Paper No.182

DEVELOPMENT OF INNOVATIVE ROTATION PLAN ANALYSIS TOOL FOR EFFECTIVE MONITORING OF HAKRA CANAL SYSTEM, SOUTH PUNJAB – PAKISTAN

Dr. Muhammad Riaz,
Muhammad Kamran,
Wasif Yousaf

DEVELOPMENT OF INNOVATIVE ROTATION PLAN ANALYSIS TOOL FOR EFFECTIVE MONITORING OF HAKRA CANAL SYSTEM, SOUTH PUNJAB-PAKISTAN

Dr. Muhammad Riaz[1], Muhammad Kamran[2], Wasif Yousaf[3]

ABSTRACT

Surface water supply operations and canal operations in Pakistan are based on heuristic approaches. This heuristic (hypothetical) management technique often depends heavily on expert human judgment. Pakistan also has one of the world's most complex supply-based irrigation networks. Water distribution within the network is challenging due to water shortages. Shortage of irrigation water is a contest normally occurs at canal tail-end user. The rotational plans only become applicable when the system is bearing the capacity constraints or shortages in water supply. To overcome these problems, Excel Based rotational plan analysis tool has been developed to evaluate the rotational programme in the canal system for effective canal monitoring system. For this study, Hakra Canal System with a command area of 1.4 million hectares has been selected. The results show that among all channels, flood channel has less Delivery Performance Ratio (DPR) and on weekly basis analysis, group C channels taking 11% more share in week 2. Similarly, in week 22 only group C channels are getting their fair shares.

Keywords: Canal Management, Water Shortages, Rotational Program

1 INTRODUCTION

The Punjab irrigation system faces numerous constraints that may limit the canal operations. Ahmed, Mahmood, and Munir (2015) stated that Punjab Irrigation System is one of the world's largest systems comprising 13 barrages and 26 main canal systems and 12 link canal systems with overall length of main and branch canals of about 6,500 km, and 2,794 distributaries and minors with overall length of about 31,050 km. GINI coefficient has been widely used as an indicator for the estimation of water distribution equity. Numerous research studies such as Melkamu & Bannor 2015, Cullis and Koppen 2007, Anwar & Haq 2013 and Anwar, Bhatti & de Vries 2016, have supported its usage in this particular context.

The rotational plans are mostly applicable up till the distributaries heads. The direct offtakes of channels are always brought into rotational. Only a couple of rotational plans exist in the system in which minors have also been rotated. On the contrary, main canals, branch canals and link canals themselves are never rotated unless any one of them is being fed by a channel that is under rotation. For example, in case of Sadqia division, Sadiq Ford Feeder acts as a distributary and feeds

[1] Director (PMIU, Irrigation Department, Lahore, Pakistan), Email: riazpmiu07@yahoo.com
[2] Water Resource Modeler (PMIU/DSS, Punjab Irrigation Department, Lahore, Pakistan), Email: kamran.pmiu@gmail.com
[3] GIS Specialist (PMIU/DSS, Punjab Irrigation Department, Lahore, Pakistan), Email: wsfyousaf@gmail.com

Fordwah Branch in the Fordwah division during the Rabi season. Sadiq Ford Feeder is being rotated under the Sadqia Rabi rotational plan which consequently brings Fordwah Branch under rotation. Moreover, rotational plans are strict and cannot be violated. The total number of priorities in the plan would always be equal to the total number of groups or subgroups, whichever is greater. Further, the number of unique waras will also be equal to the total number of priorities. It should be noticed that a group cannot repeat itself under a specific priority rank unless all the other groups have individually acquired that position in consecutive waras. As for the wara duration is concerned, the length of wara in the Punjab irrigation system varies from 7-8 days. It may be even shorter than the aforementioned time frame, however, such instances are quite rare. Adding more, there are two seasons in a year, Kharif and Rabi. Each season comprises of approximately 24 weeks and independent rotational plan is proposed for each one. It should be noticed that ideally, the number of times a group acquires the first position in the rotational plan for the whole season should be the same for every group. The shortages should be distributed equally among all the groups.

