entire state completely by about 3rd week of September. The departure of forecast received during April for JJAS for HP is given in Fig. II. The verification of two month advance seasonal forecast revealed that in the month of JJAS the percent deviation from forecast was +55, +4,-12 and -62 in 2010 and -61, +30, -25 and +16 in 2011 respectively. one month advance seasonal forecast, received during May, revealed that in the month of JJAS the percent deviation from forecast was +57, +5, -11, -56 in 2010 and -61, +30, -25, +16 in 2011 respectively. The monthly forecast verification for June, July, August, September months in HP revealed a percent deviation of +59, +3, -10 and -47 in 2010, -17, +28, -26 and +21 in 2011. It was observed that the one-month advance seasonal forecast for south west monsoon was more consistent than two months advance seasonal forecast. The forecast received for individual months is more accurate than the seasonal forecast because the seasonal forecasting has probalistic character due to which seasonal prediction become unreliable (Weisheimer and Palmer 2014; Bauer et al. 2015)

In district Kangra, the two-month advance forecast showed the percent deviation in the month of June was +59 and -55 for 2010 and 2011 respectively. While July, August and September showed lesser variations than June month +38, -15 and -8 in 2010 and -27,-10 and +15 in 2011. One month's advance forecast showed that the percent deviations from forecast were -55, +33, -31, -19 in 2010 and +60, +38, -14 and -5 in 2011 for JJAS. The monthly forecast observed percent deviation of +61, +37, -13 and 0 in 2010 and -20,

+32, -32 and -14 in 2011. In district Kullu, two month advance forecast showed the deviations from forecast values were -15, -67, -112 and -69 in 2010 and -150, +4,-146 and -1 in 2011 for June, July, August, September. In case of one month advance forecast, the percent deviations were -2,-62,-105 and -61 in 2010 and -150, +4, -146, -1 in 2011 While the monthly forecast verification were +6, -69, -100 and -49 in 2010 and -35, -1, -32 and +7 in 2011.

It was also observed that forecasting summer season monsoon rainfall one month in advance proved extremely challenging in Southeast Asia because seasonal prediction models have low potential predictability and accuracy (Ehsan 2020; Rebecca et al. 2020) especially in areas where rainfall patterns are local. In Himalayas, the land-locked regions with large orography generate intrinsic dynamics which play an important role in inter annual variability (Joshi et al. 2020). However, Phani et al. 2019 observed that the extended range forecasts for the southwest monsoon seasons clearly captured the intra-seasonal variability of monsoon including delay/early onset of monsoon, active/break spells of monsoon and also withdrawal of monsoon in the real time. Joshi et al. 2020 carried out multi-scale validation of seasonal forecasts at regional (Uttarakhand) to station scale over Central Himalaya with multi-source observations. They observed that at regional scale the interannual variability in composite observation and ensemble simulation are correlated at 99% significant level, with phase synchronization of about 75%. Various other workers have already reported that prediction of rainfall through medium range forecast during monsoon season showed higher variability in forecasted and observed values as compared to post monsoon and winter season (Rana et al. 2012; Singh and Bhardwaj 2012; Ray 2016; Das and Desai 2018; Dhami and Singh 2019)

Verification of Forecast for Winter Rains

The most common rain-giving systems over the state during the post-monsoon season are the depressions and cyclonic storms originating western disturbances from the Bay of Bengal which cause heavy to very heavy rainfall and contribute substantially to the season's total rainfall. During winter, the state receives about 14 cm of rainfall. This rainfall, though small in amount, is of utmost significance for agriculture. The forecast verification of winter rainfall is given in Fig. V. In HP, the observed percent deviation from forecast for January, February, March (JFM) was +79, +4, +78 in 2010 and +56, -31, +32 in 2011 respectively. In the month of JFM the percent deviation were +81, +6 and +85 in 2010 and +48, -10 and +56 in 2011 for Kangra district while the percent deviations for Kullu district were +88,-3 and +61 in 2010 and +58, -54.5 and -4.6 in 2011 respectively.

Paparrizos et al. (2020) while assessing the seasonal forecast performance during winter month observed that seasonal forecast had high accuracy which could lead to potential agricultural benefits. However, Gubler et al. (2020) observed that the prediction performance of winter rainfall is generally poorer and spatially and temporally more erratic in regions lying to the east of Andes. Nyadzi et al. 2019 also reported that forecast accuracy for all weather variables vary with season and location but are generally unsystematic and relatively constant with forecast lead time. However, forecasting at most preferred lead time of 1 month makes it possible to meet farmers' needs before the farming season. Palazzi et al. (2013) additionally suggest that confluence of different mountain ranges makes the topography of Himalaya so complex that the relationship between rainfall and topography remains poorly understood. Although the winter precipitation contributes only about 15% of the annual rainfall amount, it is very important for *rabi* crops sown during the season and to maintain the glacier extent of the high-altitude regions of the western Himalaya. In the mountainous regions the rainfall pattern has larger spatial variability than in the plains.The inter-annual and intra-seasonal variability analysis showed that the correlation between the precipitation of different months was to a certain extent weak, but with season it was found to be strong (Yadav et al. 2012).

