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Spatial Distribution Analysis of Seasonal Fallows Using MODIS Multi-temporal Data during Monsoon Season over the Tropical Coastal Ecosystem

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ABSTRACT

Spatio-temporal distribution of seasonal fallow on a real-time basis helps to understand the resources and to develop suitable alternate crop plans to increase the cropping intensity. The extent and distribution of seasonal fallows in Guntur and Prakasam districts of Andhra Pradesh were assessed during the **kharif** season of 2020 and 2021 using multi-temporal MODIS satellite data at Geospatial Technology Centre, ANGRAU, Guntur, Andhra Pradesh. The satellite was analyzed in a GIS environment to develop threshold-based algorithms for identifying seasonal fallows using spectral indices and band combinations. With the increase in soil moisture content, the reflectance of the red band decreased and reflectance of NIR was increased. The presence of surface soil moisture negatively influenced the Modified Bare Soil Index (MBSI). Using the combined index of NDVI and MBSI, fallow with a thick mat of grass was inseparable from the cropped land which negatively influenced the accuracy. The saturation of red band reflectance and NDVI in fallow with a thick mat of weeds was observed and the relation was non-linear. Out of the tested indices, the combined Normalized Difference Vegetation Index (NDVI) and MBSI recorded the highest overall accuracy with moderate agreement followed by the combined index of NDVI and red.

Key words : Seasonal fallows, spatio-temporal, MBSI, NDVI, threshold values

INTRODUCTION

Arable land, left without sowing during the cropping season, is called seasonal fallow. Identifying the seasonal fallows is a real challenge in the coastal tropical ecosystem using optical remote sensing during the monsoon seasons. Fragmented land holdings and heterogenous farm activities negatively influence their delineation besides continuous cloud cover during the monsoon season. Andhra Pradesh accounts for 14.60 lakh ha of seasonal fallows out of which the study area accounts for 2.24 lakh ha which is 1.8% of the total geographical area (DES, 2021). Estimating the extent and mapping the spatial distribution of seasonal fallow is highly essential for understanding its natural resources and developing a suitable cropping plan.

Fallow lands were mapped as one of the classes besides the crop types due to their considerable extent (Wu *et al.,* 2014). Indices developed using red, near-infrared (NIR) and shortwave infrared (SWIR) were most suitable to discriminate fallow from arable crops. The temporal variability in vegetation indices enables the identification of fallow period length (Ghosh *et al.,* 2017), which is highly essential to planning a suitable crop in the available sowing window. Different workers attempted to classify the fallow lands using cloud-free optical remote sensing derived NDVI (Bandyopadhyay *et al.,* 2015), dynamic threshold (Wang *et al.,* 2014), pixel-based logical or band ratio algorithm (Wallace *et al.,* 2017), hierarchical classification (Gumma *et al.,* 2016), decision-tree approach and principal component analysis (Chandna and Mondal, 2020), maximum likelihood (Szatmari *et al.,*

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2018), machine learning algorithms (Low *et al.,* 2018) and neighbourhood and temporal anomalies (Wallace *et al.,* 2017) of multi-temporal MODIS satellite NDVI data. The NDVI threshold value of 0.5 was used to differentiate the crops from other land use using AVHRR-NDVI composite data (Kaushalya *et al.,* 2014). Commercial crops like chillies in the study area are sown in August and September due to soil workability in the back soils. Chickpea is grown in the **rabi** season in the black soils of Andhra Pradesh, particularly in Prakasam and Guntur districts and land is kept as fallow during the **kharif** season. Estimating the extent, duration and spatial distribution of fallow lands during crop season is most important to identify the land unutilized during/preceding/succeeding season and plan for better use of land resources. Cloud cover in optical remote sensing data causes missing temporal data which hampers multi-temporal studies. The cloud retrieval algorithm of MODIS satellite data allows optical image analysis during the cloudy season with moderate to high accuracy, though the MODIS NDVI data cause difficulties in classifying fallow during the **kharif** season (Mondal *et al.,* 2017). Seasonal fallows have features that may or may not have vegetation. Seasonal fallow without vegetation is a result of continuous tillage operations to sow the next weed-free crop. Identifying the bare soil of arable lands was attempted by Nguyen *et al.* (2021) using a modified bare soil index. Using NDVI time-series data, annual crops were identified using their crop cycle (Mishra *et al.,* 2017). In this study, an attempt was made to map the seasonal fallows using multi-temporal MODIS satellite data-derived indices and band combinations by identifying thresholds.