Due to introduction of high yield seeds and the increase in cropping intensities, the colonial era water allowances are presently inadequate and hence the farmers frequently face water scarcity issues and involve in water thefts, tampering the outlets, and exchanges in warabandi (fixed turn water distribution quota) times (Awan, Anwar, Ahmad and Hafeez, 2016). Due to water security issues, water is distributed in IBIS on equity basis and for this purpose, a rotational plan is used in the irrigation canal system. Mishra et al. (2001) reported that the rotational irrigation system is a common phenomenon is South Asia to distribute water (Shende and Sachin,2006) addressing water security issues. Therefore, for efficient management to minimize the effect of shortage of water supply at the tail end of an irrigation canal, monitoring of the canal through innovative tools is a dire need. The main objective of current study is to analyses the rotational program of a canal system for effective management and monitoring.

2 METHODOLOGY

2.1 STUDY AREA

Hakra branch canal offtakes receive irrigation water from Eastern Sadqia canal which extracts water from Sulemanki Headworks. The design discharge of Hakra Branch Canal is 2900 cusecs with total cultivable command area of 1.4 Million hectares. Length of the canal is (285433 ft) 87 km as shown in Fig 1. The Major crops grown in the command area of Hakra Branch Canal include wheat, sugarcane, rice and cotton. It has 17 distributaries which convey water from Hakra canal to the farmers' fields via a network of water courses and farm channels. Mostly in the discharge measurement has been taken at Reduced Distance (RD) 2+000 and at 285+000 tail of Hakra branch.

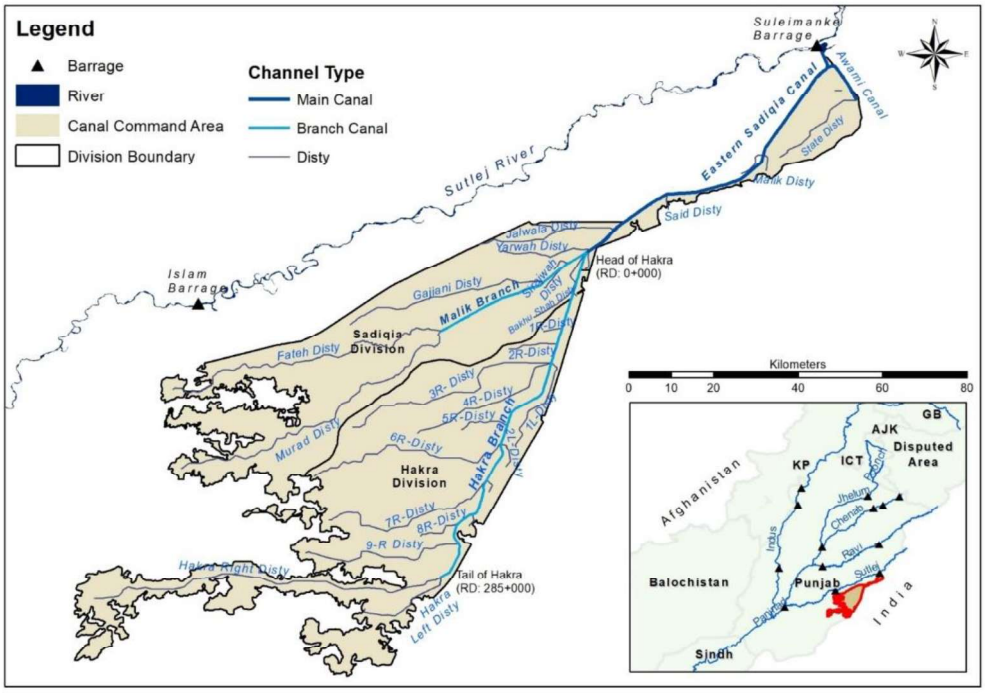


Figure 1: Study Area Map of Hakra Branch Canal Area

2.2 Data and data source

For the study purpose to evaluate the rotational program all the data given in the following table has been collected from Programme monitoring and implementation unit (PMIU) Irrigation Department;

Table-1: Data and data source

Type of Data	Source	Data Resolution
Rotational Programme	PMIU Irrigation	Seasonal
Canal discharges	PMIU Irrigation	Daily

Table-2: Rotational Program

Week No.	Start Date	End Date	Group			Sub Group					
			1	2	3	1	2	3	4	5	6
1	19/04/2017	26/04/2017	C	A	B	C2	C1	A2	A1	B2	B1
2	27/04/2017	04/05/2017	B	C	A	B1	B2	C1	C2	A1	A2
3	05/05/2017	12/05/2017	A	B	C	A2	A1	B2	B1	C2	C1
4	13/05/2017	20/05/2017	C	A	B	C1	C2	A1	A2	B1	B2

