PERFORMANCE ASSESSMENT OF KRISHNA WESTERN DELTA USING REMOTE SENSING — A CASE STUDY

P.R.K.Prasad[1]
C.Jacobs[2]
G. Subba Rao[3]
D.Srinivas[4]
A.V Suresh Babu[5]
J. Boonstra[6]
T.V. Satyanarayana[7]

ABSTRACT

The Krishna delta irrigation system, one of the earliest major irrigation projects in southern India was designed by Sir Arthur Cotton during in the middle of 19th century on river Krishna near Vijayawada. The project irrigates an ayacut of 5.14 lakh hectares covering West Godavari, Krishna, Guntur and Prakasam districts of Andhra Pradesh. Using multi-date satellite data of Krishna Western Delta (KWD), flow information, crop cutting experiment (CCE) plot data of the State Department of Agriculture (SDA) and AP Water Management (APWAM) Project obtained during kharif 2005-06, performance indicators were computed and performance of irrigation system was assessed.

Paddy was the major crop gown in KWD. Hence paddy yield model was developed using ground obtained CCE plot yield data and satellite derived normalized difference vegetative index (NDVI). Very good correlation (r = 0.7) was obtained between these parameters. Hence, it was extrapolated to the entire KWD belt. The average yield of KWD derived based on NDVI observations was closely matched with the yield data of APWAM and SDA. Highest efficiency (85%) was obtained in highlevel canal command. The lower efficiency obtained in Kommamur was due to poor condition of the canal, high conveyance losses and release of excess rain water in to the sea through the canal. The productivity of water was varying from 0.7 to 1.0 kg m^{-3} across KWD except in Kommamur which had only 0.5 kg m^{-3}.

The information on nature, extent and distribution of salt affected soils and waterlogged areas in KWD was generated based on visual interpretation of FCC imageries obtained from space-borne remote sensing satellites. It was computed that about 18,102 and 4,675 hectares of area was salt affected and waterlogged, respectively.

[1] Professor & Head (Soil Science), Agril. College, Bapatla, ANGRAU, Andhra Pradesh, India (prk_prasad@yahoo.com
[2] Scientist (Irrigation & Remote Sensing), Alterra-ILRI, Wageningen, The Nether lands.
[3] Senior Scientist (Agronomy), RARS, Lam, Guntur, Andhra Pradesh, India
[4] Senior Scientist (Soil Science), RARS, Maruteru, West Godavari, Andhra Pradesh, India
[5] Scientist-SF, National Remote Sensing Center, Balanagar, Hyderabad, India
[6] Retd.Chief Technical Advisor, Alterra-ILRI, Wageningen, The Nether lands
[7] Dean, Faculty of Agril. Engineering, ANGRAU, Hyderabad, Andhra Pradesh, India

INTRODUCTION

Satellite provides a convenient platform to observe earth features which capable of giving spatial data which is continuous in nature. Space-borne multi-spectral data by virtue of synoptic coverage of a fairly large area at regular interval are very useful in generating information on the status of irrigation commands at different time intervals for assessing performance evaluation. Hence it can be used as a tool to collect data in any irrigation command viz. cropping pattern, crop condition, crop productivity, problems of water logging and soil salinity etc. The capabilities of the technology has been proved through various studies on irrigated commands across the world by generating the information that is crucial for restoration or rehabilitation or to evaluate the performance of the system.

The objective of the study is to evaluate overall performance of irrigation system in Krishna Western Delta. Irrigation performance assessment is the systematic spatial and temporal evaluation of irrigation systems to diagnose problems. A common approach is to calculate irrigation performance indicators using remote sensing and field data. Performance evaluation of Krishna western Delta irrigation system in Andhra Pradesh State for the Kharif season of the year 2005-2006 was taken up based on various performance indicators. Multi-date satellite data of Krishna Western Delta (KWD) irrigation command during Kharif season 2005-06 are analyzed for irrigation performance assessment.

Performance evaluation of irrigation command involves knowledge of both the total demand and the distribution of demand for irrigation water over space and time. The major information required for irrigation studies is about crop types, acreages, condition and yield. From this information statistical estimates of water demands can be made. Because of the vast areas involved, time constraints and dynamic changes, remote sensing is found to be an effective tool for irrigation studies compared to conventional methods which are point based, time consuming.

Paddy yield model was developed in this study using ground observed CCE plot yield, satellite derived NDVI during 2005-06 kharif season. This has been used to extrapolate the yield for entire KWD.

In the present study, various performance indicators useful for the irrigation performance assessment of Krishna Western Delta using satellite data and flow information, CCE plot experiment data were carried out. This study has given wealth of information about KWD performance indicators.

