Project report

Crop type mapping using high-resolution Sentinel-2 Satellite Data– A case study on Gujarat State

Murali Krishna Gumma, Pranay Panjala, Ismail Mohammed
and Vineetha Pyla

ICRISAT
INTERNATIONAL CROPS RESEARCH
INSTITUTE FOR THE SEMI-ARID TROPICS

Project Objectives

Objective: Mapping following products of Gujarat state using high-resolution Sentinel-2 satellite data

1. Crop type
2. Irrigated and Rainfed area

Major Activities

• Satellite imagery acquisition/ procurement and pre-processing (Sentinel-2, 10&20 m spatial resolution).

• Field information (ground reference data) and farmer interviews at selected locations and collection of validation points.

• Satellite Imagery analysis and interpretation for land use / land cover areas including irrigated and rainfed cultivated areas.

Application of remote sensing technology

1.1 Ground data collection

Ground information was collected through surveying in field campaigns across Gujarat state and collectively used for training data (for class identification) as well as to assess accuracy (Gumma *et al.*, 2011b).

- For Gujarat state, 1413 ground data samples collected during Rabi season of the year 2019-20, of which 218 samples used for class identification and labeling and 1195 samples for validation purpose (Figure 1).
- Data were collected using stratified random sampling method: stratified by road network and randomized by distance travelled (either every 10 minutes of drive or every 10/15/20 kilometers of drive, depending on road and weather conditions or safety issues/sensitive locations).

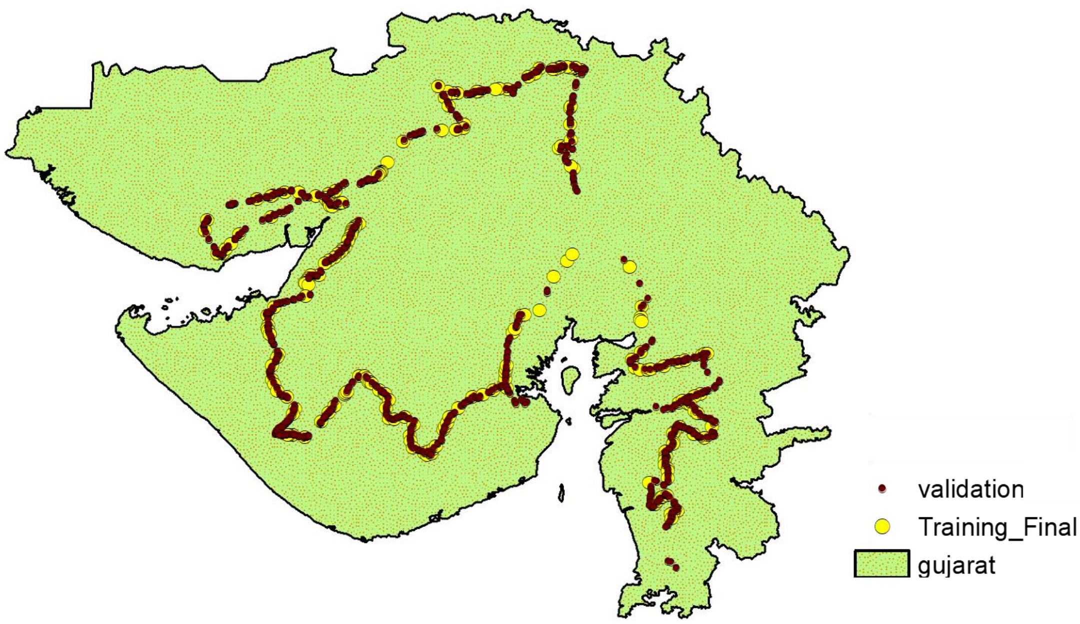

Figure 1: Ground data collection locations in* Gujarat *district

However, detailed farmer interviews conducted in some areas.

For each sample, information collected on existing crop, irrigation and soil types and land use / land cover (LULC) with a 250 m x 250 m patch size and geo-located

- Information on irrigated area surrounding the point categorized into three classes: small (≤10 ha), medium (10-15 ha) and large (≥15 ha).
- Additional information also gathered through personal interviews with farmers and with district agricultural extension officers to determine cropping intensities and crop-types during the previous year. Overall, ground data was systematically collected by adopting the following approach:
    - *Cropland water methods: irrigated or Rainfed*
    - *Cropping intensity: single crop (SC), double crop (DC) or continuous crop (Gorelick et al.)*

A minimum of two photographs captured at each location for better understanding about LULC patterns. Information also collected on planting dates, cropping intensity (single or double crop), percentage canopy cover etc. Additional information for areas not accessible due to road conditions and time constraints obtained from respective agriculture and irrigation departments. LULC names and class labels assigned in the field according to the ground data collection protocol (Thenkabail *et al.*, 2009; Gumma *et al.*, 2014).

1.2 Methodology for mapping of cropping patterns

The process begins with mapping LULC using Sentinel-2 time series data in Google Earth Engine Interface. Four bands of Sentinel-2 data at 10 m resolution along with Normalised

Difference Vegetation Index (NDVI) and Normalised Difference Water Index (NDWI) indices and Shuttle Radar Topography Mission (SRTM) Elevation obtained for Gujarat state– for the period of November 2019 to March 2020 were composite into single image. For each month, images with minimum cloud cover identified and used.

Table 1. Sentinel-2 bands used for classification, and their spatial resolutions

Band	Resolution (m)
Band 2 - Blue	10
Band 3 - Green	10
Band 4 - Red	10
Band 8 - NIR	10

First, carried out supervised classification on single composite image using training data in Google earth engine (Fig 2) and using visual interpretation if any errors found in the mixed classes, it was reclassified by masking out mixed classes by applying unsupervised classification, and identified classes using Spectral Matching Techniques (NDVI Hierarchical classification).

