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Research Article

Irrigation Potential Utilization Estimation using Time-Series Satellite Data

Sobhan Mishra[1], Shankar Muthyam[2], Raju, P.V.[1], Annie Maria Issac[1], Rao, V.V.[1]

[1]National Remote Sensing Center, Hyderabad 50037, India
[2]Formerly with National Remote Sensing Center

Correspondence should be addressed to Sobhan Mishra, *sobhanmishra91@gmail.com*

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Abstract In India, significant irrigation potential has been created to increase the agricultural crop intensity and its production. However, these irrigation systems, built with huge financial investments, exhibit significant gap in potential created and utilized. The contributing factors are multi fold and State & Central Governments initiated many programs to bridge the gap in irrigation potential created & utilized under command areas. Objective assessment of actual irrigation utilization in command areas is prerequisite for planning appropriate interventions to bridge the gap. Conventional field-based data collection mechanism is tedious and do not provide spatial patterns of irrigation utilization. Satellite data with multi-spectral and temporal dimensionality provides opportunities to estimate irrigation utilization and thus to derive its spatial patterns quantifying the gap between created and utilized. In this study, the irrigation potential utilized, as against the potential created was analyzed for Krishna basin using multi-temporal satellite data. Seasonal and annual crop map was derived from times series Advanced Wide Field Sensor (AWiFS) data through unsupervised classification. The crop area identified from the remote sensed information was separated into irrigated and rainfed classes based on temporal profiles of Normalized Differential Vegetation Index (NDVI) with in a crop season. Irrigation Potential Utilized (IPU) was determined as the gross irrigated area.
Keywords *Satellite data; Irrigation Potential Utilization; Ground truth*

1. Introduction

In India, irrigation potential has been created to increase the agricultural crop intensity and its production. However there is a significant gap between the irrigation potential created and utilized (Ramanayya et al., 2008). This may be due to lack of canals at field levels, improper design of irrigation projects, etc. Conventionally Irrigation Potential Utilized is assessed from the data collected by Irrigation Department, Revenue Department and Agricultural Department on periodic basis. This method has the limitations of data gaps and subjectivity errors. These conventional methods are highly manpower and time intensive.

Satellite remote sensing offers a great potential for routine monitoring of irrigated area due to better spatial coverage and readily available archives of satellite imagery (Jonna et al., 1992; Murali, K.G. et al. 2011). It is used for mapping out cropped areas with its source of irrigation. The images with high spectral and temporal frequencies can be used for identification of the crop type and its condition. The historic data that span from many years allow comparison of cropping pattern change, thus revealing changes in cultivation pattern in coherence through time. Estimation of cropped area from remote sensing data provides spatial distribution of cultivated area and is useful for assessing irrigation performance, improving irrigation intensities, quantifying environmental impacts and assessing irrigation water use. Crop maps generated from satellite imagery through the season on a near real time basis can be used for estimating sown areas and there by estimation of irrigation water requirement, which in turn is helpful in water resource planning and management (Raju et al., 2008).

Remote Sensing indices like green vegetation index and leaf area index can be used for estimation of land cover types (Gutman et al., 1998.). Remote sensing also is a potential tool to provide spatial and temporal information for precession crop management (Myneni et al*.,* 1995). Many studies had summarized the approach and techniques of remote sensing based crop discrimination and area estimation including single date approach based on maximum likelihood classification as well as use of hierarchical growth profile of classification of multiple crops like paddy, wheat, sorghum, groundnut, mustard and cotton (Dadhwal et al., Navalgund et al., 2000). Studies have also demonstrated the utility of multi date remote sensing derived indices like Normalized Difference Vegetation Index (NDVI) in estimation of Irrigation Potential Utilization within a command area (Shanker, M. et al., 2017)

NDVI band ratio of Near Infra-Red (NIR) and Red (R) (Rouse et al., 1974) is a remote sensing derived indicator of the crop stage and condition. The temporal profile of the of remote sensing derived vegetation indices like Normalized Difference Vegetation Index (NDVI), is used to capture the phonological development of the crop and there by identification of the crop progress through a season. The temporal profile of NDVI though exhibits a similar pattern; the quantitative values vary depending on the condition of the crop. A crop in a good condition presumed to be in irrigated condition, exhibits higher value of NDVI, there by facilitating a demarcation between the irrigated and rainfed condition within a crop type (Thenkabail et al., 2011)

In this study an attempt was made to separate cropped area seasonally with its irrigation source from time series optical datasets based on their temporal profile of NDVI. Unsupervised method of classification was adopted with set of decision rules for achieving the objective.