Description of Krishna western delta study area

Location and climate**:** The Krishna Western Delta (Krishna main canal command) covers Guntur district and a small part of Prakasam district in the state of Andhra Pradesh (Figure 1). The Krishna Western Delta (KWD) has a command area of approximately

242,000 hectares. KWD covers the districts of Guntur (210,000 ha) and Prakasam (32,000 ha).

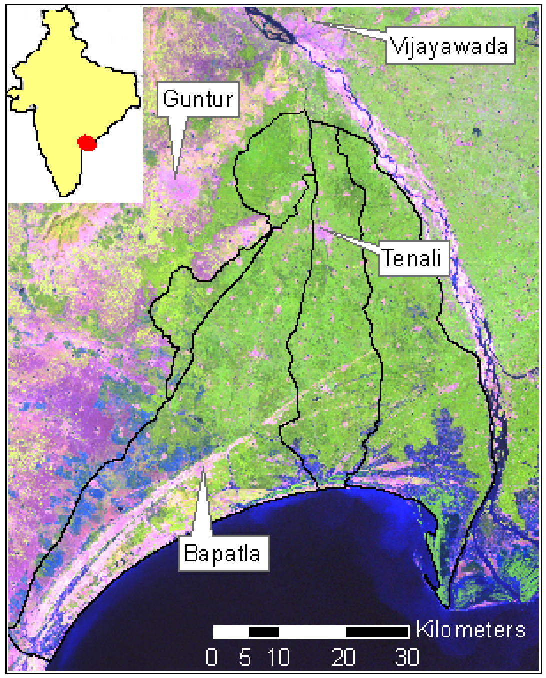

Figure 1. Krishna western Delta study area (command boundaries in black lines)

The climate of the Krishna Western Delta is dominated by the southwest monsoon which provides most of the precipitation for the region. The mean annual rainfall amounts to 800 - 900 mm, and about 90% of the rainfall is received during the monsoon months of May to October. The climate can be classified as sub-humid, with minimum and maximum average temperatures ranging from 12.8 to 26.0 °C and 29.7 to 46.5 °C respectively (Srinivasulu et al., 2003).

MATERIALS AND METHODOLOGY

Irrigation performance assessment

Irrigation efficiency is one of the most important indicators to determine the performance of an irrigation scheme. However, efficiency alone is not a sufficient indicator to define and improve the performance of an irrigation system. The concept of efficiency depends upon scale, and can be misleading (Bos et al, 2005; Jacobs et al, 2006). What is considered as “losses” at a certain scale can be a source of water at another scale. For instance, percolation “losses” at field level contribute to a recharge of the aquifer and this water can be recovered later. Such recycling can result in high overall efficiencies.

A general accepted figure for field scale irrigation efficiency is 45%, while efficiency regarded from the river basin as a total system (with recycling of percolated water) can be as high as 80 to 100% (Bastiaanssen et al., 2003). These scale considerations are often disregarded, and improvements in on-farm irrigation efficiency are expected to result in additional water supply for other districts.

Efficiency assessments should therefore be accompanied with water productivity studies, which implies a more "basin wide" assessment of water use. The International Water Management Institute (IWMI) has started a strong lobby to change the nomenclature from water use efficiency into water productivity, which is now also followed by other Consultative Group on International Agricultural Research (CGIAR) institutes and the Food and Agricultural Organization of the United Nations FAO (Bastiaanssen et al., 2003).

In the Krishna Western Delta study the following performance issues are assessed:

- Uniformity of water application;
- Spatial distribution of crop yields
- Effect of salinity on crop yields
- Irrigation efficiency
- Productivity of water

Satellite images and field data are used to calculate GIS based irrigation performance indicators. Performance indicators are partly selected from the handbook on irrigation performance assessment (Bos et al., 2005).

Performance Indicators

Uniformity of water application: The uniformity index (UI) refers to the variation (or non-uniformity) in the amounts of water applied to locations within the irrigated area and is defined as:

$$UI\ (-) = \frac{V_i / A_i}{V_j / A_j}$$

Where:

V_j = total irrigation volume supplied to KWD (m^3);
V_i = irrigation volume measured at the head intake of command *i* (m^3);
A_j = total irrigated area KWD (ha);
A_i = irrigated area in command *i* (ha).

Irrigation efficiency**:** The Overall Command Efficiency refers to the degree in which water supply and water demand are matched. The indicator assesses irrigation efficiency at command area scale, since irrigation volumes are only measured at the head intake of each main command. The Overall Command Efficiency (OCE) is defined as:

$$OCE\ (-) = \frac{(WR_{command,i})}{(WS_{command,i})}$$

Where:

$WR_{command,\,i}$ = Irrigation Water Requirement at command *i* (mm);
$WS_{command,\,i}$ = Irrigation Water Supply at command *i*, measured at head intake (mm).