MATERIALS AND METHODS

The study was carried out during **kharif** season of 2020 and 2021 cropping season for the Guntur and Prakasam districts of the Andhra Pradesh state. Geographically, the study area is located between the longitudes of 79°56' to 80°01' E and the latitudes of 15°35' to 16°39' N spread over an area of 2, 901 sq. km (Fig. 1). Climatologically, it is characterized by a tropical monsoon climate with distinct summer, rainy and winter seasons. The normal annual rainfall is 853 and 872 mm for Guntur and Prakasam districts, respectively (DES, 2021). The physiography of the study area can be divided into two zones viz., coastal plains and the Eastern Ghats. Coastal plains are fertile alluvial depositions with high rainfall and part is under Krishna western delta command area, while the Eastern Ghats and the transition zone are less fertile with medium to low rainfall as compared to coastal plains, and part of the area is under Nagarjuna Sagar right canal command area.

Arable land left without sowing during the cropping season was called seasonal fallow. Seasonal fallows comprised ploughed/un-ploughed fallows, ploughed fallows with sparse grass and fallows with a thick mat of grass. To identify the seasonal fallows, 16 days composited multi-temporal MODIS satellite product MOD13Q1 was downloaded from *https://earthexplorer.usgs.gov/* and extracted the bands of NDVI, reflectance bands of Red, NIR and MIR for this study. The reflectance properties of red, NIR and MIR bands were studied to find out the suitability of the bands in identifying various land features/conditions/coverage viz., fallow, ploughed fallow, ploughed fallow with sparse grass, fallow with a thick mat of grass, wide row crops during the vegetative stage and crops at the maximum vegetative stage. Multi-temporal data from the beginning of June month to the end of October for 2020 and 2021 years were downloaded and processed using QGIS 3.16 software. Ground truth observations were collected randomly during the cropping seasons. Using the ground truth observations, spectral behaviour of

Fig. 1. Study area.

seasonal fallows and other land use were interpreted and based on the interpretations and suitability of the bands for delineating the seasonal fallow from other land use, the bare soil index was modified to fit the MODIS bands. The Modified Bare Soil Index (MBSI) is a normalized ratio of middle infrared (MIR) and near infra-red (NIR).

$$MBSI = (MIR - NIR)/(MIR + NIR)$$

The NDVI was used to differentiate the bare soil, crop cycles, other land use, and change in vegetation (annual crops and weeds) feature with the progress of the season.

$$NDVI= (NIR-R)/(NIR+R)$$

Where, NIR was the near-infrared reflectance band and R was the red band reflectance. To identify the current fallows with different land cover features, a threshold-based index was developed using NDVI and MBSI indices (Fig. 2). Further for better discrimination of seasonal fallows with different land cover features a threshold-based index was developed using NDVI and MBSI indices (Fig. 3). The NDVI values less than 0.4 were considered as seasonal fallow in agricultural lands based on the interpretation of multi-temporal data sets. In addition to the above, red band reflectance was interpreted for different land cover features during the study period and arrived at threshold values for estimating the seasonal fallows using NDVI as detailed below.

The threshold values for all the criteria used in the study were arrived at considering the ground data, Department of Agricultural Data, high-resolution satellite data and expert knowledge. The resultant products were masked using the potential agricultural area map to highlight the areas of seasonal fallows present in agricultural lands and accuracy estimation was calculated to derive the kappa index.

