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Delineation of Rice-wheat Cropped Area using Geo-spatial Techniques

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Abstract: Rice and wheat are the most important food crops of India in term of area, production and consumer preference. India is world's second largest producer of rice and wheat crop and Punjab, Haryana are the most productive states of rice wheat cropping system. But due to over exploitation of groundwater resources to irrigate both the crops in these areas, sustainability of rice–wheat cropping is under high threat. In this paper, rice-wheat cropped area was delineated for Agro Climatic Region (ACR-VI) comprising Punjab, Haryana by using remote sensing and GIS analysis. Landsat ETM+ and IRS LISS III images were analyzed to delineate area under rice-wheat cropping system during *kharif* and *Rabi* season. Spatial analysis on effective rainfall varied within 230-466 mm during monsoon period in ACR-VI. Based on the rainfall distribution, groundwater table depth and soil type, potential areas under rice and wheat crops were identified so that most of the crop water requirement could be met through rainfall and there will be check in use of groundwater to maintain sustainable use of natural resources.

Keywords: Agro Climatic Region-VI, Rice-wheat cropped area, GIS, Remote sensing, Landsat ETM+

Rice and wheat are the major cereals grown all over the world. In India, rice and wheat production is 103.04 million tonnes and 94.88 tonnes respectively. Punjab is one of the most productive states for rice and wheat cropping, which contributes 12 and 20% to India's rice and wheat production respectively from only 1.5% of the geographical area. The expansion of rice–wheat cropping system under the green revolution turned Punjab and Haryana states into the food bowl of India, has led to degradation of the natural environment. More than 90% area in northern states like Punjab and Haryana is irrigated through groundwater resources and groundwater decline, rising groundwater table and salinity is the major concern. Hence sustainability of rice–wheat cropping system is a big challenge. Global positioning system (GPS) and geographic information system (GIS) technologies have been adopted for better management of land and other resources for sustainable crop production. Acquiring spatial data in GIS platform and remote sensing (RS) plays a major role in information management systems. RS is an accurate, efficient, economical and reliable technique to prepare a comprehensive inventory of the natural resources of an area (Palaniswami et al 2011, Dhanasekarapandian et al 2015). Many studies demonstrated the effectiveness of using remotely sensed data as a powerful tool to detect land use change for critical environmental areas, vegetation dynamics and urban expansion breakthrough in the method of acquiring information on land resources, agriculture, forestry, ocean resources and other studies (Yasodharan et al 2011, Wulder et al 2012, Crews-Meyer 2004, Laney 2004). The integration of remote sensing data into monitoring frameworks has the potential to standardise monitoring approaches across different spatial scales (Vanden et al 2011). Spectral and contextual information from remote sensing images and thematic data processed together resulting in delineation of polygons that is used to support mapping in field surveys (Schiewe 2002). In object-based image analysis, region-based multi-resolution segmentation approach is commonly used. This is a bottom up region-merging technique in which pixels are merged into homogeneous land parcel units based on the parameters defined by homogeneity criteria for different colours and shapes. However, the algorithms used can lack objective and reproducible means for defining the parameter values (Ouyang et al 2011, Tian and Chen 2007). A plethora of research reports have corroborated the suitability of mapping and monitoring land cover as an important scientific goal (Collins et al 2001). Land suitability analysis of Anjarakandi River basin was carried out using various topographic maps and satellite imagery. Satellite data from Landsat ETM+ were used for preparing land use, drainage and contour maps. It used a weighted overlay methodological approach to integrate all thematic layers for achieving the designed objectives (Gopal Krishna and Regil 2014). In this paper, remote sensing and GIS was used to delineate rice-wheat coverage areas in ACR-VI region of India and to perform suitability of rice-wheat cropped area based on soil properties, cropping pattern and rainfall distribution in ACR-VI.

