INFRASTRUCTURE MAPPING AND PERFORMANCE ASSESSMENT OF IRRIGATION SYSTEM USING GIS AND REMOTE SENSING

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Abstract

Hence evaluating and improving performance of irrigation systems in of paramount importance in the field of Irrigation Water Management. Many attempts are being made by researchers to evaluate and benchmark the performance of irrigation systems and all of them have concluded that non availability of detailed database limits their efforts. Keeping this in mind an attempt is made in this pilot project titled "Infrastructure mapping and Performance Assessment of Irrigation system using GIS and Remote Sensing".

The results indicate that the performance of Irrigation system is satisfactory but the water supplied is not adequate if surface water (canal water) is only source of irrigation. The analysis of feedback collected from farmers indicates that the project positive impact on agricultural productivity and socio-economics in the command area.

Key words: Infrastructure mapping, Crop Water Requirement, Irrigation Water Management.

1. Introduction

Irrigated agricultural will play a major role in determining the future food security of most of the Asian countries, and it will also be the major contributor to the additional food production required as world population expands. There is, however, increasing concern about the unutilized irrigation potential, low operating efficiency, less crop productivity of the irrigation systems etc. Irrigated land`s baseline inventory in spatial and time domains using spatial information technologies (satellite remote sensing, digital image processing, GIS and GPS) provides an array of performance evaluation matrices to address these issue.

For Land use and Land cover map using multi-spectral data of IRS LISS is now well-established operational tool in India. Based on the crop calendar, optimal satellite datasets covering the entire crop season (e.g., Rabi crop season, one data set each month during November to April) could be selected. Before classification of an image, few pre-processing steps, like geometric rectification of satellite data using ground control points (GCPs) and normalization of multi-sensor image data needs to be followed. Geometrically rectified multi-date satellite data can be sequentially analyzed with maximum likelihood classifier algorithm supported with ground-truth collected during field visit. Satellite based GPS provides accurate geo-referenced (in terms of latitude, longitude & altitude) position on the ground.

The major objectives of this study are:

a) Irrigation Infrastructure Mapping using high Resolution Cartosat-1 data and Database Preparation for Command area.
b) Estimation of Spatially Distributed Crop Water requirement for major crops in the Command.
c) Performance Evaluation of the Mula Irrigation project.

The aim of this research is infrastructure mapping of the Irrigation system using high resolution Cartosat-1 data with two specific objectives:

- to prepare the database for the command area and
- to assess the performance of irrigation project based on irrigation water demand estimated using RS data.

2. Methodology

2.1 Description of Command Area

Irrigation command area located at Bargaon Namdur in Rahuri Taluka of Ahmednagar district, Maharashtra State (India) (Fig. 1). The Gross Command area of this project is around 161386 Ha with Irrigation Command Area (ICA) of 82920 Ha. Study area is located within $19^0$15' N to $19^0$45' N and $74^0$30' E to $75^0$15' E. The command is approximately 1400 km away from India's capital, New Delhi. The Right Bank Canal along with its two branches i.e. Branch I and Branch II cover an area of 52693 ha and Gross Command Area (GCA) of Pathardi Branch is 28998 ha. The length of the Right Bank Canal is 52.00 km, Branch I Canal is 30 km, Branch II Canal is 29.75 km and Pathardi Branch Canal is 43.00 km.

Fig.1: Location of study area

2.2 Data used

Multi temporal LISS-III data of Resourcesat-1 & 2 are used (October 2011 to June 2012) to map the cropped area in the command. The irrigation infrastructure of the project is mapped using orthorectified Cartosat-1 data (October 2011 to June 2012) and index maps collected during field visits. The distributed irrigation water requirement for major crops in the command is estimated using vegetation index and Kc relations derived for the area. The potential evapotranpiration is estimated using daily meteorological data and CORPWAT 8 software. The irrigation supply of main canal and each branch canal as well as supply schedule was obtained from Irrigation authorities during field visit. [1], [3]

2.3 *Infrastructure Mapping:* The Infrastructure mapping of Mulla Irrigation project was done using high resolution Cartosat-1 data. Fig.2 shows the steps followed in this process.