Week No.	Start Date	End Date	Group			Sub Group					
			1	2	3	1	2	3	4	5	6
5	21/05/2017	28/05/2017	B	C	A	B2	B1	C2	C1	A2	A1
6	29/05/2017	05/06/2017	A	B	C	A1	A2	B1	B2	C1	C2
7	06/06/2017	13/06/2017	C	A	B	C2	C1	A2	A1	B2	B1
8	14/06/2017	21/06/2017	B	C	A	B1	B2	C1	C2	A1	A2
9	22/06/2017	29/06/2017	A	B	C	A2	A1	B2	B1	C2	C1
10	30/06/2017	07/07/2017	C	A	B	C1	C2	A1	A2	B1	B2
11	08/07/2017	15/07/2017	B	C	A	B2	B1	C2	C1	A2	A1
12	16/07/2017	23/07/2017	A	B	C	A1	A2	B1	B2	C1	C2
13	24/07/2017	31/07/2017	C	A	B	C2	C1	A2	A1	B2	B1
14	01/08/2017	08/08/2017	B	C	A	B1	B2	C1	C2	A1	A2
15	09/08/2017	16/08/2017	A	B	C	A2	A1	B2	B1	C2	C1
16	17/08/2017	24/08/2017	C	A	B	C1	C2	A1	A2	B1	B2
17	25/08/2017	01/09/2017	B	C	A	B2	B1	C2	C1	A2	A1
18	02/09/2017	09/09/2017	A	B	C	A1	A2	B1	B2	C1	C2
19	10/09/2017	17/09/2017	C	A	B	C2	C1	A2	A1	B2	B1
20	18/09/2017	25/09/2017	B	C	A	B1	B2	C1	C2	A1	A2
21	26/09/2017	03/10/2017	A	B	C	A2	A1	B2	B1	C2	C1
22	04/10/2017	11/10/2017	C	A	B	C1	C2	A1	A2	B1	B2
23	12/10/2017	19/10/2017	B	C	A	B2	B1	C2	C1	A2	A1

3.0 Development of rotational plan tool

A mathematical “Post-Seasonal Rotational Plan Evaluation Tool” has been developed that possess the capacity to analyses operated rotational plans. Performance indicators are used to comment on the effectiveness of an implemented seasonal rotational plan in terms of equity in water distribution and the percentage of plan being followed.

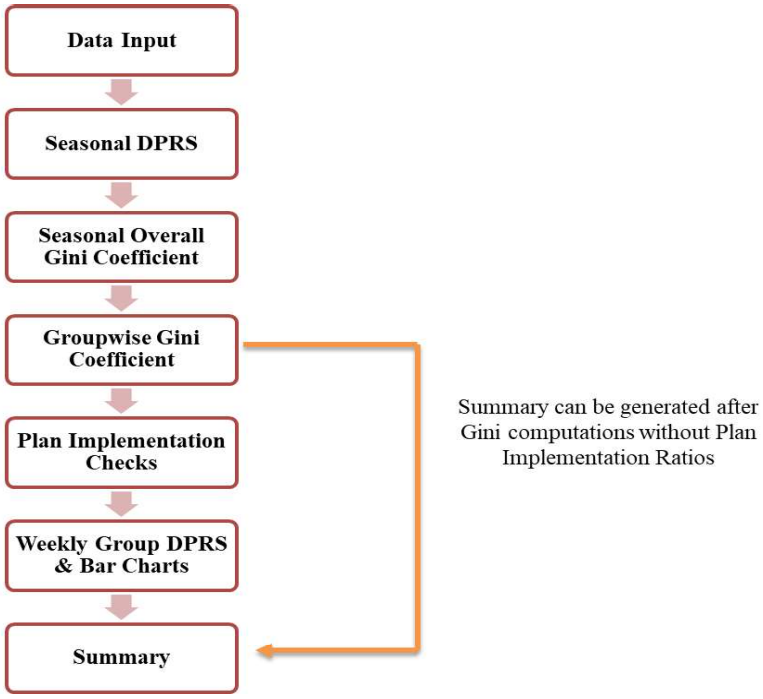


Figure 2: Methodology Flow Chart

Performance parameters in water sharing equity

Performance parameters or indicators are the measurable values that are used to assess the performance of rotational plans in terms of equity in water distribution and percentage of plan implementation. These parameters can assist in performance assessment of irrigation canals and guide water managers to take necessary operational decisions.