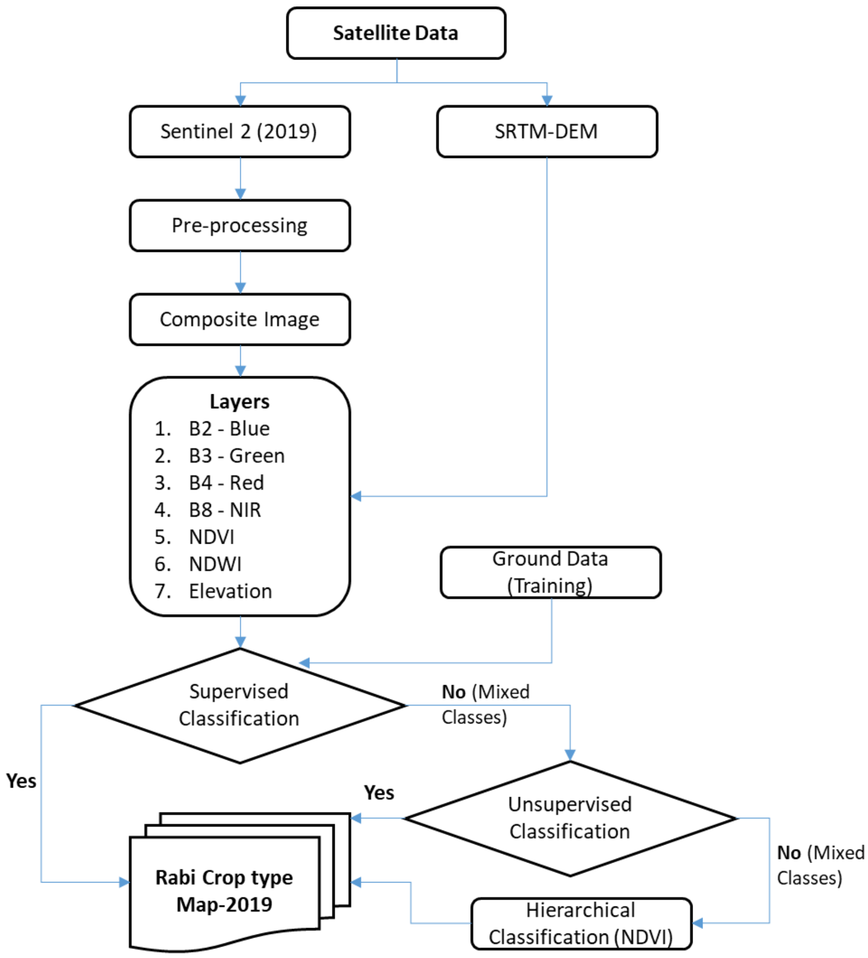

Figure 2: Methodology used for crop type mapping of Gujarat state

The process of labelling and class identification was done based on spectral matching techniques (SMTs) (Gumma *et al.*, 2015; Gumma *et al.*, 2016; Gumma *et al.*, 2018). Initially, 160 classes grouped from the unsupervised classification based on spectral similarity or closeness of class signatures. Each group of classes, then matched with ideal spectral signatures and ground survey data, and class names assigned. Classes with similar time series and land cover merged into a single class, and classes showing significant mixing, e.g., homogeneous irrigated areas and forest masked and reclassified using the same ISOCLASS algorithm. While class aggregation could have been performed statistically using a Euclidean or other distance measure, we employed a user-intensive method that incorporates both ground survey data and high resolution imagery in order to avoid lumping classes that might be spectrally similar but have distinct land cover. The signatures of some classes differed only in one or two months, which would have resulted in merging of the classes if an automated similarity index used.

The integration of both supervised and unsupervised classified helps in classification of mixing classes.

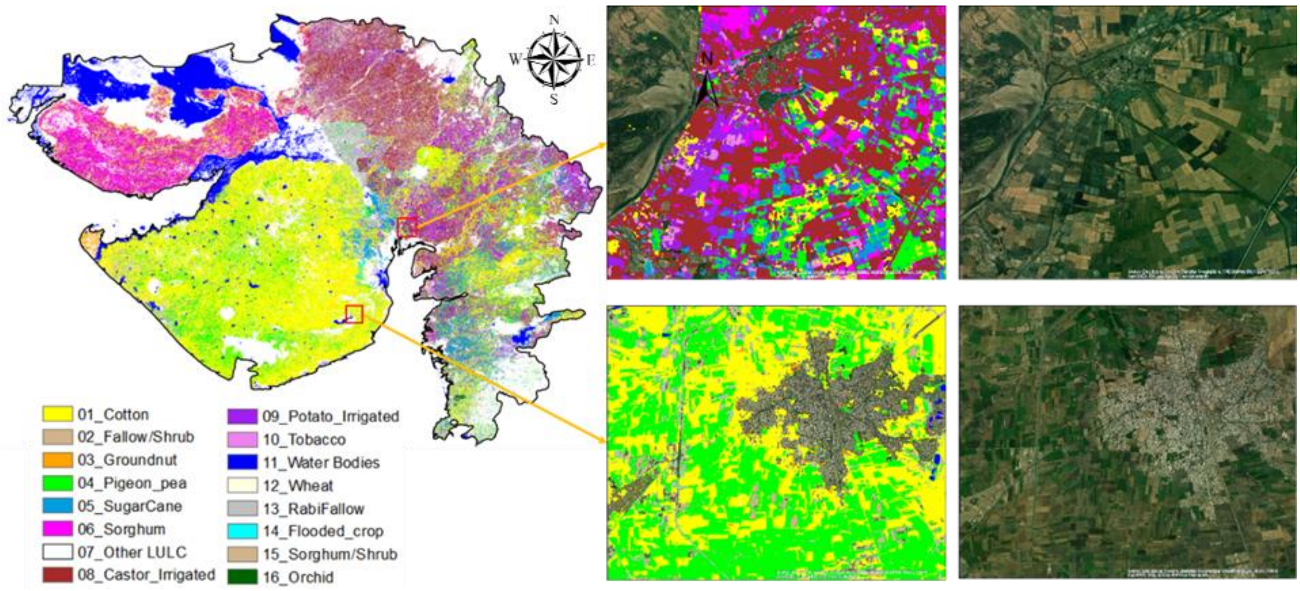

Figure 3: Crop type map for Gujarat state for Rabi 2019-20.

The above figure 3 shows the crop type map for Rabi season for entire Gujarat state, the major crops mapped were cotton, groundnut, pigeon pea, sugarcane, sorghum, castor, potato, tobacco and wheat, and mapped other LULC and water bodies.

