J. Indian Water Resour. Soc., Vol. 37, No. 4, Oct., 2017

IRRIGATION PERFORMANCE ASSESSMENT OF A CANAL IRRIGATED AREA: A CASE STUDY OF SAMRAKALWANA VILLAGE IN ALLAHABAD

Z. Renthlei[1], Denis M. D.[2], Kumar R.[3], Kumar. M.[4], Srivastava S.[5], Denis A.[6], Suryavanshi S.[6] and Yadav A[7].

ABSTRACT

Irrigation performance assessment is an important management tool to implement, monitor and evaluate activities for water delivery services. The aim of this research is to quantify the water needs of the crops, irrigation performance indicators and the irrigation potential achieved at the Samrakalwana village at Allahabad. The actual and potential evapotranspiration along with the irrigation water demands for all crops grown throughout the year in the village were estimated. The Delivery Performance Ratio, Depleted Fraction, Field Application Ratio, Relative Water Supply, and irrigation potential were estimated. The temporal variation in water availability at the irrigated area is successfully demonstrated for each performance indicator. The irrigation potential achieved for the canal irrigated village was found to be 66.6%. The study reveals the rainfall is ignored while determining water requirement of the irrigated area. Canal water does not reach to all agricultural plots. The study also reveals that irrigation performance indicators can be used successfully to evaluate the performance of a canal irrigated village. It also indicates the level of efficiency of water delivery services in the entire Cultural Command Area of which this village is a part.

Keywords: *Irrigation Performance Assessment, Delivery Performance Ratio, Depleted Fraction, Field Application Ratio, Relative Water Supply, Irrigation potential.*

INTRODUCTION

Water covers 70% of the world surface (Seckler et al., 1998). The availability, usability, affordability and acceptability of clean water has become a major challenge with the increasing need of providing food and water security for an ever increasing population. Therefore the available resources must be used efficiently. This involves innovation and more precision in its utilization. This becomes more important especially when it is used in abundance, like agriculture. Agriculture consumes maximum water hence it is necessary to develop technologies and monitoring methods for it's more efficient use.

The contribution of agriculture to the Gross Domestic Product (GDP) is gradually diminishing in India. Recent huge investments in irrigation infrastructure ensure the success of food security programs. This increases the living standards of the local population living in the Gross Command Area, contributing to the overall increase in GDP of a country (Briscoe and Malik, 2006; CWC, 2011). Hence it is essential to regularly evaluate the performance of these irrigation projects. Several researchers have stated the need of usage of performance indicators to evaluate and monitor in time and space existing irrigation projects (Behcet and Tarkan, 2014; Bos et al., 1993; Bos and Nugteren, 1974; Bumbudsanpharoke and Prajamwong, 2015; Ingle et al., 2015; Small and Svendsen, 1992; Özmen and Kaman, 2015; Ray et al., 2002; Reeling et al., 2012; Zwart and Leclert, 2010). Irrigation water supply and management in India is based on government estimates and not on the level of the farmer's demands. Presently these evaluations are only based on utilization of resources such as production and profitability. However a proper alternative should be on the use of spatial and temporal operational indicators that not only refer to production and profit, but also to the quality of service, crop water demand and crop water use. This type of diagnosis process can be achieved through performance assessment (ICID, 2010).

Irrigation performance assessment is considered an important management tool to implement, monitor and evaluate activities for water delivery services in a Cultural Command Area (CCA). An ideal or reference irrigation is the one that provides the required water at the right time and right amount for the entire area with minimum possible losses. Performance indicators are used to assess performance of an irrigation system, including irrigation efficiency, adequacy of water supply, as well as land and water productivity (Balderama et al., 2014; Bos. et al., 2005; Denis, 2013). Inputs that are required to assess the physical irrigation performance include measurements of different terms of the water balance such as discharge, evapotranspiration, effective precipitation, as well as measurements of crop yields, and estimates of irrigated area and cropping intensities. Water balance indicators such as Delivery Performance Ratio (DPR), Depleted Fraction (DF), Relative Evapotranspiration (RE), Crop Water Deficit (CED) and Field Application Ratio (FAR) are mostly used. These indicators can assess the irrigated areas in time and space. Considering the above rational a part of the CCA of Tons Pump Canal, Samrakalwana, the study area was undertaken to assess how close is the irrigated area to an ideal one. This will also give an indication of the level of efficiency of the water delivery services provided in the entire CCA.

1. *Irrigation and Drainage Engineer,*
2. *Professor , Dept. of Soil, Water, Land Engineering and Management (SWLEM), Vaugh School of Agricultural Engineering and Technology(VSAET), Sam Higginbottom Institute of Agriculture Technology and Sciences(SHIATS),*

   Director General, Uttar Pradesh Council of Agriculture and Research(UPCAR), Lucknow
3. *Assistant Professor, Associate Professor[4],Dept. of SWLEM, SHIATS, Assistant Professor[5],Department of Civil Engineering , SHIATS, Senior Research Fellow[6],SWLEM, VSAET, SHIATS, Allahabad.*

Corresponding author: derrickmdenis@gmail.com

Manuscript No.: 1451

MATERIALS AND METHOD

Study Area

The study area, Samrakalwana village in Allahabad is situated in the cultural command area of Tons Pump Canal Command Area. It lies at 25°17’ North latitude and 81°49’ East longitudes. The soils in the irrigated area are clay loam to sandy loam (230 km^2) and the remaining soils are loam to sandy loam (71.4km ^{2}). The major crops grown are wheat and paddy. The total C.C.A is 301.4 km^2. The main source of water for the canal is the Tons river and has a drainage area of 16860 km^2.

