Agrotechnology
ISSN: 2168-9881

Kumar, et al., Agrotechnol 2014, 3:1
DOI: 10.4172/2168-9881.1000122

Research Article | Open Access

Irrigation Performance Assessment of Left Bank Canal, Nagarjuna Sagar Project, India During *Rabi* Using Remote Sensing and GIS

Avil Kumar K*, Reddy MD, Uma Devi M, Narender N, Neelima TL, Ramulu V, Praveen Rao V and Raghavaiah R

Water Technology Center, Acharya N. G. Ranga Agriculture University, Rajendranagar, Hyderabad-30, India

***Corresponding author:** Avil Kumar K, Water Technology Center, Acharya N. G. Ranga Agriculture University, Rajendranagar, Hyderabad-30, India, Tel: +919951335111; E-mail: avil2k@gmail.com

Rec date: Mar 05, 2014, **Acc date:** May 12, 2014, **Pub date:** May 14, 2014

Abstract

An Investigation on irrigation performance assessment of Mudimanikyam and Janpahad major, Left bank canal, Nagarjuna Sagar Project (NSP), Andhra Pradesh, India using remote sensing and GIS was carried during *rabi* (2008-09 and 2009-10) at Water Technology Center, ANGRAU, Rajendranagar, Hyderabad. Multi temporal remote sensing (RS) data-based crop inventory and Normalized Difference Vegetation Index (NDVI), which is very sensitive to the presence of the green vegetation and is a ratio of near infrared radiation minus red radiation and near infrared ratio plus red radiation. The NDVI was generated for Mudimanikyam and Janpahad major command of NSP, using Indian Remote Sensing Satellite (IRS-P6) Linear Imaging and Self Scanning–III (LISS-III) data. In this study, remote sensing based indicators ie., irrigation intensity(target value of 100%), water utilization index (WUI), depth of water applied, overall consumption rate (e_p), relative water supply (RWS), output per unit cropped area ($/ha), output per unit cultivable command ($/ha) and water productivity (w_p) were estimated for the command area. This study demonstrates how the remote sensing based estimates of crop area and production combined with water release data from project and climatic data can provide better estimates of irrigation performance. A principle benefit of the described approach is that it allows identification of areas where agricultural performance is less than potential, thereby providing insights into where and how irrigation systems can be managed to improve overall performance and increase water productivity in a sustainable manner.

These parameters varied from 92.39 to 123.19 for irrigation intensity against target of 100 per cent, 86.04 to 148.96 for WUI against the target of 141.24 ha Mcum-1 of wet crop, 0.40 to 0.80 for e_p, against target of 0.56, 0.42 to 0.75 for RWS against target value of 2.0 and 0.152 to 0.203 for w_p against value of 0.35 kg m-3 during *rabi* 2008-09 and 2009-10, respectively. These performance indicators showed that irrigation performance of Janpahad major was better than Mudimanikyam. The e_p indicators for the majors during *rabi* 2009-10 were lower (0.40 and 0.52) than the target value and WUI was higher for Janpahad major during both the years.

Keywords: Remote sensing; GIS; Irrigation project; Water utilization index; Water productivity

Introduction

Satellite remote sensing and Geographic Information System (GIS) offer great promise for natural resources management. These techniques have potential to predict and zonate different levels of crop response in a spatial and temporal dimension, when coupled with relevant information. Suitable blend of these technologies will aid in efficient management of resources to enhance the crop productivity in a sustainable basis.

Sustainable production increase can be achieved by two ways in irrigated agriculture, either new irrigation projects can be developed or existing schemes can be evaluated and their performance can be improved. In recent years, improving irrigation systems performance is more preferable than developing new irrigation areas. Performance assessment is the spatial and temporal evaluation of irrigation system to diagnose problems and is considered as the most critical element for improving irrigation management [1]. System performance monitoring, evaluation, and diagnostic analysis are keys to appreciate the improvement or inefficiency in irrigation projects.