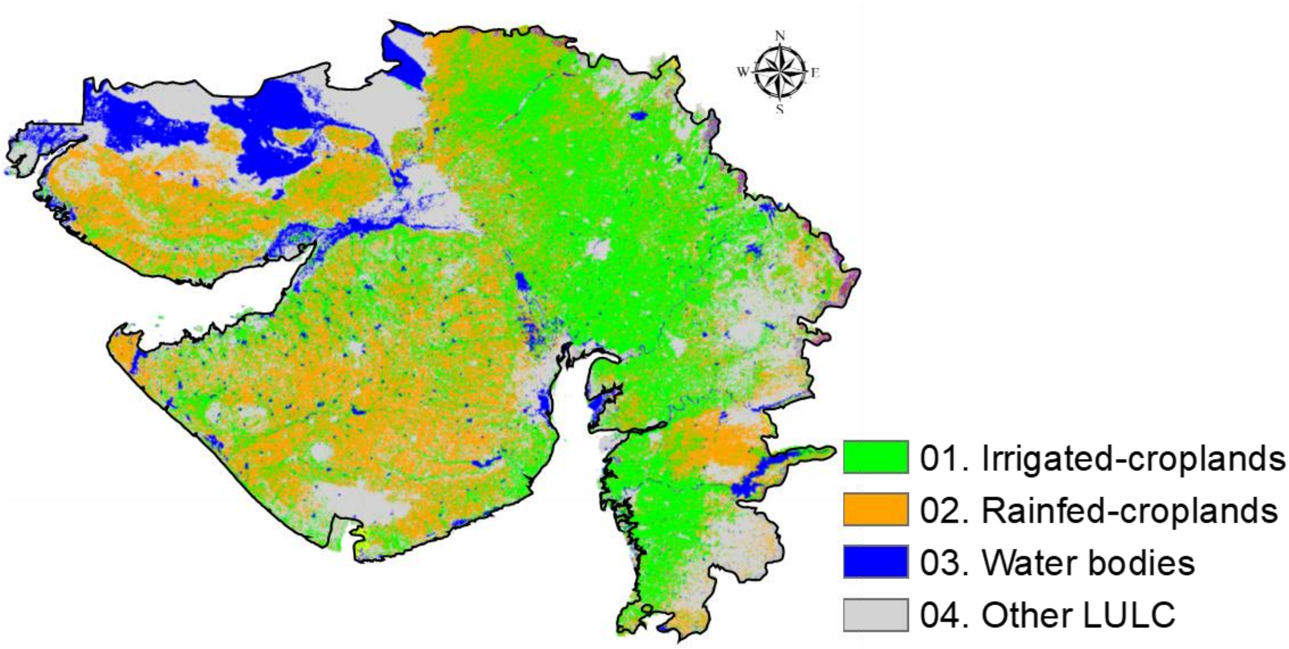

Figure 4a: Irrigated and Rainfed Cropland map for Gujarat state for Rabi 2019-20

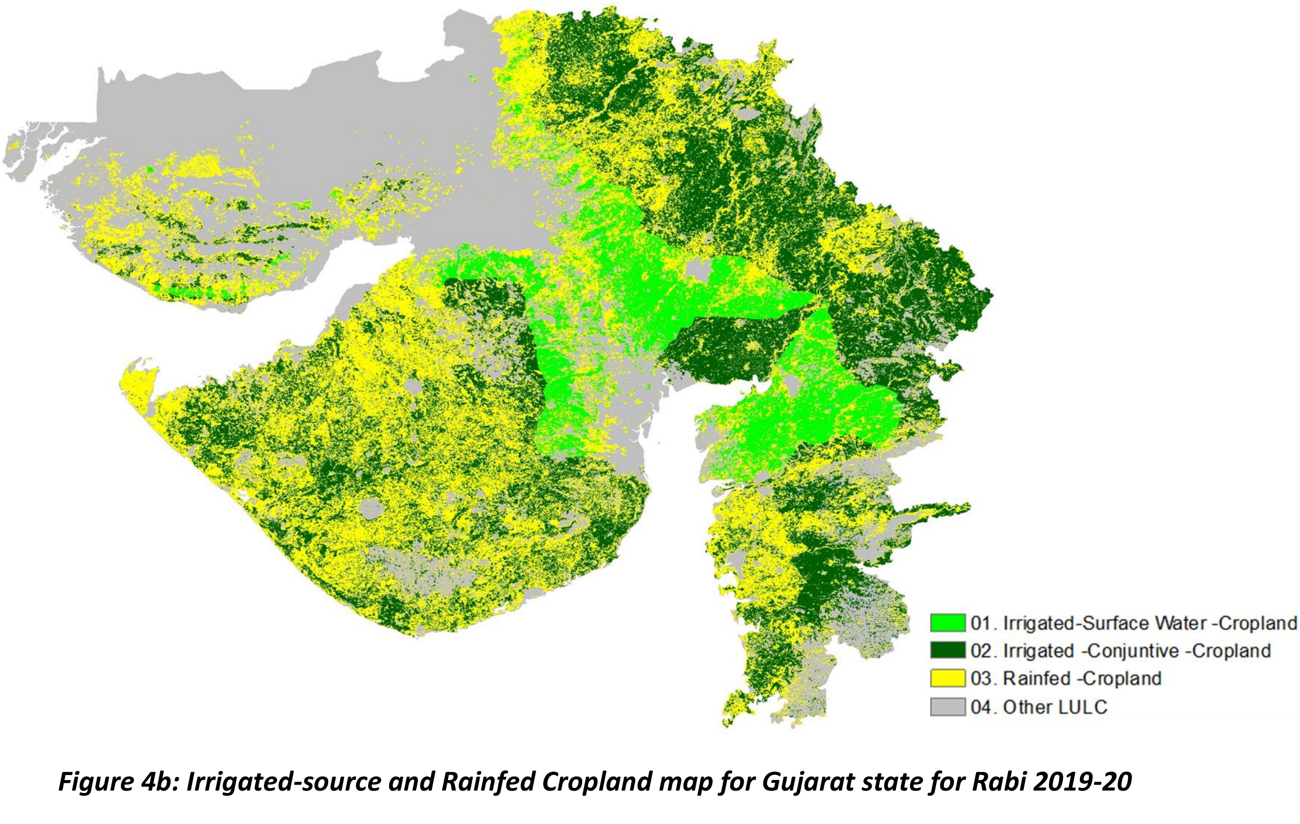

Figure 4b: Irrigated-source and Rainfed Cropland map for Gujarat state for Rabi 2019-20

The above figure 4a and figure 4b represents the Irrigated and Rainfed croplands of entire Gujarat state. This map helps in mapping Irrigated crops and Rainfed crops.

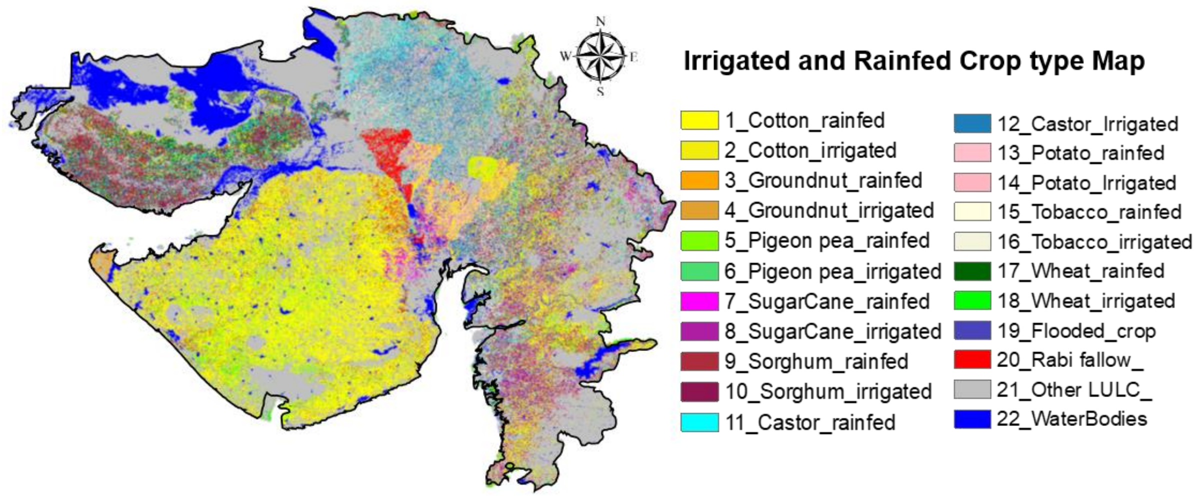

Figure 5: Irrigated and Rainfed Crop type map for Gujarat state for Rabi 2019-20.