Climate

The study has a humid subtropical climate and has an annual mean temperature of 26^0 C. The minimum temperature of 2^0 C in winter and a maximum of 48^0 C in summer exhibits extreme climates. Allahabad experiences three seasons that are the hot dry summers, extending from mid of March to end of June. This is followed by warm and humid monsoon which begin in early July and lasts till September. The winters are cool and dry and extend from mid of November till the end of February.

METHODOLOGY

Reference Evapotranspiration from Penman-Monteith

To quantify the crop needs of the irrigated area, the Penman Monteith equation (Allen et al., 1998.; Monteith, 1965; Rijtema, 1965; Smith, 1992) was used to get the potential evapotranspiration of the region as given by equation (1);

(Note:- Equations and their symbols shall be typed in word for more clarity)

$$ET_p = \frac{86400 \times 10^3}{\lambda_{pw}} \frac{\nabla_v (R_n - G_0) + \rho_{air}[\frac{e_{sat} - e_{act}}{r_{a,h}}] \times C_{air}}{\Delta_v + \gamma_{air}[1 + \frac{r_{c,min}}{r_{a,h}}]} \quad (1)$$

Where,

∇_v is the slope of the saturated vapour pressure temperature relationship [kPa K^{-1}], R_n is the net radiation flux density above the canopy [W m^{-2}], G_0 is the soil heat flux density [W m^{-2}], ρ_{air} is the mean air density at constant pressure[kg m^{-3}], C_{air} is the heat capacity of moist air per unit mass [J $kg^{-1}K^{-1}$], e_{sat} is the saturated vapour pressure [kPa], e_{act} is the actual vapour pressure [kPa], λ is the latent heat of vaporization [J kg^{-1}], γ_{air} is the psychometric constant [kPa K^{-1}], r_c is the minimum value of the surface resistance of canopy when water is not limited. In this condition the canopy resistance rc reaches a maximum value rc, min [sm^{-1}], $r_{a,h}$ is the aerodynamic resistance for heat transport [sm^{-1}]. The aerodynamic resistance ra,h [sm^{-1}] is calculated as a function of crop height h_c,[m] and wind speed u_z [m s^{-1}],(Howell and Evett, 2011).

Crop Evapotranspiration

The crop evapotranspiration taking into consideration the Crop Coefficient was obtained using equation (2).

$$ETc = Kc * ETo \quad (2)$$

Where,

ETc is the Crop Evapotranspiration [mm/day], Kc is the Crop coefficient [dimensionless] and ETo is the Reference Crop Evapotranspiration [mm/day].

Irrigation depth

The soil water balance of the root zone is obtained on a daily basis, hence planning the exact amount of water needed to irrigate. The soil water availability in the root zone and root zone depletion at the end of each day is calculated. The total water in the root zone is expressed as:

$$TAW = 1000(\theta_{Fc} - \theta_{WP})Z_r \quad (3)$$

Where,

TWA, is the total available water in the root zone [mm], θ_{Fc} is the water content at the field capacity [m^3m^{-3}], θ_{WP} is the water content at the wilting point [m^3m^{-3}] and Z_r is the rooting depth[m].

The fraction of the TAW that the crop can use or extract from the root zone without experiencing water stress is the readily available water. This is a fraction of the WTA and is expressed as:

$$RAW = pTAW \quad (4)$$

Where,

RAW, is the readily available water in the root zone [mm],

P is the average fraction of the total available soil water that can be depleted from the root zone before moisture stress occurs (FAO 56, 1998). The root zone depletion, D_r in mm is expresses as:

$$D_r = TAW(1 - K_s(1 - p)) \quad (5)$$

The initial depletion $D_{r,i-1}$ in mm is expressed as :

$$D_{r,i-1} = 1000(\theta_{FC} - \theta_{i-1})Z_r \quad (6)$$

Where, θ_{i-1} is the average soil water content for the effective root zone [m^3m^{-3}].

The net irrigation depth I_i in mm, on a daily basis that infiltrates the soil and to be compensated by irrigation is expressed as:

$$I_i = D_{r,i-1} - D_{r,i} - (P - RO)_i - CR_i - ET_{c,i} + DP_i \quad (7)$$

Where,

P_i is the depth of precipitation[mm], RO_i, is the runoff from the soil surface [mm], CR_i is the capillary rise from the ground water table [mm], $ET_{c,i}$ is the crop evaporation[mm day-1], DP_i is the water loss out of the root zone by deep percolation [mm].