First the irrigation water requirement for rice at field level (net irrigation requirement, WR_{field}) is determined as:

$$WR_{field}\ (mm) = (ET_p - P_e) + LP$$

Where:
ET_p = Potential Evapotranspiration from transplanting to harvest (mm)
P_e = Effective rainfall (mm)
LP = Land Preparation and nursery demand (mm)
Consequently the irrigation requirement at command intake level (gross irrigation requirement, $WR_{command}$) is determined as:

$$WR_{command,i}\ (mm) = \frac{WR_{field}}{C * P}$$

Where:
WR_{field} = Water demand at field level (mm)
C = Correction factor for conveyance efficiency (-).
P = Correction factor for field application efficiency (-)
The overall command efficiency ratio is calculated both on a seasonal basis as well as on a monthly basis.

Water productivity**:** The water productivity indicator quantifies the yield per volume of irrigation water supplied. Comparing this indicator for different command areas illustrates the spatial variation in productivity.
The Water Productivity (WP) is defined as (Molden et al., 1998):

$$WP\ (kg/m^3) = \frac{Y_{command,i}}{V_{command,i}}$$

Where:
$Y_{command,\ i}$ = Rice yield in command *i* (kg);

$V_{command,\ i}$ (m3). = Irrigation volume measured at the head intake of command *i*

To assess yield performance, WP results should be related to the intended (target) yields for the KWD area. The WP values should however not be compared to WP levels in other regions or for different seasons, as they are heavily influenced by local climate.

Temporal and spatial assessment of irrigation

Temporal assessment**:** The assessment is done for the Kharif season of 2005. Uniformity and productivity are assessed on a seasonal basis while efficiency is also addressed on a monthly basis.

Spatial assessment**: Since** irrigation water is controlled up to the main command level (i.e. water volumes are available at the head intake of the command areas), performance indicators are calculated at command level, and no differentiation *within* the commands was possible.

Data acquisition

Remote Sensing data: The Indian Resourcesat-1 Satellite (IRS P6) LISS III sensor (Linear Imaging and Self Scanning) was used for the study. Resource sat – 1 is especially designed for integrated land and water management and agricultural applications.

The Krishna Western Delta is covered by one IRS image and is referenced as path 102, row 61/62 (row 61 with 50% shift downwards). Figure 2 shows an IRS footprint to illustrate the Krishna Western Delta's coverage.

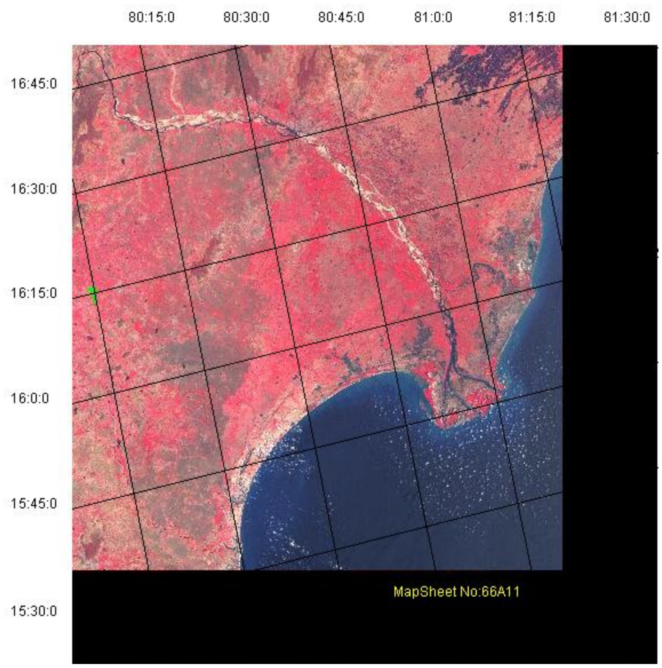

Figure 2. Footprint IRS P6 LISS III K W D, path 102, row 61 (50% shift South)

Selection of dates: Because of the large spreading in rice transplanting during Kharif, two images were acquired, representing the vegetative (September) and reproductive/ripening stage of rice (November).In August the cloud coverage was very high, so this month was excluded from the analysis. For salinity assessment, one image was selected in April 2006, where most of the land is fallow. The following set of IRS P6 LISS3 data were obtained from NRSA for 2005/2006 (Table 1).

Table 1. IRS P6 LISS III images

No.	Date	Purpose
1	27 September 2005	Vegetative stage rice
2	14 November 2005	Ripening stage rice
3	07 April 2006	Salinity assessment

Field campaigns: During the time of satellite overpass, three field campaigns were organised by ANGRAU to collect field data. For the crop yield assessment, a number of 60 sample points were identified in Krishna Western Delta using a GPS (Figure 3). The sample points represent the head, middle and tail reaches of KWD and covers various land uses (rice, other crops and fallow land). For salinity assessment, a number of 57 soil samples were taken.