A set of performance indicators describes the system performance of irrigation schemes in different dimensions for the benefit of decision-makers. The temporal and spatial variations of such indicators will help in improving the quality of system performance. Appropriate remedial actions could be made to the process, by using the real time data. Remote sensing provides an opportunity to measure the crop yield without field measurements and this opens the possibility to study the variability of water productivity within an irrigation system.

Nagarjuna Sagar dam, a multipurpose project constructed during 1956-1974, across river Krishna near Nandikonda village of Nalgonda district, Andhra Pradesh, is a storage project and priority has been given to raise irrigated dry crops in rabi season in Kharif harvested fallows. Due to availability of water in the reservoirs, paddy is grown in the upper reach. The major problem presently is the water shortage at the tail end along the main canal and down the distributary system. The objective of this study is to determine the irrigation performance of irrigation majors of Nagarjuna sagar left bank canal using satellite remote sensing and GIS.

Citation: K Avil Kumar, MD Reddy, M Uma Devi, N Narender, TL Neelima, et al. (2014) Irrigation Performance Assessment of Left Bank Canal, Nagarjuna Sagar Project, India During *Rabi* Using Remote Sensing and GIS. Agrotechnol 3: 122. doi:10.4172/2168-9881.1000122

Study area

The study area is Mudimanikyam and Janpahad major command, Left Bank canal Nagarjuna Sagar Project. Mudimanikyam major is located at 38 km (160 49' 56.54" N and 790 26' 31.51" E) with the length of 34.8 km and designed discharge of 410 cusecs. The ayacut area of 12410 ha with 9 water users Associations spreads in Tripuraram, Nidamanoor and Damarcherla mandals of the Nalgonda district. Janapahad major is located at 90.54 km (160 56' 12.8" E and 790 42' 0.7" N) with the length of 24 km and designed discharge of 555.13 cusecs. The ayacut area of 15395 ha with 11 Water users Associations spreads in Nereducherla, Garidepally and Mattampally mandals of the Nalgonda district.

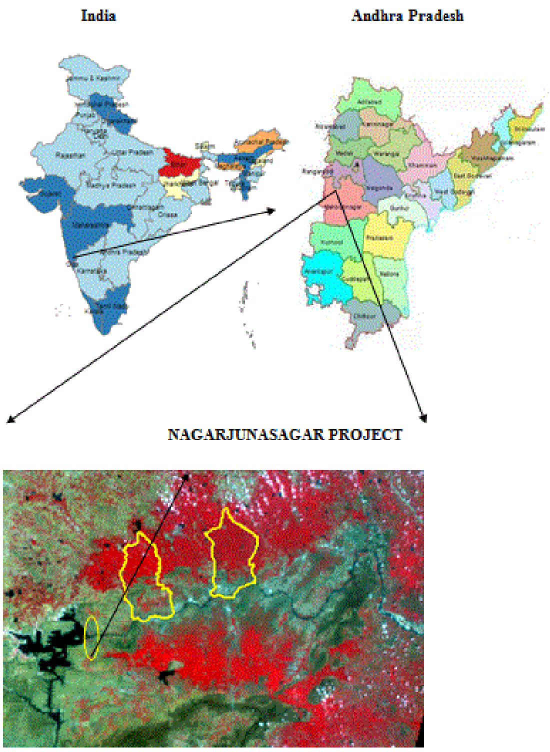

Figure 1: Location map of Nagarjuna Sagar, showing Mudimanikyam and Janpahad majors under Left bank canal, Nalgonda district of Andhra Pradesh.