Farmer's perception and feedback (individual or/and participatory approach):

During the survey 40 sampled farmers in the two selected districts i.e., Kangra and Kullu were exclusively questioned through interview schedule regarding the long-range weather forecast and its use in agriculture. The data was quantified, classified, tabulated and presented on the basis of percentages. All the farmers agreed that weather forecasting was essential for planning various agricultural operations. 100 percent farmers of the sampled households were opined that there are differences in the forecasted and observed rainfall. Television was considered as the best source of information dispersal on weather forecast and nearly 97.39 percent farmers listened to the weather forecast based agro-advisory. Among the sampled farmers only 13 percent farmers were of the opinion that they require forecast for more than 5 days. Maximum numbers of farmers were not interested in daily forecast rather they would prefer forecast on weekly basis at least 20-30 days in advance. The seasonal forecast seems to be important as more lead time availability helps farmers to plan their crop operations more precisely. Majority of farmers in Kangra district revealed that the rainfall forecast during winter period will be more desirable for wheat as they can escape irrigation which is a precious natural resource. Similarly, the farmers of Kullu region responded that snowfall forecasts influence the quality of Apple crop and reliable seasonal forecasts during the winter months will make them more climate smart to get higher economic returns without external support. ERF for one month or 15 days was required for effective crop management as perceived by 88 percent farmers. Quantitative forecasts will be more valuable than probabilistic forecasts as suggested by the majority of farmers. They were also of the opinion that winter rainfall should be forecasted just like southwest monsoon rainfall. The weather information available at that time was very much useful in managing the situation arising due to the excess/deficit rainfall through real time agromet advisories. As a real time response by using long range weather forecasts, different agro met advisories were prepared and issued for rainfall and temperature and disseminated to the selected farmers of Kangra and Kullu region. Those who used these advisories were immensely benefited by saving the crop loss. The weather information available through ERF was very much useful in managing the situation arising due to excess/deficit rainfall through real time agro-advisories issued to the farmers of Kangra and Kullu district. Due to increase in lead time the time required for dissemination of agro advisories was also reduced thereby increasing the adaptive capacity of the farming community through reduced cost of cultivation and reduced risk from drought and other extreme events (Kichar et al. 2020). Following advisories were issued during July to October, 2010 based on the forecast available at that time.

Maize: In the month of July the rainfall is expected to be normal in the region. Ensure proper drainage in the maize field and keep the fields weeds free to obtain more yield. Earthling up, inter-cultivation and intercropping operation may be taken at proper time. In the month of August ensure proper drainage and keep the field weed free. Remove the leaf below the cobs after tasseling and silking. Stem borer attack is expected during normal rainfall conditions. Ensure proper spray to control them. In September, ensure proper drainage and harvesting could be delayed due to prolonged rains. In October, the weather is good for sun drying of the crop. Ensure proper moisture in grains (12%) for good storage.

Wheat: In October, sowing of wheat may be delayed as less rainfall is expected.

Apple: Harvest the fruit at optimum maturity to ensure the proper marketability and to achieve good market value. Fungicidal sprays are effective against growth and spread of Sooty blotch (fungal disease) occurring due to high rainfall. It will be useful to combat dark coloring occurring due to heavy rainfall during the harvest time. Spray calcium to prolong the shelf life of the fruits can be stored for a longer period of time. Use of corrugated fiberboard cartons, which are superior to other packaging like wooden boxes, pine needle board etc. For local marketing and cold storage, use plastic crates. Enclosing a commercial sachet of $KMnO_4$ crystal 2g/Kg fruit in a polythene bag with a venting area 0.5% results in quality retention during transportation and storage.

4. Conclusion

The present study deals with the evaluation and dissemination of ERF with a lead time of 25-30 days in predicting seasonal rainfall during south west monsoon (JJAS) and winter season (JFM) in real time mode for the two districts of HP. The climatic information provided to the farmers through ERF proved more useful for planning agricultural operations by increasing the lead time required for dissemination of agro-advisories. The assessment of ERF was found more reliable for one month in case of South west monsoon rainfall while winter rainfall forecast requires more accuracy. Monthly forecasts were more desirable for stage specific management of crops. This study demonstrates that better forecasting coupled with a risk management approach had the ability to help vast numbers of farming households to cope with the risks of an uncertain monsoon.

