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Review

Canal based irrigation scheduling and conjunctive water use planning for optimal cropping pattern - A review

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In irrigation projects, the success of the water delivery system is measured based on whether water is delivered according to the predetermined water delivery goals in an adequate, dependable, efficient and equitable fashion. One of the most critical issues affecting the inequitable distribution of water at the farmer's field is due to the seepage loss that makes farmers at the tail end to get less water compared to farmers at the head of the water course. Therefore, a modeling approach can be adopted for incorporating the seepage loss along the length of water course /or it's branch. Conjunctive-use management has been the most suitable alternative for optimum utilization of available land and water resources. Many attempts have been made by different researchers to optimally allocate the land, water, and other resources of an area to meet different specific objectives. Therefore, in this study a comprehensive review of literature is undertaken considering the past, present methodologies applied to address these issues and future projections for efficient canal based Irrigation scheduling and conjunctive water use planning for optimal cropping pattern.

Keywords: Canal irrigation, scheduling, performance indicators, equitable distribution.

INTRODUCTION

In India, nearly 83% of developed water resources are utilized for agriculture, and irrigated agriculture contributes 56% of all food grain production (Planning Commission 2002). Agriculture has been the primary source of livelihood for over 75% of the population of India, and it contributes to 30% of gross domestic product (GDP) and 60% employment. Provision of assured water supply to the agriculture is, therefore, considered as the top most priority of the water resources program of the country. In canal irrigation system one of the most important services that the canal field functionaries provide to the farmers is the delivery of irrigation water, considering farmers point of view in terms of (i) timing, (ii) flow-rate, and (iii) duration of irrigation applications. It is just as an electrical engineer has to control voltage and amperage, the hydraulic engineer has to control pressure and flow in a piped system, and water level and flow in a free-flow canal. This is the double problem of canal hydraulics (Operation and Maintenance Guidelines for Canals, 2009). Irrigation canal scheduling is the activity of preparing an optimal schedule of flow through the outlets on supply canal as per need of farmers, subject to canal system constraints. Efficient operation and management of an canal irrigation system plays an important role in the sustainability of irrigated agriculture (Mishra et al. 2001; Kumar and Singh 2003). One of the most important management's strategies is to supply a maximum amount of water to the scheduled canals and to evacuate the

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excess through the drainage system (Khepar et al. 2000). However, traditional canal irrigation management problems include less capacity than the peak demand of water distribution system, irregular delivery rates, and low irrigation efficiency and uniformity. The major reason for the low performance of canal irrigation system is the inaccurate water distribution due to the lack of monitoring system for water delivery (Lozano and Matoes 2008; Matoes et al. 2010). In several cases the irrigation networks are found to be extensively degraded, and large conveyance losses have diminished the amount of water delivered at the field. Therefore, it is a challenge and necessity of time to strategically compare the estimated irrigation demands with the actual water supplies for decision making in order to maintain the water supply according to the demand.

One of the approaches for water management improvement is to assess the water delivery performance indicators of the open irrigation canals, which is essential for identifying the key issues to address them accordingly. Automatic water gauge are generally applied to measure the depth of flow, and using area velocity method, actual discharges are measured at different location of the canals, then different irrigation efficiencies are calculated from the spatial and temporal distribution of the water supply. The calculated performance indicators are useful to understand the irrigator behavior and general irrigation trends, and serve as an indicator for accurate canal distribution system design and operation.

Flow are generally measurements at the delivery points in order to assess the canal irrigation water delivery (Unal et al. 2004), and accurate monitoring and management are needed in order to prevent unscheduled use of water (McCready et al. 2009; Mishra et al. 2013). Generally, in most of the cases, it is found that the irrigation water deliveries are not measured, or not measured as precisely as required, in the open canal irrigation delivery system particularly at the sub-minor and distributory level. Moreover, the flow rates at the intake of the delivery canals are generally not recorded, as per schedule. The lack of water management make implementation and monitoring of irrigation efficiencies difficult. Therefore, it is observed that in most performance assessment studies focused on external performance objectives such as crop production, water supply, and water delivery capacity at the main canal level or reservoirs. Therefore, it becomes inevitable to strategically compare the estimated irrigation demand with the actual water supplies for decision making in order to maintain balanced water supply according to the water demand.