1.1. Study Area

The Krishna Basin extends over the states of Andhra Pradesh (10.07%), Telangana (19.74%), Maharashtra (26.34%) and Karnataka (43.82%). The basin has a maximum length and width of about 701 km and 672 km and lies between 73°17’ to 81°9’ East Longitudes and 13°10’ to 19°22’ North Latitudes. The basin is roughly triangular in shape and is bounded by Balaghat range on the North, Eastern Ghats on the South and Bay of Bengal on the east and Western Ghats on the West as illustrated in Figure 1. The basin falls under division-All drainage flowing into Bay of Bengal and Region-Rivers draining in Bay of Bengal, delineated primarily based upon drainage of rivers to outlet. Figure 2 shows the distribution of basin area over the three states. Krishna Basin is having a total area of 254746 sq. km which is nearly 8% of the total geographical area of the country.

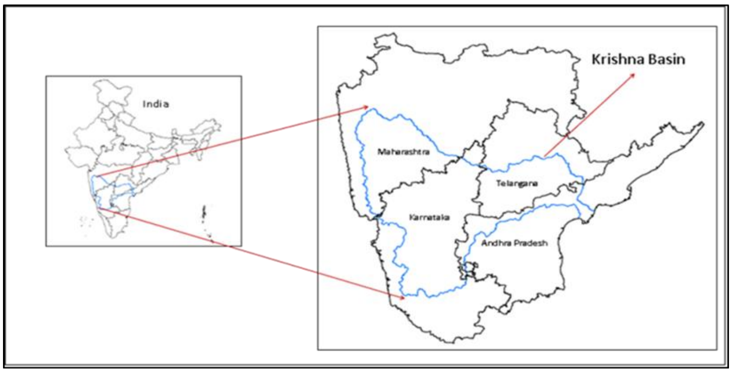

Figure 1: Location of Krishna Basin

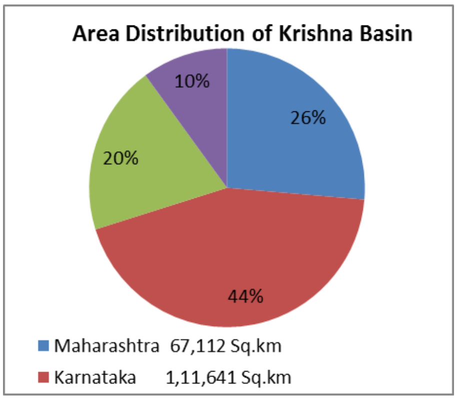

Figure 2: Distribution of Geographical Area

2. Materials and Methods

Obtaining seasonal and annual crop area maps with the help of remote sensing derived geospatial database is an age old practice for irrigation engineers and hydrologists. Recent studies have shown the utilization of remote sensing derived data for identification of crop types in a study area with its irrigation sources. In this paper decision rule based approach of unsupervised classification of time series monthly and fortnightly NDVI was adopted for identification of different crop types and its irrigated condition as illustrated in Figure 3. The datasets used in the study are discussed in the following sections.

2.1. Datasets Used

2.1.1. Satellite Imagery

Advanced Wide Field Sensor (AWiFS) optical datasets derived from Resourcesat were used in this study. It has a temporal frequency of 5 days, spatial resolution of 56m and has four bands in Visible and NIR (VNIR). The datasets were obtained from National Remote Sensing Center (NRSC) archives for two water years spanning from 2015 June to 2017 May.

