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# Performance evaluation of water delivery system for command area of Som-Kagdar Irrigation Project, Rajasthan

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## ABSTRACT

Distributary wise water delivery performance of the Left Main Canal (LMC) and Right Main Canal (RMC) of Som-Kagdar Irrigation Project was examined, using adequacy and relative water supply indicators. These indicators were calculated for ten distributaries of LMC and RMC for five month irrigation period of *Rabi* season, using measured water deliveries and calculated crop water requirements. Daily depth of water at each distributary was recorded to measure the discharge during the season. Crop water requirements were calculated using CROPWAT model. The distributary wise water delivery performance indicators have shown good to fair in head and fair to poor in middle and poor in tail reaches of the LMC and RMC, respectively. Considering the irrigation season and the system as a whole, the calculated indicator's average values were found as poor for adequacy and relative water supply. These results have also shown that there is a systemic water delivery problem in the system. The analysis of results of the spatial and temporal dimensions of these indicators have shown that factors causing this problem are derived partly due to physical state of system and partly due to improper operation and management.

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**Key words :** Water delivery performance, Irrigation water delivery; Open canal system

Water is one of the most important, valuable and saced inputs in the agriculture today. Ever increasing population of the country coupled with limited availability of cultivable land and water resources are putting tremendous stress on the environment. Limited availability of water resource made it mandatory to use them optimally. It is envision that half to two third of increase in agriculture production would come from the irrigated land. Indian agriculture is highly dependent on monsoon which is erratic, inadequate and uncertain. Practicing irrigation is indispensable to increase production, it has reflected in increased irrigation area in the country from 22 mha to 90 mha over the period of time.

Due to increasing cost in developing new water resources, the only option left is to enhance the current level of performance of water deliveries and distribution in irrigation systems. Maintenance of irrigation water delivery and distribution system is essential for sustainability of agricultural production. There is a definite need for performance measures that relate design and management decisions for achievement of measurable objectives. It is necessary to evaluate the separate contributions of these components to the overall performance of the system.

Adequacy and relative water supply are performance objectives considered when evaluating irrigation water delivery system. Adequacy can be defined as the ability of an irrigation system to meet the required amount of water. Relative water supply is the ratio of total water supplied to the total demand at field level.

Various researchers in the country and overseas have developed optimization model for irrigation planning of Som Kamla Amba irrigation project (Mahla and Gupta, 1997), optimization model for better water allocation integrating soil-water-balance model (Wardlaw, 1999) to produce the linked model (IISMOPT), a new planning model for canal scheduling for rotational irrigation (Santhi and Pundarikanthan, 2000) with multi-objectives *viz*., equity, adequacy and timeliness which showed better performance as compared to the conventional scheduling procedures. An irrigation scheduling model was developed for irrigation scheduling for single and multiple fields (George *et al.,* 2000). Two models, ISM and CROPWAT, gave similar values of soil moisture but showed variation after second irrigation. Simulated bean yield was slightly higher than measured yield in both single and multiple field cases. A model for optimized crop and water planning decisions was developed in Thailand to optimize collective system objectives *i.e.* productivity, equity and security (Sahoo *et al.,* 2001). An alternative delivery scheduling approaches was developed (Mishra *et al.,* 2002) to overcome low efficiency in Indian irrigation projects. This proposed alternate schedule results in a better match between supply and demand which results in 13 per cent water saving as against existing schedules. Rotational water supply (RWS) system was observed to increased credibility and reliability, enhanced equity in water distribution, proper utilization of water resources and increased water use efficiency (Dobaria, 2005). Canal water distribution as per RWS system committed implementation and regular monitoring on many irrigation projects in Gujarat has resulted into increased irrigation intensity, water use efficiency and crop yields. The review suggested that under different climatic condition different models of irrigation planning and scheduling were developed. Hence, it was desirable to develop appropriate model for study area to suggest optimal cropping pattern to maximize net return at different water availability levels and to make optimal operating policies.