Poor distribution and management of water in irrigation system has been found as major factor leading to low performance efficiency and thus, empathies need to assess the extent to which existing canal irrigation system in the area achieve their targeted distribution aim (Mateos 2008; Yercan et al. 2009). Irrigation system performance describes the effectiveness of the physical system and operation decision to deliver irrigation water from a water source (Irmak et al. 2011). In irrigation projects, the success of the water delivery system is evaluated based on whether water is delivered according to the predetermined water delivery goals in an adequate, dependable, efficient and equitable fashion (Molden and Gates 1990).

One of the most critical factors affecting the inequitable distribution of water at the farmer's field is due to the seepage loss along the water course making farmers at the tail end to get minimum water compared to farmers located at the head of the water course. The rate of seepage loss increases along the length of the water course from head to tail. Inequity has a direct influence upon productivity, as the parts of system that receives less water than their potential demand, and another area which receives more water than they actually need, do not cause improve yield, and causes reduces production in both the conditions (Abernethy 1986). It shows that the farmers at the tell end must be compensated for the seepage loss. Malhotra (1982) suggested to divide the water course into 3-4 segments, that will ensure the farmers being allotted time on the basis of actual flow in each segment. Moreover, in actual conditions even in a short length of water course there may be significant difference in the flow even within the same segment, and therefore, each farmer needs to be allotted time according to the actual discharge being received by him. Therefore, a exhaustive modeling approach is required to incorporating the seepage loss along the length of water course/branch, ensuring the equitable distribution of water according to the land holding of a farmer irrespective of his location on the water course.

Further, the rising demand for water, specifically for irrigated agriculture, which consumes about 80% of the water resources in the world (Wolff and Stein 1999), has brought new challenges to water resources planners and managers. As a major part of the consumable water resources exists as groundwater, sustainability of irrigated agriculture, requires either the development of additional water resources or efficient management of the available water resources under the existing scenarios. Shortages of surface water supplies make it necessary to develop groundwater in many canal commands that can be supplemented for irrigation optimally in conjunction with surface water supplies. The combined application and management of surface-water and groundwater for reliable required supply and minimize damage to the quantity or quality of the resources is known as conjunctive use (Hanson et al. 2010). Conjunctive-use management has been the most suitable alternative for optimum utilization of available land and water resources and an exhaustive literature survey reflecting the benefits of conjunctive use has been presented by many researchers such as Nieswand and Granstrom (1971), Panda et al. (1983), Latif and James (1991), Panda et al.

(1996), Mohan and Jothiprakash (2003), Azaiez et al. (2005), Khare et al. (2007), Yang et al. (2009), Montazar et al. (2010), and Lu et al. (2011) Khan and Jain (2015). A thorough review is presented below for three important components viz., (a) crop water requirement, (b) performance indicators, and (c) conjunctive use, affecting the overall system performance for optimal application of water and for maximum annual returns as discussed below.