2.1.2. Geospatial Datasets

Command area boundary and sub basin boundary was collected from India WRIS. Command area boundaries were digitized from high resolution datasets and the sub-basin boundaries were obtained from terrain processing of Digital Elevation Models.

2.1.3. Ground Truth Samples

Geo-Tagging of fields was done by using mobile application developed indigenously by National Remote sensing Center. The objective was to collect field information such as crop types, its growth stage, sowing and harvesting date and irrigation source. Around 800 ground truth points were collected in the projects of Krishna River Basin in two years 2015-16 and 2016-17.

2.1.4. Ancillary Datasets

The Land Use Land Cover information from generated in the Natural Resources Census (NRC) from AWiFS 56m for entire India for the year 2010-11 (Scale: 1: 250,000) was used for deriving the agriculture mask over which the classification was done.

2.2. Procedure

2.2.1. Generating Data Base

Top of atmospheric corrected AWiFS datasets were downloaded from archives of NRSC for the areas covering Krishna River basin. The datasets were preprocessed and corresponding NDVI images were generated. A temporal series of maximum NDVI at a time step of 15 days and one month was generated throughout the season.

The mask of non-agriculture areas was identified from the land use land cover map discussed in Section 2.1.4. The classification and its following analysis were carried out only on the agriculture area to avoid the error due to mixed pixels. A reference NDVI profile of different land covers were established in conjunction with the ground truth information. In order to avoid the possible inaccuracies inherent with multiple spectral reference profiles for multiple crops, the crops having similar temporal profile were aggregated and reference profiles for general crop groups were generated through out a year comprising of two seasons as seen in Figure 3.

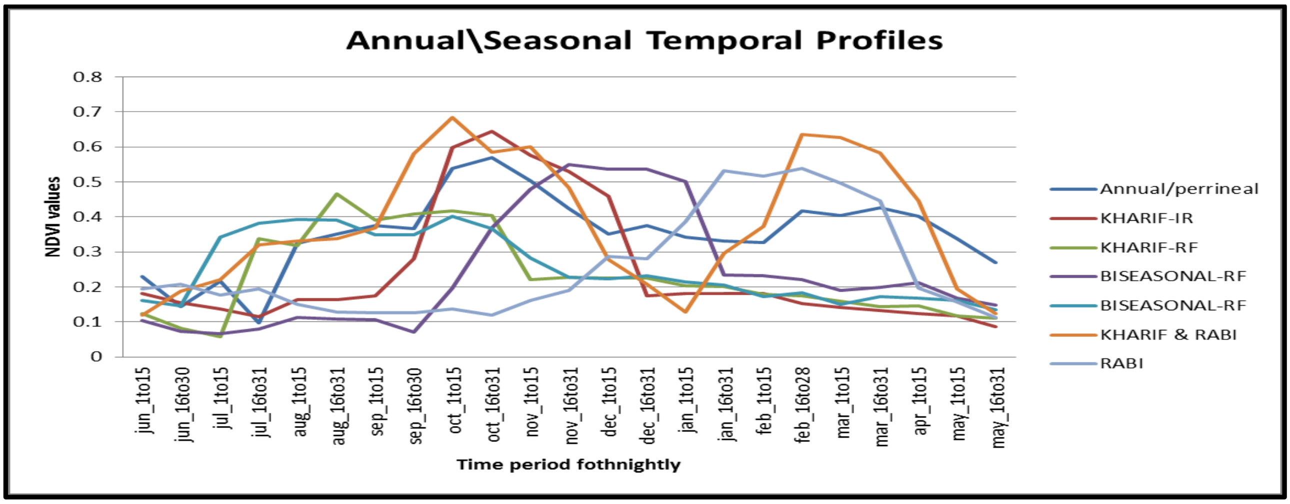

Figure 3: *Temporal signatures for different seasonal crop groups collected from ground truth data*

2.2.2. Decision Rule based Classification

Krishna basin was divided in to 8 sub basis as seen in Table 4. Classification was carried out sub basin wise to account for the spatial variation in crop calendar. The time series NDVI image was subjected to unsupervised classification. The image was classified into multiple classes and the classes were assigned with the general crop groups based on similarity with the reference signature (obtained from the ground truth). The categorization of the classes into crop groups was done by visual judgment. The criteria followed for classification is as described in Table 1.