Performance Assessment through indicator for assessment of irrigated areas

Performance assessment of an irrigated area supports the planning and its irrigation implementation (Bos et al., 1991;

Perry, 2005). It includes the water balance indicators, water service indicators and the ETa based criteria for assessment of an irrigated area to ensure equity in the supply of water and to optimize the efficiency of water distribution. However there are a large number of indicators available for assessing an irrigated area, but here we have selected a few as the availability of the data was limited. The performance indicators are as following:

Delivery Performance Ratio (DPR): it is an indicator of the change in quality of service to the water users. It quantifies the uniformity and equity of water delivery to the irrigated areas over time (M.G. Bos et al., 1991; Clemmens and Bos, 1990; Molden et al., 2010). The DPR is defined as the ratio of the actual and intended water delivered for the crop growing period and at any location in the irrigated area. The target level of DPR as per standards is set at 0.8 while the critical level is at 0.6. A DPR of 1.0 is an ideal situation.

$$DPR = \frac{Iw_{actual}}{Iw_{intended}} \quad (8)$$

Depleted Fraction (DF): The DF on a temporal scale shows the change in actual water use while spatially quantifies the differences in the water balance considering the actual evapotranspiration, surface water supply and precipitation at the irrigated area. It also quantifies the amount of water that can be diverted to the dry months. At a critical DF value of 0.6 it is implied that the ETa is less than the water made available to the irrigated area (Bos, 1997; Bos et al., 2005) thus causing ground water table to rise. Any value of DF more than of 0.6 indicates loss of ground water storage.

$$DF = \frac{ET_a}{P_e + V_c} \quad (9)$$

Relative Evapotranspiration (RE): The RE explains the adequacy of the irrigation water delivered to the irrigated area as a function of time. It quantifies relative reduction in evapotranspiration and detects water short areas. RE between 0.8 and 1.0 indicates an adequate level of water supply and below 0.8 indicates inadequate level of water supply, hence soil moisture stress.

$$RE = \frac{ET_a}{ET_p} \quad (10)$$

Crop Water Deficit (CWD): The CWD quantifies reduction in evapotranspiration on a temporal scale and spatially detects water short areas. It is defined as the difference in depth (mm) between the potential and actual evapotranspiration of the cropped area over a period of time. It does not include the water entering into the system through rainfall.

$$CWD = ET_p - ET_a \quad (11)$$

Field Application Ratio (FAR) : This value varies according to the actual volume of water being delivered to the field. The difference between the potential evapotranspiration and effective precipitation depends upon the crop grown, climate and irrigation intervals. The numerator contains the volume of water reaching the irrigated areas to avoid undesirable stress in the crops all along the crop growing period. FAR is one of the water balance ratios.

$$FAR = \frac{ET_p - P_e}{Volume\ of\ supplied\ to\ the\ field} \quad (12)$$

Relative Water Supply (RWS) : The RWS is the ratio between the total water supply and the crop water demand.

$$RWS = \frac{Total\ water\ supply}{Crop\ water\ demand} \quad (13)$$

Irrigation potential

The assessment of the irrigation potential was based upon the fact as to how much area is irrigated when compared with the intended area to be irrigated.

Required data

The required meteorological data were collected from the automatic weather recording station at Sam Higginbottom University of Agriculture Technology and Sciences, Allahabad. This includes the maximum and minimum temperatures (°C), wind speed (m/s), humidity, sunshine hours, atmospheric pressure in (hpa) and rainfall data in (mm) on an hourly basis. This data was later converted on a daily basis.

RESULTS AND DISCUSSION

Actual irrigation water requirement of Samrakalwana village.

The ETa, for the crops grown on irrigated agricultural plots in the village during the rabi and kharif season are obtained. (Figures 1(a) and 1(b)). The normalized ETa of the irrigated area for the rabi and Kharif crop growing seasons of 2013-14 is shown in figure 2. The overall estimated irrigation demand during the crop growing season of 2013-14 on decadal basis is shown in figure 3.

Irrigation Performance Assessment

The performance indicators influencing the irrigated areas irrigated by canal is discussed. They are also represented graphically over the irrigated period. Their critical or threshold values of these performance indicators help the field engineer to know how close the irrigated area is to an ideal one. Accordingly management decisions can be taken.

Delivery Performance Ratio. The DPR is chosen over others as an performance indicator owing to the fact that no structure was available to measure the flow rate. Under such conditions time is the only parameter that can be used to quantify the water delivery performance. The DPR on a time line shows the change in quality of service in the irrigated area, while spatially quantifies the uniformity and equity issues of water delivery.

The DPR throughout the crop growing Rabi and Kharif seasons is varying. This indicates difference between the actual and intended water supply. Water supply is fluctuating with some periods having excess. This can be observed for Kharif months of August, September and October 2013. This is due to the fact that the amount of rainfall was not considered while releasing the water to the irrigated area. From figures 4 and 6 it can be seen that an increase in rainfall increases the DPR. However if irrigation is not supplied during this period the DPR may be within the desired range. Most of the farmers grow paddy as the Kharif crop. Paddy is harvested in the October. From October to the months of

November, December, DPR is found to be low. Investigations into the reasons for reduced DPR revealed that a majority of farmers grow potato. Since potato is harvested late, wheat is sown late. Hence major Rabi season farming activity begins from October through November and December demanding more water while supply does not change. Winter rains helps in maintaining a better DPR late December and January. As the winter withers away, the ETc increases and the water demand goes higher as shown in Figure 1, 2 and 3. During this period the water supply must meet the demand. But in the village this is not met hence low DPR is observed. A low DPR indicates moisture stress. The results indicate that water providers are not taking into consideration the increase in ETc while deciding how much water is to be released into the canal. The Rabi months of November, December and February 2013-14 have high water demand hence more water must be released into the canal. A low DPR results in low and uneven distribution of water. This results in yield heterogeneity and low yields (Denis et al., 2016). This can be seen in figure 5. The desired levels, upper desired levels and the ideal levels of DPR are 0.6, 0.8 and 1.0 respectively. When compared it very clearly indicates the irrigation performance of the sampled irrigated area. The uniformity of water delivery is quantified as the standard deviation of DPR and is found to be at 0.55.