## METHODOLOGY

### Description of the study area:

The Som-Kagdar Irrigation Project was constructed on Som river a tributary of Mahi. The site of Som-Kagdar dam was near village Kagdar-Ki-Pal situated in the west of national highway 08, about 77 km away from Udaipur. The location of dam was 11 km from Rishabhdev village, Tehsil-Kherwara, District-Udaipur. The dam site was located at $24^0 1^{l} 45^{ll}$ North Latitude and $73^0 37^{l} 45^{ll}$ East Longitude. Gross storage capacity of the dam was 36.19 x $10^6$ $m^3$. Gross command area, culturable command area and irrigated command area of the project were 9125, 5731 and 4550 ha, respectively. The distribution system consisted of two main canals; the right main canal (RMC), left main canal (LMC) and ten distributaries. The RMC was 12.31 km long, while the LMC was 29.96 km.

The climate of the project area is sub-humid. Most of the command area consists of hilly track. The soil is clay loam. It has two distinct crop seasons *i.e. Kharif* and *Rabi*. *Kharif* season prevail from mid-June to September. The duration which receives the rain. *Rabi* season is spread over October to mid March. Aaverage annual rainfall is 599 mm, received during June to September. This experiment was conducted in 2007-08.

### Determination of crop water requirement and irrigation water required:

Data on actual irrigated crop area and climate within the selected outlets were obtained from the irrigation department of Rishabhdev sub-division. Crop sowing dates were obtained from interviews with the farmers. Monthly net crop irrigation requirements were calculated using CROPWAT. Reference evapotranspiration ($ET_O$) was calculated using CROPWAT on monthly basis by Penmen-Monteith method. Crop coefficients ($K_C$) were developed for the main crops using FAO guidelines. Net crop irrigation requirement was computed as the difference between crop evapotranspiration ($ET_C$) and effective precipitation ($P_e$). Net crop irrigation requirement for each outlet ($Q_R$) was calculated using crop irrigation requirement, irrigated area and conveyance efficiency for each outlet.

### Measurements of flow rate and water delivered :

The flow in the minor as well as in the outlets was measured by using a digital current meter. The channel cross-sectional area was trapezoidal in shape. Discharge was calculated by using the equation Q= AxV, where A is cross-sectional area and V is velocity of the stream. The depth of flow in each outlet was noted during entire irrigation season (November, 04 to March, 05), date and duration of irrigation was also recorded. A stage level recorder was installed at the head of Amarpura minor to measure the depth of water, to calculate total water delivered to minor daily.

### Determination of performance indicators:

Adequacy ($P_A$) and relative water supply (RWS) were measured to evaluate the system performance

$$\mathbf{P_A = \frac{1}{T} \sum_{time} \left[ \frac{1}{R} \sum_{area} P_A \right]}$$

$$\mathbf{RWS = \frac{Irrigation + Rainfall}{Gross\ water\ requirement}}$$

In these expressions, adequacy ($P_A$) was calculated as a spatial and temporal average of $Q_D/Q_R$, eq. (1). When $Q_D > Q_R$ the delivery was considered adequate, regardless of the magnitude of excess and $Q_D/Q_R$ was taken as one. The time period (T) was the five-month period of irrigation season, sub region (R) was delivery points within the system, which were the ten outlets of minors. $Q_D$ is the volume of water delivered and $Q_R$ is the volume of water required.

## RESULTS AND DISCUSSION

The results of the present study as well as relevant discussion have been summarized under following heads:

### Existing cropping pattern and major state variables:

On the basis of last Five year records obtained from Irrigation Department and the information collected from farmers, the existing cropping pattern found in the command area was wheat, barley and gram in *Rabi* season. The area under various crops was 2592, 353 and 273 ha, respectively. As per existing cropping pattern the maximum area was under wheat crop in *Rabi* season.

### Water delivery performance:

To measure the success of an irrigation water delivery system a diagnostic appraisal of the irrigation system, water delivery performance has been evaluated in terms of adequacy. An intensive set of field measurements were made during *Rabi* season of year 2007, to evaluate the performance of the LMC and RMC. The water was delivered on a rotation schedule from the LMC and RMC to its distributaries during the period canal remained open. The volumes of water required ($Q_R$) and volume of water delivered ($Q_D$) have been estimated over five months duration *i.e. Rabi* season. Daily observations were made for water level in LMC and RMC and its water courses during entire period of canal running. Table 1 shows the distributary wise monthly total water required ($Q_R$) and total volume of water delivered ($Q_D$).