Table 1: *Criteria for Categorization*

General Crop Group	No. of Peaks	Duration of the Profile (Base Period)	Trend of Peaks
Kharif – Irrigated	1	June- October	High
Kharif - Rainfed	1	June - October	Low
Bi-seasonal- Irrigated	1	June - February	High
Bi-seasonal- Rainfed	1	June - February	Low
Double Crop	2	June- May	High
Rabi	1	November - May	High
Annual/Perennial	1(Consistent)	June- May	High

2.2.3. Irrigation Potential Utilization Estimation

After classifying the time series NDVI image into the above crop classes, the area of each class was obtained. The Irrigation Potential Utilized (IPU) was estimated as the Gross Irrigated Area (GIA). Also, the Net Irrigated Area (NIA), Gross Sown Area (GSA) and Net Sown Area (NSA) were also estimated sub basin wise taking into consideration the crop areas as described in Table 2.

Table 2: *Estimation of GIA, NIA, GSA and NSA*

	Kharif-Irrigated	Kharif-Rainfed	Bi- seasonal Irrigated	Bi- seasonal Rainfed	Rabi	Double Crop	Annual/ Perennial
GIA / IPU	x		x		x	x (Twice)	x
NIA	x		x		x	x	x
GSA	x	x	x	x	x	x (Twice)	x
NSA	x	x	x	x	x	x	x

2.2.4. Accuracy Assessment by Kappa Statistics

800 ground truth samples were collected during two study years 2015-16 and 2016-17. Ground truth points were overlaid on the thematic map generated and compared for the accuracy of the classification with respect to the crop type, crop season and source of irrigation. The accuracy was estimated by computing the Kappa Statistics. Kappa statics is an inter observer variation that can be measured in any situation in which two or more independent variables are evaluating the same classes (Anthony J.V., and Joanne M.G., et al., 2005). The agreement of the classification with the reality is estimated by the Kappa value as described in Table 3.