Crop Water Requirement

Hajare et al. (2008) analyzed the original form of adjustment factor c in the modified Penman method by interpolation as well as by empirical models. The study suggested use of empirical model for estimation of adjustment factor in estimation of crop water requirement. Hashim et al. (2012) used Neutron probe and lysimeter measured Evapotranspiration (ET) data acquired at different crop growth stages to assess the total water requirements of different crops for an entire growing season. The crops included in the study encompassed seasonal crops (wheat, corn, broad beans, millet, cowpea, okra and eggplant) and forage crops (alfalfa, blue panic grass, rhodes grass and Sudan grass) grown in Makkah region, Saudi Arabia. The investigations were carried out at the Research Farm of King Abdul-Aziz University, Hoda Al-Sham, Makkah area. Results revealed that crop water requirements were found to vary from 303 to 727.8 mm in seasonal crops and from 436.7 to 1821.94 mm in forage crops. In addition, crop water productivity (CWP) of summer season crops (1.478 kg/m3) was found to be higher than the values associated with forage (1.079 kg/m3) and winter season (0.942 kg/m3) crops. The lowest value of CWP was observed in corn (0.794 kg/m3), while the highest value of 1.724 kg m-3 was associated with okra. Karim et al. (2013) used remote sensing and FAO 56 crop water model for estimating crop water requirement for paddy crop located in the main branch canal of Bhadra Command Area in Karnataka, India. The result obtained showed that water requirements of *Rabi* crops was higher than those of the *Kharif* crops. The estimated total irrigated area from the IRS image was found as 29,353 ha. It was also found that paddy crop acreage with 18,257 ha was covering 62 % of the total irrigated area of the command area, Arecanut 20 %, coconut 15 % and sugarcane with other crops 3 %. The water requirement for paddy was found as 1180.4 mm for its entire growth period. The total water requirement for irrigation supply for crops in the entire command area was found as 5,790 cusecs per ha at a demand of 0.10501 cusecs per ha. Jinglei et al (2013) combined the principal component analysis (PCA) and geographically weighted regression (GWR) to estimate the spatial distribution of water requirement of the winter wheat in North China while the effect of the macro- and micro-topographic as well as the meteorological factors on the crop water requirement was taking into account. In the study, spatial distribution characteristic of the water requirement of the winter wheat and its formation based on the spatial variation of the main affecting factors and the regression coefficients were analyzed. It was observed in the study that the collinearity can be effectively reduced when PCA is applied to process all of the affecting factors. The regression coefficients of GWR displayed a strong variability in space, explaining in a better way the spatial differences of the effect of the affecting factors on the crop water requirement. The evaluation index of the proposed method was found to be more efficient than the widely used Kriging method. Singh et al. (2013) evaluated various methods for estimation of evapotranspiration to predict water requirement of soybean and wheat crops for nine selected districts of Madhya Pradesh under vertisols. Four methods (PenmannMontieth, Hargreaves, SCS-Blaney-Criddle and Thornthwaite) for estimation of reference evapotranspiration (ET0) were compared for assessing their predictive capability for Bhopal and Indore districts using meteorological data. All the four methods for estimation of evapotranspiration were applied as per the availability of the climatic data. Reference evapotranspiration was estimated by using Penmann-Montieth method for two districts (Bhopal and Indore) for which data on solar radiation were available and Hargreaves method for remaining seven districts (Chhindwara, Dhar, Guna, Hoshangabad, Jabalpur, Khandawa and Raisen). Crop water requirements were also determined through field experiments conducted during 2008-2010 for soybean and 2008-2011 for wheat crops using non-weighing type lysimeters at research farm of Central Institute of Agricultural Engineering, Bhopal. The study revealed that among the four methods, Hargreaves method estimated ET0 values with minimum deviation (4.24%) for Bhopal as compared to Penmann-Monteith. The water requirement of soybean and wheat estimated by Penmann-Monteith method was in close agreement (-2.58% and 9.26% deviation) with the measured average water requirement (401.6 and 352.2 mm) respectively, followed by Hargreaves method for Bhopal district. It was also inferred that in absence of solar radiation data Hargreaves method could be considered for predicting water requirement of soybean and wheat crops. These water requirement values were recommended for effective planning of irrigation scheduling of the soybean and wheat crops in the State. Barman et al. (2014) used readily available pan evaporation data to estimate the ET0 for hot and humid region of West Bengal considering the factor of pan coefficient (Kp) depending on fetch, wind speed, and relative humidity. The estimation of ETc for tossa jute crop was carried out by using soil moisture depletion method. The ratio of ETc to ET_0, called the crop coefficient (Kc), was calculated on weekly basis for irrigation scheduling of jute in a hot and humid region of West Bengal. Khandelwal and Dhiman (2015) estimated the net irrigation water requirement for different crops in Limbasi branch canal command area of Mahi Right Bank Canal (MRBC) project located in Gujarat, India. The Hargreaves-Samani approach for reference crop evapotranspiration (ETo) estimation was used with thirteen years of available data. The potential crop evapotranspiration (ETc) and net irrigation requirement (NIR) of different crops in kharif, rabi and summer season were estimated. It was shown that the NIR values (mm) for kharif crop paddy was 166.8; rabi crops jowar, tobacco & wheat were 404.3, 504.2 & 564.7 and summer crops paddy & bajri were 851.1 & 619 mm, respectively. Mangrio et al. (2016) applied Mehran model for crop water requirement and irrigation scheduling while crop-based irrigation operation (CBIO) model was used for secondary canal scheduling/rotation. It was found that by implementing the modeling approach for canal scheduling in the area, more than 34% of irrigation water could be saved.

Performance Indicators

Mishra et al. (2013) assessed the performance of a rehabilitated and turned over flow based minor irrigation project with respect to irrigation, agriculture and institutional aspects. The irrigation system was found performing better, however, inadequacy of irrigation water availability in dry season and spatial inequity of water distribution, even after rehabilitation and irrigation management transfer were the couple of short comings which were observed. In the study in order to augment the water resource of the system, the feasibility of introducing secondary storage reservoir in each outlet command was conceptualized and field tested. Nam et al. (2016) introduced an approach to assess the water delivery performance indicators of the open irrigation canals. The irrigation efficiencies according to the water delivery performance indicators were measured in the irrigation canals and these were calculated considering the spatial and temporal distribution of the water supply. The calculated performance indicators were useful to understand the irrigator behavior and general irrigation trends. Analysis of the results presented insights into possible improvement methods, useful for formulating water management policies that enable irrigation planners to improve the temporal uniformity and equity in the water distribution.