3.0.1 Delivery Performance Ratio (DPR)

The delivering performance ratio (DPR) is defined as the ratio of actual discharge to design discharge. If a channel is functioning at a DPR value of 1, it means that the channel is withdrawing its design share. Normally, the irrigation site staff have a cushion to operate a channel up to a DPR value of 1.2. Similarly, channels are not operated under a DPR value of 0.6 so that they are not subjected to siltation.

Where;

$$DPR = \frac{Q_A}{Q_D} \qquad \text{Eq-1}$$

DPR = Deliver performance ratio (unit less);

QA = Discharge at which the channel is being operated (cusecs);

QD = Channel design discharge (cusecs). In case of rotational plans,

QD will be the discharge of the channel that has been allocated in the rotational plan. This discharge might not be equal to the full design capacity of the channel.

3.0.2 GINI Coefficient

GINI coefficient is an indicator that can be used to quantify the equity in water distribution in the system. Its value ranges between zero (0) and one (1). Zero represents a uniform distribution of water whereas one shows fully inequitable distribution.

$$G = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}|x_i - x_j|}{2n\sum_{i=1}^{n} x_i} \qquad \text{Eq-2}$$

Where; G= GINI Coefficient;

x = Seasonal average DPR of a channel;

n = Total number of channels;

i, j = Columns & rows of the matrix.

For user convenience, GINI has been reported in inverse format. This will reverse the evaluation criteria i.e., value one (1) for perfect equality and value zero (0) for inequality.

$$GINI\ Index = 100 - x(\%age) \qquad \text{Eq-3}$$

GINI coefficient is a function of channels DPR's and it can only be computed at the completion of the season. Computing a GINI coefficient for a specific wara or number of waras may not provide reasonable results. In case of rotational plans, GINI coefficient will indicate the extent up till which the executed rotational plan was able to ensure the water equity among the consumers. However, it is important that this coefficient is analyzed in parallel with other performance indicators. A schematic for computing the GINI is shown in the Figure-3 below:

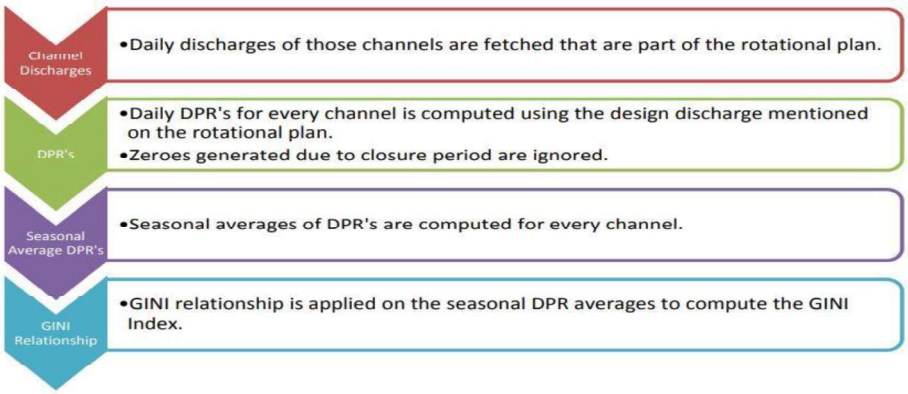


Figure 3: Schematic for computing GINI Index

3.0.3 Plan Implementation Ratio

An in-house logic has been developed to estimate the percentage of plan implementation of the executed rotational plan during a season. The logic can be implemented on individual waras as well as for the complete season. This flexibility is provided to the user so that percentage of plan implementation could be tracked for desired time window.