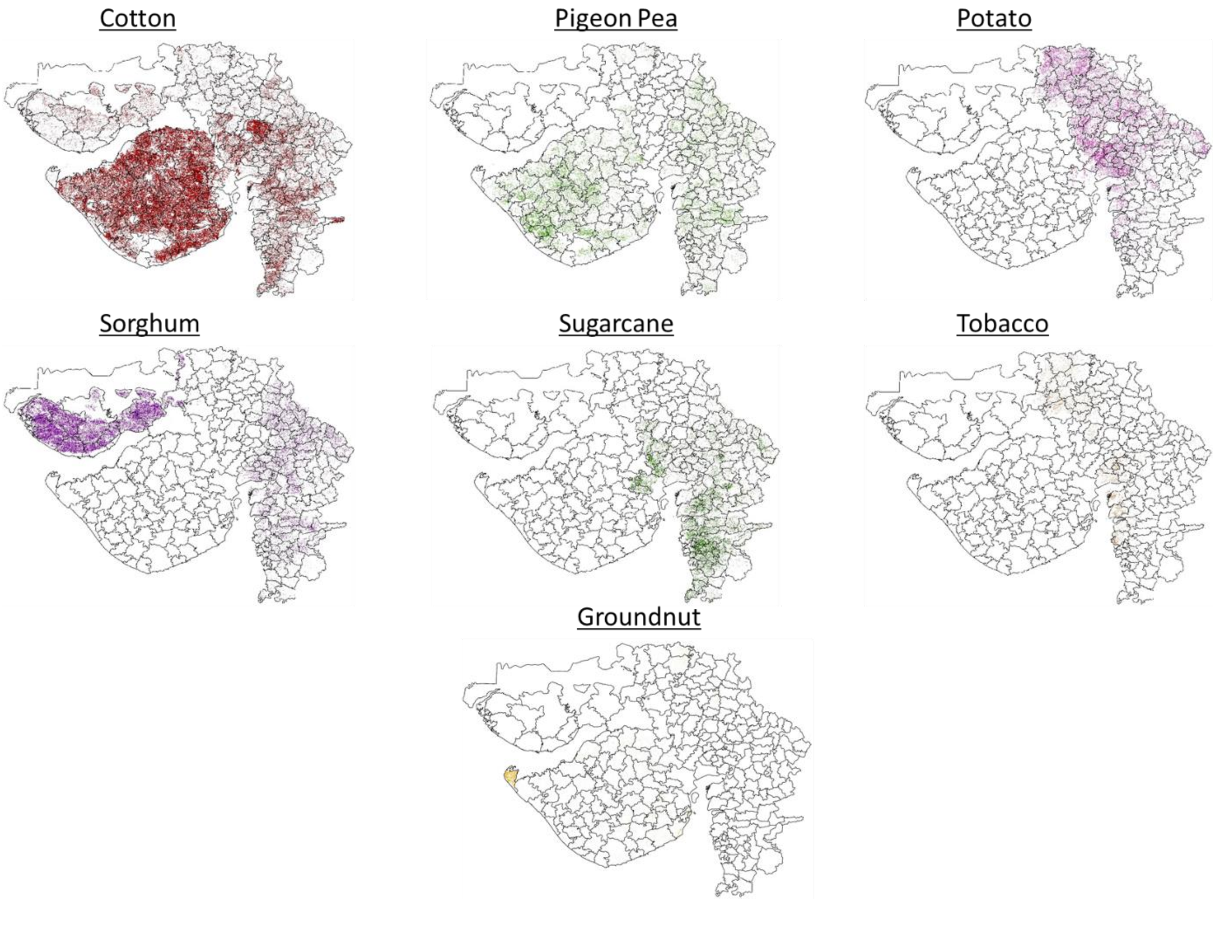

Figure 6: Specific Crop type map for Gujarat state for Rabi 2019-20.

The above figure 5 illustrates the Irrigated and Rainfed crops for entire Gujarat. With the help of Crop type map and Irrigated and Rainfed cropland map, the crops classified accordingly.

Figure 6 shows the specific crop type maps with taluk boundaries (2015)

1.3 Accuracy assessment

Ground data points were used to assess the accuracy of the classification results based on a standard procedure (Jensen, 1996; Congalton and Green, 1999; Congalton and Green, 2008), to generate an error matrix and accuracy measures for each land use/land cover map. 1195 sample points were used for validation of LULC maps. Error matrices (Farr and M. Kobrick), Cohen's kappa coefficient (κ) are commonly used for accuracy assessment. These are useful when building models that predict discrete classes or when classifying imagery. κ can be used as a measure of agreement between model predictions and reality (Congalton, 1991) or to determine if the values contained in an error matrix represent a result significantly better than random (Jensen, 1996). κ is computed as:

$$\kappa = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} \times x_{+i})} \qquad (1)$$

where, N is the total number of sites in the matrix, r is the number of rows in the matrix, x_{ii} is the number in row i and column i, x_{+i} is the total for row i, and x_{i+} is the total for column i (Jensen, 1996). The error matrices for the classified map for *rabi* season, including overall accuracy, producer's and user's accuracies, and kappa coefficient is given in Table 2.

The producers and Users accuracy's' calculated for every crop class of final image. The overall accuracy obtained was nearly 74 percent and Kappa coefficient was 0.64

Table 2: Error matrix for Rabi season crop pattern map of Gujarat State

	Cotton	**Ground Nut**	**Pigeon Pea**	**Sugar Cane**	**Sorghu m**	**Castor**	**Potato**	**Total**	**User's**
Cotton	412	13	41	33	26	25	2	552	0.75
Ground Nut	3	21				3		27	0.78
Pigeon Pea	15	2	17	13	9	1		57	0.30
Sugar Cane	3		6	66	10	8		93	0.71
Sorghum	3		11	7	81	19		121	0.67
Castor	4		2	4	40	247	12	309	0.80
Potato							36	36	1
Total	440	36	77	123	166	303	50	1195	
Producer's	0.94	0.58	0.22	0.54	0.49	0.82	0.72	**Overall Accuracy /Kappa**	**0.736 /0.64**

Crop Map Statistics for Gujarat

- The below areas obtained for the year 2019-20 Rabi season and units are Hectare
- The area obtained is Rabi season-Sown area
- The area were extracted using recent district map of Gujarat (2015)

Table 3: District wise Irrigated and Rainfed area statistics of Gujarat State

S.No	District	Irrigated (ha)	Rainfed (ha)
1	Banas Kantha	506936	408605
2	Kachchh	349134	1141844
3	Sabar Kantha	428667	141004
4	Patan	280117	221057
5	Mahesana	332261	106615
6	Gandhinagar	167310	30900
7	Surendranagar	352636	440773
8	Ahmadabad	336795	217630
9	Panch Mahals	189215	62266
10	Dohad	72535	88905
11	Kheda	277230	51770
12	Rajkot	268723	548515
13	Jamnagar	274435	462276
14	Vadodara	286841	148888
15	Anand	229964	31278
16	Bhavnagar	222498	356669
17	Bharuch	202739	164450
18	Narmada	36558	101588
19	Amreli	107987	426493
20	Porbandar	65244	65831
21	Junagadh	194339	311938
22	Surat	325748	152133
23	The Dangs	3384	18537
24	Navsari	118350	25886
25	Valsad	96489	62623

Crop Type –Gujarat (ha)

Table 4: Crop wise statistics of Gujarat State for Rabi 2019-20

S.no	District	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Banas Kantha	12704.9	18674.1	3800.2	3426.5	2902.7	6369.1	258.5	11319.9	5995.5	125583.3	197919.1	72801.5	96195.5	14338.6	12656.5	2559.1	0.0	0.0
2	Kachchh	166089.9	18874.9	17.3	47.8	58.5	158.6	0.0	543542.6	198910.4	227881.0	77529.0	22.9	7.9	2.6	1.3	144560.7	0.0	306.7
3	Sabar Kantha	16284.2	72743.5	61.0	150.3	14326.2	46337.5	25741.7	19150.7	61251.1	20079.7	58713.0	25404.0	57540.8	860.2	2502.3	0.0	0.0	0.0
4	Patan	11168.9	13647.8	80.1	136.7	1183.4	2617.3	920.6	10439.5	7041.3	47961.9	81402.1	25832.3	41951.3	12226.1	16915.9	5359.8	0.0	23334.2
5	Mahesana	5813.7	27506.8	952.9	1372.4	787.2	2706.5	3173.6	519.7	1858.4	33787.3	112678.3	19879.3	52950.3	2994.1	7754.7	4.9	0.0	5360.3
6	Gandhinagar	4495.5	72731.9	79.6	333.8	9215.5	845.9	5637.6	317.5	2406.9	3484.4	20992.3	3513.1	19022.5	206.7	1033.6	0.0	0.0	0.0
7	Surendranagar	224322.2	212110.2	4926.5	3525.2	34991.4	29605.1	5689.3	0.0	0.0	330.8	79.0	874.9	984.8	0.0	0.0	2498.7	0.0	132533.5
8	Ahmadabad	72116.4	129948.7	27.0	17.3	863.5	705.6	116542.5	8.7	55.5	10659.8	10460.9	32468.2	72275.9	154.7	472.3	13.3	2.8	17855.1
9	Panch Mahals	15501.6	51598.4	0.0	0.0	7209.0	21005.2	28719.3	11400.2	39111.9	6578.2	17080.7	9507.7	23899.6	305.3	1400.0	0.0	0.0	0.0
10	Dohad	8439.1	10594.4	0.0	0.0	8699.9	8669.9	21416.2	15121.4	11422.7	12126.2	14867.1	19305.8	12914.5	1255.9	1198.4	0.0	0.0	0.0
11	Kheda	12313.0	85380.1	0.0	0.0	4742.8	26757.0	19981.4	5048.8	28653.6	9265.6	41452.7	9840.7	54608.3	2075.8	7788.9	0.0	0.0	0.0
12	Rajkot	374059.3	193059.3	3977.2	2513.8	107266.7	38118.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2197.7	0.0	26539.3
13	Jamnagar	267111.0	187832.3	26549.3	5122.2	72525.2	33222.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1293.5	0.0	34607.7
14	Vadodara	55556.3	114153.6	0.0	0.0	14800.8	21856.3	76186.7	18004.8	30710.4	9854.0	25769.0	9584.3	18315.0	1341.3	2709.2	0.0	0.0	0.0
15	Anand	4827.9	39256.5	0.0	0.0	1525.2	13983.2	13549.0	3540.4	30318.8	5921.6	53569.4	8594.1	56329.3	3196.0	13599.4	0.0	0.0	0.0
16	Bhavnagar	258600.8	155180.4	8066.5	6237.9	21917.6	16207.9	599.0	0.0	0.0	0.0	0.0	27.5	19.1	0.0	0.0	3167.8	4396.4	25752.2
17	Bharuch	38650.2	48234.1	0.0	0.0	24337.6	23878.9	59888.2	21510.2	17859.1	15517.4	24307.2	15646.7	17786.1	9352.2	9907.4	0.0	0.0	0.0
18	Narmada	41880.8	18134.1	0.0	0.0	20847.3	3260.5	18359.2	12286.0	1927.8	3431.6	1526.8	2750.3	1132.7	150.7	238.9	0.0	0.0	0.0
19	Amreli	325053.6	79686.5	4639.8	1443.8	56525.7	11849.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3971.6	58.8	6722.0
20	Porbandar	31526.9	40904.6	543.7	900.6	10757.9	8389.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	123.9	0.0	10143.2
21	Junagadh	178979.1	121100.5	2866.3	2187.4	89681.9	36509.6	3830.9	441.7	438.3	213.9	451.1	259.2	306.2	67.9	176.2	2285.6	0.0	14586.6
22	Surat	25130.9	67213.1	0.0	0.0	20565.8	26122.8	141508.9	24287.2	24003.9	8965.5	16199.1	7536.4	15141.5	1916.1	8542.3	0.0	0.0	0.0
23	The Dangs	2161.7	491.1	0.0	0.0	2939.2	245.0	2258.5	406.9	113.9	256.5	47.0	258.0	52.6	55.3	19.3	0.0	0.0	0.0
24	Navsari	6037.8	38177.6	0.0	0.0	2096.3	6459.5	35481.3	1487.3	5441.5	802.7	3521.0	608.3	3156.9	199.4	1098.3	0.0	0.0	0.0
25	Valsad	14167.7	38415.1	0.0	0.0	8240.3	3990.0	28684.7	3692.5	2166.5	1838.7	1964.9	1460.1	930.5	321.3	250.1	0.0	0.0	0.0