Canal Water Distribution System

Khepar et al. (2000) developed a model to ensure equitable distribution of water to the farmers located on a watercourse in proportion to their land holdings giving due compensation for the seepage loss. In this study a modelling approach was considered with homogeneous soil throughout the length of flow and negligible evaporation loss. The developed model provided an equitable distribution of water to the farmers according to their land holding. In comparative study of existing and revised time allocation revealed that the farmers located in the upper reaches were getting more time (12.2 min per unit area), while the farmer located in the lower reaches were getting less time (upto 28.1 min per unit area). The existing allocation of time of 0.75 h per unit area to all the farmers according to the old rules was revised to 0.546 -1.219 h per unit area from head to tail. It was recommended that strategy developed could be adopted in other canal command areas where existing system of irrigation distribution requires equitable distribution of canal water. Upadhyaya et al. (2002) identified the constraints in water delivery from canal and develop performance indicators from the point of view of water users and canal managers in Patna Canal Command under Sone Canal System in India which reflects that there are multi-dimensional problems like technical, socio-economic, hydraulic, managerial, institutional and financial related to water release, allocation, distribution and utilization in canal command and lack of frequent communication and dialogue among water users and canal managers. The major problem reported by the water users was mismatch/wide gap between water supply and demand leading to water stress conditions either due to excess or deficit availability and ultimately adversely affecting the crop. Performance indicators revealed that there was plenty of scope for improvement in performance of Patna Canal as well as water productivity in the canal command provided works related to command area development, onfarm water management, timely operation and maintenance of canal, frequent dialogue and meetings among water users and canal managers, training and awareness campaign are initiated in participatory mode involving wider constituency of stake holders. Mathur et al. (2009) proved that canal scheduling is an important activity that significantly influence production of crops compared to other aspects of agriculture. The problem of optimal operational scheduling of irrigation canal with provision to open some outlet at specific time slot as per request of user using Genetic Algorithm was presented, in the study. The optimal operational schedule obtained with Genetic Algorithm approach was compared with previously published operational schedule for the Famen secondary canal of Feng-Jia-Shan Irrigation District, China, obtained using integer programming. The result showed that Genetic Algorithm approach gives sufficient flexibility in decision making regarding the group formation of various outlets. It was an efficient tool for irrigation manager to prepare optimal schedule of irrigation canals as per time slot demanded by users. Kannan et al. (2011) developed an approach to model canal irrigation systems and irrigation best management practices (BMPs) to adequately simulate the water balance of irrigated watersheds. The approach is based on the water requirement of crops, number and frequency of irrigation, and critical crop water requirement stages. In the study, two irrigation BMPs were modeled as water savers rather than physical changes in irrigation appurtenances. The developed approach was tested with a 1,692 km2 intensively cultivated, canal-irrigated watershed using the Soil and Water Assessment Tool (SWAT). It was found that the approach captures water balance and observed runoff hydrograph of the study area adequately. Kanooni and Monem (2014) Proposed three modules for the optimization model. In First module, they produced crop–water production functions for different crops, in second module , optimal allocated water to each crop from the first module, in third module, determination of optimal water delivery scheduling among outlets of the secondary canal was conducted using a genetic algorithm (GA). The decision variables are delivery discharge to each outlet, the number of outlets grouped in a block which receive water sequentially, and the sequence of water delivery to the outlets in each block. They applied proposed approach on the K canal of the Moghan Irrigation Network in the north-west of Iran. The optimal water delivery scheduling of a secondary canal, based on the optimal water allocation among several crops, and intra-seasonal irrigation scheduling are presented, which shows the utility of the integrated approach. Ren et al. (2015) applied the model HYDRUS-1D, coupled with the FAO-56 dual crop coefficient approach (dual Kc), to simulate the water and salt movement processes. They conducted Field experiments for maize, sunflower and watermelon crops in the command area of a typical irrigation canal system in Hetao Irrigation District during 2012 and 2013.They calibrated and validated the model in three crop fields using two-year experimental data. Simulations of soil moisture, salinity concentration and crop yield fitted well with the observations. It was found in the study that when applying water saving measures, close attention should be paid to cropping pattern distribution and groundwater control in association with irrigation scheduling and technique improvement. Kim et al. (2016) emphasized analysis of canal network flows for proper distribution of crop water requirements. This study developed a hydraulic analysis model for irrigation canal flow by using the Storm Water Management Model (SWMM) module in a rice paddy field in the Daesan District located in the western part of South Korea. In this study, importance of hydraulic study was presented in improving irrigation scheduling by precisely observing and modeling flow travel time, water level and flow amount.