MATERIAL AND METHODS

Study area: The study was undertaken in Agro Climatic Region-VI, which covers the major portion of Punjab and Haryana state, located between 27.63 ^{0} N 72.64 ^{0} E and 32.47 ^{0} N 77.59^0 E and covers the area of 11.4 million ha. Rice during *Kharif* and wheat during *rabi* season are widely grown in this region. The region has three distinct seasons, viz. winter (November–March), summer (April–June) and rainy season (July–October). Average annual rainfall varied within 600-900mm, out of this 80% occurs during monsoon season of July–September. The normal annual rainfall is 720 mm in the Haryana districts and 628 mm in the Punjab districts. The climate is semi-arid to dry and sub-humid and the soil is alluvial. Over 80% of the land is sown and over 80% of the sown area is irrigated (Verma et al 2006).

Remote sensing image analysis: A total of 12 Landsat ETM+ images with distinctive paths and rows from website http://glcf.umd.edu for ACR-VI (the states of Punjab and Haryana) were downloaded for rice area delineation. Out of 12 scenes, acquisition period of three images were in the month of September 2000 (paddy crowing season) and rest nine images were for October 2000 (paddy harvesting season). Similarly, all total 14 IRS LISS III images in January 2012 (8 images) and February 2012 (6 images) were used for wheat area delineation. ERDAS 9.2 software was used for data analysis. As acquisition of all the images were not for the single date so pixel values of each image was different. So while comparing the images, crop coverage in particular locations were identified and then analyzed. Then all the images were processed for mosaicing due to variation in pixel values and individual districts were clipped out of the images. False colour composite of band combinations 2,4,7 and 2,3,4 bands of Landsat ETM+ images were considered for better identifications of land category. For wheat area, false colour composite was prepared using green, red, and near infra red bands of the satellites scenes of IRS LISS III sensor. In order to assist these image interpretation elements like shape, size, tone, texture, association and pattern were used. Published crop pattern map developed by Space Application Centre, Indian Space Research Organization was used as secondary data to compare the classified image. All the images were compared to identify the rice cultivated areas for the months of September and October. Similarly wheat areas were identified for the month of January and February. Then delineated rice and wheat areas were compared with the published report of the state.

GIS (Geographic Information System) analysis: Topographic maps of Punjab and Haryana were geo referenced to real World Geodetic Co-ordinate System (WGS 1984). District wise polygon shape file was generated to delineate the study area of ACR-VI with attributes containing the districts name and geographical area. In first phase, a snapshot was taken from Harmonized world soil database (HWSD) viewer indicating the ACR-VI boundary with its all districts boundary. Appropriate soil classes were selected to cover the entire ACR-VI. The snapshot as image file was saved and imported to geographic information system (GIS) interface. With reference to survey of India (SOI) topo-sheets, the image was geo-referenced, and then digitized to get a polygon shape file with attributes containing the soil parameters. The basic soil properties (types) of ACR-VI were obtained from the HWSD and database was prepared. Later using the soil texture triangle, soil textural classes were obtained and map was prepared. Soil texture map was chosen as first thematic layer for analysis. Then cropping pattern map of Punjab and Haryana published by Space Application Centre, Indian Space Research Organization was taken, geo-referenced and overlaid over district wise polygon shape file of ACR-VI. The dominant crop pattern for each district and the same was inserted in the attribute table of ACR-VI shape file. On this basis, cropping pattern map was developed. Daily rainfall data of 37 locations within the ACR-VI was acquired from Indian Meteorological Department (IMD) for the period from 1994 to 2010. The mean monthly rainfall depths were calculated for each location and the monthly effective rainfall depths were estimated by adopting the USDA SCS method using the FAO CROPWAT ver. 8.0 software. Rainfall depths occurring during the pre-monsoon (March, April, May, and June), monsoon (July, August, September) and post-monsoon (October, November, December, January and February) were estimated besides the effective rainfall depths during these periods. Geographically, to visualise and observe the distribution pattern over ACR-VI, point shape file was created importing the coordinates of those 37 locations, attribute table was created putting the effective rainfall values in the columns. Interpolation technique was adopted for getting the values at unknown locations within ACR VI. Krigging technology was applied to get the effective rainfall range and their spatial distribution pattern in the study area. Finally, spatial mapping of effective rainfall was carried out. Then overlay of thematic layers were performed to identify the suitability of growing rice and wheat crop in ACR–VI.