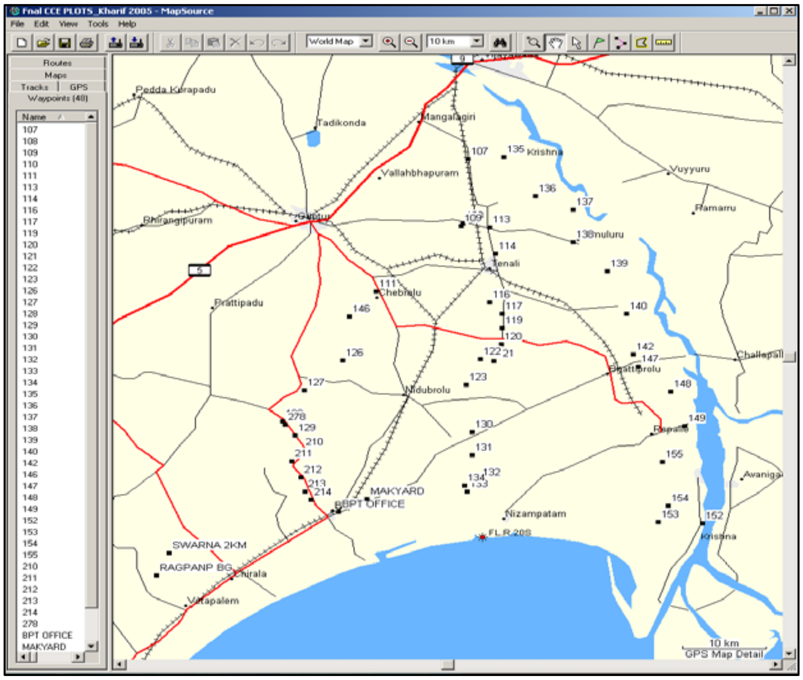

Figure 3. Location of sample points for crop mapping Krishna Western Delta

RESULTS AND DISCUSSION

Classification

A supervised classification was performed, where pixels were clustered into classes using the ground truth information. The planting of rice progresses over a large period of about 1 to 1.5 month on a continuous basis, from July to September. Therefore categories of rice stages (early-mid-late) were made, based on the collected field data. From these categories, reflectance characteristics ("signatures") were extracted which formed the classes to perform the supervised classification (Table 2 & Figure.4).

Table 2. Pre-defined classes for supervised classification

Class name	Class description
Rice Early	Crop planted between July 20 and August 10
Rice Mid	Crop planted between August 11 and August 31
Rice Late	Crop planted after 1st September
Annual crops	Includes irrigated crops other than rice such as banana, sugarcane, turmeric, chillies.
Prawn	Prawn cultivation
Mangroves	Mangrove cultivation
Waterlogged	Waterlogged areas (water ponding on surface)*

* From remote sensing only waterlogged areas can be detected with standing water on the surface.

