Infrastructure mapping and performance assessment of irrigation system using GIS and remote sensing

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Abstract. Hence evaluating and improving the performance of irrigation systems is of paramount importance in Irrigation Water Management. Researchers are making many attempts to evaluate and benchmark the performance of irrigation systems. All of them have concluded that the non-availability of a 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 Irrigation system's performance is satisfactory, but the water supply is not adequate if surface water (canal water) is the only source of irrigation. The analysis of feedback collected from farmers indicates that the positive project impacts agricultural productivity and socio-economics in the command area.

1 Introduction

Irrigated agriculture will play a major role in determining the future food security of most Asian countries. It will also be the major contributor to the additional food production required as the 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 issues [1-3].

Land use and Land cover map using multi-spectral data of IRS LISS is now a 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 the 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 [4, 5]. Geometrically rectified multi-date satellite data can be sequentially analyzed with a

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maximum likelihood classifier algorithm supported with ground truth collected during a field visit. Satellite-based GPS provides accurate geo-referenced (in terms of latitude, longitude & altitude) position on the ground [6-14].

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 projects based on irrigation water demand estimated using RS data.

2 Methods

2.1 Description of Command Area

Irrigation command area located at Bargaon Namdur in Rahuri Taluka of Ahmednagar district, Maharashtra State (India) (Figure 1). The Gross Command area of this project is around 161386 Ha with the Irrigation Command Area (ICA) of 82920 Ha. The study area is located within $19^{\circ}15'$ N to $19^{\circ}45'$ N and $74^{\circ}30'$ E to $75^{\circ}15'$ 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 the 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 [1].

Fig.1. Location of study area

2.2 Data used

Multi-temporal LISS-III data of Resourcesat-1 and 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 evapotranspiration is estimated using daily meteorological data and CORPWAT 8

software. The irrigation supply of the main canal and each branch canal and the supply schedule were obtained from Irrigation authorities during the field visit [1, 3].

2.3 Infrastructure Mapping

The Infrastructure mapping of the Mulla Irrigation project was done using high-resolution Cartosat-1 data. Figure 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) (Figure 3). After digitizing the canal network using ArcGIS, attribute information of the Irrigation Command Project was created.[2], [4]
Adding an 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 (Figure 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:

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

[1]

where:	$L\lambda$	= Spectral Radiance at the sensor's aperture in [W/(m2* sr * μ m)]
	QCAL	= the quantized calibrated pixel value in DN
	$LMIN\lambda$	= the spectral at-sensor radiance that is scaled to QCALMIN in watts/(m ² * ster * μ m)
	$LMAX\lambda$	= the spectral at-sensor radiance that is scaled to QCALMAX in watts/(m ² * ster * μ m)
	QCALMIN	= the minimum quantized calibrated pixel value (corresponding to $LMIN\lambda$) 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 $LMAX\lambda$) in DN, = 255

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

$$\rho_p = \frac{\pi * L_\lambda * d^2}{ESUN_\lambda * \cos \theta_s} \quad (2)$$

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 the following:

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (3)$$

Land use/Land cover (*LULC*) map: To create the LULC map, unsupervised classification was used, including 20 classes. Using LISS-3 satellite data and ground truth data, supervised classification was further used to prepare a crop area map for three major crops (wheat, gram, and sugarcane).

For calculating potential evapotranspiration (PET), daily meteorological data from the Rahuri weather station was used. Hourly meteorological data were 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):

$$AET = K_c * ETo \quad (4)$$

Where: K_c is crop coefficient, ETo is Potential Evapotranspiration, (mm).

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

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

$$RIS = \frac{I}{AET - P_e} \quad (5)$$

Where: I is irrigation (mm), AET is actual evapotranspiration (mm), P_e is effective precipitation (mm)

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

The efficiency of water use was calculated using the following equation:

$$Eff = \frac{AET}{I} \quad (6)$$

Where AET is actual evapotranspiration (mm); I is irrigation (mm).

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

3 Results and Discussion

3.1 Infrastructure mapping

The basic objective of 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 assess the performance of the irrigation project based on irrigation water demand estimated using RS data. The canal network of the 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, divided into Branch-1, Branch-2, and Pathardi Branch Canal (PBC). The length of Branch-1 is 30 km, Branch-2 is 52 km, and Pathardi Branch is 43 km.

Fig. 6. Orthorectified images

Fig. 7. Canal Network Classification

Direct Outlets: The direct outlets on all the canals in the Mula Right Bank Canal network are digitized using a canal network map generated using cartosat data and the line diagrams obtained during field visits.

3.2 Land Use and Land Cover (LULC) map

Fig. 8. NDVI of Mula Irrigation Command

DVI map: The NDVI images of Mula Irrigation Command are shown in Fig. 8.
Crop area Mapping: The multi-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). The 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. 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.

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

Fig. 12. AET maps of Mula Irrigation Command.

3.3 Performance Evaluation

Reliability: Canal Supply reliability is a function of adequacy and timely supply. To know the adequacy of the water supply has been evaluated using three different indicators and evaluated the timeliness 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	ft ³ /sec	23241.0	20936.0	27463.0	17835.0
	m ³ /s	658.1	592.8	777.7	505.0
	Discharg	56860863.1	51221506.4	67190305.2	43634675.5
Br-1	ft ³ /sec	2541.0	5204.0	4433.0	2882.0
	m ³ /s	72.0	147.4	125.5	81.6
	Discharg	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	11038949.0	7657781.6	13414573.9	13832938.3
PBC	ft ³ /sec	3069.0	3927.0	3746.0	1327.0
	m ³ /s	86.9	111.2	106.1	37.6
	Discharg	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 Table 2. The Seasonal CWR is given in Table 3.