The delivery flow rates were converted to monthly volumes $Q_D$, and monthly volumes of water required $Q_R$ were computed from data on climate, crops, soils and irrigation practices using CROPWAT model. Seasonal crop water requirements of wheat, mustard, gram and barley were calculated and found to be 33.39 cm, 31.81 cm, 21.85 cm and 29.99 cm, respectively.

### Adequacy:

The adequacy in the present analysis has been computed in terms of relative water supply (RWS) and Gates adequacy indicator (GAI) at the outlet of the different distributaries. To determine adequacy, the total water supply ($Q_D$) for each distributary, for each month of the season was measured with the help of daily data collected on water depth and velocity of flow and discharge of distributaries. The corresponding total water requirement ($Q_R$) was measured using CROPWAT model.

### Gates adequacy indicator:

Table 1 shows the $Q_D$ (total water delivered) and $Q_R$ (total water required) determined for outlet of each minor. The water was delivered from Som-kagdar dam during November 2007 to March 2008. During this period, monthly average number of irrigations given was five.

**Table 1: Monthly $Q_D$ and $Q_R$ for distributaries of command area (*Rabi* season)**

| Main canal | Reaches | Distributary | Variables ($10^3$ $m^3$) | Months | | | | | Total ($10^3 m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Nov. | Dec. | Jan. | Feb. | March | |
| LMC | Head | Ambakhor | $Q_D$ | 20.19 | 39.69 | 39.69 | 55.18 | 41.34 | 176.09 |
| | | | $Q_R$ | 14.03 | 16.93 | 39.94 | 56.62 | 47.41 | 174.93 |
| | | Masaro ki Obri | $Q_D$ | 51.84 | 98.49 | 98.49 | 139.96 | 129.6 | 518.38 |
| | | | $Q_R$ | 32.79 | 55.21 | 123.51 | 176.67 | 144.20 | 532.38 |
| | Middle | Deopur | $Q_D$ | 216.00 | 410.40 | 410.40 | 677.8 | 598.10 | 2312.7 |
| | | | $Q_R$ | 156.25 | 239.95 | 539.17 | 774.23 | 753.16 | 2462.76 |
| | | Amarpura | $Q_D$ | 68.56 | 353.04 | 280.12 | 410.13 | 469.68 | 1581.53 |
| | | | $Q_R$ | 43.00 | 179.58 | 405.98 | 585.91 | 499.66 | 1714.13 |
| | | Rampur | $Q_D$ | 72.96 | 137.89 | 137.89 | 195.83 | 108.60 | 653.17 |
| | | | $Q_R$ | 46.96 | 174.11 | 168.40 | 243.52 | 184.99 | 817.98 |
| | Tail | Kanpur | $Q_D$ | 34.90 | 175.03 | 88.92 | 196.43 | 64.89 | 632.17 |
| | | | $Q_R$ | 44.18 | 198.90 | 123.51 | 276.67 | 144.20 | 787.46 |
| | | Rathora | $Q_D$ | 305.67 | 466.71 | 571.2 | 812.13 | 451.00 | 2606.71 |
| | | | $Q_R$ | 383.64 | 648.22 | 788.40 | 1139.3 | 985.77 | 3945.31 |
| RMC | Head | Badli | $Q_D$ | 15.55 | 29.55 | 74.43 | 82.50 | 51.42 | 253.45 |
| | | | $Q_R$ | 6.55 | 29.70 | 65.55 | 92.7 | 73.47 | 267.97 |
| | Middle | Barna | $Q_D$ | 15.55 | 29.55 | 49.24 | 50.06 | 28.48 | 172.88 |
| | | | $Q_R$ | 4.80 | 20.94 | 46.74 | 66.75 | 54.78 | 194.01 |
| | Tail | Oda | $Q_D$ | 51.67 | 97.75 | 107.73 | 138.25 | 77.20 | 472.60 |
| | | | $Q_R$ | 66.22 | 109.93 | 156.66 | 224.39 | 188.26 | 745.46 |