Class_Names	
1_Cotton_rainfed	10_Castor_rainfed
2_Cotton_irrigated	11_Castor_Irrigated
3_Groundnut_rainfed	12_Potato_rainfed
4_Groundnut_irrigated	13_Potato_Irrigated
5_Pigeon pea_rainfed	14_Tobacco_rainfed
6_Pigeon pea_irrigated	15_Tobacco_irrigated
7_SugarCane_irrigated	16_Wheat_irrigated
8_Sorghum_rainfed	17_Flooded_crop
9_Sorghum_irrigated	18_Rabi fallow_

2. Cropland Map of Maharashtra and West Bengal

2.1 Irrigated and Rainfed cropland maps

The Irrigated and Rainfed cropland maps (Fig 9 & Fig 12) were prepared using Sentinel -2 satellite images of 10m resolution and Ground data. The preparation of maps starts with stack of Maximum NDVI for all months in respective seasons/crop year and arranging the respective ground data. The whole process carried out using machine-learning algorithms in Google Earth Engine (Fig 7).

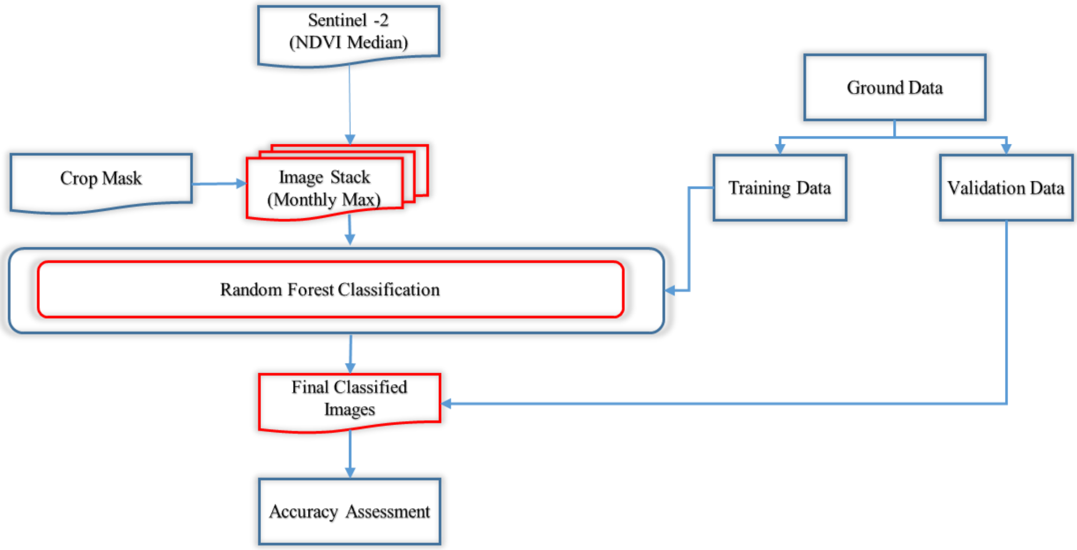

Fig 7: Classification procedure using Google Earth Engine

2.2 Crop Type Mapping

Crop type maps (Fig 10 & Fig 13) were prepared using MODIS satellite images of 250m resolution data and ground data with the help of Spectral Matching Techniques as shown in figure 8.