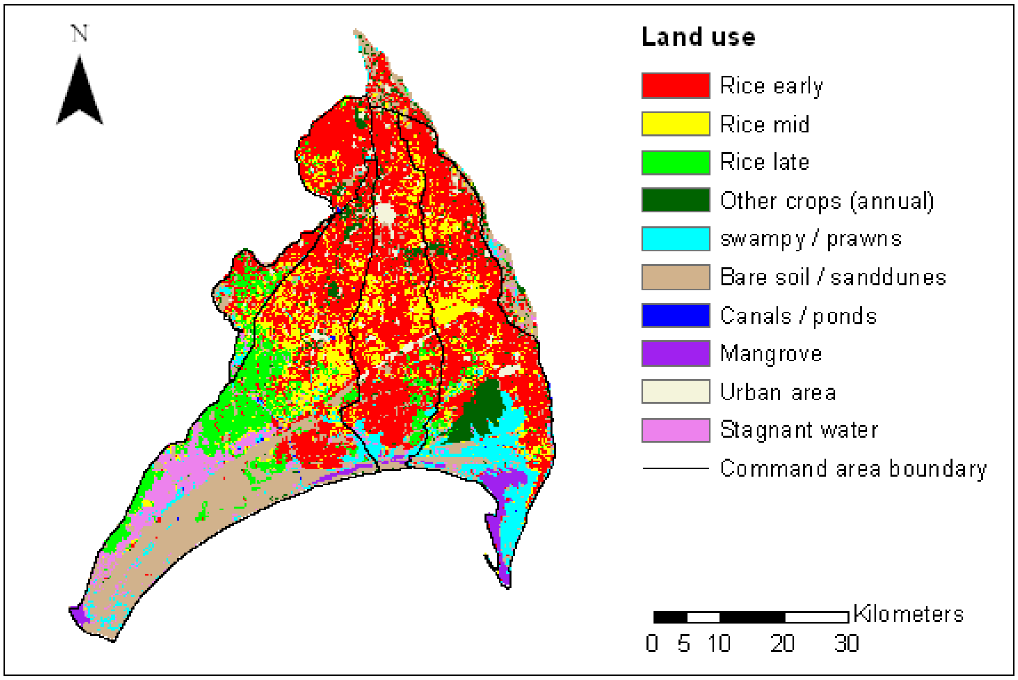

Figure 4. Crop map Krishna Western Delta, Kharif 2005

As can be seen from the figure 4. lowest irrigation intensities appear at the tail ends of the command areas. Further, one can distinguish a general trend from head to tail. Rice crop was sown at early stages appear mostly in the head part of the delta, whereas late sown rice is found at the tail end part. An exception is found in the most southern part of the delta (tails ends of the Nizampatnam canal), where rice is sown at early stages.

Crop yield map: A crop yield map was created from the established yield model (Figure 5). Total yields for the command areas are summarized in Table 3.

Table 3. Rice yields in the KWD commands (Kharif 2005)

	Rice cultivation (ha)	Average rice yield (t/ha)	Production (tons)	Yield variation (spatial coefficient)
C1 KWB Canal	45,698	5.0	230,442	0.61
C2 Nizampatnam	42,252	5.2	217,769	0.68
C3 Kommamur	57,300	5.3	300,965	0.68
C4 High Level Canal	12,381	5.4	67,155	0.56
C5 AM Channel	8,803	5.4	47,371	0.60
Total KWD	166,435	5.2	863,701	-

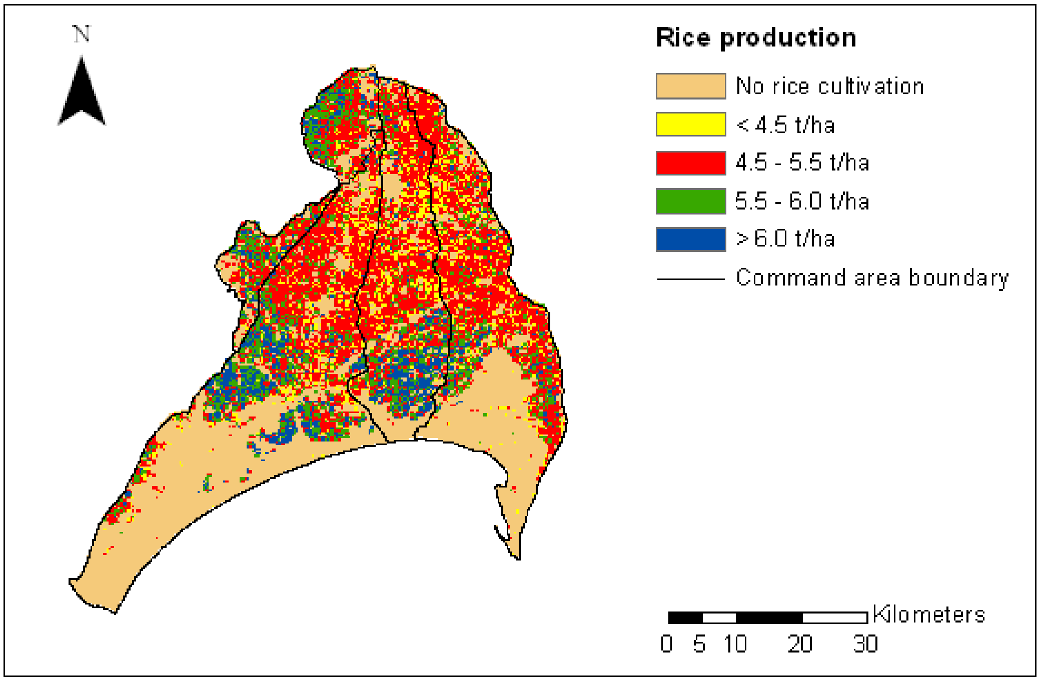

Figure 5. Spatial variability of rice yield in Krishna Western Delta (Kharif 2005)

Irrigation water requirements

Net irrigation requirements: The CRIWAR model (Bos et al, 1996) was used to determine the crop water requirements. Crop water requirements are defined here as net irrigation requirements, quantified as the difference between the potential evapotranspiration and (effective) precipitation. It refers to the amount of irrigation water needed at field level, without any corrections for field application efficiency.

Meteorological records from two weather stations located in the study area were used: (i) Bapatla meteo station and (ii) Lam meteo station, located near Guntur. The meteorological stations are approximately 45 km apart and represent two different climatic regions.

The CRIWAR model does not include the land preparation and nursery phase for rice. Water requirements for this phase are estimated as 200 mm for land preparation and 50mm on 1/20 of the rice area for growing nurseries. These numbers are based on local experience. The net irrigation requirements for the different command areas are presented in Table 4.