Depleted Fraction

The DF obtained as a function of time quantifies the water balance components. The monthly values of DF are shown in figure 5. As given in the figure for DF equals to 0.6 implies that if Eta is less than 0.6(P+Vc), a portion of available water goes into storage. This storage causes ground water to rise. Shortage decreases if vice versa. According to this study the DF is low enough from the critical range. Due to heavy rainfall excess water move in as storage. The water balance for the irrigated area is shown in Figure 6. The most important factor influencing the DP is the rainfall followed by actual evapotranspiration and actual irrigation water supply.

Field Application Ratio (FAR)

The FAR is also known as the overall consumed ratio. The FAR quantified for the irrigated area is shown in Figure 7. The influence of climate is very well seen in the FAR with rainfall depths more than the potential evapotranspiration. The rainfall for the months of July, August, September, October and January was observed as 361, 347, 122, 292 and 116 mm, respectively. The ETp for the same months was observed as 190, 162, 118, 292 and 32 mm, respectively. Hence the FAR is negative in the above mentioned months. For the months of March and April the demand is more and supply is less. This is very critical period for wheat and other Rabi crops, hence water must be diverted to the irrigated areas in these months. Bos et al. 1991 recommends that if the FAR is more than 0.6, ground water extraction or more water from the canal be diverted to avoid water stress to the crops. The study further revels that more water has to be diverted to the irrigated area in the months of November 2013, March and April 2014.

Relative Water Supply (RWS)

The RWS relates the water made available for crops, including surface irrigation, groundwater pumped and rainfall, to the amount crops need. This study shows that availability of water is very high for the months of July, August, September, October and January. However the months of November, December and April show water scarcity. The water supply for the months of February and March seems adequate. This can be seen in Figure 8. The study again revels that excess water supplied in the months of water abundance may be diverted to water scarce months.

Irrigation Potential

The crop water demand of the irrigated area and the water supply from the canal system is shown in Figure 9. The total area of the cultural command area in the village is 86.583 ha. The total Irrigation demand during the growing season of 2013 -14 was 206.42 cusec and the canal water supply for the whole growing period was 137.55 cusec. Therefore, taking in consideration the demand and supply only 66.6% of the area can be irrigated i.e. 57.66 ha. Hence a total of 29.92 ha is irrigated by pumps or are rainfed.

CONCLUSIONS

The irrigation performance and water balance parameters as influenced by the insitu crop and climate conditions and the irrigation water supply for the canal irrigated area of Samrakalwana village have been analysed thoroughly. The performance indicators are affected by the canal water supply and ETa as well as the precipitation over the irrigated area.

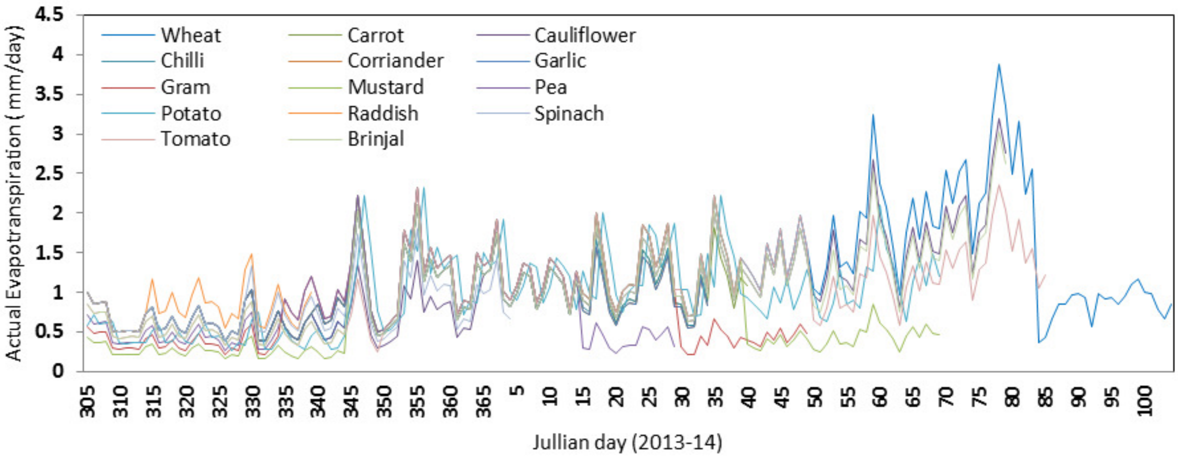

Fig.1(a): Actual Evapotranspiration of crops for the growing period of 2013-14 (Rabi season)