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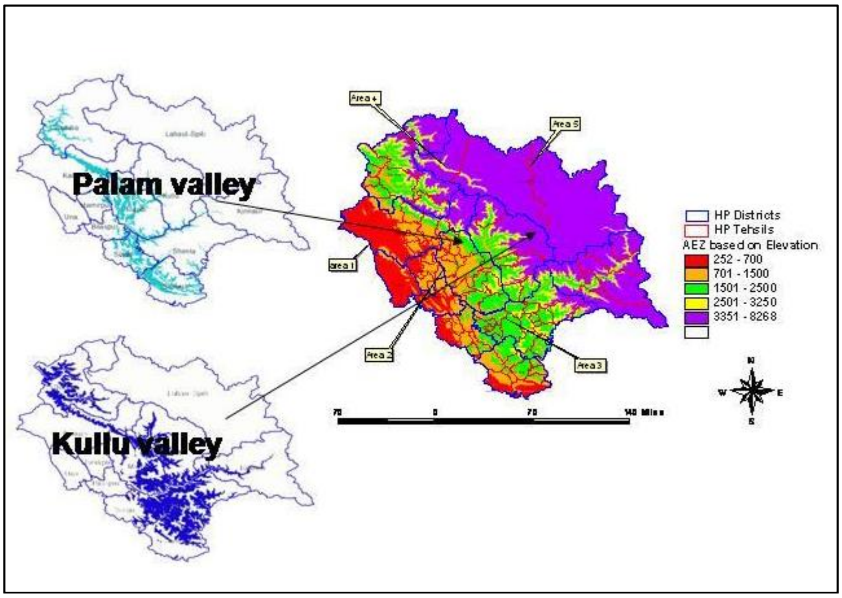

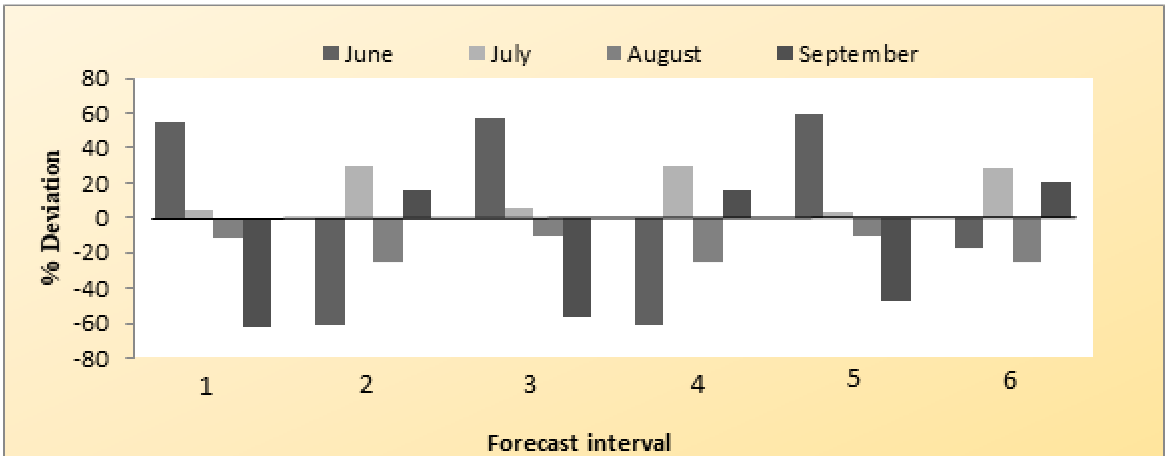

Fig.II % deviation from extended range forecast for SW monsoon in Himachal Pradesh

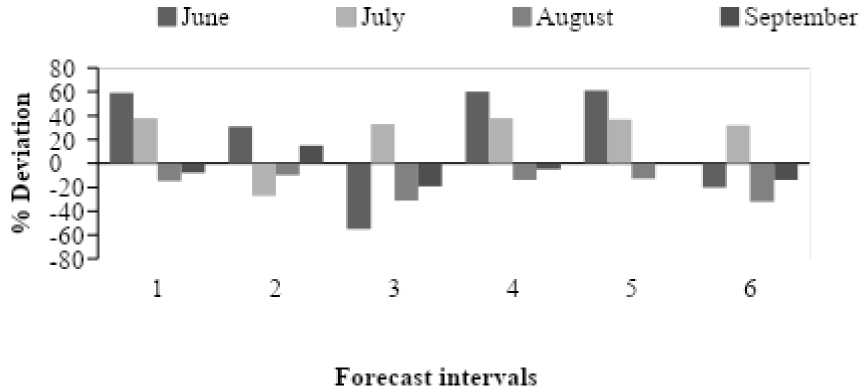

Fig III. % deviation from the extended range forecast for SW monsoon in Kangra district