Materials and Methods

The performance indicators are computed for Mudimanikyam and Janpahad major command area. The main output considered is crop production and the major inputs are water and land. The performance indicators namely irrigation intensity, water utilization index, depth of water applied, overall consumption rate, relative water supply, output per unit cropped area, output per unit command area, and water productivity were computed based on cropped area, command area, potential evapotranspiration, water diverted from the main canal, rainfall and crop production. The multispectral data from LISS-III sensor of IRS–P6 (Resourcesat-1) acquired on 17th march 2009 and 2010 were utilized for delineation of major crops grown in the study area. The image was classified using maximum likelihood algorithm as per the training windows defined for various crops and other land use classes based on the ground truth information. Rice mask map was generated based on classified image. The pixels thus generated were multiplied with 24 mx24 m to estimate paddy area. Crop cutting experiments were conducted (3 m×3 m) randomly at selected points in the command area and the corresponding GPS readings were taken. Paddy grain weight at 14 per cent moisture was taken. Normalized Difference Vegetation Index (NDVI) proposed by Rouse et al., [2] was used in this study for estimation of crop yield as it is very sensitive in the presence of green vegetation. NDVI can be defined by following equation

NIR and R are the reflectance in the near infra-red and red regions, respectively.

The red and infra-red channel data pertaining to the IRS P6 LISS III image were transformed into NDVI image in ERDAS IMAGINE 9.3 Modeler panel by running the NDVI model. The resultant NDVI image of the paddy crop was used for yield estimation. Maximum NDVI image derived using 2008-09 *rabi* season satellite data was used to establish the relationship between NDVI and paddy yield observed at CCE plots through the development of regression model.

Data on command area and water diverted were collected from Divisional executive engineer, Left bank canal, Nagarjuna Sagar Project, located at Miryalguda, Nalgonda district, A.P., India. The weather data of ARI Rajendranagar, Hyderabad was considered for computation of PET and water requirement. Potential Evapotranspiration was computed using the Penman-Monteith method with CROPWAT 8.0 computer model. The above mentioned indicators were calculated as shown below:

Irrigation Intensity

The intensity of irrigation is defined as the percentage of area irrigated to the culturable command area [3]. Usually the area to be irrigated during each crop season is expressed as a percentage of the culturable command area.

Overall Consumption Rate (ep)

The Overall consumption rate (efficiency) quantifies the degree to which the crop irrigation requirements are met by irrigation water in the irrigated area. The ratio is expressed [4] as follows:

Where, ET_p and P_e are Potential evapo-transpiration and Effective rainfall. The value (ET_p–P_e) was calculated using CROPWAT software and V_c is the volume of irrigation water supplied to command (m3). A target overall consumed ratio should be set within an existing irrigated area and compared to the actual ratio [5]. The product (0.56) of water application efficiency (0.70) and conveyance efficiency (0.80) accepted by irrigation and CAD department, Government of A.P should be set as target value at field level in the conditions of study area.

Relative Water Supply (RWS)

The relative water supply used as an indicator of adequacy of irrigation water delivery *ie.,* it compares supplied water with that of demanded [6]. It is calculated as follows

Where, P_g is gross precipitation in mm, V_c is the volume of irrigation water in mm and ET_p is the potential evapotranspiration in mm. The target value of RWS indicator was considered as 2.0 [7].

Water Utilization Index (WUI)

Water utilization index is defined as the ratio of the crop area irrigated in an irrigation command and the water delivered to that irrigation command [8]. In broader sense, this is a measure of effective utilization of water in an irrigation command area and this index enables to compare the performance of irrigation system across the command ie., at disaggregated level.

Estimation of WUI involves converting the areas under various crops in terms of a single major crop grown in the command area. In this present study paddy, chilies, cotton and orchard crops were brought at par with the wet crop (paddy) taking the crop water requirements into consideration.

Depth of water applied

The depth of irrigation water supplied is reciprocal of Water Utilization Index [9].

WUI and Delta were used in analyzing the spatial irrigation service performance across the command area during the time periods.

Output per Cropped Area

This indicator specifies production per unit of irrigated cropped area and expressed [7] as

SGVP is the Standardized gross value of Production (SGVP) and is calculated by the following equation

Yi is the yield of crop i,

Pi is the local price of crop i,

Ai is the area cropped with crop i, and

Pb is the local price of the base crop.

Output per Unit Command Area

This indicator specifies production per unit command area and defined [7] as

Water Productivity

The water productivity indicator quantifies the yield per volume of irrigation water supplied. The water productivity is expressed as [7]. The target value considered to be 0.35 kg m^{-3}.