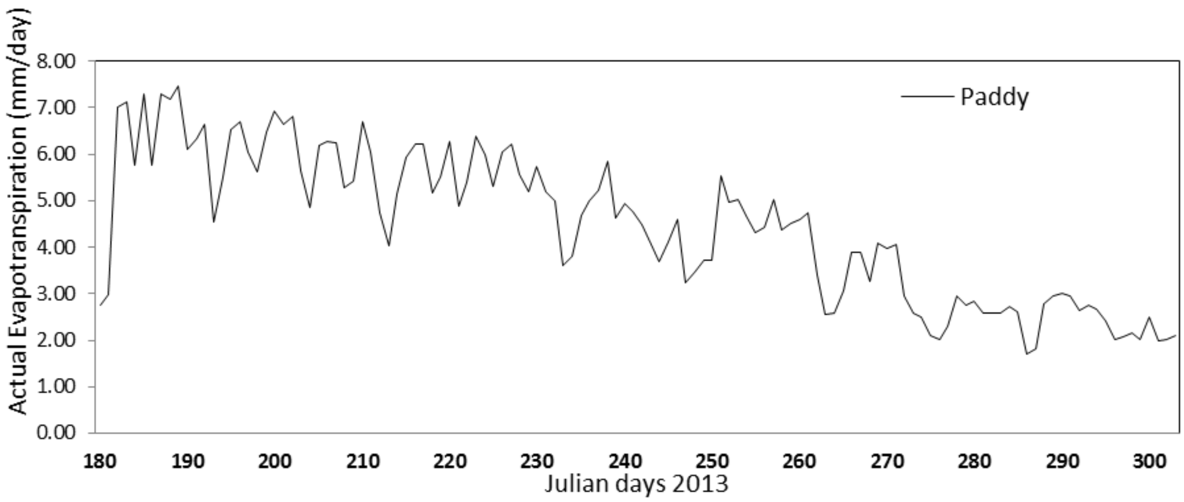

Fig. 1(b): Actual Evapotranspiration of paddy for the growing period of 2013-14 (Kharif season)

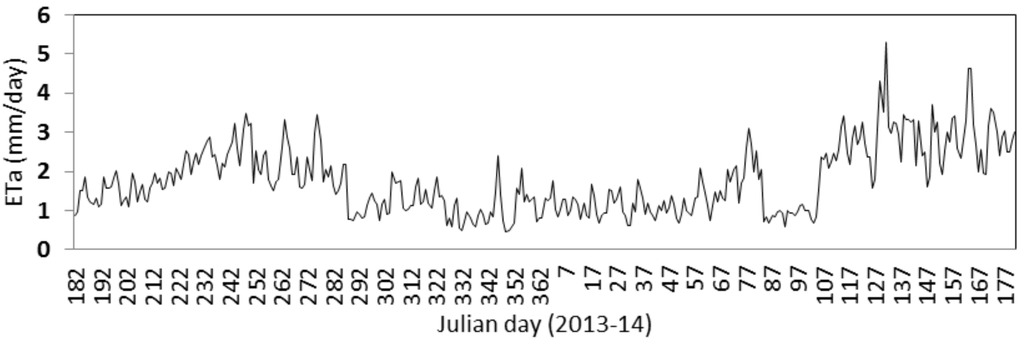

Fig. 2: Normalized Actual evapotranspiration from the village for crop growing period of 2013-14.

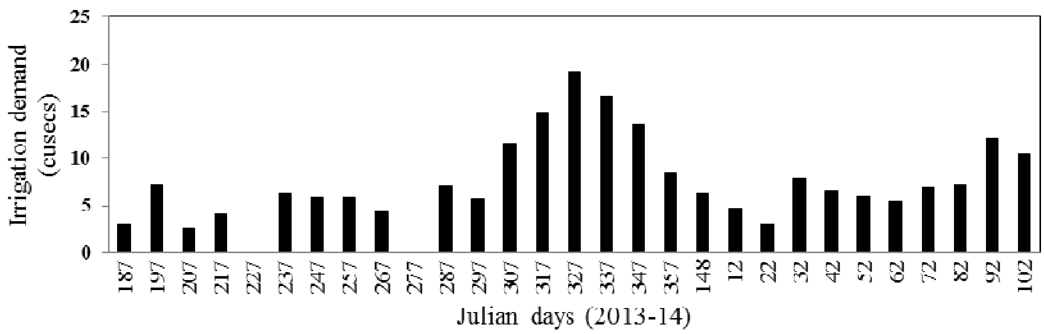

Fig. 3: Irrigation water demand during the cropping season of 2013-14

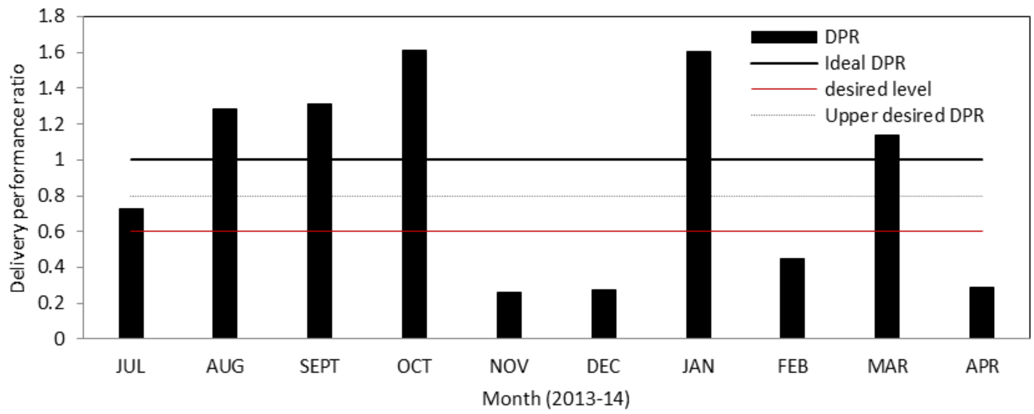

Fig. 4: The delivery performance ratio for the irrigated area for the year 2013-14.