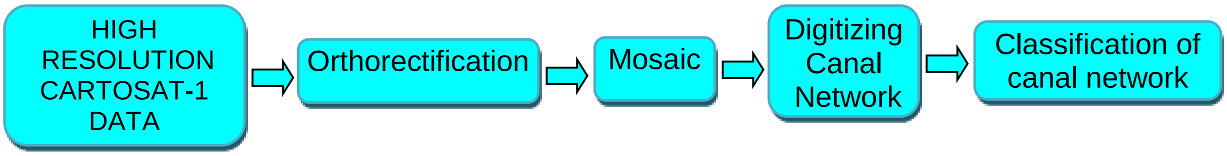

Fig.2 Infrastructure mapping using high resolution Cartosat-1 data

Mosaic: Cartosat-1 – data (2011-2012) was merged using ERDAS 9.1 Software

Digitizing Canal Network: Canal network of Irrigation Command was digitized using high resolution Cartosat-1 data (2011-2012) (Fig. 3). After digitizing of the canal network using ArcGIS, attribute information of Irrigation Command Project was created.[2], [4]

Adding attribute to each canal: The design discharge, Crop Command Area (CCA), Irrigation Command Area (ICA), Gross Command Area (GCA), design length of the canal etc. are added as attribute information to each digitized canal (Fig.4).

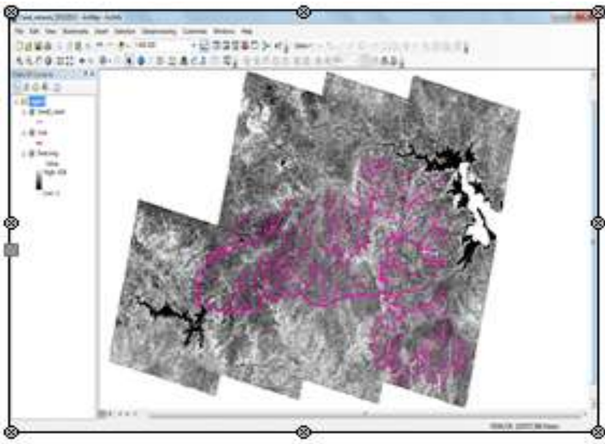

Fig. 3: View of Digitizing Canal Network

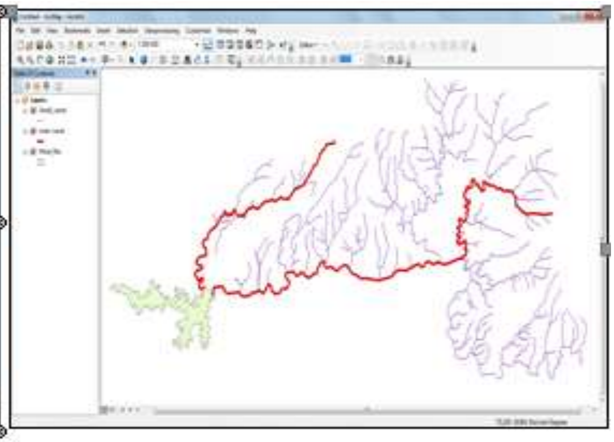

Fig. 4: View of Classification of canal network

2.4 Land Use & Land Cover (LULC) map:

Figure 5 shows the steps followed in pre-processing and processing of Satellite images for generating crop area as well as actual evapotranspiration (AET) maps.

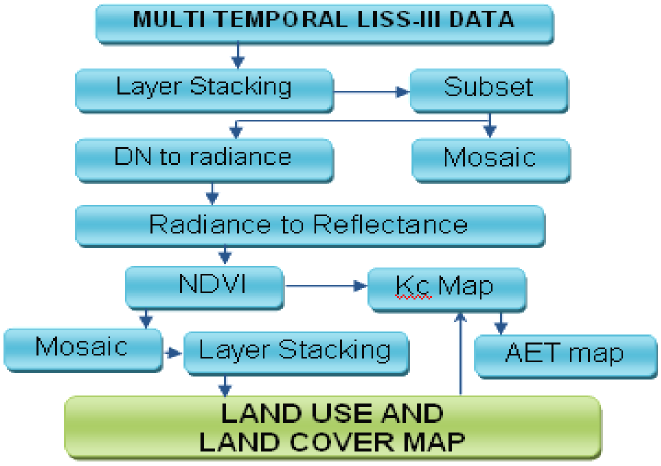

Fig. 5: Flow chart of Image Processing Methodology

Digital number (DN) to Radiance: The following equation is used to convert DN value back to an at-satellite minimum spectral radiance:

$$L\lambda = ((LMAX\lambda - LMIN\lambda)/(QCALMAX-QCALMIN)) * (QCAL-QCALMIN) + LMIN\lambda \qquad [1]$$

where: Lλ = Spectral Radiance at the sensor's aperture in [W/(m2* sr * μm)]

QCAL = the quantized calibrated pixel value in DN

LMINλ = the spectral at-sensor radiance that is scaled to QCALMIN in watts/(m^2 * ster * μm)

LMAXλ = the spectral at-sensor radiance that is scaled to QCALMAX in watts/(m^2 * ster * μm)

QCALMIN = the minimum quantized calibrated pixel value (corresponding to LMINλ) in DN
=1 for LPGS products
= 1 for NLAPS products processed after 4/4/2004
= 0 for NLAPS products processed before 4/5/2004

QCALMAX = the maximum quantized calibrated pixel value (corresponding to LMAXλ) in DN, = 255

Radiance to Reflectance: For converting radiance to reflectance combined surface and atmospheric reflectance of the Earth is computed with the following for:

$$\rho_\rho = \frac{\pi * L_\lambda * d^2}{ESUN_\lambda * \cos\theta_s} \qquad [2]$$

Where: ρ_p = Unit less planetary reflectance

L_λ = Spectral radiance at the sensor's aperture

d = Earth – Sun distance in astronomical units from an Excel file

$ESUN_\lambda$ = Mean solar exoatmospheric irradiance

θ_s = Solar zenith angle in degrees

NDVI calculation: NDVI maps are generated from all the images using following for:

$$NDVI = \frac{NIR - \mathrm{Re}\,d}{NIR + \mathrm{Re}\,d} \qquad [3]$$

Land use/Land cover (LULC) map: For creating LULC map unsupervised classification was used which include 20 classes. Using LISS-3 satellite data and ground truth data supervised classification was further used to prepare crop area map for three major crops (wheat, gram, and sugarcane).

For calculating potential evapotranspiration (PET) daily meteorological data from Rahuri weather station was used. Hourly meteorological data was converted into daily data for the period of October, 2011 to June, 2012. The FAO – Penman Monteith method (Allen et al., 1998) applying the CROPWAT 8.0 was used to estimate daily PET.

Actual evapotranspiration (AET) on the monthly scale was calculated using crop coefficient maps and monthly PET as described by Allen et al. (1998):

$$AET = Kc * ETo \qquad [4]$$

Where: Kc – crop coefficient, ETo – Potential Evapotranspiration, (mm).

Performance indicators: The performance of Right Bank Canal system was evaluated based on *adequacy*, *reliability*, *efficiency* and *environmental performance*.

Adequacy of the supply can be evaluated using following performance indicator which is called Relative Irrigation Supply (RIS):

$$RIS = \frac{I}{AET - P_e} \qquad [5]$$

Where: I – irrigation (mm), AET – actual evapotranspiration (mm), P_e - effictive precipitation (mm)

To identify reliability of canal supply schedule we considered the adequacy and time.

Efficiency of water use was calculated using following equation:

$$Eff = \frac{AET}{I} \qquad [6]$$

Where AET– Actual evapotranspiration (mm); I – irrigation (mm).

The environmental performance of Irrigation system was evaluated using the field observed data collected during the field visits.