RESULTS AND DISCUSSION

The agricultural activities in the study region accelerated during the 2nd fortnight of June with the onset of monsoon. Weeds that emerge due to pre-monsoon showers were ploughed after the onset of monsoon showers to prepare the land for crop sowing. The fallow lands were

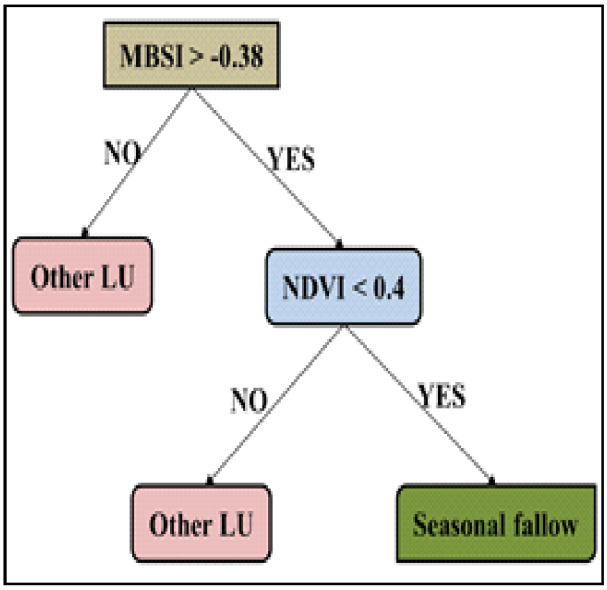

Fig. 2. Combined index of NDVI and MBSI.

broadly categorized in the study area as ploughed fallow, fallow with sparse vegetation, fallow with a thick mat of vegetation, annual crops during the initial stages and annual crops during the maximum vegetative stage (Fig. 4). Follow with a thick mat of vegetation was a special condition in low land areas where the previous crop was rice and due to the presence of high moisture weeds covered the ground surface which accounts for less than 1% of the total study area. The R band reflectance range for different land covers viz. ploughed fallow, fallow with sparse vegetation, and initial stages of crop growth in croplands were narrow with the highest reflectance in fallow with sparse vegetation. The NIR band reflectance was maximum in fallow land with a thick mat of vegetation followed by fallow land with sparse vegetation and ploughed fallow. Similarly, crops at the maximum growth stage recorded the highest NIR band reflectance than initial stages or ploughed fallows. This compiled with the findings of several researchers who observed the increase in NIR reflectance with vegetation cover. Increase in moisture content of the soil, reflectance of red band decreased and reflectance of NIR increased. The MIR band reflectance increased with an increase in vegetative cover in fallow land and observed an inverse relation in annual crops. Considering these observations NIR followed by red bands were found promising in differentiating the fallows from other land

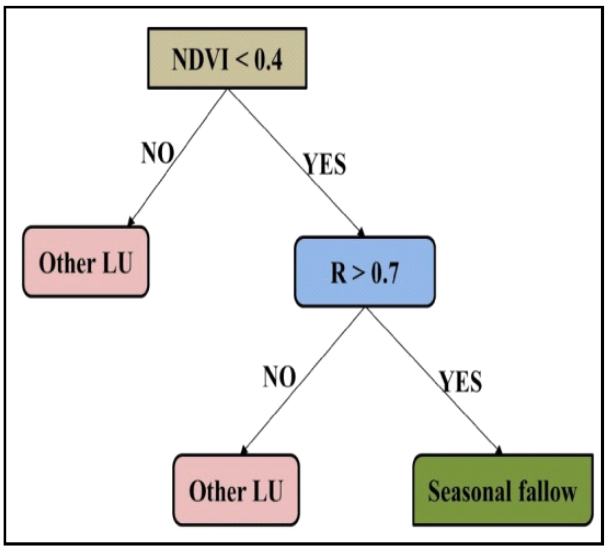

Fig. 3. Combined index of NDVI and R.