Results and Discussion

Crop Area Estimation

The crop area under Mudimanikyam and Janpahad major during *rabi* season 2008–09 and 2009-10 has been derived from multi temporal satellite data. Major crop grown in the command area was Paddy and other crops are chilles, cotton, sweet orange and mango (Table 1). The satellite derived crop estimates for Mudimanikyam and Janpahad major under NSP left canal command indicate that paddy occupied 75 to 86 per cent of the total culturable command area during 2008-09 and 2009-10 *rabi* seasons.

Area wise distribution statistics of different land use classes obtained from the classified map of the study area are presented in Figure 2a, Figure 2b, Figure 3a and Figure 3b. The area under paddy was estimated to be 9382.4 and 9547.1 ha in Mudimanikyam major and 13045 and 13248.9 ha in Janpahad major during *rabi* 2008-09 and 2009-10, respectively. Chillies and cotton were combined and classified as other crops and orchards were classified separately. There was a slight increase in irrigated area during 2009-10 (10501 and 16473 ha) than the previous year (10413 and 15562 ha). The classification error matrix has an overall kappa accuracy of 95 and 94.5% for Mudimanikyam major and 99 and 98% for Janpahad major during *rabi* 2008-09 and 2009-10, respectively.

	Mudimanikyam		Janpahad	
	2009	2010	2009	2010
Rice	9382.4	9547.1	13045.0	13248.9
other crops	754.1	570.1	1509.6	1960.6
orchards	277.6	383.9	1233.3	1264.3
shrubs	4485.9	4288.4	2737.5	1719.3
barren land	8458.3	8561	4936.2	5078.1
settlements	3245.7	3284.9	2199.6	2187.8
water	150.5	99.4	485.2	673.3
Total	26754.5	26734.8	26146.4	26132.3

Table 1: Satellite derived crop area (ha) of Madimanikyam and Janpahad major in Nagarjuna Sagar Project left canal during *rabi* 2008-09 and 2009-10.

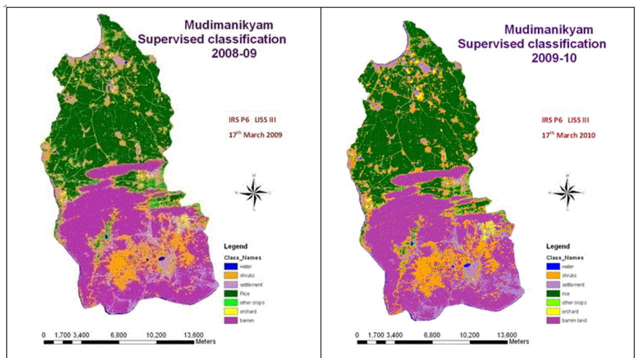

Fig 2a. Supervised classification image of Mudimanikyam major during *rabi* 2008-09

Fig 2b. Supervised classification image of Mudimanikyam major during *rabi* 2009-10

Paddy Yield Assessment

Maximum NDVI image derived using *rabi* season satellite data (March month images) was used to establish the relationship between NDVI and Paddy yield observations at CCE plots through the development of regression model. The model developed for Mudimanikyam and Janpahad major for *rabi* 2008-09 and 2009-10 is given in Figure 4a, Figure 4b, Figure 5a and Figure 5b. The developed regression equation is fit into yield model generated in ERDAS 9.3 software and paddy yield map (Figure 6a, Figure 6b, Figure 7a and Figure 7b) was generated. The minimum, maximum and mean yields of the study area was taken from the satellite derived yield map and presented in Table 2. Paddy productivity was low under Mudimanikyam (2.4 t/ha) and high under Janpahad (3.2 t/ha) during

Citation: K Avil Kumar, MD Reddy, M Uma Devi, N Narender, TL Neelima, et al. (2014) Irrigation Performance Assessment of Left Bank Canal, Nagarjuna Sagar Project, India During *Rabi* Using Remote Sensing and GIS. Agrotechnol 3: 122. doi:10.4172/2168-9881.1000122

both the years. Mudimanikyam major located near the project might have recorded low yields due to excess of water delivered near the head reach.. Chakraborthi et al. [8] reported that paddy productivity reduced from 4.55 to 4.0 t/ha from the period 1990 to 1998 for Nagarjuna Sagar left bank canal.