3. Results and Discussion

3.1 Infrastruture mapping

The basic objective this pilot project is infrastructure mapping of the Mula irrigation project using high resolution Cartosat-1 data, to prepare the database for the command area and to assess the performance of irrigation project based on irrigation water demand estimated using RS data. The canal network of Mula irrigation project is mapped using orthorectified Cartosat-1 data. The Irrigation system has two main canals, e.g., Mula Right Bank Canal (MRBC) and Mula Lift Bank Canal (MLBC). The length of the Right Bank Canal is 52 km which is devided into Branch-1,

Branch-2 and Pathardi Baranch Canal (PBC). The length of Branch-1 is 30 km, Branch-2 is 52 km and Pathardi Baranch is 43 km.
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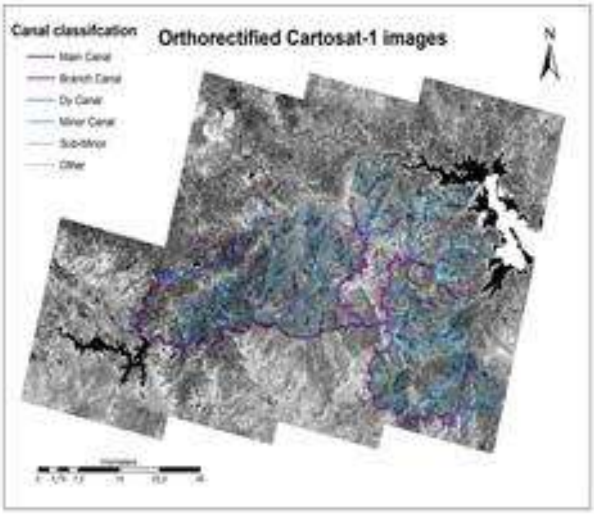

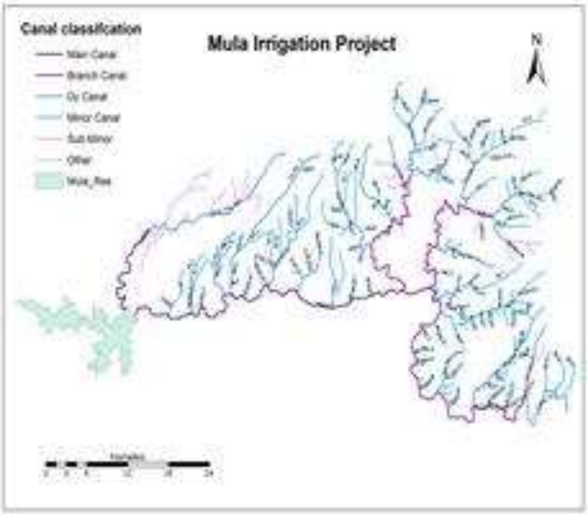

Fig. 6: Orthorectified images Fig. 7: Canal Network Classifacation

Direct Outlets: The direct outlest on all the canal in Mula Right Bank Canal network are degitized using canal network map generated using cartosat data and the line digrams obtained during field visits.