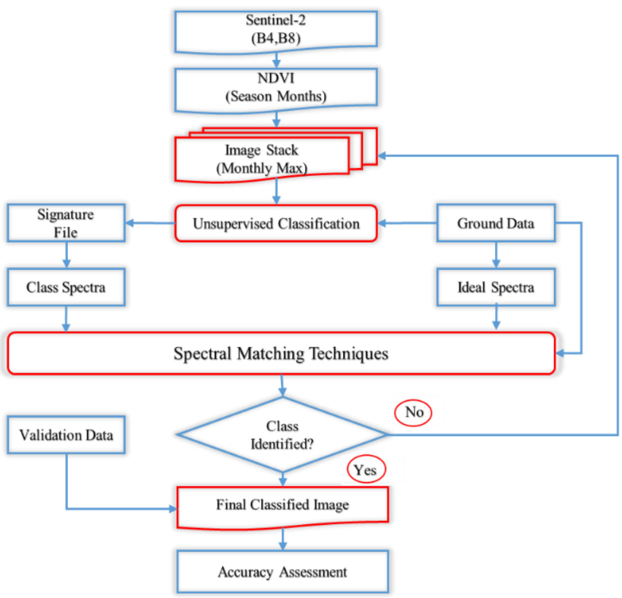

Fig 8: Classification procedure using Google Earth Engine

Maharashtra - Croplands

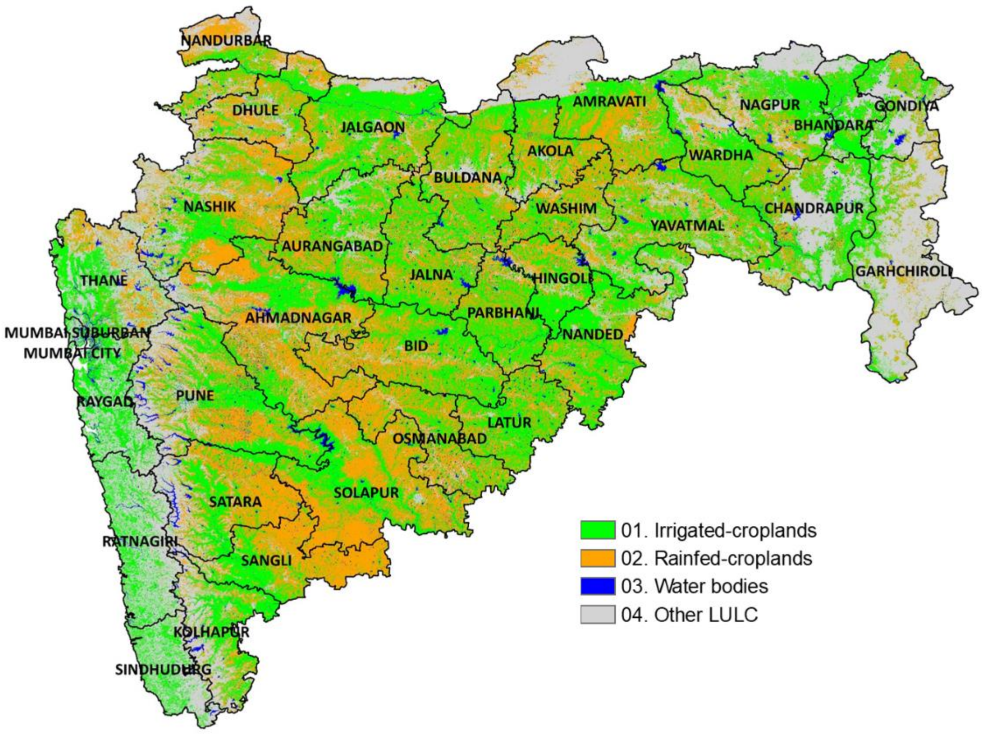

Fig 9: Spatial Distribution of Irrigated and Rainfed croplands of Maharashtra (2014-15)

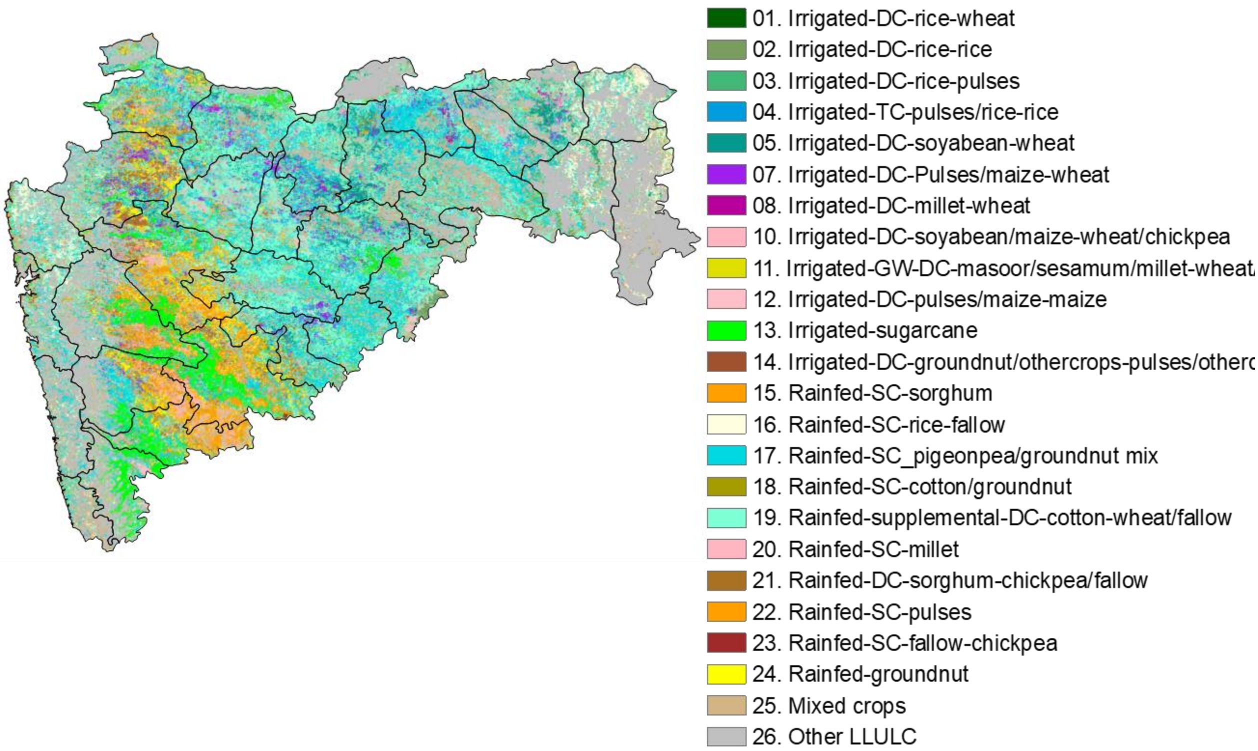

Fig 10: Spatial Distribution of crop types of Maharashtra (2014-15)

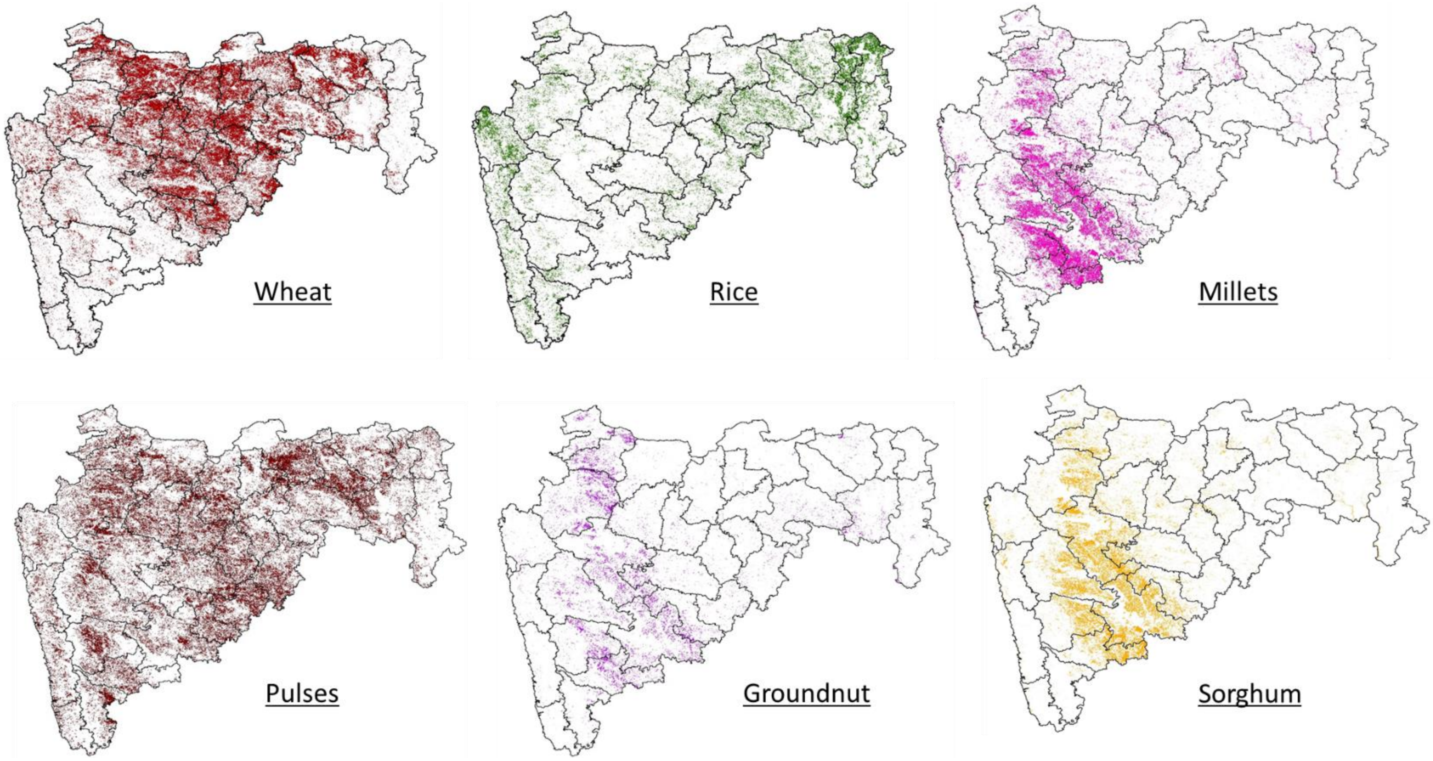

Fig 11: Spatial Distribution of Specific crops of Maharashtra (2014-15)