uses using MODIS data on temporal analysis. The Modified Bare Soil Index (MBSI values of the study region varied from -1 to +1 in different periods). Threshhold values for different land conditions were arrived at considering the ground observations, high-resolution satellite data, Google earth, information from Department of Agriculture, and expert knowledge for 1500 random points. The bare fallow soils either ploughed or un-ploughed recorded MBSI values of more than -0.33. The MBSI values of -0.33 to -0.38 were identified to better represent just sown crops or fallow with sparse vegetation, whereas the index values of -0.38 to -0.44 were representing crops

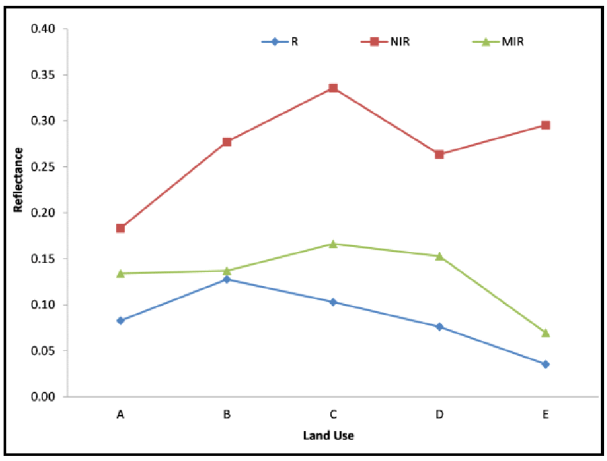

Fig. 4. Reflectance of Red, NIR and MIR bands in (A) Ploughed fallow, (B) Fallow with sparse vegetation, (C) Fallow with a thick mat of vegetation, (D) Annual crops during initial stages and (E) Annual crops during the maximum vegetative stage.

in initial stages or fallow with a thick mat of weeds and -0.44 and less indicated the maximum vegetative stage to physiological maturity stage of the crop. The MBSI is suitable for identifying bare soils over the study region but seasonal fallows include ploughed/ un-ploughed soil with sparse weeds and un-ploughed land with a thick mat of weeds like rice fallows.

The bare soil area gradually decreased from the beginning of the season to the end of the season (Fig. 5). During the first acquisition **kharif** 2020, the major area in both the districts was classed as fallow or fallows with sparse vegetation, while crops were identified in the areas with assured irrigation under bore wells limited to a very small region. The area under bare soils gradually decreased the extent of fallow due to the progress of sowings. Differentiating the just sown crop and field with sparse to moderate weed growth was challenging using the MBSI index as both features were representing a very narrow range of differentiation. In addition to that, The MBSI index for cropland at seedling emergence stage, just sown crop, and seasonal fallow with sparse and seasonal fallow with moderate weed growth was found to overlap due to which use of MBSI index for their differentiation was challenging. The MBSI index values of the fallow area with

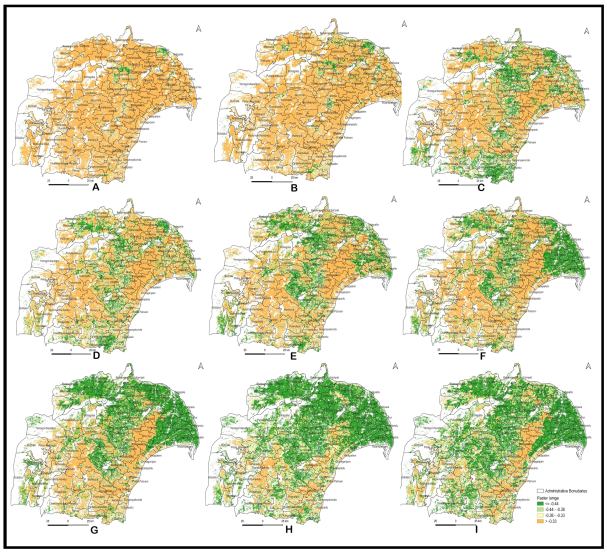

Fig. 5. Spatiotemporal MBSI during **kharif** 2020 cropping season. (A) 09th June, (B) 25th June, (C) 11th July, (D) 27th July, (E) 12th August, (F) 28th August, (G) 13th September, (H) 29th September and (I) 15th October.

sparse/thick mat of weeds and initial stages of crop growth might be due to the influence of soil and canopy moisture on MIR and NIR band reflectances.