3.2 Land Use and Land Cover (LULC) map

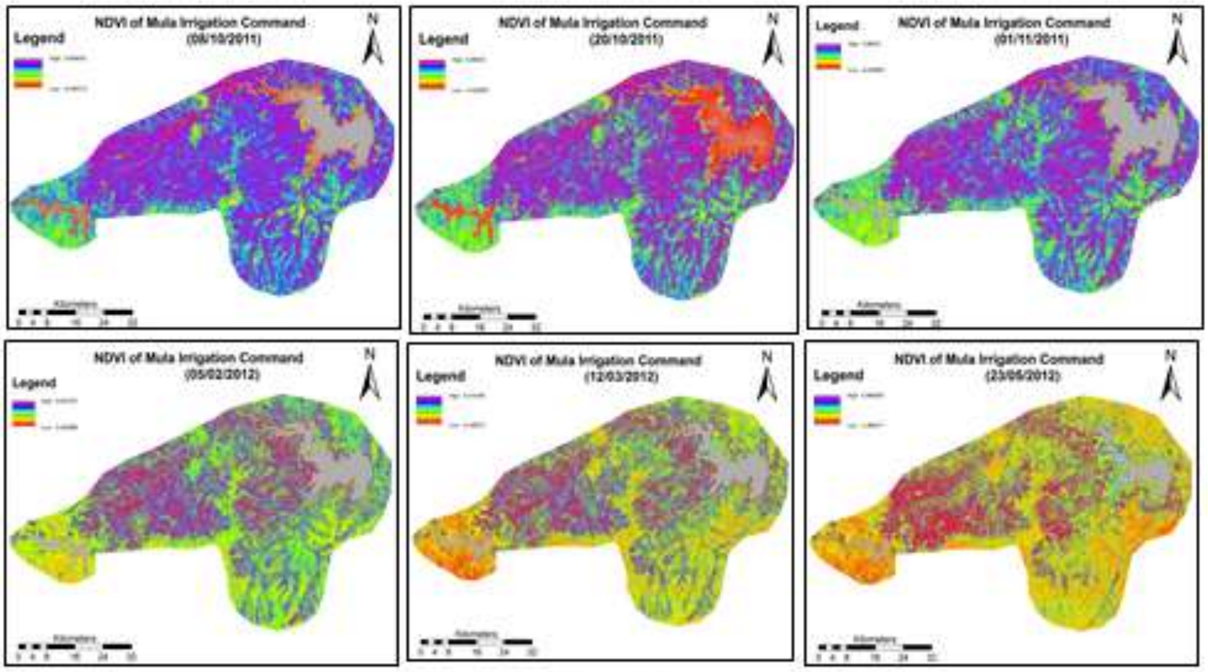

Fig. 8: NDVI of Mula Irrigation Command

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DVI map: The NDVI images of Mula Irrigation Command are shown in Fig. 8.

Fig. 8: NDVI of Mula Irrigation Command

Crop area Mapping: The multy-temporal data has been used to map the LULC of the command area for October, 2011 to June, 2012. Classification has been done to map eight major classes, which are Water Body, Natural vegetation, Grazing Land, Fallow Land, Gram, Wheat, Sugar Cane (January) and Sugar Cane (June). Total area of the command was comprised as follows: Natural Vegetation 16 %, Grazing Land 7 %, Fallow 13 %, Wheat 12 %, Sugar Cane (January) 21% and Sugar Cane (June) %. The LULC map of the Irrigation Command is shown in Fig. 9. and the graphical representation of the percentage of LULC in the area is shown in Fig. 10.

Fig. 9: LULC map.

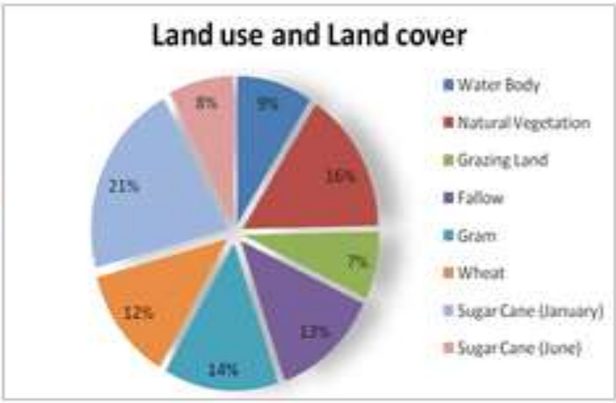

Fig. 10: Percent Distribution of LULC.

11. Crop coefficient (Kc) maps for November (2011) and April (2012) are shown in Fig.

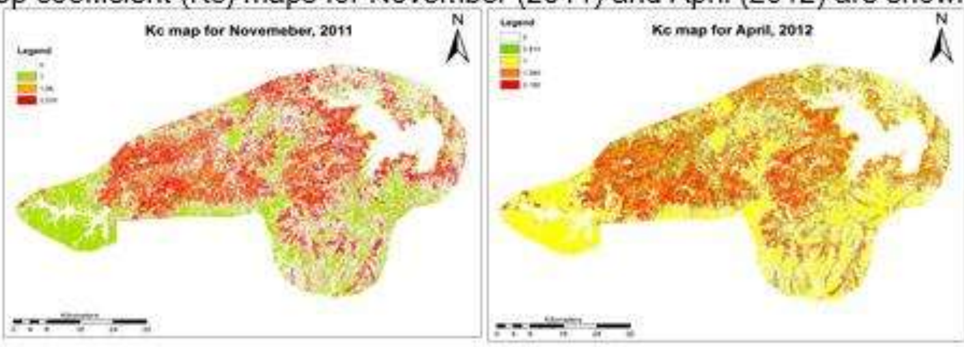

Fig 11: Crop coefficient (Kc) maps of Mula Irrigation Command.

Actual evapotranspiration (AET) maps are shown in Fig. 12.