**Table 2 : Temporal average value of Gates adequacy indicator (GAI)**

| Main canal | Reaches | Distributary | $Q_D/Q_R$ | | | | | GAI | Performance classes |
|---|---|---|---|---|---|---|---|---|---|
| | | | Nov. | Dec. | Jan. | Feb. | March | | |
| LMC | Head | Ambakhor | 1 | 1 | 0.99 | 0.97 | 0.87 | 0.97 | Good |
| | | Masaro ki Obri | 1 | 1 | 0.79 | 0.79 | 0.89 | 0.89 | Fair |
| | Middle | Deopur | 1 | 1 | 0.76 | 0.87 | 0.79 | 0.88 | Fair |
| | | Amarpura | 1 | 1 | 0.69 | 0.70 | 0.94 | 0.86 | Fair |
| | | Rampur | 1 | 0.79 | 0.81 | 0.80 | 0.58 | 0.79 | Poor |
| | Tail | Kanpur | 0.79 | 0.88 | 0.72 | 0.71 | 0.45 | 0.71 | Poor |
| | | Rathora | 0.79 | 0.72 | 0.72 | 0.71 | 0.45 | 0.68 | Poor |
| RMC | Head | Badli | 1 | 1 | 1 | 0.89 | 0.70 | 0.91 | Good |
| | Middle | Barna | 1 | 1 | 1 | 0.75 | 0.52 | 0.85 | Fair |
| | Tail | Oda | 0.78 | 0.88 | 0.68 | 0.61 | 0.41 | 0.61 | Poor |

Hence, $Q_D$ and $Q_R$ values were determined on monthly basis. The tail farmers' claimed that they get very less water than head farmers. To study this claim, $Q_D$ and $Q_R$ were determined separately for the minors of LMC and RMC.

Table 2 shows the temporal average value of GAI. Fig. 1 and 2 show the temporal average value of GAI for outlet of each distributary. Temporal average value of GAI for each outlet is the average of ($Q_D/Q_R$) for each month of the season. The temporal average values of GAI observed were 0.97, 0.89, 0.88, 0.86, 0.79, 0.71, 0.68, 0.91, 0.85 and 0.61 for Ambakhor, Masaoro ki Obri, Deopur, Amarpura, Rampur, Kanpur, Rathora, Badli, Barna and Oda distributary, respectively. According to Gates, these values showed that the performance was good to fair in head and fair to poor in middle and tail reaches of the LMC and RMC, respectively.