The **kharif** 2021 results are presented in Fig. 6. Results revealed that, in Fig. 6A and Fig. 6B majority of the areas were bare similar to the **kharif** 2020 crop season. In Fig. 6C, the area with MBSI values of < -0.44 was increased which was a representation of crops with high vegetation but during the ground verification, it was observed that the area was still fallow with sparse weeds. Bare soil area gradually decreased by the end of the **kharif** season but in the southern part of the study area majority of the crop area was represented as seasonal fallows where the crop was in the initial stages of its growth due to unequal distribution of rainfall during the season as compared to the previous **kharif** 2020 season. MBSI can be used as a proxy for identifying the extent of bare soil area but the presence of high surface soil moisture and stage of crop growth in wide row spacing crops is challenging to differentiate. In addition, fragmented land holdings and heterogeneity in crops grown and stage of growth within a pixel might be the reason for the misrepresentation of the indices while using coarse resolution satellite data. MBSI index values less than -0.44 differentiated the crops which covered the ground surface with its canopy more accurately than the other two classes.

Using interpreted results of NDVI and MBSI in the study area, threshold values of NDVI less than 0.4 and MBSI values less than -0.38 represented the uncultivated lands. Temporal series of arable land which fell under uncultivable categorised as seasonal fallows. The spatial distribution of seasonal fallows estimated using a combined index of NDVI and MBSI for **kharif** 2020 and 2021 depicted in Figs. 7 and 8 indicated a gradual decrease in the extent with the lowest value by the end of the season.

The extent of the area under seasonal fallows was higher during **kharif** 2021 as compared to 2020. The combined index of NDVI and MBSI included the fallow with a thick mat of grass, sparse grass, initial stages of crops grown in wide row spacing, and re-growth of the harvested crop as seasonal fallow due to low NDVI values and MBSI values. The area under seasonal fallows estimated using the combined index of NDVI and MBSI was recorded with an overall accuracy of 86.4% with a good agreement. Satellite data acquired during the wet conditions have high background reflectance under partial canopy cover showing a high negative influence on NDVI values thereby resulting in

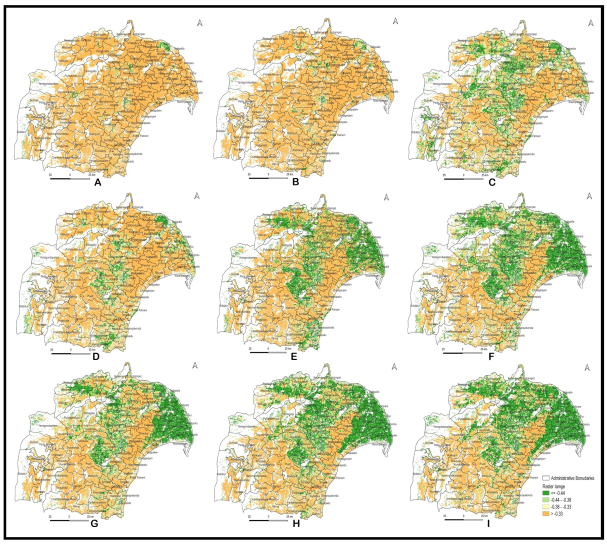

Fig. 6. Spatiotemporal MBSI during **kharif** 2021 cropping season. (A) 09th June, (B) 25th June, (C) 11th July, (D) 27th July, (E) 12th August, (F) 28th August, (G) 13th September, (H) 29th September and (I) 15th October.