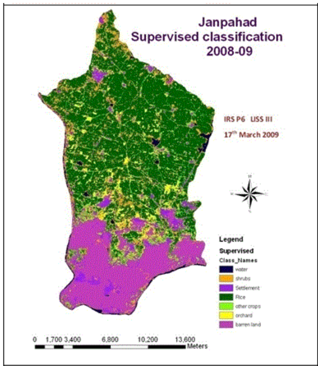

Fig 3a. Supervised classification image of Janpahad major during *rabi* 2008-09

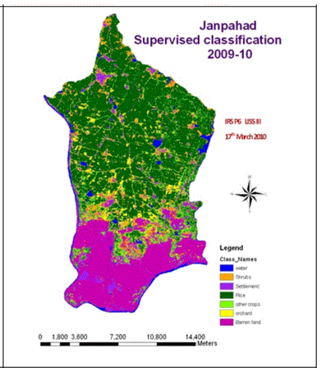

Fig 3b. Supervised classification image of Janpahad major during *rabi* 2009-10

Yield Levels	Mudimanikyam		Janpahad	
	2009	2010	2009	2010
Minimum	2151	2094	2812	3466
Maximum	7549	7713	7916	7411
Mean	2449	2392	3149	3190

Table 2: Satellite derived yield levels (kg/ha) of Mudimanikyam and Janpahad majors of Nagarjuna Sagar Left canal during *rabi* season 2008-09 and 2009-10.