Table 5: District wise Irrigated and Rainfed Croplands of Maharashtra (2014-15)

District	Irrigated (ha)	Rainfed (ha)
Bhandara	205024	36943
Amravati	360042	393863
Nagpur	386230	210995
Jalgaon	586457	333122
Wardha	273997	208864
Buldana	402823	394735
Nandurbar	132820	190369
Akola	216466	252519
Nashik	369489	578421
Garhchirol	147040	138140
Aurangabad	420942	389902
Chandrapur	379497	225953
Yavatmal	546180	445925

Thane	216654	166595
Ahmadnagar	530068	729492
Nanded	550943	324813
Pune	486167	380458
Bid	464245	487417
Mumbai_sub	4546	200
Raygad	179083	21779
Mumbai_cit	223	8
Latur	363613	252621
Osmanabad	235729	416827
Solapur	504500	807473
Satara	286593	292312
Ratnagiri	57436	3066
Sangli	247625	401542
Kolhapur	241929	92614
Sindhudurg	34451	2696
Dhule	184487	272201
Gondiya	162288	96495
Washim	181132	270564
Hingoli	245105	151350
Parbhani	339761	231704
Jalna	377473	328226

- The above areas obtained for the year 2014-15 and units are Hectare
- The area obtained is Net Sown area
- Net Sown Area: 19.8 Mha

West Bengal - Croplands

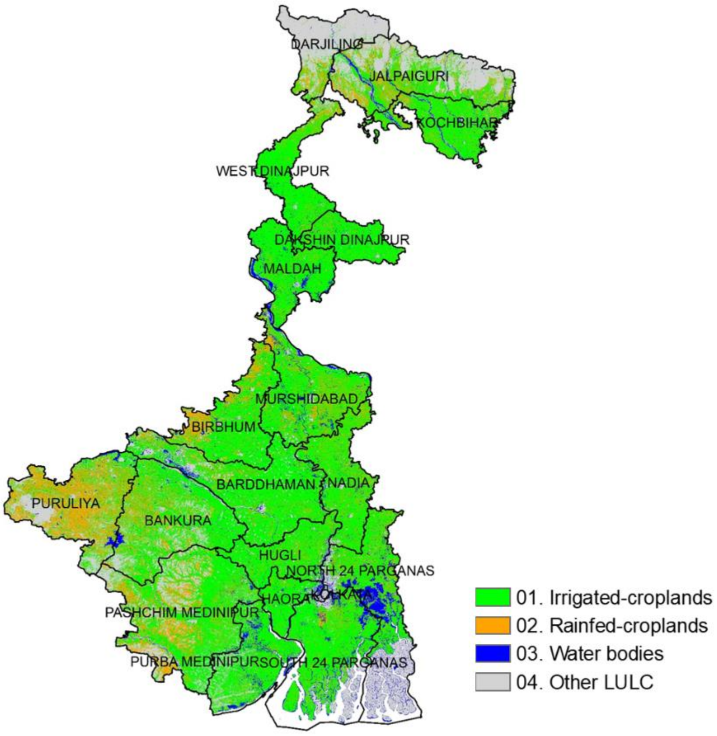

Fig 12: Spatial Distribution of Irrigated and Rainfed croplands of West Bengal (2014-15)

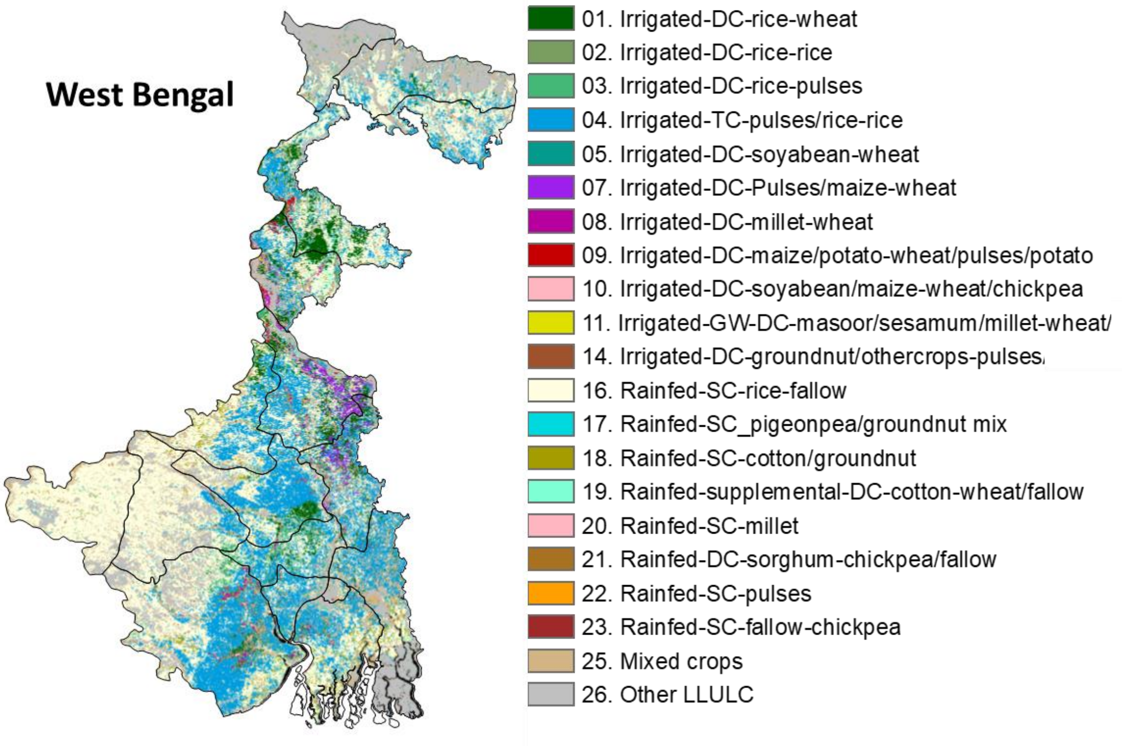

Fig 13: Spatial Distribution of crop types of Maharashtra (2014-15)