Table 4 Irrigation requirements, Kharif 2005

Command area	PotentialEvapotranspiration ETp (mm)	Net irrigation requirements (mm) (ETp-Pe)
C1 Krishna Western Bank	710	215
C2 Nizampatnam	711	211
C3 Kommamur	690	238
C4 High Level canal	707	199
C5 AM channel	681	229

Figure 6 shows the variability within the Kharif season of precipitation, irrigation and potential evapotranspiration for the total Krishna Western Delta.

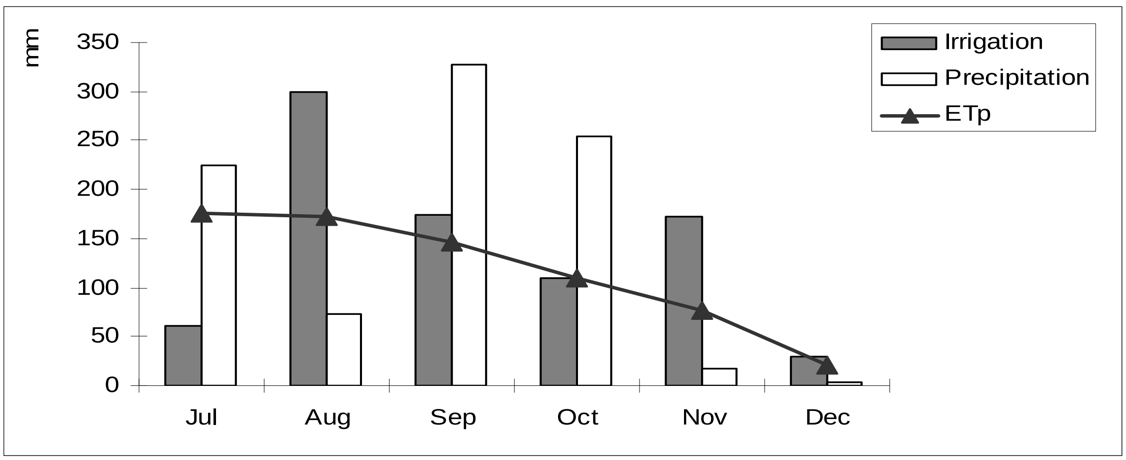

Figure 6. Seasonal variability of precipitation, irrigation and potential evapotranspiration (ETp) in mm for KWD, Kharif 2005

Gross irrigation requirements**:** To convert net irrigation requirements to gross irrigation requirements, a correction for field application (percolation) and conveyance was made. For field application, an efficiency of 60% was used for the KWD area (Srinivasulu, 2003). For conveyance losses, an efficiency of 70% was maintained. The efficiency percentages were confirmed by the Irrigation Department.

Performance assessment

Performance indicators: Table 5 summarises the irrigation supplies, irrigated areas, irrigation requirements and rice yields, from which the performance indicators were calculated and presented in Table 6.

Table 5. Overview irrigation data KWD commands

	Irrigation (mm)	Rice area (ha)	Rice intensity ** (%)	Gross irrigation requirements (mm)*	Rice yield (kg)	Average yield (t ha-1)
C1 KWB	757	45,698	87	512	230,441,600	5.0
C2 NIZ	660	42,252	97	503	217,768,796	5.2
C3 KOM	1135	57,300	96	566	300,965,171	5.3
C4 HLC	557	12,381	92	475	67,154,487	5.4
C5 AMC	738	8,803	97	544	47,370,539	5.4

* Gross irrigation requirements are defined as (ETp – Pe), corrected for application and conveyance

** Rice intensity refers to rice cultivation as a percentage of irrigated area

It was estimated that 26% of the water required for land preparation and for growing nurseries needed to be supplied by canal water; according to the rice staggering dates the remaining part could be met from rainfall.

Table 6. Performance indicators at KWD command area scale, Kharif 2005

Command name	Uniformity index (-)	Overall Command Efficiency (-)	Water productivity (kg/m3)
C1 Krishna Western Bank	0.9	68	0.7
C2 Nizampatnam	0.8	76	0.8
C3 Kommamur	1.3	50	0.5
C4 High Level Canal	0.7	85	1.0
C5 AM Channel	0.9	74	0.7

<u>Uniformity (spatial variability in canal water supplies</u>**)**: Comparing the different command areas, it can be seen from the uniformity index that water was distributed in a fairly uniform way. This means that the command areas received similar volumes of water for each hectare. An exception is Kommamur command, which received an excessive amount of water.

It should be noted that equity of water distribution *within* the command area (head- and tail-reach) could not be quantified. This is because the irrigation volumes are available at command level (head intake) only.

<u>Overall command irrigation efficiency</u>: On a yearly basis, the average irrigation efficiency at command level is 71%, which is reasonable. A correction was already applied for water that will not reach the fields due to conveyance and percolation, indicating that the remaining 29% of the water which was not efficient was drained into the sea or was stored in ponds.