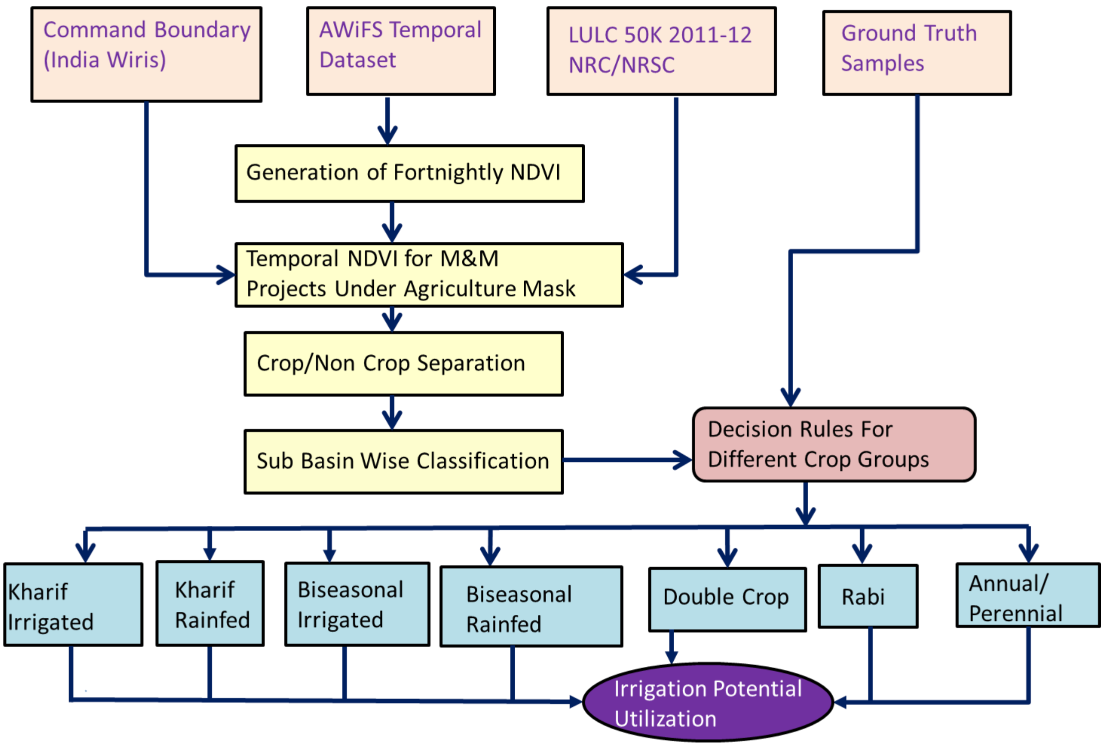

Figure 4: *Flow chart showing the methodology for carrying out classification and obtaining IPU*

Table 3: *Range of Kappa Values and the Agreement*

Kappa	*Agreement*
< 0	Less than chance agreement
0.01–0.20	Slight agreement
0.21– 0.40	Fair agreement
0.41–0.60	Moderate agreement
0.61–0.80	Substantial agreement
0.81–0.99	Almost perfect agreement

3. Results and Analysis

The classified map of Krishna basin showing irrigated / rainfed classes is shown in Figure 5 & 6 for 2015-16 and 2016-17 respectively. Sub-basin wise IPU (GIA) along with NIA, GSA, NSA are presented in Table 4 & Table 5 for the years 2015-16 and 2016-17. There was an increase in irrigated areas for Bhima Lower, Tungabhadra Lower and Tungabhadra Upper in the later year. This can be attributed to the increase in the implementation of lift irrigation schemes in theses sub basins in the years under study.