RESULTS AND DISCUSSION

Mapping of rice-wheat area using remote sensing image analysis: Rice–wheat cropping area was delineated for ACR–VI by using remote sensing and GIS. Landsat ETM+ and IRS LISS III data with maximum likelihood classifier approach in image classification were used for delineation of crop coverage in the study area. It was observed that out of total area, 2.63 and 1.05 million ha area is under rice in Punjab and Haryana respectively. In ACR–VI, about 3.68 million ha area is under rice area (Fig. 1). Similarly wheat area was delineated for ACR–VI. Resourcesat–2 LISS III data with two stage classification approach i.e. unsupervised iso–data followed by maximum likelihood supervised classification methods were used for delineation of wheat crop coverage areas. Wheat area was estimated at 3.51 and 2.46 million ha in Punjab and Haryana respectively. A total of 5.9 million ha wheat area was delineated in ACR VI region (Fig. 2). Areas under rice–wheat crop sequence were 2.053 million ha, which is around 49.06 % of state′s total cultivated area. Similarly combined rice–wheat cultivated areas were estimated at 4.16 million ha (more than 90% of cultivated areas).

Image analysis showed that maximum rice areas were delineated in Punjab. District wise analysis showed that Ludhiana and Sangrur districts in the Central Plain Zone (CPZ) of Punjab showed the maximum areas under rice. More than 60% of the total cultivated area in the state in the *kharif* season is occupied by rice. In sub–montane undulating zone and undulating plain covering large parts of districts Ropar, Hoshiarpur, Gurdaspur and Patiala of Punjab state, rice area has virtually spread to occupy all of the plain land. Availability of canal and tube well irrigation supplemented by rain makes large–scale growing of rice quite feasible and available in the undulating plain zone. Agro climatologically, the CPZ falls in the low rainfall zone of 400–800 mm. There is good network of canal system in the state, apart from that minor irrigation census 2011 showed that Punjab, Haryana and UP state of India account for 55 per cent of the tube wells in India. On an average there are 28 tube wells per sq. km. of net sown area in Punjab alone. The area irrigated by government canals covers only 29 per cent of the total irrigated area of the state. On the other hand, net area irrigated by wells covers 71 per cent of the total irrigated area of the state. The problem of overexploitation of groundwater resources is most severe in central Punjab, usually called sweet water zone and dominated by rice crop in the *kharif* season. While the average annual fall in groundwater table in the central Punjab was about 17 cm during the 1980s and about 25 cm during the 1990s, it was alarmingly high at 91 cm per annum during 2000– 2005 (Singh 2011). Analysis revealed that rice and wheat remained the dominant crops which occupy 57.8 and 64.9% of total agricultural area, respectively (Choudhury et al 2013). Similarly, Haryana state is also dominated by rice crop during the *kharif* season. Eastern zone of Haryana including districts of Ambala, Yamunanagar, Kurukshetra, Karnal, Sonipat, Faridabad, Gurgaon and parts of Rohtak comprises the major rice–growing area of Haryana. The Kurukshetra–Karnal–Sonipat–Gurgaon–Faridabad belt is famous for *Basmati* rice production. Groundwater quality in this area is poor and marginal; hence most of the area is dependent on canal system of irrigation (Narang and Virmani 2001). Landsat ETM+ satellite image was also used to delineate and estimate rice crop areas in Haryana state. Remote sensing and GIS analysis resulted an area of 1051,000 ha under rice crop, where as the published report indicated an area of 1049,000 ha under rice for the state of Haryana (Sethi et al 2014). In Haryana rice is grown in 18 districts out of 21 districts under irrigated condition only. This has been well represented in the delineated map of ACR–VI (Table 1). Satellite image analysis showed that nearly 2626000 ha is under rice in Punjab, where as published report showed 2611000 ha area is under rice. Similarly, area under rice in Haryana is 1051,000 ha as per image analysis, whereas it is 1049,000 ha as per the published report.