Irrigation efficiency was highest in the High Level Canal command, which means that here the best match between irrigation demand and supply was found. Lowest efficiency was found in Kommamur, where about twice the amount needed was supplied to crops. Part of the irrigation water was directly drained from Kommamur canal.

On a monthly basis, the five commands showed similar variations within the Kharif season (Figure 7). Water supply matched water demand fairly well except for the cyclone months of September and October, where severe over-irrigation took place. In these months the rainfall fulfilled the crop water demand, and no irrigation was needed. The reason for the over-irrigation in this period is that the maximum capacity of Prakasam barrage is reached in the months of September – October. Excess water cannot be stored in this period and needs to be released (spilled) from the barrage. It is a political decision to spill the excess water through the canals, instead of directly to sea.

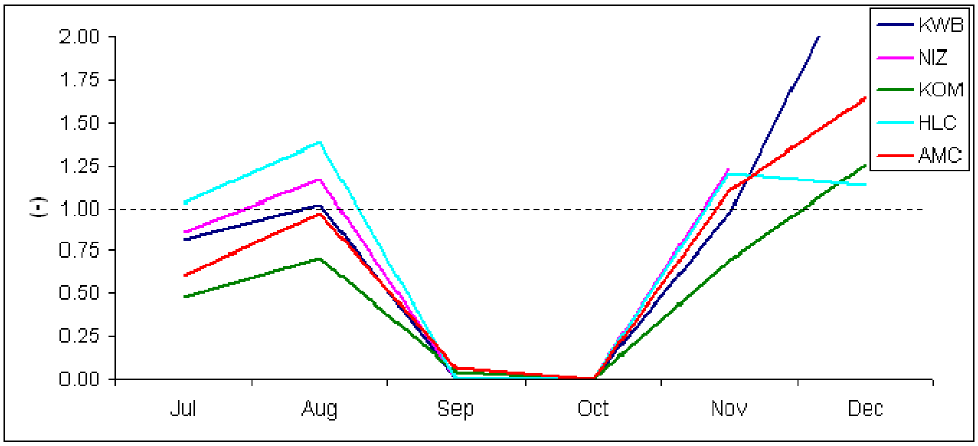

Figure 7. Monthly variability in irrigation efficiency (-) KWD commands, Kharif 2005

Water productivity: Water productivity levels were fairly high within the KWD command, except for Kommamur command (0.5 kg/m^3). The low productivity in Kommamur can be explained by the supply of excess water, hampering probably crop production as well.

Distribution of salt affected Soils

The study also revealed the distribution of salt affected soils in the five distributory command areas of the delta area. The distribution of salt affected soils is given in Table. 8 and depicted in Figure 8

Table 8. Area statistics of salt affected soils in different commands (in hectares)

Category	K W Bank command (C1)	Nizam. east command (C2)	Nizam. west command (C3)	Komm. command (C4)	A M channel command (C5)	Total
Slightly saline	65.78	--	--	1896.88	30.13	1992.79
Moderately saline	5352.70	407.54	156.83	2094.70	877.45	8889.21
Strongly saline	6199.05	1.29828	289.26	730.16		7219.77
Total	11617.54	408.84	446.09	4721.74	907.59	18101.79

From the above table it is evident that the occurrence of saline soils was more in Krishna western bank command (11618 ha) followed by Kommamur command (4722 ha).

Water logging

In the study area water logging is observed along the canals and in swale complex regions. Satellite data enabled to map only the surface water logging. An area of 4675 hectares was found to be waterlogged (Table 9). The spatial extent of waterlogged areas is given in the table below.

Table 9. Area statistics of waterlogged areas in different commands (in hectares)

Category	K W Bank command (C1)	Nizam. east command (C2)	Nizam. west command (C3)	Komm. command (C4)	A M channel command (C5)	Total
Water logging with salinity	---	----	----	718.24	----	718.24
Waterlogged	380.96	707.40	----	2868.98	---	3957.35
Total	380.96	707.40		3587.22		4675.59

Besides the problem of water logging and salinity occurrence of saline soils noticeable area (3892 hectares) is under mangroves which are strongly saline.