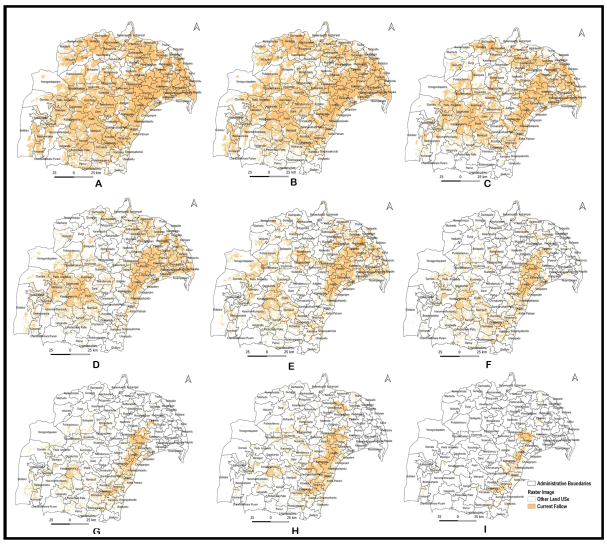

Fig. 7. Spatiotemporal combined index of NDVI and MBSI during **kharif** 2020 cropping season. (A) 09th June, (B) 25th June, (C) 11th July, (D) 27th July, (E) 12th August, (F) 28th August, (G) 13th September, (H) 29th September and (I) 15th October.

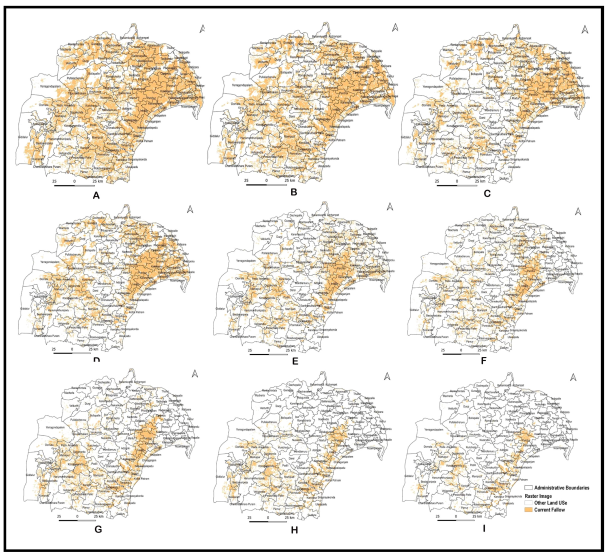

Fig. 8. Spatiotemporal combined index of NDVI and MBSI during **kharif** 2021 cropping season. (A) 09th June, (B) 25th June, (C) 11th July, (D) 27th July, (E) 12th August, (F) 28th August, (G) 13th September, (H) 29th September and (I) 15th October.

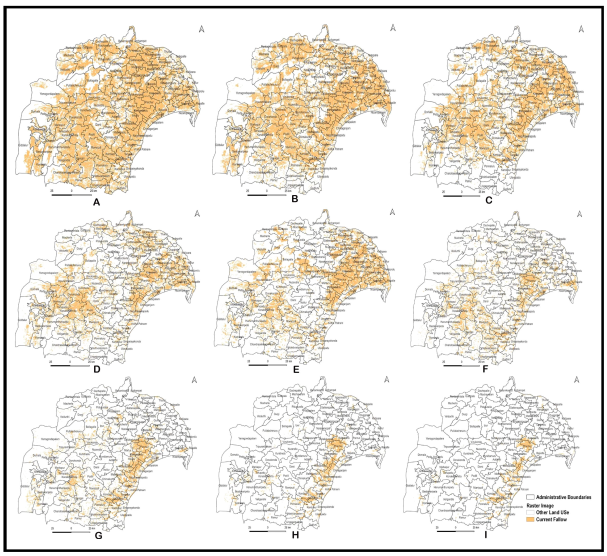

Fig. 9. Spatiotemporal combined index of NDVI and red band during **kharif** 2020 cropping season. (A) 09th June, (B) 25th June, (C) 11th July, (D) 27th July, (E) 12th August, (F) 28th August, (G) 13th September, (H) 29th September and (I) 15th October.