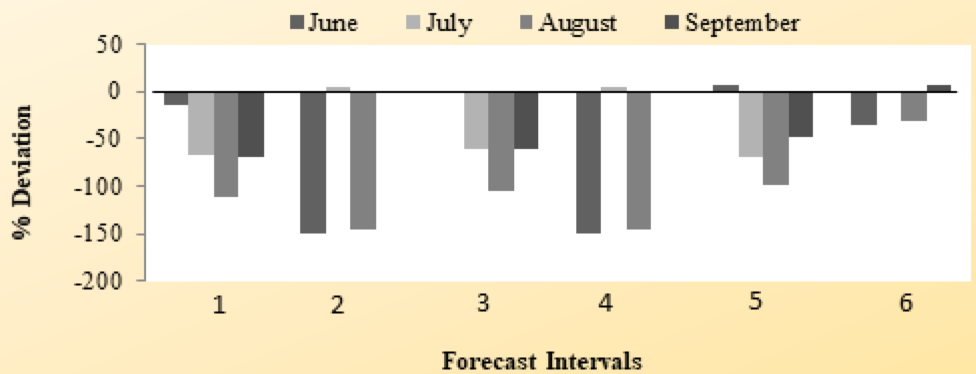

Fig IV. % deviation form the extended range forecast for SW monsoon in Kullu district

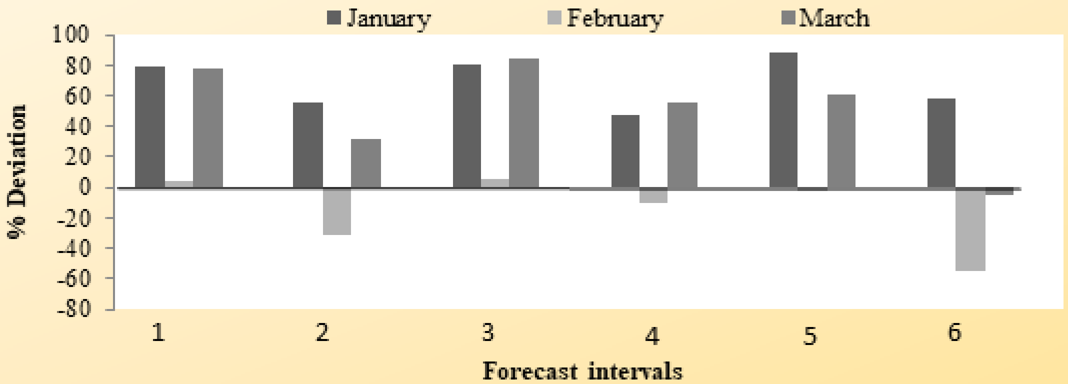

Fig V. % deviation from extended range forecast for winter rains in H.P, Kangra and Kullu district

Table I. Characteristic features of the Kangra and Kullu districts of Himachal Pradesh

Characteristic features	Kangra District	Kullu District
Agro-Climatic Region	Western Himalayan Region	Western Himalayan Region
Latitude	30o 05' N* To31 o 2' N	31o.52 To 31o.58 N
Longitude	75o 13'- E To 75o 45'- E	76o 13 To 76o 44 E

Altitude	250-6975 m	1230 m
Geographical Area	5776 sq km	5503 sq km
Net sown area	116.3 thousand ha	36.3 thousand ha
Net irrigated area	35.6 thousand ha	2.8 thousand ha
Rain fed area	107.2 thousand ha	33.6 thousand ha
Cropping intensity	184%	179%
Cropping Systems	Wheat-Paddy; Wheat-maize; Tea	Wheat-Paddy, Offseason vegetable, horticulture
Average Annual Rainfall	1539 mm	918 mm
SW monsoon (June-Sep)	1216 mm	529 mm
NE Monsoon (Oct – Dec)	54.4 mm	63 mm
Winter (Jan – Feb)	127 mm	154 mm
Summer (March – May)	143 mm	172 mm

NICRA (2012)

Table 2. Farmer's perception regarding extended range weather forecasting

Statement	**Farmers Perceptions (% response)**
Television and news paper best source on weather information	84.21
Weather forecasts more than 5 days required	13.15
Listen weather forecast services report	97.39
Benefit from weather forecast services	89.47
Loss from weather forecasting services	18.42
Necessity for Weather forecast	100.0
Anomaly between forecasted and observed weather	100.0
Rain and temperature forecasts are most important	57.89
Rain is the most important weather factor in agriculture	67.10
LRF for month or 15 days is required for planning agricultural operations	56.57
LRF based advisory for entire month required	87.45
Forecasts as deterministic / probabilistic	78.22
Daily schedule of forecast for 15 days	68.46
Acceptance of LRF	76.0
Outlook for winter rains as SW monsoon	82.0