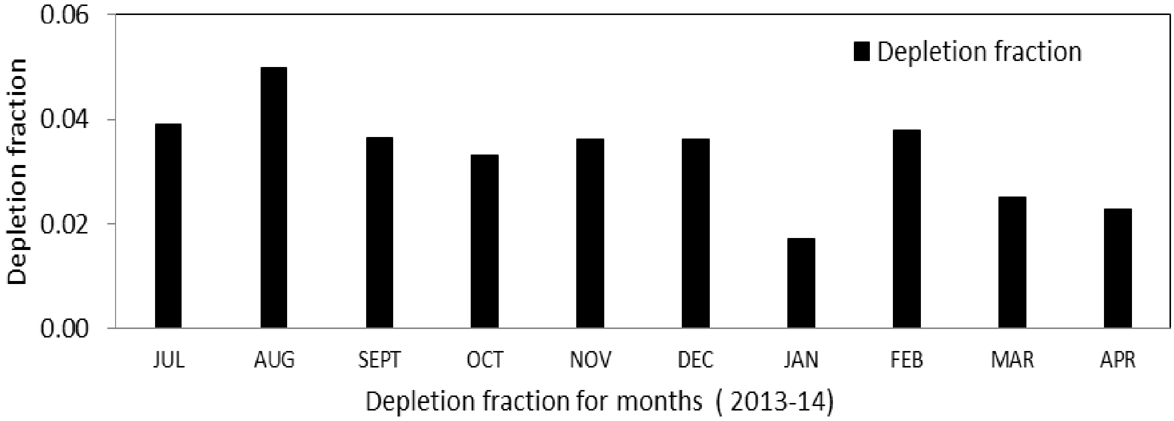

Fig. 5: The Depleted fraction of the irrigated area for the year 2013-14.

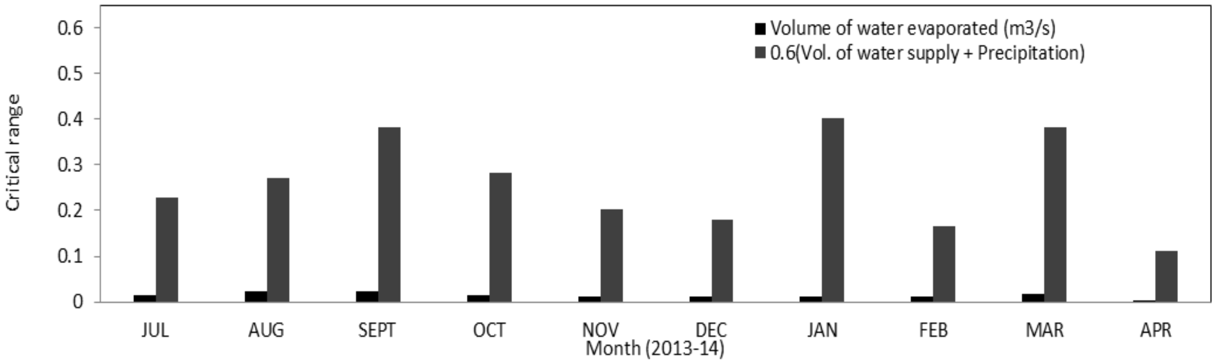

Fig. 6: Water balance over the irrigated area for the year 2013-14.