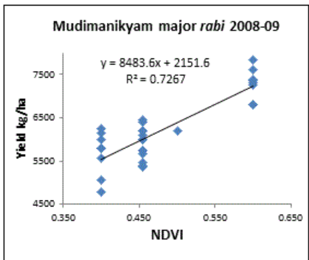

Fig 4a Paddy yield model developed for Mudimanikyam major during *rabi* 2008-09

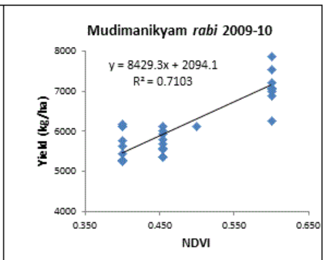

Fig 4b Paddy yield model developed for Mudimanikyam major during *rabi* 2009-10

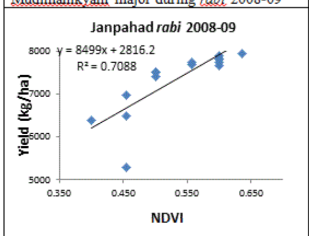

Fig 5a Paddy yield model developed for Janpahad major during *rabi* 2008-09

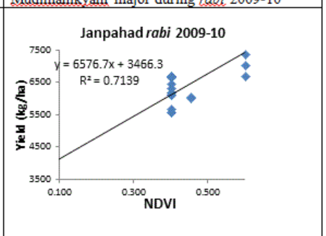

Fig 5b Paddy yield model developed for Janpahad major during *rabi* 2009-10

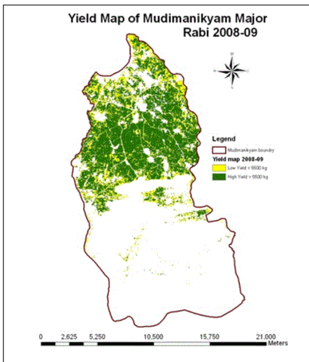

Fig 6a. Yield mask of Mudimanikyam major duing *rabi* 2008-09

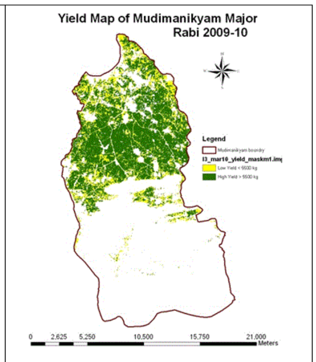

Fig 6b. Yield mask of Mudimanikyam major duing *rabi* 2009-10

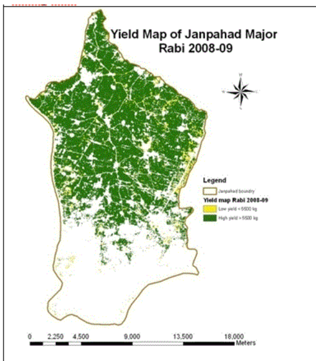

Fig 7a. Yield mask of Janpahad major duing *rabi* 2008-09

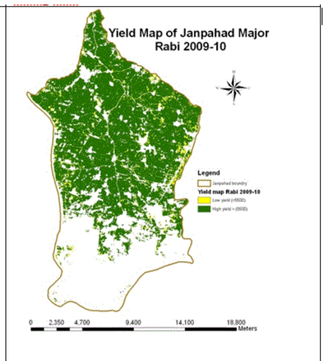

Fig 7b. Yield mask of Janpahad major duing *rabi* 2009-10

Performance indicators

Irrigation intensity

Irrigation intensity for Mudimanikyam ranged from 92.39 to 93.17 and for Janpahad ranged from 116.38 to 123.19 during rabi 2008-09 and 2009-10 (Table 3). In principle the irrigation intensities across the command area may not exceed 100 percent in a single season. But in case of Janpahad during both the years, it has exceeded and for Mudimanikyam it is less. In Janpahad major paddy was cultivated under canal and tank fed irrigation. The canal command authorities have not included the tank area in the ayacut hence the irrigation intensity might be higher as the satellite image provides the entire irrigated area within the boundry. Prasad et al., [9] also reported irrigation intensity ranging from 68 to 111% for Krishna western delta.

Water Utilization Index (WUI)

Water utilization index (WUI) defined as area irrigated per unit volume is a measure of water delivery performance and constitute one of the important spatial performance indicators of an irrigation system. WUI also forms basis for evaluating the adequacy of seasonal irrigation supplies in an irrigation system. It is estimated based on the equivalent wet area and amount of water released. The trend observed in estimates of WUI during the study years is given in table 3. In general the WUI was low during *rabi* 2009-10 (86.04 and 117.78 ha Mcum-1) than previous year (121.65 and 148.96 ha Mcum-1) for Mudimanikyam and Janpahad major, respectively.

The target value of WUI is 141.24 ha Mcum-1 of wet crop cultivated during *rabi*. Janpahad major during *rabi* 2008-09 has better WUI (148.96) and low WUI for Mudimanikyam major may be attributed to low yields due to excess water. On the other hand WUI during *rabi* 2009-100 was less for both the majors due to more water release. During the two years of study, the WUI was higher (121.65 and 148.96 ha Mcum-1) during 2008-09 than in 1998-99 (92 ha Mcum-1) for Nagarjunasagar project command [8]. On the other hand, in 2009-10, the WUI was lower in Mudimanikyam and higher in Janpahad than that reported in 1998-99.

Indicators	Mudimanikyam		Janpahad	
	2009	2010	2009	2010
Irrigation Intensity	92.39	93.17	116.38	123.19
Water Utilization Index (ha Mcum-1)	121.65	86.04	148.96	117.78
Depth of water applied (m)	0.82	1.16	0.67	0.85
Overall consumption rate (efficiency)	0.68	0.40	0.80	0.52
Relative water supply	1.53	2.06	1.12	1.36
Output per cropped area ($ ha-1)	685	748	1673	1855
Output per command area ($ ha-1)	633	697	1947	2285
Water Productivity (kgm-3) (Volume of irrigation water supplied)	0.286	0.196	0.433	0.335

Table 3: Performance indicators calculated for Mudimanikyam and Janpahad major for *rabi* 2008-09 and 2009-10.