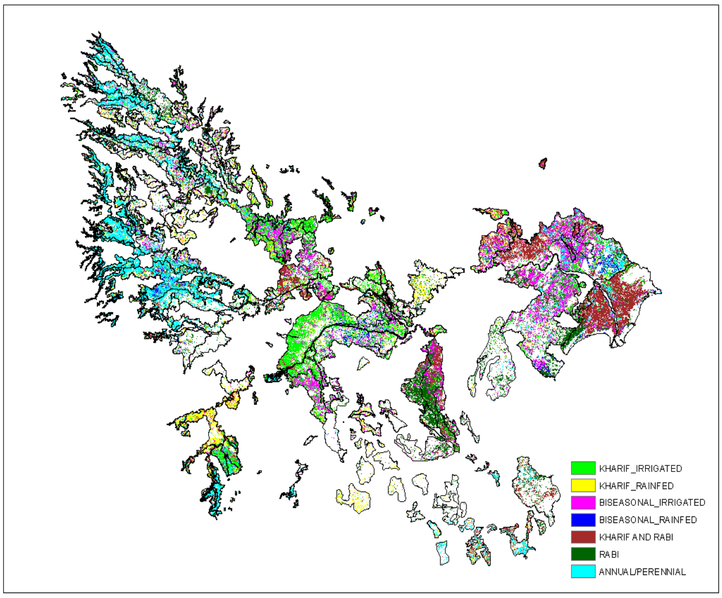

Figure 5: *Crop classes present in Krishna Basin for the year 2015-16*

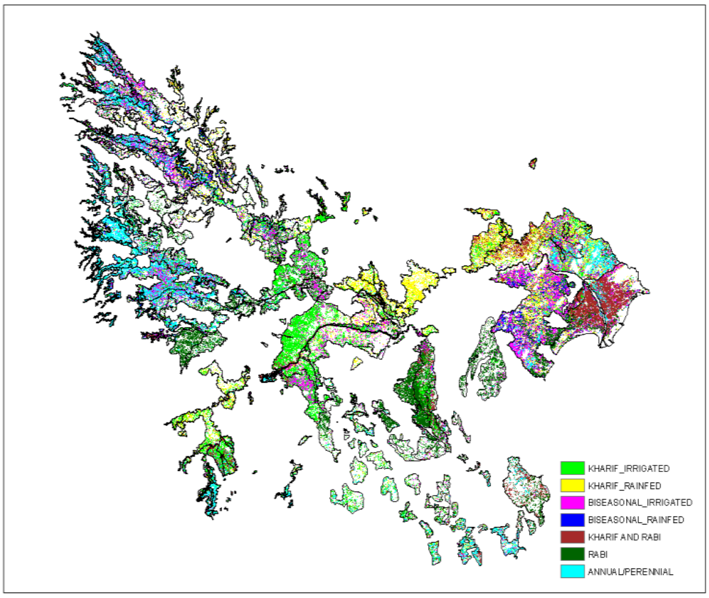

Figure 6: *Crop classes present in Krishna Basin for the year 2016-17*

Table 4: *Sub-basin wise IPU, NIA, GSA and NSA for 2015-16*

2015-16			**(Area in ha.)**	
Sub Basin	**Irrigation Potential Utilized (IPU)**	**Net Irrigated Area (NIA)**	**Gross Sown Area (GSA)**	**Net Sown Area (NSA)**
Bhima Lower	2,38,873	2,38,873	3,04,968	3,04,968
Bhima Upper	8,36,385	7,73,509	10,91,260	10,28,384
Krishna Lower	18,81,481	14,54,291	24,04,275	19,77,085
Krishna Middle	89,701	72,602	2,67,148	2,50,049
Krishna Upper	15,64,168	14,96,245	16,23,029	15,55,106
Tungabhadra Lower	6,85,652	6,39,821	7,53,899	7,08,068

Tungabhadra Upper	3,42,907	2,80,230	4,19,441	3,56,764
Projects Outside Krishna basin	12,32,010	10,87,467	12,74,290	11,29,747
Net Area	**68,71,177**	**60,43,038**	**81,38,310**	**73,10,171**

Table 5: *Sub-basin wise IPU, NIA, GSA and NSA for 2016-17*

2016-17			(Area in ha.)	
Sub Basin	**Irrigation Potential Utilized (IPU)**	**Net Irrigated Area (NIA)**	**Gross Sown Area (GSA)**	**Net Sown Area (NSA)**
Bhima Lower	3,77,287	3,67,375	4,65,206	4,55,294
Bhima Upper	8,91,144	8,24,984	10,14,505	9,48,346
Krishna Lower	22,10,477	15,97,151	23,50,571	17,37,246
Krishna Middle	1,97,166	1,53,940	2,43,995	2,00,769
Krishna Upper	14,60,818	12,58,367	16,29,996	14,27,545
Tungabhadra Lower	6,60,336	6,24,563	7,79,149	7,43,376
Tungabhadra Upper	3,08,085	2,42,785	4,32,659	3,67,360
Projects Outside Krishna basin	9,40,123	7,49,294	10,20,042	8,29,213
Net Area	**70,45,436**	**58,18,459**	**79,36,125**	**67,09,149**

3.1. Irrigation Potential Utilization (IPU) for Krishna Basin

The details of Irrigation Potential Utilization (IPU), Net Irrigated Area (NIA), Gross Sown Area (GSA), Net Sown Area (NSA) during 2015-6 and 2016-17 in Krishna basin is shown in Figure 7. The seasonal distribution of irrigated / rainfed classes is shown in Figure 8. There is an increase in the irrigated and sown area in the year 2016-17 as compared to the earlier year. The irrigated area increased by 4% in the later year due to the reduced rainfall in the year.