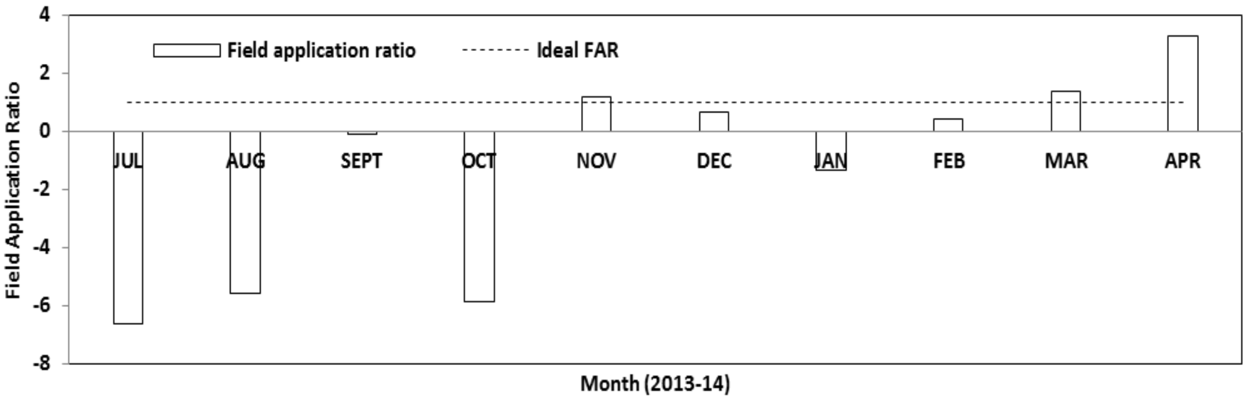

Fig. 7: Field Application ratio for the growing season of 2013-14

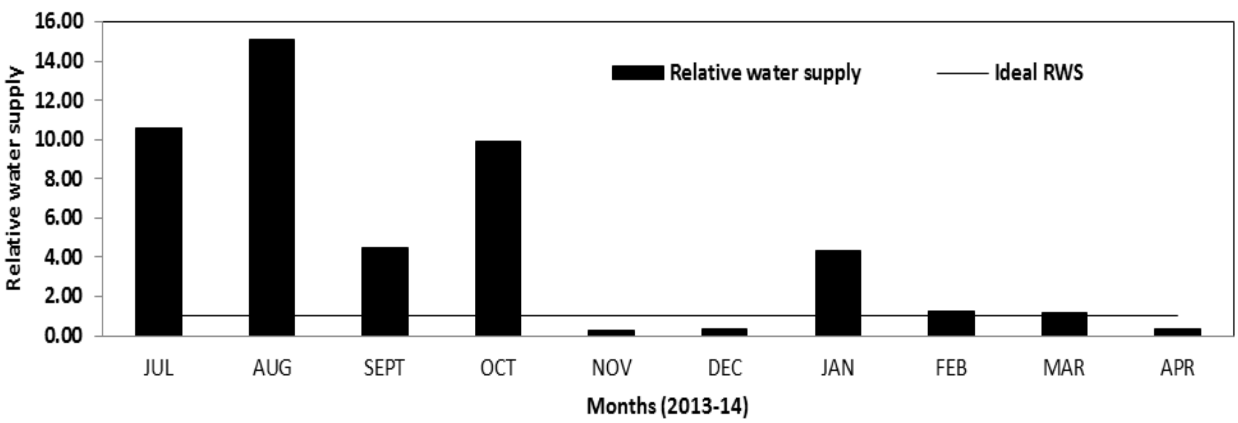

Fig. 8: Relative water supply over the AOI for the growing period of 2013-14

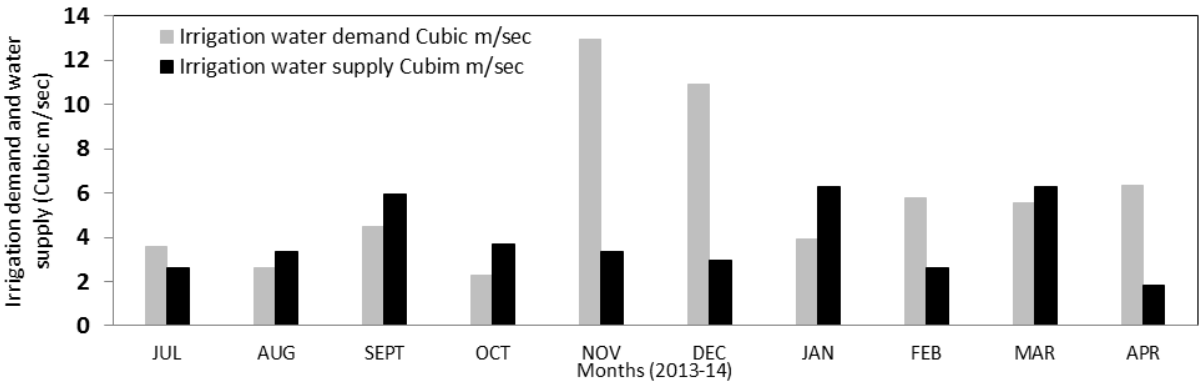

Fig. 9; Irrigation water demand and water supply graph for the growing season of 2013-14.

The most important parameter being the rainfall. The performance indicators showed that a gap exists between the water supplied and the demand for the agricultural fields at the village. This is due to the excess water as a result of heavy rain or water stress resulting from poor canal water supply. The irrigation can cover 57.6 ha land out of 86.58 ha which is 66.6%. This assessment of the irrigated area using actual ETa can help in understanding the issues of adequacy and equity of water supply. The overall performance of the system can be considered satisfactory else rainfall. For improvements, water supplied to the irrigated area should match the actual water demand.

ACKNOWLEDGEMENT

The authors would like to acknowledge the U.P. Council of Agricultural Research (UPCAR) for funding this study through the project ―Farming system based water budgeting for Samrakalwana Village in Allahabad.