The logic is a function of the daily discharges of the channels and compares them to compute the implementation percentage. The user is required to input the rotational plan and define two threshold values of DPR's i.e. Upper DPR threshold and Lower DPR threshold. Currently, value of 1.2 and 0.8 have been selected. Daily discharges of the channels, which are part of the rotational plan, are taken from Irrigation Department database against the dates during which the analysis is intended. These dates can be for the complete season or any particular waras. Fetched discharges are arranged in a row wise pattern against the dates and follows the preference order that is mentioned in the rotational plan. Their corresponding daily DPR's are computed and arranged in the similar way. Once DPR values are properly ordered, maximum DPR value of each group is identified and placed against the dates in the similar row wise fashion.

It is to be noted that maximum DPR of the least priority group is of no interest for logic implementation and therefore ignored. After the processing of data, DPR of every channel is compared with the user defined thresholds and the maximum DPR of the consecutive group. Based on the comparison, the developed logic could either be true or false. This activity is continued till the intended last date of the analysis. In the end, the total instances of TRUE and FALSE decision occurrences are counted for calculating the plan implementation percentage. It is to be mentioned that the above logic is applied for all the channels on each day. The channels residing in the least priority groups, however, are not considered in the analysis and therefore skipped. A schematic for computing the plan implementation percentage is shown in the Figure-4. During the closure period in Rabi season, plan implementation is computed by analyzing the head discharge of the parent channel. If the head discharge is zero during the planned closure date, the conditions are counted as TRUE, as the channel has been closed according to the rotational plan, and vice versa.