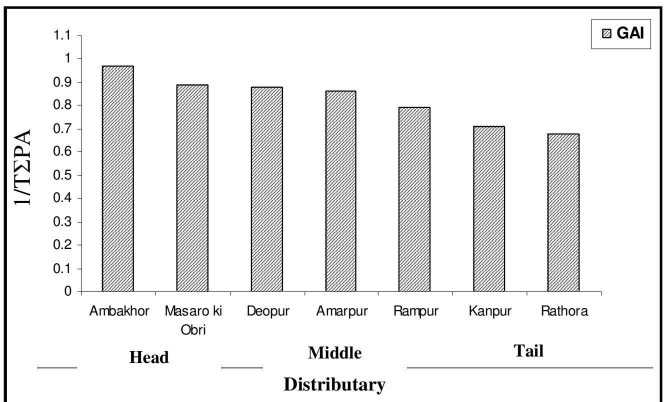


**Fig. 1 : Temporal average value of gates adequacy indicator for LMC**

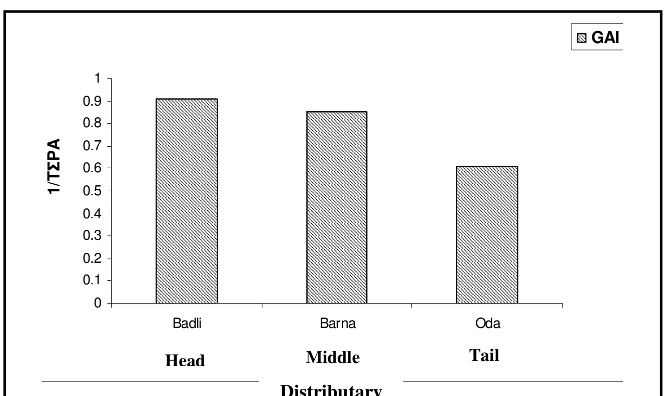


**Fig. 2 : Temporal average value of Gates adequacy indicator for distributaries of right main canal**

## Relative water supply on seasonal basis:

The seasonal adequacy of water supply varies across the outlets. The relative water supply on seasonal basis was measured by calculating the total water applied, including rain water, during whole season in the area and total gross water requirement of the area. Table 3 shows the seasonal relative water supply for distributaries of command area. The values of adequacy for the system were 1.01, 0.97, 0.93, 0.92, 0.80, 0.80, 0.66, 0.94, 0.89, and 0.63 for Ambakhor, Masaro ki Obri, Deopur, Amarpura, Rampur, Kanpur, Rathora, Badli, Barna and Oda distributary, respectively. Fig. 3 shows comparison

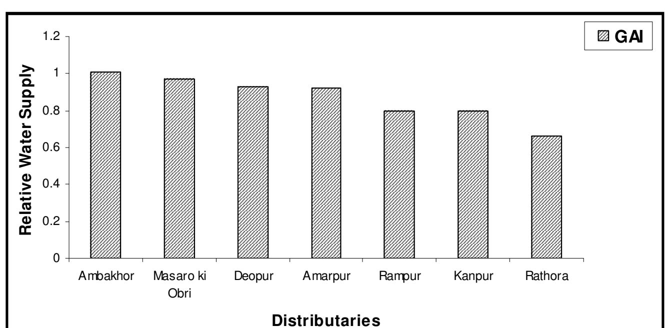


**Fig. 3 : Comparison of relative water supply along the distributaries of LMC**

**Table 3 : Seasonal relative water supply for distributaries of command area**

| Main canal | Sr. No. | Distributary | Total water applied ($10^3$ $m^3$) | GIR ($10^3$ $m^3$) | RWS |
|---|---|---|---|---|---|
| LMC | 1. | Ambakhor | 176.09 | 174.93 | 1.01 |
| | 2. | Masaro ki Obri | 518.38 | 532.38 | 0.97 |
| | 3. | Deopur | 2312.7 | 2462.76 | 0.93 |
| | 4. | Amarpura | 1581.53 | 1714.13 | 0.92 |
| | 5. | Rampur | 653.17 | 817.98 | 0.80 |
| | 6. | Kanpur | 632.17 | 787.46 | 0.80 |
| | 7. | Rathora | 2906.71 | 3945.31 | 0.66 |
| RMC | 8. | Badli | 253.45 | 267.97 | 0.94 |
| | 9. | Barna | 172.88 | 194.01 | 0.89 |
| | 10. | Oda | 472.60 | 745.46 | 0.63 |

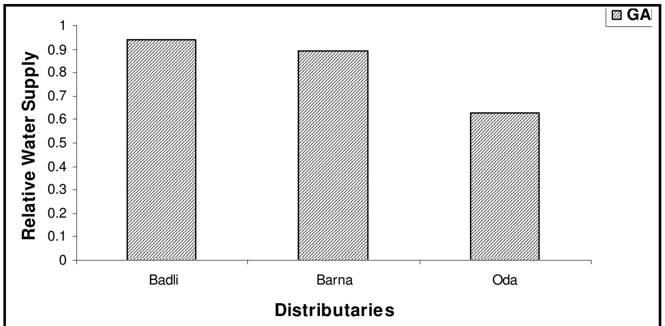


**Fig. 4 : Comparison of relative water supply along the distributaries of RMC**

of relative water supply along the distributaries of LMC and Fig. 4 shows comparison of relative water supply along the distributaries of RMC. Head and middle reaches of the LMC and RMC had relatively good adequacy. The main reason of low value of relative water supply of command was due to the fact that canal water not reaching in sufficient quantity at tail ends of the LMC and RMC. The canal water supply is supplemented by tube well water to meet the crop water requirement in the tail reaches of study area.