REFERENCES

1. *Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. 1998. "Crop evapotranspiration, guidelines for computing crop water requirements", FAO Irrigation and Drainage paper 56(Food and Agricultural Organization of United Nations (FAO) Rome, Italy), pp 300.*
2. *Balderama, O. F., Bareng, J. L. R., & Alejo, L. A. 2014. "Benchmarking for Performance Assessment of Irrigation Schemes: The Case of National Irrigation Systems and Small Water Impounding Projects in Cagayan River Basin", International Conference of Agricultural Engineering, Zurich, 06-10.07.*
3. *Behcet, J. O., & Tarkan, S. A. 2014. "Performance evaluation for irrigation water management: A case study of the Karacabey irrigation scheme in Turkey", International Journal of Irrigation Management and Drainage Engineering, Volume, 9 www.internationalscholarsjournals.org.*
4. *Bos, M. G. 1997. "Performance indicators for irrigation and drainage", Irrigation and Drainage Systems, 11, 119 - 137.*
5. *Bos, M. G., Burton, M. A., and Molden, D. J. 2005. "Irrigation and drainage performance assessment: practical guidelines", IWMI Books Reports, International Water Management Institute, No H037064.*
6. *Bos, M. G., Murray-Rust, D.H., M., D.J., J., H.G., and Snellen, W. B. 1993. "Methodologies for assessing performance of irrigation and drainage management", Irrigation and Drainage Systems, 7(4). Kluwer Academic Publishers, Dordrecht).*
7. *Bos, M. G., and Nugteren, J. 1974. "On Irrigation Efficiencies", ILRI publication no.19. International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands.*
8. *Bos, M. G., Wolters, W., Drovandi, A., and Morabito, J. A. 1991. "The Viejo Retamo secondary canal, Performance evaluation case study", Mendoza, Argentina, Irrigation and Drainage Systems, 5,77-88.*
9. *Bos.M.G., Burton, M. A., and Molden, D. J. 2005. "Performance Indicators for Irrigation and Drainage", Irrigation and Drainage Performance Assessment: Practical Guidelines.*
10. *Briscoe, J. and Malik, R. P. S. 2006. "India's water economy bracing for a turbulent future".*
11. *Bumbudsanpharoke, W. and Prajamwong, S. 2015. "Performance Assessment for Irrigation Water Management: Case Study of the Great Chao Phraya Irrigation Scheme", Irrigation and Drainage, 64(2), 205-214.*
12. *Clemmens, A. J., and Bos, M. G. 1990. "Statistical methods for irrigation system water delivery performance evaluation", Irrigation and Drainage Systems, 4, 345 - 365.*
13. *CWC 2011. "Annual Report", Ministry of Water Resource, Government of India.*
14. *Denis, D. M. 2013. "Irrigation Performance Assessment using SEBS and SCOPE. A case study of Tons pump Canal Command in India", Master's thesis(Enschede, The Netherlands).*

15. *Denis, D. M., M. Kumar, S. Srivastava, S. Suryavanshi, F. A. Denis, R. Singh and Mishra., H. 2016. "A High Resolution Assesment Of Water Footprint Of Wheat To Understand Yield And Water Use Hetrogeneity", Water Resources Management (DOI 10.1007/s11269-016-1305-y . I).*

16. *Howell, T. A., and Evett, S. R. 2011. "The Penman-Montheith Method" http://www.cprl.ars.usda.gov/pdfs/PM%20COLO%20Bar%202004%20corrected%209apr04.pdf.*

17. *ICID 2010. Draft paper on International Congress on Irrigation and drainage. www.icid.org.*

18. *Ingle, P. M., S.E.Shinde, Mane, M. S., Thokal, R. T., and B.L, A. 2015. "Performance Evaluation of a Minor Irrigation Scheme", Research Journal of Recent Sciences, 4,19-24.*

19. *Small, L.E.and Svendsen, M. 1992. "A framework for assesssing irrigation performance", Washington, D. C. International Food Research Institute. Working Paper on Irrigation Performance, 1.*

20. *Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M. A., and Kijne, J. 2010. "Improving agricultural water productivity: Between optimism and caution", Agricultural Water Management, 97(4), 528-535.*

21. *Monteith, J. L. 1965. "Evaporation and the environment. In: The state and movement of water in living organisms", 19^{th} Symp. Soc. Biol, 205 – 234.*

22. *Özmen, S. and Kaman, H. 2015. "Assessing the performance of irrigation schemes in Antalya valley located in Mediterranean Region of Turkey", Water Resources, 42(3), 397-403.*

23. *Perry, C. 2005. "Irrigation reliability and the productivity of water: A proposed methodology using evapotranspiration mapping", Irrigation and Drainage Systems, 19, 211-221.*

24. *Ray, S. S., Dadhwal, V. K. and Navalgund, R. R. 2002. "Performance evaluation of an irrigation command area using remote sensing: a case study of Mahi command, Gujarat, India", Agricultural Water Management, 56(2), 81-91.*

25. *Reeling, C. J., Lee, J., Mitchell, P., Halimi, G. H. and Carver, A. 2012. "Policy options to enhance agricultural irrigation in Afghanistan: A canal systems approach", Agricultural Systems, 109, 90-100.*

26. *Rijtema, P. E. 1965. "An analysis of actual evapotranspiration", Agric. Res Pudoc,Wageningen Rep, 659,107.*

27. *Seckler, D., Molden, D., Barker, R. 1998. "Water scarcity in the twenty-first century",IWMI Water Brief, Colombo, Sri Lanka: International Water Management Institute.*

28. *Smith, M. 1992. "CROPWAT, a computer program for irrigation planning and management", Irrigation and Drainage, FAO, Rome, Italy., Paper 46.*

29. *Zwart, S. and Leclert, L. 2010. "A remote sensing-based irrigation performance assessment: a case study of the Office du Niger in Mali", Irrigation Science, 28(5), 371-385.*