Table 2. Water Requirement 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

Continuation table 2

Months		Sugarcane	Wheat	Gram	Other	Sum
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 (cubic m)					0

Table 3. Seasonal Water Requirement (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 the Mula project is calculated	51.8
Adequacy	Standard Value should be $\geq 1,25$	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 the field visit, the data regarding waterlogging and soil salinity problems in the command was collected by interacting with framers. The data points are well distributed in the command. 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 project's environmental performance is fine.	

All performance indicators indicate that the Mula irrigation project supplies adequate irrigation water in the rabbi season. The supply is also reliable, and this project does not have any environmental degradation problem in its command. But the values of overall irrigation efficiency on a monthly scale, which are in the range of 30 to 40 %, indicate that

there is scope for improvement in the performance of the Mula irrigation system, as the expected irrigation efficiency from major irrigation projects is in the range of 65%. The seasonal irrigation efficiency of the Mula system is high because there is no surface water supply in January. This could raise a question about the reliability of irrigation supply, but as per the information collected from the farmers in the command, the non-supply period of the canal is covered up by groundwater pumping in the area.

4 Conclusion

In the present study, performance evaluation of the Mula irrigation system is done using RS & GIS. The irrigation infrastructure of the project is mapped using high 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) are estimated using the LULC map. ET_0 estimated using meteorological data, and K_c map derived using equations suggested by State Agriculture University. Performance of the Mula irrigation project is evaluated using the criteria's, such as irrigation efficiency, relative irrigation supply, reliability, and environmental performance. Results of this study indicate that:

- The overall seasonal irrigation efficiency of the project is 51.8 %. Still, the monthly irrigation efficiency of the 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 January. This could raise a question about the reliability of irrigation supply. The results of irrigation efficiency indicate that there is scope for improving the Mula project's irrigation efficiency.
- The adequacy of the 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 qualifies for an 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.

References

1. Nikam B. R. et al. Application of Remote Sensing and GIS in Performance Evaluation of Irrigation Project at Disaggregated Level, Journal of the Indian Society of Remote Sensing, 48(7), pp. 979-997, (2020)
2. Osborne P. E., Alonso J. C., Bryant R. G. Modelling landscape-scale habitat use using GIS and remote sensing: a case study with great bustards, Journal of applied ecology. 38(2), pp. 458-471, (2001)
3. Sakthivadivel R. Performance evaluation of the Bhakra irrigation system, India, using remote sensing and GIS techniques, IWMI, 28, 1999.
4. Zwart S.J., Leclert L.M. A remote sensing-based irrigation performance assessment: a case study of the Office du Niger in Mali, Irrigation Science, 28(5), pp. 371-385, (2010)

5. Bastiaanssen W.G.M., Molden D.J., Makin I.W. Remote sensing for irrigated agriculture: examples from research and possible applications, *Agricultural water management*, 46 (2), pp. 137-155, (2000)
6. Gumma M. K. Mapping irrigated areas of Ghana using fusion of 30 m and 250 m resolution remote-sensing data, *Remote Sensing*, 3(4), pp. 816-835, (2011)
7. Thenkabail P.S. Global irrigated area map (GIAM), derived from remote sensing, for the end of the last millennium, *International Journal of Remote Sensing*, 30(14), pp. 3679-3733, (2009)
8. Allen R.G., Pereira L.S., Raes D., Smith M. Crop evapotranspiration. FAO Irrigation and Drainage Paper 56, Food and Agricultural Organization of the United Nations, Rome, p. 300, (1998)
9. Ray S.S. Dadhwal V.K. Navalgund R.R. Performance evaluation of an irrigation command area using remote sensing: a case study of Mahi command. *Remote Sensing Applications Area, Space Applications Centre (ISRO)*, Ahmedabad 380 015, Gujarat, India Accepted 13 February (2002)
10. Gapparov F., Nazaraliev D., Eshkuvatov Q. Assessment of Chimkurgan water reservoir sedimentation processes, *IOP Conf. Series: Materials Science and Engineering* **883** (2020) 012039, doi:10.1088/1757-899X/883/1/012039.
11. Matyakubov B., Begmatov I., Raimova I. and Teplova G. Factors for the efficient use of water distribution facilities. *IOP Conf. Ser. Mater. Sci. Eng.* 883, 012025 (2020).
12. Uralov B., Rakhmatov N., Khidirov S., Uljaev F., Raimova I. Hydraulic modes of damless water intake. *IOP Conf. Ser. Mater. Sci. Eng.* 1030(1), 012123 (2021)
13. Bazarov D., Markova I., Raimova I., Sultanov Sh. Water flow motion in the vehicle of main channels. *IOP Conf. Ser. Mater. Sci. Eng.* 883, 012025 (2020).
14. Bastiaanssen W.G.M. Remote sensing in Water Resources Management: the state of the art, *International Water Management Institute (IWMI)*, Colombo, Sri Lanka, pp.118. (1998)