**Relative water supply and Gates adequacy indicator during different months:**

Relative water supply (RWS) and Gates adequacy indicator (GAI) were also calculated for every rotation of canal water supply. The values obtained, gave the true picture of adequacy in the study area. The GAI valued ranges from 0.66 to 0.94 with an average value of 0.82 for LMC and RMC. The average GAI was observed to be 0.94 and 0.92 during November and December. But it decreased in subsequent months. The average values were observed in January, February and March which were 0.82, 0.78 and 0.66, respectively. These results showed that there is an acute shortage of canal water supply during January to march (Table 4 and Fig. 5). The crop water requirement during these months was high but water supply was relatively low. The seasonal values of relative water supply ranged from 0.66 to 1.10 with an average value of 0.87. It was observed to be 1.07 and 1.10 in November and December which was considered as good. However, the RWS values were 0.76, 0.76 and 0.66 in January, February and March and adequacy status was poor during this period. Table 5 shows the seasonal RWS during different months. Fig. 6 illustrates monthly comparison of RWS.

The result indicated that seasonal average value of

**Table 4: Gates adequacy indicator during different months for minors**

| Month | Ambakhor | Masaro ki Obri | Deopur | Amarpura | Rampur | Kanpur | Rathora | Badli | Barna | Oda | GAI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nov. | 1 | 1 | 1 | 1 | 1 | 0.79 | 0.79 | 1 | 1 | 0.78 | 0.94 |
| Dec. | 1 | 1 | 1 | 1 | 0.79 | 0.88 | 0.72 | 1 | 1 | 0.88 | 0.92 |
| Jan. | 0.99 | 0.79 | 0.76 | 0.69 | 0.81 | 072 | 0.72 | 1 | 1 | 0.68 | 0.82 |
| Feb. | 0.97 | 0.79 | 0.87 | 0.70 | 0.80 | 0.71 | 0.71 | 0.89 | 0.75 | 0.61 | 0.78 |
| March | 0.87 | 0.89 | 0.79 | 0.94 | 0.58 | 0.45 | 0.45 | 0.70 | 0.52 | 0.41 | 0.66 |

**Table 5 : Relative water supply indicator during different months**

| Months | Total water applied ($10^3$ $m^3$) | GIR ($10^3$ $m^3$) | RWS |
|---|---|---|---|
| November | 852.89 | 798.42 | 1.07 |
| December | 1838.10 | 1673.47 | 1.10 |
| January | 1858.11 | 2457.86 | 0.76 |
| February | 2758.27 | 3636.74 | 0.76 |
| March | 2020.31 | 3075.9 | 0.66 |

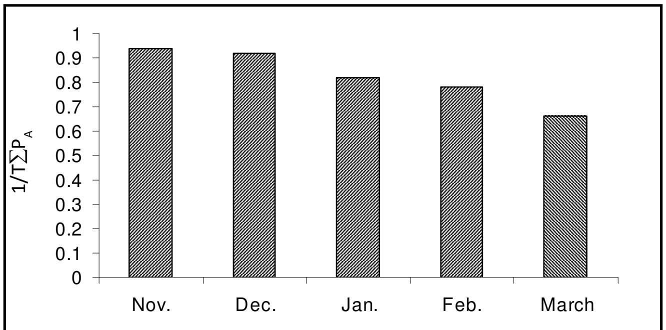


**Fig. 5 : Spatial average value of Gates adequacy indicator**

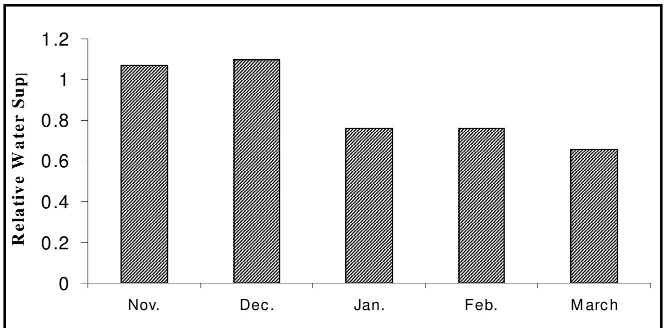


**Fig. 6 : Comparison of relative water supply on monthly basis**

GAI was smaller as compared to seasonal RWS. Use of relative water supply as an indicator of adequacy was sometimes tending to conceal, what is actually happening within a season. If one simply takes the average of monthly RWS values, higher than GAI, giving no indications that substantial undersupply exist during January, February and March is being masked with oversupply in the other months (Table 6).