Depth of Water Applied

The depth of water applied is calculated based on satellite derived crop estimates and volume of water supplied to majors. The depth of water application increased from 0.82 m in 2008-09 *rabi* to 1.16 m in 2009-10 *rabi* for Mudimanikyam and 0.67 in 2008-09 *rabi* to 0.85 m in 2009-10 *rabi* for Janpahad major (Table 3). This indicated that depth of water applied to both the majors is much higher during *rabi* 2009-10 because of more water availability than 2008-09. Similar results of increased depth of water application have been reported for Bhadra Right Bank Canal [10].

Overall consumption rate

The overall consumption rate derived from water requirement estimated using Potential Evapotranspiration (PET) and Pe (effective rainfall) during both the years is used to assess the irrigation performance across Mudimanikyam and Janpahad major command area during *rabi* 2008-09 and 2009-10 (Table 3). The water requirement was derived through CROPWAT model. The e_p indicator for the majors during *rabi* 2009-10 (0.40 and 0.52) was less than the target value (0.56) which indicates that excess water was supplied during that particular year. However, during *rabi* 2008-09 e_p indicator was above the target value indicating insufficiency of water. During the period with low ratios, the non-consumed fraction of the water will cause the ground water table to rise if the water is applied to the field [4], while during the period with a ratio of above 0.56, ground water must be pumped and stored to avoid water shortage. In a study carried out in Lower Gediz basin in western Turkey, e_p values ranged from 0.47 to 1.66 during *Kharif* 2004 [11].

Relative water supply

Relative water supply is a suitable indicator to inform the irrigation manager whether sufficient water is being supplied to a large area of cropped land in order to meet the total crop water demand. RWS and e_p have an inversely proportional relationship [12]. The target value of RWS indicator were considered as 2.0 and the values ranging between 1 to 2 indicate sufficient water supply related to demand and values above 2 indicates excess water supply [7].

RWS values ranged from 1.53 to 2.06 for Mudimanikyam and 1.12 to 1.36 for Janpahad during *rabi* 2008-09 and 2009-10, respectively indicating that sufficient water supply to Janpahad and excess water supply to Mudimanikyam. During 2009-10 RWS for Mudimanikyam major exceeded the target value indicating adequate water supply during that period. The RWS for many irrigation systems ranged from 0.8 to 4.0 indicating that value above 2.0 have greater supply of water than demand [7].

Output per cropped area

The output per cropped area gives information about income generated per unit cropped area. It was computed for Mudimanikyam and Janpahad command area by dividing the total production obtained by multiplying satellite irrigated area with the standardized gross value product (SGVP). The SGVP is calculated by converting all the crop prices to a common base crop price (Paddy). It was computed to be 685 and 748 $ ha^{-1} for Mudimanikyam and 1673 and 1855 $ ha^{-1} for Janpahad during *rabi* 2008-09 and 2009-10, respectively. The Janpahad major gave higher income than Mudimanikyam major during both the years.

Output per culturable command area

The output per culturable command area expresses the average returns of each command area. The output per culturable command area for Mudimanikyam major was 633 and 697 $ ha^{-1} and for Janpahad major was 1947 and 2285 $ ha^{-1} during *rabi* 2008-09 and 2009-10, respectively. It is clear that Janpahad major gave higher returns during both the years.

Water productivity

Productivity of water is one of the irrigation performance indicator used in irrigation performance assessment as it can establish the relation between the amount of water supplied to irrigation command and the production of paddy realized from the command. The water productivity observed in command area on supply basis was 0.286 and 0.196 kg m^{-3} for Mudimanikyam and 0.433 and 0.335 kg m^{-3} for Janpahad during *rabi* 2008-09 and 2009-10, respectively. Chari et al. [10] reported that water productivity improved from 0.28 to 0.5 for Bhadra irrigation project from 1986 to 1994. The project water productivity reduced during *rabi* 2009-10 for both the majors because of more water was released during *rabi* 2009-10 compared to the previous year.