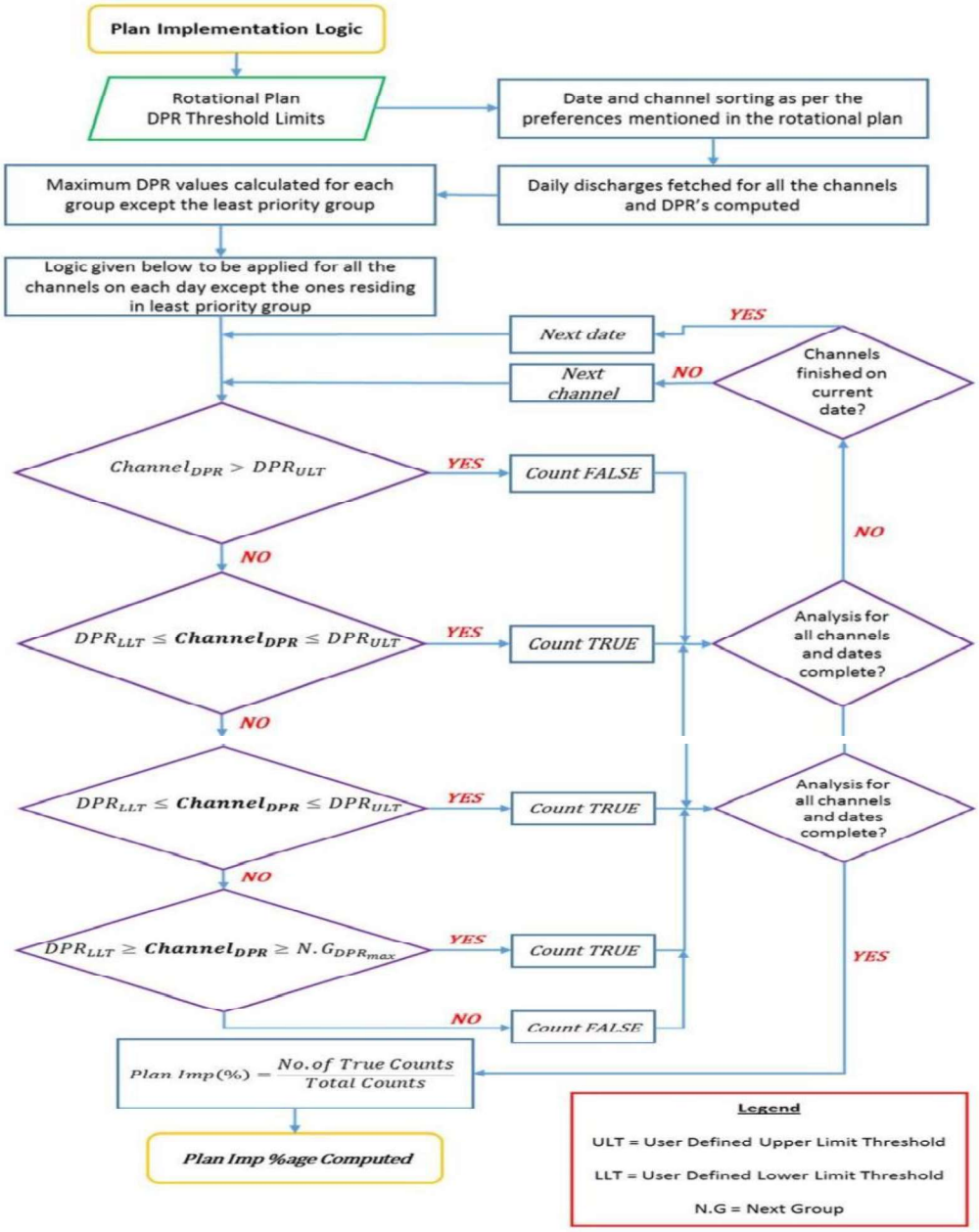


Figure 4: Schematic for computing plan implementation percentage

4.0 RESULTS AND DISCUSSION

Rotational Analysis tool for the Hakra Irrigation canal is developed. It can be seen from the figure that the rotational plan has been strictly followed. It can be seen that from the result in the week 22 only group-C is facilitated and rest of the group could not get their fair.