The Irrigation Potential Utilization (IPU) of Krishna basin is assessed as 68.71 Lakh ha. and 70.45 Lakh ha., Whereas Net Irrigated Area (NIA) is assessed as 60.43 Lakh ha. and 58.18 Lakh ha. during the study years of 2015-16 and 2016-17 respectively. Hence, it is observed that IPU and NIA are more or less same during both the years. However, the annual rainfall in the Krishna basin decreased by 18.75% from 2015-16 to 2016-17. Therefore, the stable IPU, in spite of reduction in annual rainfall, could be due to increased ground water utilization during 2016-17 compared to 2015-16.The marginal increase in IPU (2.53%) and a marginal decrease in NIA (3.72%) from 2015-16 to 2016-17, may be attributed to an increase in kharif and rabi irrigated area (double crop irrigated) from 11% to 18%.

3.2. Accuracy Assessment

The user's accuracy producer's accuracy for the season specific crop class classification was calculated for both the years are shown in the Table 6 and Table 7. The classification of the season specific crop class for the year 2016-17 was found to be more accurate as compared to the preceding year. The kappa statistics were computed for both the years. For the year 2015-16 the value is 25.33 and for the year 2016-17 the value is 34.22. This can be attributed to the fact that the fact that the later year had more number of satellite data sets which resulted in a smoother profile of NDVI and better classification.