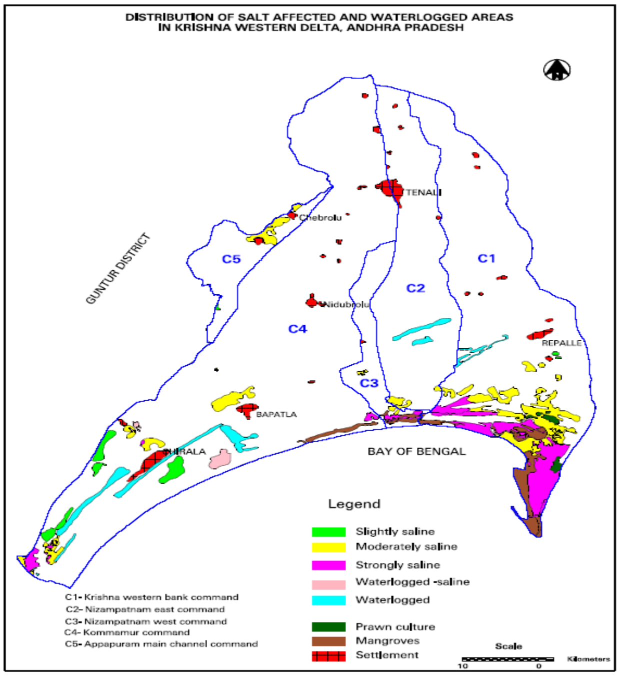

Figure 8. Salt affected and waterlogged areas in KWD

Effect of Water Logging and Soil Salinity on Irrigation System Performance: It was observed that the water logging and soil salinity exists in tail ends of Kommamur canal command where it is coinciding with paddy area. It is estimated from paddy crop mask during 2005-06 that 6200ha is under water logging and soil salinity. This is only 2% of the total ayacut under Krishna Western Delta. This may not influence the irrigation system performance in total, however, these areas need attention for reclamation measures and avoid further degradation.

CONCLUSIONS

The Krishna Western Delta case study demonstrates the use of satellite remote sensing for quantifying the irrigated area and productivity in a large irrigation system in India. Irrigation performance indicators were calculated for uniformity, efficiency and productivity.

In the Krishna Western Delta, water was applied at rather uniform levels. An exception appeared to be the Kommamur command, which received a relatively large amount of water.

Through remote sensing, the average rice yield for the Krishna Western Delta was found to be 5.2 t/ha. Average rice yields for the commands were relatively uniform throughout the area and highest variation in yields were found in the Kommamur and Nizampatnam commands. Some clear higher yielding areas were found in the tail reaches, which can be explained by lower irrigation applications than in head reaches, where farmers tend to over-irrigate. The yield model established to estimate the rice yields was found to be reasonable, but could be improved in future studies by adding more field samples and at better locations.

Irrigation at command scale was reasonably efficient for the overall season, however on a monthly basis, there was a mismatch in demand and supply during the cyclone months (September and October). Although sufficient rainfall was available to meet the water demand in this period, a large amount of canal water was supplied. The reason for this is that excess water in this period could not be stored in the Prakasam reservoir and needed to be released (spilled) to sea. For political reasons water is released through the canals, instead of directly to sea.

Comparing irrigation performance in the KWD commands, the best performing command appeared High Level canal, showing highest efficiency (85%) and the largest water productivity (1 kg/m^3). Poor performance was demonstrated by the Kommamur command, with an efficiency of 50% and a water productivity of 0.5 kg/m^3, due to excess irrigation supplies.

A systematic visual interpretation of space borne multi-spectral data enabled generation of information on the nature, extent, spatial distribution of salt affected soils and water logged areas in the Krishna western delta. Salt -affected soils have been found to be associated mostly in the coastal region.

In Krishna Western Delta (KWD) the salt affected soils are categorized into 3 classes of salinity (slight, moderate, strong). About 18101 hectares of salt- affected soils were found to occur in the command area and the satellite data was found to be useful in identification and mapping of surface water logging in Krishna Western delta and they were found in 4675 hectares.

REFERENCES

Bastiaanssen, W.G.M., J.C. van Dam and P. Droogers, 2003. In: Van Dam et al 2003 (Eds): Water productivity of irrigated crops in Sirsa district, India. WATPRO final report, 173 pp**.**

Bos, M. G., J. Vos, R. A. Feddes. 1996. CRIWAR: a simulation model on crop irrigation water requirements. Wageningen, The Netherlands, ILRI Publication 46, 117 pp

Bos, M.G., M.A. Burton and D.J. Molden, 2005. Irrigation and Drainage Performance Assessment: Practical Guidelines. CABI Publishing UK, 158 pp

Jacobs, C, 2006. Case Study Progress “Irrigation Performance Assessment Krishna Western Delta using Remote Sensing”. Report of mission to ANGRAU Hyderabad and Bapatla Network Centre, March 24 – April 4, 2006. Wageningen, Alterra, APWAM Technical Report no. 17, 36 pp

Srinivasulu, A., M. Ravi Kumar, T. V. Satyanarayana and J.L.N. Sai Sudha, 2003. Comparison of Crop Water Requirements and Actual Water Applied in Krishna Western

Delta. In: Watershed Hydrology, Vijay P. Singh and Ram Narayan Yadava (editors), 2003. Allied publishers, 560 pp