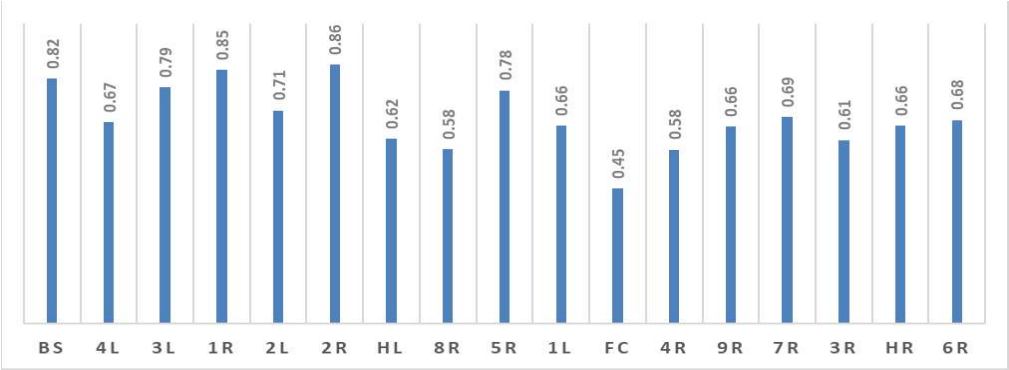


Figure-5: Average DPR of Individual Channel



Figure-6-A: Group wise DPR

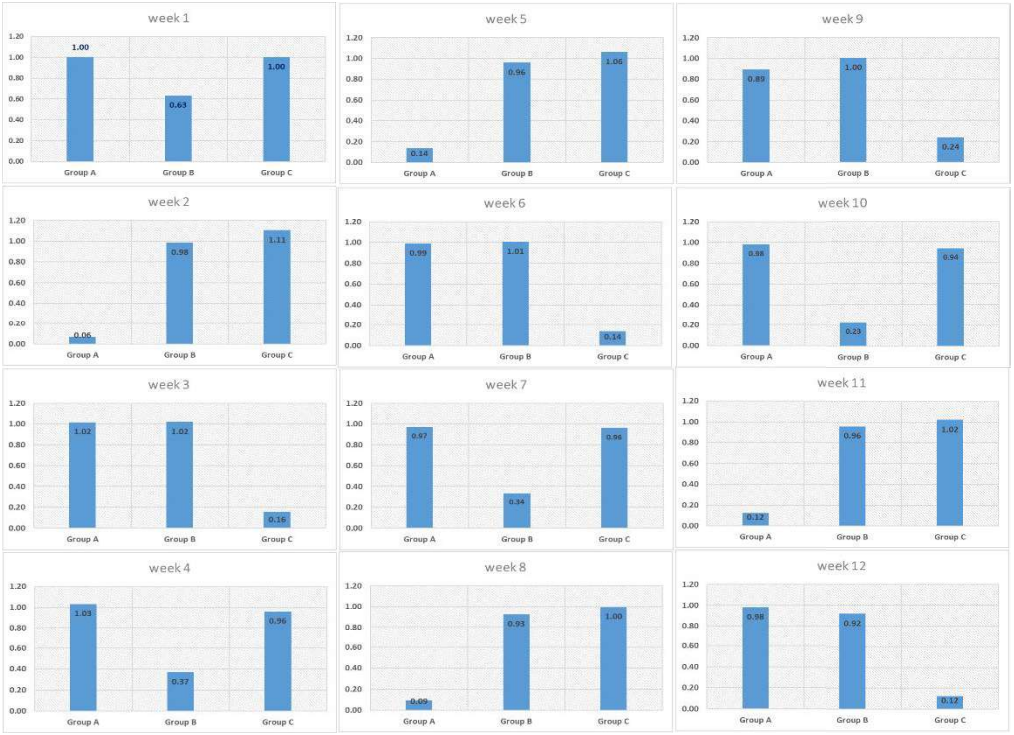


Figure 6-B: Group wise DPR

Table-3: Results Summary

Plan Implementation Statistics		**Equity (GINI)**
Total Checks	920	Overall GINI= 92%
True Checks	528	
False Checks	392	
Impl. Ratio logic _0	57%	Group A=97%
Impl. Ratio logic _1	82%	Group B=90%
Impl. Ratio logic _2	84%	Group C=99%

Rotational Plan is prepared at division level on seasonal basis (Rabi and Kharif) for Hakra canal division. In the rotational plan the 1st priority canals run on their design discharge with (±10% variation of the design discharge which is depicted in the results. Similarly, 2nd and 3rd priority channels in the rotational plan run as per water availability in the parent channel It can be seen from Table-3 that plan implementation percentage and GINI index are in direct relationship, however, it does not necessarily have to be directly proportional. it can be seen from Figure 6-A and Figure 6-B that among three groups, one group of the channels for rotational plan possess an average DPR greater than 80%. The average DPR of as

mentioned in the figure 5 vary from 0.45 to 0.86 means inequitable distribution among the canals but in the GroupWise it shows that the distribution among the group is equitable. It was also observed that DPR in week 8 (Wara 8) the canal at 2nd priority run as 100% of their design discharge but the 1st priority canals run as 93% which is a clear violation of the rotational plan. The study neglect the design and other operational factors are major explanation for the gap between the potential and actual performance of irrigation system.

4 CONCLUSIVE REMARKS

i. This tool can also assist in forecasting the impacts of decisions related to canal operations. It is often the case that the division encounters unprecedented circumstances and demands decision that may have unexpected consequences. Under such conditions, the numerical modeling can be helpful in reinforcing and facilitating the management decisions.

ii. It will help the water managers to identify the instances during which the rotational plan has been violated. This analysis session may be performed at the end of each wara or the complete season

iii. Analyzing plan implementation ratio in parallel with other performance indicators will allow the water managers to evaluate the effectiveness of their proposed rotational plan in a more realistic way.

5 ACKNOWLEDGEMENTS

The study was carried out as part of the project “Improvement and Modernization of Irrigation and Water Resource Management System in the Punjab” under the Task C. Authors are highly thankful to (PMIU), Irrigation Department providing discharge, and hydraulics structural detail data.

6 Conflict of Interests

The authors declare that they have no conflict of interests regarding the publication of this paper.

7 REFERENCES

Ahmed, N., Mahmood, S., & Munir, S. (2015). Estimation of Potential and Actual Crop Evapotranspiration Using Weap Model. *Science International*, *27*(5), 4373–4377. Retrieved from http://www.sci-int.com/pdf/636341765972616191.pdf

Awan, U. K., Anwar, A., Ahmad, W., & Hafeez, M. (2016). A methodology to estimate equity of canal water and groundwater use at different spatial and temporal scales: a geo-informatics approach. *Environmental Earth Sciences*, *75*(5), 409. https://doi.org/10.1007/s12665-015-4976-4

Khan, M. Z., & Ghumman, A. R. (2008). Hydrodynamic modelling for water-saving strategies in irrigation canals. *Irrigation and Drainage*, *57*(4), 400–

410. https://doi.org/10.1002/ird.375

Mandavia, A. B. (1999). Modernization of irrigation system operational management by way of canal automation in India. *RAP Publication (FAO)*. Retrieved from http://agris.fao.org/agris-

Shende, S., & Sachin. (2006). Database-driven hydraulic simulation of canal irrigation networks using object-oriented high-resolution methods.