Conclusions and Recommendations

The Irrigation performance indicators computed for Mudimanikyam and Janpahad major, of Nagarjuna Sagar Project left bank canal, based on remote sensing and GIS indicated that the irrigation intensity ranged from 92.39 to 123.19, overall consumption rate from 0.4 to 0.08, relative water supply from 1.12 to 2.06 and water productivity from 0.196 to 0.433 kg m^{-3}.

Based on the performance indicators, it can be concluded that irrigation performance of Janpahad major was better than Mudimanikyam due to production of higher output per unit of water compared to Mudimanikyam major. Within two years of study, during *rabi* 2009-10, the overall consumption rate was 0.4 and 0.52 for Mudimanikyam and Janpahad indicating more water was used than required. Further, in comparison to the Remote sensing and GIS estimation of NSP left canal in 1998-99, the water utilization index has increased (86 to 148 ha Mm^{-3}), depth of water application has reduced (0.67 to 1.17 m) and the yields of paddy under the two majors have decreased (2.4 to 3.2 t/ha) during study period. Hence, periodical monitoring of the irrigation projects using remote sensing and GIS should be carried out for taking remedial measures to improve the efficiency of irrigation service.

Acknowledgements

The authors are grateful to ICAR, New Delhi, India for providing the financial assistance under Niche Area of excellence programme on "Capacity building and research on improving agricultural water productivity". Grant number F.N.10 [12]/2006-E.P.D, Dt 02-01-07.

References

1. Abernethy CL, Pearce GR (1987) Research needs in third world irrigation. Hydraulics Research Limited. Wallingford, U.K.
2. Rouse JW, Haas RW, Schell JA, Deering DW, Harlan JC (1974) Monitoring the vernal advancement and retrogradation of natural vegetation. NRSA/GSFCT Type III final report, Greenbelt, MD, USA.
3. Sakhivadivel R, Thiruvengadachari S, Upali A, Bastiannssen WGM, David M (1999) Performance evaluation of the Bhakra irrigation system, India, using remote sensing and GIS techniques. Research Report 28: 20
4. Bos MG, Nugteren J (1990) On Irrigation Efficiencies, International Institute for Land Reclamation and Improvement. (4thedn), ILRI Publication 19, Wageningen, Netherlands.
5. Bos MG, Burton MA, Molden DJ (2005) Irrigation and Drainage Performance Assessment: Practical Guidelines. CABI Publishing, UK: 158.
6. Perry C (1996) Irrigation reliability and the productivity of water: a proposed methodology using evapotranspiration mapping. Irrigation and Drainage Systems 19: 211-221.
7. Molden DJ, Sakthivadivel R, Perry CJ, Charlotte DF, Kloezen WH (1998) Indicators for comparing performance of irrigated agricultural systems. Research report 20, International Water Management Institute: 26.
8. Chakraborti AK, Rao VV, Shanker M, Suresh Babu AV (2002) Performance evaluation of an irrigation project using satellite remote sensing, GIS & GPS. Water Resources Group, National Remote Sensing Agency, Hyderabad, India.
9. Prasad PRK, Kalpana D, Satyanarayana TV (2006) Irrigation performance assessment of Krishna western delta using remote sensing – A case study. Report of mission to ANGRAU Hyderabad and Bapatla, India.
10. Chari ST, Jonna S, Raju PV, Murthy CS, Hakeem KA (1994) System Performance Evaluation and Diagnostic Analysis of Canal Irrigation Projects, Water Resources.
11. Bekir SK, Akkuzu E, Halil BU, Serafettin, A, Musa A (2009) Using satellite remote sensing to assess irrigation performance in water user associations in the Lower Gediz Basin, Turkey. Agricultural water Management 96: 982-990.
12. Bastiaanssen WGM, Van der Wal T, Visser TNM (2001) Diagnosis of regional evaporation by remote sensing to support irrigation performance assessment. Irrigation and Drainage Systems 10: 1-23.