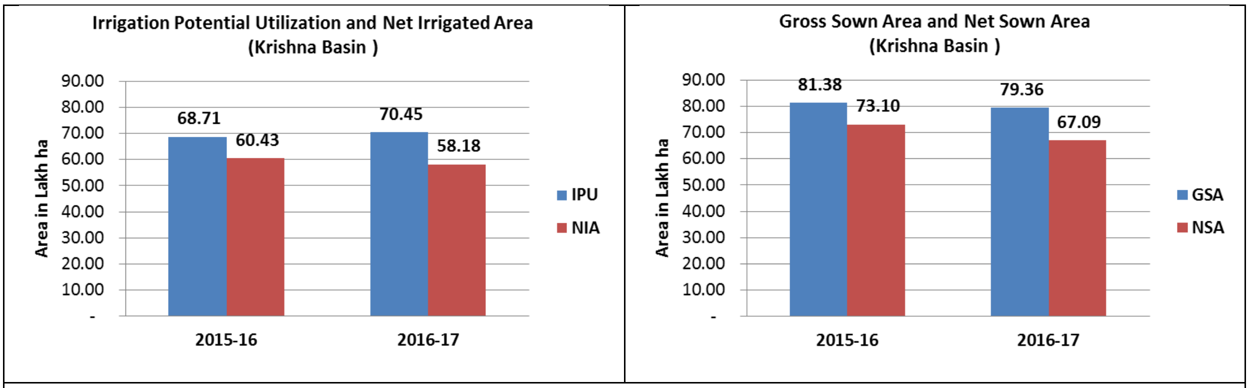

Figure 7: *Status of IPU, NIA, GSA, NSA during 2015-16 & 2016-17*

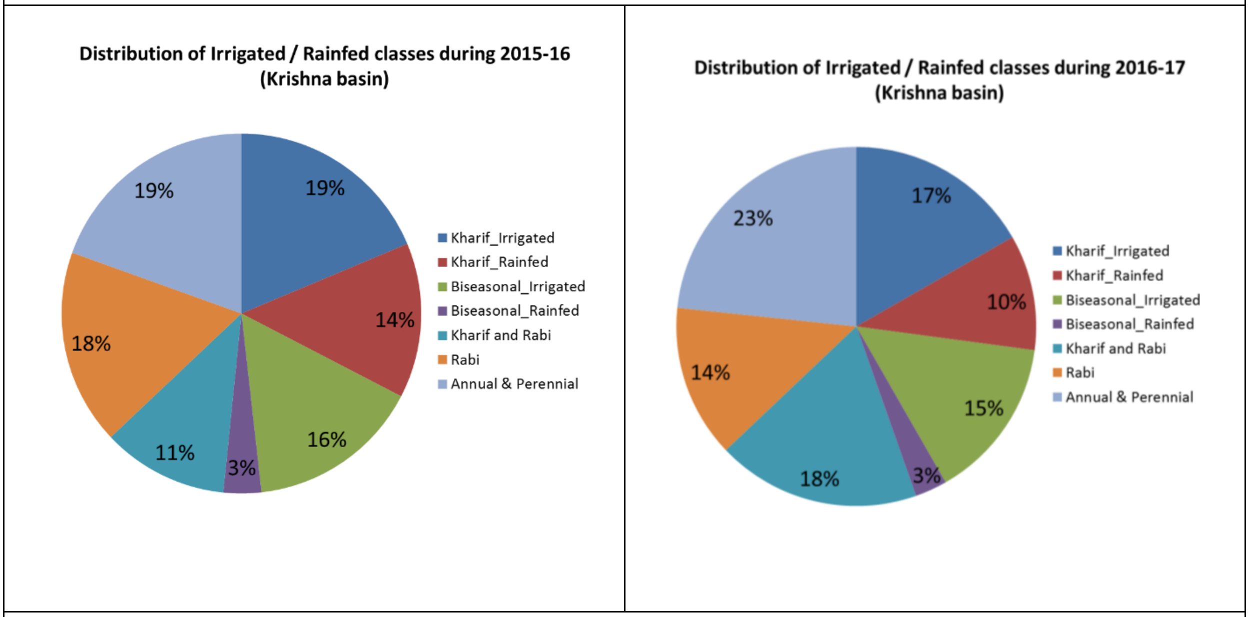

Figure 8: *Seasonal distribution of Irrigated / Rainfed classes during 2015-16 & 2016-17*

Table 6: *Accuracy assessment for seasonal crop group for the year 2015-16*

	Crop class obtained by Classification							
	Crop group	**Kharif**	**Rabi**	**Biseasonal**	**Annual**	**Unclassified**	**Total**	**Users accuracy**
Crop Class obtained by Ground truth	**Kharif**	91	20	17	14	22	164	55.5
	Rabi	20	39	19	4	3	85	45.9
	Biseasonal	26	8	24	1	2	61	39.3
	Annual	17	23	15	35	8	98	35.7
	Total	154	90	75	54	35	408	
	Producers Accuracy	59.09	43.33	32	64.8			
	Kappa							**25.33**

Table 7: *Accuracy assessment for seasonal crop group for the year 2016-17*

	Crop class obtained by classification							
	Crop Group	**Kharif**	**Rabi**	**Biseasonal**	**Annual**	**Unclassified**	**Total**	**Users accuracy**
Crop class based on ground truth	**Kharif**	117	10	22	6	23	178	65.73
	Rabi	11	85	17	6	12	131	64.88
	Biseasonal	35	11	45	2	27	120	37.5
	Annual	18	15	17	28	19	97	28.86
	total	181	121	101	42	81	526	
	Producers Accuracy	64.64	70.24	44.55	66.66			
	Kappa							**34.22**

4. Conclusions

The study aimed at assessment of Irrigation Potential Utilized in command areas of Krishna basin using temporal satellite data. Irrigation Potential Utilized was estimated as the Gross Irrigated Area in a water year using season specific crop types, irrigated and rainfed categories. The study used a vegetation phonological approach, derived using time-series satellite data for separating season specific crop types, irrigated and rainfed categories in Krishna river basin. Time series maximum NDVI was generated on monthly and fortnightly basis. Reference temporal profiles of NDVI were generated for different crops in different season using ground truth collected. The irrigated or rainfed condition of the crop in Kharif and Rabi season was identified based on the peak of NDVI temporal profile and comparing with reference profiles. The Irrigation Potential Utilized in Krishna Basin was 68, 71,177 ha and 70, 45,436 ha during 2015-16 and 2016-17, respectively. The accuracy of the crop area estimates were carried out by deriving the Kappa statistic indicating fair agreement with the ground observations. Incorporating more intensive ground truth on crop type, irrigation jurisdiction maps, actual irrigation deliveries would help in improving the discrimination of irrigated and rainfed regions with improved accuracies. Also, using additional multi-spectral indices derived water absorption & thermal spectral regions would also improve the accuracy of irrigated area mapping.

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