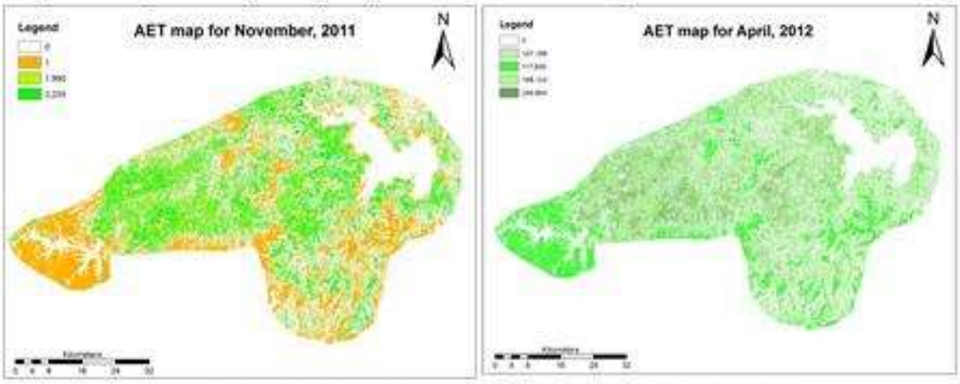

Fig. 12: AET maps of Mula Irrigation Command.

3.3 Performense Evaluation

Reliability: Canal Supply reliability is a function of adequacy and timely supply. To know the adequacy of water supply has been evaluated using three different indicators and evaluated the timelyness of supply of the canal operational schedule. The canal water supply schedule is given in Table 1.

Table 1. Water supply schedule of Mula Right Bank Canal

Name of Canals		**Months**			
		November 2011	**December 2011**	**February 2012**	**March 2012**
MRBC	*ft³/sec*	23241.0	20936.0	27463.0	17835.0
	m³/s	658.1	592.8	777.7	505.0
	Discharg m³/day	56860863.1	51221506.4	67190305.2	43634675.5
Br-1	*ft³/sec*	2541.0	5204.0	4433.0	2882.0
	m³/s	72.0	147.4	125.5	81.6
	Discharg m³/day	6216748.6	12731979.3	10845669.5	7051030.8
Br-2	*ft3/sec*	4512.0	3130.0	5483.0	5654.0
	m3/s	127.8	88.6	155.3	160.1
	Discharg m3/day	11038949.0	7657781.6	13414573.9	13832938.3
PBC	*ft³/sec*	3069.0	3927.0	3746.0	1327.0
	m³/s	86.9	111.2	106.1	37.6
	Discharg m³/day	7508540.5	9607702.3	9164872.1	3246605.8

Crop Water Requirement (CWR): The Monthly Water Requirement for Sugarcane, Wheat, Gram and other crops is given in Tab. 2. The Seasonal CWR is given in Tab. 3.

Table 2. Water Requirment for different crop types (Rabi season)

Months		Sugarcane	Wheat	Gram	Other	*Sum*
November	Area, Ha	9201	8234	3960	8826	*30221*
	CWR (mm)	167	0	0	60	226.5
	IWR (mm)	256	0	0	92	*348.46*
	Total CWR (cubic m)	15319665	0	0	5295600	*20615265*
	Total IWR	23568715	0	0	8147077	*31715792*
	Irrigation Supply (cubic m)					*56860863*
December	Area, Ha	9201	8234	3960	8826	*30221*
	CWR (mm)	143	14	54	60	*270.99*
	IWR (mm)	220	21	83	92	*416.91*
	Total CWR (cubic m)	13157430	1136292	2145924	5295600	*21735246*
	Total IWR	20242200	1748142	3301422	8147077	*33438840*
	Irrigation Supply (cubic m)					*71430221*
January	Area, Ha	9201	8234	3960	8826	*30221*
	CWR (mm)	94	40	75	60	*268.47*
	IWR (mm)	145	61	115	92	*413.03*
	Total CWR (cubic m)	8642499	3275485	2960496	5295600	*20174081*
	Total IWR	13296153	5039208	4554609	8147077	*31037047*
	Irrigation Supply cubic m)					*0*
February	Area, Ha	9201	8234	3960	8826	*30221*
	CWR (mm)	131	83	72	60	*346.33*
	IWR (mm)	201	128	112	92	*532.80*
	Total CWR (cubic m)	12022487	6848218	2870604	5295600	*27036908*
	Total IWR	18496133	10535720	4416314	8147077	*41595244*
	Irrigation Supply (cubic m)					*80284378*
March	Area, Ha	9883	0	0	11338	*21221*
	CWR (mm)	184	111	42	60	*397.075*
	IWR (mm)	283	171	65	92	*610.88*
	Total CWR (cubic m)	18152600	0	0	6802800	*24955400*
	Total IWR	27927077	0	0	10465846	*38392923*
	Irrigation Supply cubic m)					*67885133*
April	Area, Ha	9883	0	0	11338	*21221*
	CWR (mm)	221	107	0	60	*388.66*