Hence, there was good agreement on delineation of total rice area in both the states; however, district wise analysis showed variation on rice area for these states. Remote sensing approach was used in other areas for delineating rice areas. Supervised classification was carried out to make clusters of pixel values of similar rice crop with same spectral signature (Dhumal et al 2013). Similarly simplified approach was used to map rice area in the Indo–Gangetic Basin (IGB) by combining remotely sensed imagery, national census and meteorological data. The statistical rice cropped area and production data were synthesized to calculate district–level land productivity, which is then further extrapolated to pixel–level values using MODIS NDVI product based on a crop dominance map. (Cai and Sharma 2010).

GIS analysis for ACR-VI

Soil analysis: Rice–wheat is the major cropping pattern of ACR–VI (Fig. 3) followed by cotton–wheat. Mostly, Indo–Gangetic Plain (IGP) is under continuous deposition of alluvium from the hills and mountains from both sides of the plains – the Himalayas in the north and Deccan Plateau in the south. So, soils of the IGP are Ustochrepts, Aquents, Naturstalf, and Hapludolls (Tarai region). There are large

Table 1. Comparison of rice and wheat cropped area

State	No. of districts	Area (Govt. records) '000 ha	Area (Image classification analysis) '000 ha
Rice			
Punjab	23	2611	2626
Haryana	21	1049	1051
Wheat			
Punjab	23	3528	3511
Haryana	21	2522	2464

lowland patches of heavier soils (silty clay loam to clayey) in almost all states in the IGP where rice-wheat cropping system is practiced (Prasad 2007). While delineating soil map of ACR-VI, all total thirty two numbers of polygons representing uniform land parcel units were created by digitization, which comprised of ten number of soil groups. Major soil groups were presented in Fig. 4 and details of soil characteristics were shown in Table 2. The sand, silt and clay percentage varied within 16-89, 6-47 and 5-53 respectively. The organic carbon content varied within 0.4 to 1.4. The area is mainly dominated by loamy texture soil. On superimposing the soil texture map with the cropping pattern map, it was found that rice-wheat cropping pattern is mainly dominated in loam soil (Fig. 5). In the loamy soils, the soils were neutral to alkaline in nature (pH ranged from 6.2 to 8). Organic carbon content varied within 0.6 to 1.4%. The Leptosol-LP, Lixisol-LX, Regosol-RG and Cambisol-CM were high in soil organic carbon content whereas the rest of the soil groups were low to medium in soil organic carbon content.

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Rainfall analysis: Monsoon rainfall varied within 51 to 651 mm in the study area but the rice-wheat areas receive 195 to 484 mm of rainfall with effective rainfall of 156 to 300 mm (Fig.5). Major crops grown during *kharif* season in these areas are rice. Water requirement of *kharif* rice in Punjab and Haryana is 730 mm (ENVIS Centre, Punjab 2013). This showed that maximum water requirement is met through rainfall if rice is grown in *kharif* season only. Similarly pre-monsoon rainfall varies within 0-67 mm with effective rainfall between 7-64 mm. Post monsoon rainfall varies within 3-32 mm with same amount of effective rainfall. On superimposing

Table 2. Details of soil characteristics of the study area

Id	Soil Group	Sand (%)	Silt (%)	Clay (%)	Organic carbon content (% weight)	Bulk density (kg/dm^3)	pH	Soil texture
1	Luvisol-LV	81	9	10	0.57	1.41	6.20	Loamy sand
2	Fluvisol-FL	35	47	18	0.60	1.39	8.00	Loam
3	Sand dunes-DS	89	6	5	0.40	1.50	6.40	Sand
4	Calcisol-CL	40	37	23	0.56	1.31	7.90	Loam
5	Solonchak-SC	16	31	53	0.58	1.25	8.30	Clay
6	Leptosol-LP	43	34	23	1.40	1.30	7.60	Loam
7	Arenosol-AR	89	6	5	0.40	1.50	6.40	Sand
8	Lixisol-LX	47	32	21	0.82	1.42	6.20	Loam
9	Regosol-RG	47	34	19	0.97	1.21	6.40	Loam
10	Cambisol-CM	42	36	22	1.00	1.37	6.60	Loam