lower values inland features of initial stages of crops grown in wide row spacing. Due to this, overall accuracies were lower. NDVI values of 0.36 to 0.46 were recorded by initial stages of wide row sown crops and fallow with a thick mat of weeds. Even though the initial stages of wide row sown crops were classified as follows, in subsequent temporal images due to an increase in the NDVI, the same were classified as cropped areas.

The combined index of NDVI and R band revealed that, with the season progress, the seasonal fallow area gradually decreased and reached the lowest by the end of the **kharif** 2020 (Fig. 9). **Kharif** 2021 results are presented in Fig.10. By the end of August (Fig. 10F) majority of the agricultural areas were cropped. A similar trend was observed in **kharif** 2021. The extent of area under seasonal fallows was more in the **kharif** 2021 than the previous season. The combined index of NDVI and R band excluded the sparse grass where NDVI was less than threshold values. The saturation of the red band reflectance and NDVI was observed in fallow with a thick mat of weeds in low land paddy areas (Fig. 10E) before the transplanting of rice was observed besides the cropped areas where canopy was completely covered the ground surface. The overall

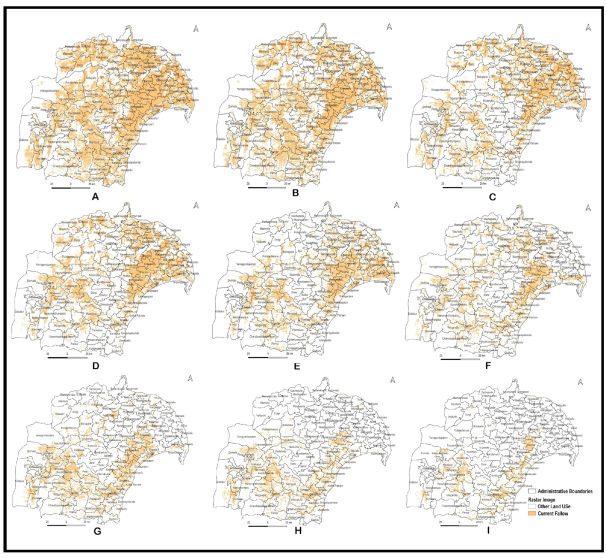

Fig. 10. Spatiotemporal combined index of NDVI and red band during **kharif** 2021 cropping season. (A) 09th June, (B) 25th June, (C) 11th July, (D) 27th July, (E) 12th August, (F) 28th August, (G) 13th September, (H) 29th September and (I) 15th October.

accuracy of the combined index of NDVI and R band is 75.6% with a moderate agreement.

CONCLUSION

Multi-temporal satellite data are more reliable to delineate the seasonal fallow over the

tropical coastal ecosystem during the monsoon season. The interpretation of MIR, NIR, and R bands reflectance over different land cover features of arable lands i. e. ploughed fallow, fallow with sparse vegetation, fallow with a thick mat of vegetation, annual crops during initial stages and annual crops during the maximum vegetative stage helped to develop an MBSI spectral index. The presence of surface soil moisture negatively influenced the MBSI index. Using the combined index of NDVI and MBSI, fallow with a thick mat of grass was inseparable from the cropped land which negatively influenced the accuracy. The saturation of red band reflectance and NDVI in fallow with a thick mat of weeds was observed and the relation was non-linear. The coarse-resolution satellite data like MODIS helped to identify and monitor the large areas of seasonal fallows on a spatio-temporal basis where technical interventions were needed to bring the land under cultivation by overcoming the constraints. Further, the threshold values used in the study may slightly vary from one ecosystem to other based on the type of vegetation and the ground cover.

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