Consunctive Water Use

Raul et al. (2012) developed ISM to predict actual crop yield under different irrigation strategiesnamely, full and deficit depths of irrigation. The crop yield obtained by the ISM under different irrigation management strategies was used in the LPM to optimize the land and water resources of the canal command at different probability of exceedances of net irrigation requirement and canal-water availability. In this study, the net annual return was found to decrease with the increase in the level of deficit with maximum return under full irrigation strategy. The uncertainty factor did not show any visible effect on the cropping pattern, which in turn is reflected in the overall water resources utilization pattern of the canal command. From the sensitivity point of view, cropping area should be given emphasis, followed by the market price and cost of cultivation of different crops during the course of further study. Khan and Jain (2015) developed a dynamic programming approach for optimization of seasonal allocation of water for multiple crops (Wheat, Barley, Mustard and Gram). Gamma distribution was applied to assess the stochastic nature of canal water releases of Golewala distributary utilizing 20 years of data from 1982-2001. Applying Gamma distribution of canal release data different expected values were computed such as 3766.41, 4138.76, 4422.2, 4674.5 and 4918.95 ha-m corresponding to 10%, 20%, 30%, 40% and 50% risk levels of canal water releases in the distributary. It was found in this study that the net returns for 10% and 50% risk levels of canal water release and 30% ground water application were 8.51% and 32.42% higher than existing observed net returns in the command area .Usman1 et al. (2016) found variations in conjunctive water management practices, groundwater productivity and crop profitability in Chuharkana irrigation sub-division in Punjab. They collected physical and questionnaire based data from 120 farmers using stratified random sampling technique from vicinity of four watercourses of Lagar distributary. They employed trajectory method to measure tubewells' discharge for evaluating groundwater productivity across watercourse reaches. EC, SAR and RSC were measured to evaluate groundwater quality. Results showed prevalence of surface and groundwater use for irrigation. Area under conjunctive use decreased from 76.6% at head to 46% at tail due to decreased canal water supply towards tail while area irrigated by groundwater-only increased from 20% to 54% across head to tail. Analysis of groundwater samples showed lower quality levels. EC, SAR and RSC ranged between 1.27-1.55 dS m^{-1}, 6.39-9.54 (mmol L^{-1}) ^{½} and 3.75-4.18 meL^{-1} respectively, with higher values towards tail. Groundwater productivity for wheat was relatively higher at the head, while that of rice did not vary much across watercourse reaches. Conducive soil conditions and more reliance on groundwater for timely irrigation resulted gross margins at the tail.

CONCLUSIONS

The goal of this study was to review the earlier work carried out related to performance indicators, equitable distribution of water and conjunctive use of surface and ground water, maximizing annual return with optimal water application. The performance evaluation of canal irrigation system such as adequacy, efficiency, dependability, and equity are well known for assessment of spatial and temporal distributions of the required and delivered water of secondary canals. Need of equitable canal water distribution is inevitable to achieve the goal and was emphasized in this study. Moreover, optimization modeling of conjunctive use of water for optimal cropping pattern is important and is also presented in this study. The study provided an insight into irrigation management methods needed in order to improve the temporal uniformity and equity in the water distribution by evaluating the efficiencies of water supply and delivery. It is revealed that the existing rotational system of irrigation results in inequitable distribution of canal water, resulting in social injustice. The farmers located in the upper half of the watercourse have been getting more water than those in the lower half, though the farmers located in the tail end are the greatest sufferers. The strategy needs to be developed ensuring an equal distribution of water per unit area to all the farmers being provided irrigation from a common watercourse irrespective of the location of their land holding from the watercourse inlet. Considering limited availability of surface water and ground water, conjunctive use of these water resources should ensure adequate irrigation to the crops to maximize the crop production and net annual return. Taking this into consideration, the most beneficial crops with comparatively lower water requirements, such as pulses and vegetables, should be given priority, and the present practice of extensive rice cultivation should be limited to the minimum possible extent, which will be helpful for the protection of the environment because of reduction in greenhouse gas emissions.

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