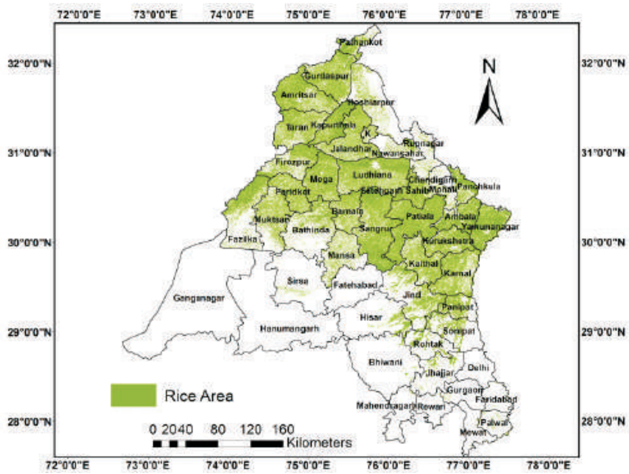

Fig. 1. Delineated rice area in Agro-climatic Region VI (Satellite Image Analysis)

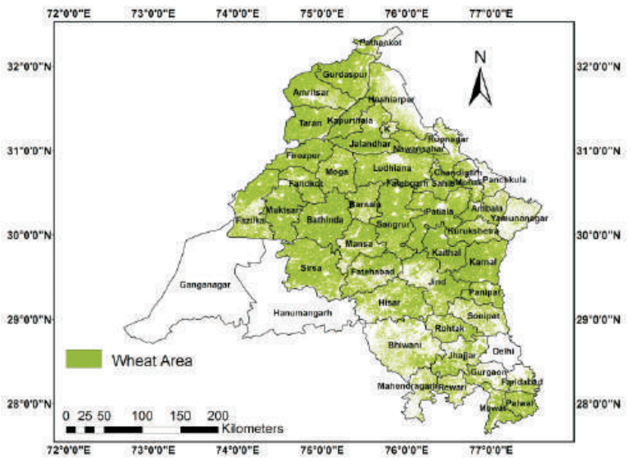

Fig. 1. Delineated wheat area in Agro-climatic Region VI (Satellite Image Analysis)