**Table 6 : Relative water supply and Gates adequacy indicator during Nov. to March**

| Months | RWS | GAI |
|---|---|---|
| November | 1.07 | 0.94 |
| December | 1.10 | 0.92 |
| January | 0.76 | 0.82 |
| February | 0.76 | 0.78 |
| March | 0.66 | 0.66 |
| Seasonal average | 0.87 | 0.82 |

A more accurate picture is obtained by Gates adequacy indicator, which is based on the monthly values of GAI. The GAI takes into account only usable water in case of over supply, as in November and December. Hence, the value was less as compared to RWS. Fig. 7 shows monthly fluctuation in RWS and GAI as compared to seasonal average of GAI.

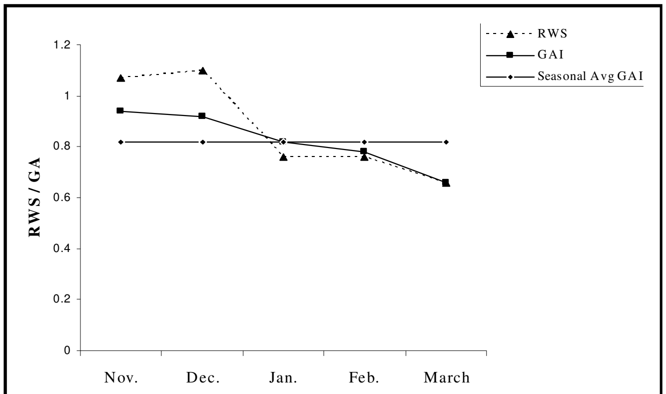


**Fig. 7 : Variation of relative water supply and GAI during *Rabi* season**

## Consluion:

The insufficient canal water supply and poor performance of the system were the major problems of Som-kagder irrigation project. To evaluate the system, performance measures has been developed that allowed effective analysis of irrigation-water-delivery systems for purposes of evaluation. In this study, water delivery performance of the command area was evaluated according to the indicators of adequacy. Spatial and temporal distributions of required and delivered water were used to calculate the performance indicators. The indicators could contribute to effective water delivery monitoring and identifying the problems causing the poor performance of the system.

The distributary wise study of command area was carried out for five month irrigation season. For the irrigation season of year 2007, the temporal average values of GAI obtained were 0.97, 0.89, 0.88, 0.68, 0.79, 0.71, 0.88, 0.91, 0.85 and 0.61 for Ambakhor, Masaoro ki Obri, Deopur, Amarpur, Rampur, Kanpur, Rathora, Badli, Barna and Oda, respectively. These values showed that the performance was good to fair in head and fair to poor in middle and poor in tail reaches of the LMC and RMC, respectively. The analysis of results of the spatial and temporal dimensions of the indicator showed that, factors causing this problem are derived partly due to physical state of system, improper operation and management.

– The values of adequacy for the system were 1.01, 0.97, 0.93, 0.92, 0.80, 0.80, 0.66, 0.94, 0.89, and 0.63 for Ambakhor, Masaoro ki Obri, Deopur, Amarpur, Rampur, Kanpur, Rathora, Badli, Barna and Oda, respectively for the system. Head and middle reaches of the LMC and RMC had relatively good adequacy.

– The GAI value ranged from 0.66 to 0.94 with an average value of 0.82 for LMC and RMC. The average GAI was observed as 0.94 and 0.92 during November and December. However, it decreased in the subsequent months. The average values were observed in January, February and March as 0.82, 0.78 and 0.66, respectively. These results showed that there was an acute shortage of canal water supply during, Jan to march.

– The seasonal values of relative water supply ranged from 0.66 to 1.10 with an average value of 0.87. It was observed to be 1.07 and 1.10 in November and December, respectively and was considered good. However, the RWS values were 0.76, 0.76 and 0.66 in month of January, February and March, respectively and adequacy status was rated poor during this period.

– Water balance analysis indicated that water delivered and water required was fairly balanced if canal was running according to existing record in a *Rabi* season.

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