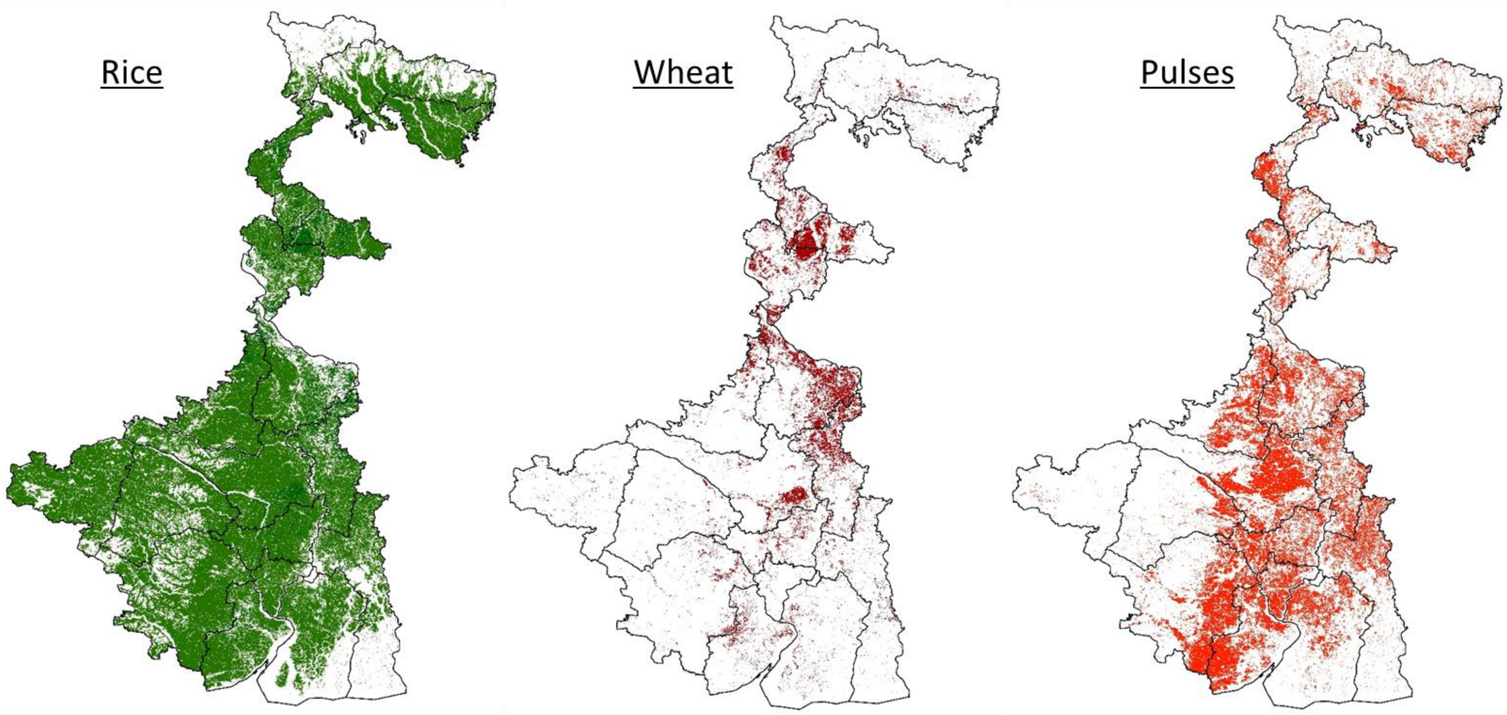

Fig 14: Spatial Distribution of Specific crops of Maharashtra (2014-15)

Table 6: District wise Irrigated and Rainfed Croplands of West Bengal (2014-15)

District	Irrigated (ha)	Rainfed (ha)
Darjiling	13012	15796
Jalpaiguri	113193	82754
Maldah	241230	24175
Murshidaba	306553	100473
Purba_medi	214409	27880
Pashchim_m	431817	189654
Birbhum	276185	100773
Nadia	198630	54779
Barddhaman	455269	68438
Puruliya	151124	266697
West_dinaj	229902	32817
Bankura	363772	124994
North_24_p	148228	38315
Hugli	212680	33701

Haora	70960	8285
South_24_p	272972	44106
Kolkata	58	14
Kochbihar	171536	35314
Dakshin_di	175742	17915

- The above areas obtained for the year 2014-15 and units are Hectare
- The area obtained is Net Sown area
- Net Sown Area: 5.3 Mha

3. Limitations and challenges

- The crop classification also requires extensive ground data. Visiting fields for 2 to 3 times in a season helps in attaining good accuracy and also helps in collecting other parameters
- It’s very difficult to differentiate the sources of irrigation. This require more ground data as well as secondary data
- The model requires the temporal analysis of croplands for at least 3 to 4 years to get accurate results (Gumma *et al.*, 2020), also results can improve with data fusion techniques (Gumma *et al.*, 2011a; Gumma *et al.*, 2015).
- In some areas, even though under command area, there is usage of ground water. So, identifying such areas requires secondary data from local agencies

4. Summary

The mapping of crop type and Rainfed and Irrigated croplands for the Rabi 2019-20 was carried out using Sentinel 2 (10 m) data with the help of ground data. Nearly 73.6 percent of accuracy was attained for crop classification using error matrix. With the help of rainfed and Irrigated cropland map, extracted source wise crop type map for entire Gujarat.

The attempt was made to differentiate the Surface water as well as ground water usage areas, but in some areas, the usage of ground water in command areas is high. This can be improved with secondary data. The most of the areas in Gujarat is under Conjunctive water use i.e. both Ground and Surface water usage.

Finally, District wise Irrigated and Rainfed croplands was extracted using updated 2015 Gujarat district Map.

Acknowledgements: We would like to thank to Tata-Cornell University to execute this project. We would like to thank Ms Bhavani Panjala for preliminary LULC classification.

Reference

Congalton, R.G., 1991. Remote Sensing and Geographic Information System Data Integration: Error Sources and. Photogrammetric Engineering & Remote Sensing 57, 677-687.

Congalton, R.G., Green, K., 2008. Assessing the accuracy of remotely sensed data: principles and practices. CRC press.

Farr, T.G., M. Kobrick, 2000. Shuttle Radar Topography Mission produces a wealth of data,. EOS Transactions 81, 583-585.

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., Moore, R., 2017. Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote sensing of Environment 202, 18-27.

Gumma, M.K., Thenkabail, P.S., Deevi, K.C., Mohammed, I.A., Teluguntla, P., Oliphant, A., Xiong, J., Aye, T., Whitbread, A.M., 2018. Mapping cropland fallow areas in myanmar to scale up sustainable intensification of pulse crops in the farming system. GIScience & Remote Sensing 55, 926-949.

Gumma, M.K., Thenkabail, P.S., Hideto, F., Nelson, A., Dheeravath, V., Busia, D., Rala, A., 2011a. Mapping irrigated areas of Ghana using fusion of 30 m and 250 m resolution remote-sensing data. Remote Sensing 3, 816-835.

Gumma, M.K., Thenkabail, P.S., Maunahan, A., Islam, S., Nelson, A., 2014. Mapping seasonal rice cropland extent and area in the high cropping intensity environment of Bangladesh using MODIS 500m data for the year 2010. ISPRS Journal of Photogrammetry and Remote Sensing 91, 98-113.

Gumma, M.K., Thenkabail, P.S., Nelson, A., 2011b. Mapping irrigated areas using MODIS 250 meter time-series data: A study on Krishna River Basin (India). Water 3, 113-131.

Gumma, M.K., Thenkabail, P.S., Teluguntla, P., Rao, M.N., Mohammed, I.A., Whitbread, A.M., 2016. Mapping rice-fallow cropland areas for short-season grain legumes intensification in South Asia using MODIS 250 m time-series data. International Journal of Digital Earth 9, 981-1003.

Gumma, M.K., Tummala, K., Dixit, S., Collivignarelli, F., Holecz, F., Kolli, R.N., Whitbread, A.M., 2020. Crop type identification and spatial mapping using Sentinel-2 satellite data with focus on field-level information. Geocarto International, 1-17.

Gumma, M.K., Uppala, D., Mohammed, I.A., Whitbread, A.M., Mohammed, I.R., 2015. Mapping direct seeded rice in Raichur district of Karnataka, India. Photogrammetric Engineering & Remote Sensing 81, 873-880.

Jensen, J.R., 1996. Introductory digital image processing: A remote sensing perspective. Upper Saddle River, New Jersey: Prentice Hall.

Thenkabail, P.S., Biradar, C.M., Noojipady, P., Dheeravath, V., Li, Y., Velpuri, M., Gumma, M., Gangalakunta, O.R.P., Turral, H., Cai, X., Vithanage, J., Schull, M.A., Dutta, R., 2009. Global irrigated area map (GIAM), derived from remote sensing, for the end of the last millennium. International Journal of Remote Sensing 30, 3679-3733.