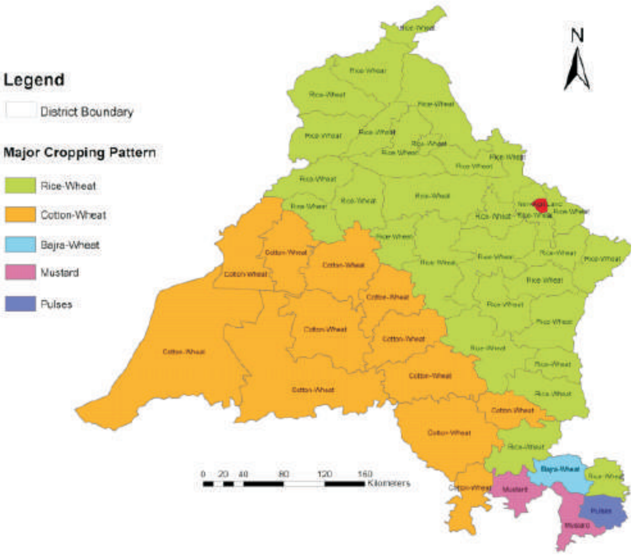

Fig. 3. Major cropping pattern of ACR-VI

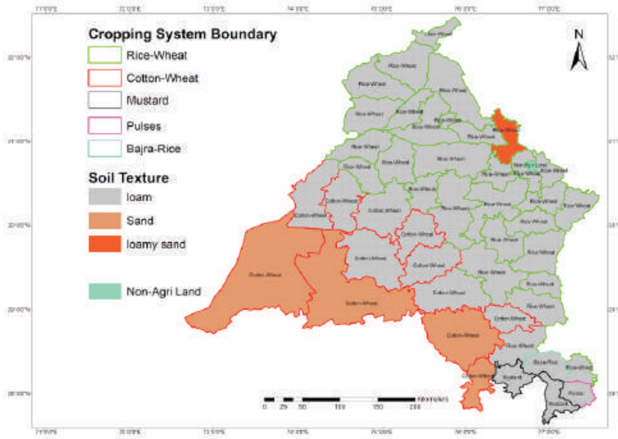

Fig. 4. Cropping pattern with soil texture in ACR VI

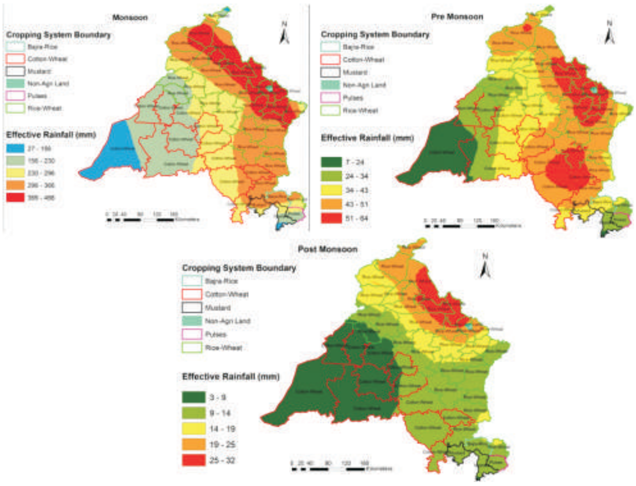

Fig. 5. Effective rainfall distribution pattern with respect to cropping system

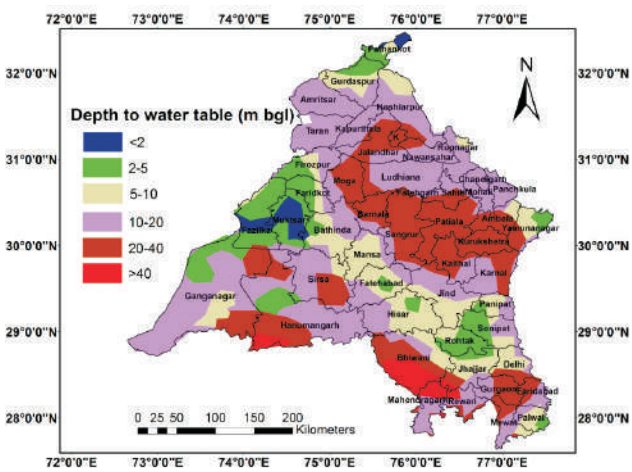

Fig. 6. Status of groundwater table depth in ACR-VI

major cropping pattern of ACR–VI with effective rainfall distribution, it showed that effective rainfall for rice–wheat cropping system varied within 230–406, 34–64 and 9–32 mm during monsoon, pre monsoon and post monsoon season respectively.

Groundwater table depth: Spatial variation of depth to water table as per *ground water year book* in ACR–VI is presented in Fig. 6. In rice–wheat cropping system maximum area (24.67 million ha) lies under the water table depth of 10–20 m followed by 19 million ha under 20–40 m depth to groundwater (Fig. 6). It has been reported that overexploitation of groundwater resources is most severe in central Punjab. The average annual depletion in groundwater table in the central Punjab was about 17 cm during the 1980s and about 25 cm during the 1990s; it was alarmingly high at 91 cm per annum during 2000–2005 (Singh 2011). Out of 142 blocks in the state, water table is declining in 110 blocks due to over–extraction of water than the proportionate recharge. By the year 2023, the water table depth in central Punjab is projected to fall below 21 m in 66 % area, below 30 m in 34 % area and below 40 m in 7 % area (Sidhu et al 2010).

CONCLUSION

The rice–wheat area of ACR–VI was mapped through remote sensing analysis using Landsat ETM+ and IRS images respectively. There was a good correlation in terms of quantitative estimation of rice and wheat area between the analyzed data and the reported information by respective government departments under the study area. From rice–wheat delineated areas, the major part of crop water requirement is not met through rainfall. Hence groundwater is being extensively used in most part of ACR–VI. Hence choice of low water requirement crops, appropriate cropping pattern to fitting the rainfall, improved soil–water–crop management technologies as well as water saving irrigation methods should be promoted inorder to sustain the agriculture system within the limited available water resources.

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