	IWR (mm)	341	165	0	92	*597.94*
	Total CWR (cubic m)	21886892	0	0	6802800	*28689692*
	Total IWR	33672141	0	0	10465846	*44137987*
	Irrigation Supply (cubc m)					*0*

Table 3. Seasonal Water Requirment (Rabi season)

Rabi season		
1	CWR (mm)	1898.02
2	IWR (mm)	2920.01
3	Total CWR (cubic m)	143206592
4	Total IWR (cubic m)	220317833.8
5	Irrigation Supply (cubic m)	276460594.1
6	Irrigation Efficiency (%)	51.8

	Note	Results
Irrigation Efficiency (%)	Overall Irrigation efficiency of Mula project is calculated	51.8
Adequacy	Standard Value should be ≥1,25	1.93
Reliability	Irrigation water was supplied for four months out of five months considered in Rabi season. The Irrigation supply was adequate and timely hence qualify as reliable.	
Environmental Performance	During field visit the data regarding waterlogging and soil salinity problem in the command was collected by interacting with framers. The data points are well distributed in the command and after analyzing the information collected from the field it can be concluded that there are no problems of waterlogging or soil salinity in the command, So the environmental performance of the project is fine.	

The results of all performance indicators, indicates that the Mula irrigation project supplies adequate irrigation water in the rabbi season. The supply is also reliable and this project do not have any environmental degradation problem in its command. But he values of overall irrigation efficiency on monthly scale, which are in the range of 30 to 40 % indicates that there is scope for improvement in the performance of Mula irrigation system, as the expected irrigation efficiency from major irrigation projects is in the range of 65%. The seasonal irrigation efficiency of Mula system is high because, there is no surface water supply in the month of January. This could raise question about the reliability of irrigation supply but as per the information collected from the farmers in the command, the non-supply period of canal is covered up by groundwater pumping in the area.

4. Conclusion

In present study performance evaluation of Mula irriagtion system is done using RS & GIS. The irrigation infrastructure of the project is mapped using hight resolution Cartosat-1 data. The crop area is mapped using multi-temporal LISS-III data. The distributed Crop Water Requirement (CWR) and Irrigation Water Requirement (IWR) is estimated using LULC map. ET_0 estimated using meteorological data and Kc map derived using equations suggested by State Agriculture University. Performance of Mula irrigation project is evaluated using the criteria`s, such as irrigation efficiency, relative irrigation supply, reliability and environmental performance. Results of this study indicates that:

- ✓ The overall seasonal irrigation efficiency of the project is 51.8 %, but the monthly irrigation efficiency of Mula project is in the range of 30 to 37 % which is very low compared to the designed irrigation efficiency of 65 %. The seasonal irrigation efficiency value is high because there is no surface irrigation supply in the month of January. This could raise question about reliability of irrigation supply. The results of irrigation efficiency indicates that there is scope for improvement of irrigation efficiency of Mula project.
- ✓ The adequacy of Mula irrigation project evaluated using Relative Irrigation Supply (RIS) indicates that the irrigation supply was adequate, e.g., 1.92 (any project having RIS value more than 1.25 qualifiers for adequate project).
- ✓ There is not waterlogged area and saline lands, which indicates that the environmental performance of the canal system is satisfactory.
- ✓ Overall performance of the canal system (deoband branch) is satisfactory, but there is scope for improving the irrigation efficiency of this project.

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