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Review Article

CANAL BASED IRRIGATION SCHEDULING AND CONJUNCTIVE WATER USE PLANNING FOR OPTIMAL CROPPING PATTERN-A REVIEW

KUMAR DEEPAK[1*], TIWARI M.K.[2] AND VYAS D.K.[3]

[1,2]Department of Soil and Water Engineering, College of Agricultural Engineering & Technology, Anand Agricultural University, Godhra, Gujarat, India
[3]Department of Renewable Energy Engineering, College of Agricultural Engineering & Technology, Anand Agricultural University, Godhra, Gujarat, India
*Corresponding Author: Email-dk720244@gmail.com

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Abstract- The success of water delivery in canal irrigation projects is measured based on whether water is delivered according to the required water delivery targets 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 strategies has been found to be the most suitable choice for optimum utilization of available land and water resources. Many attempts have been made in the previous studies 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.

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Introduction

In India, nearly 83% of developed water resources are utilized for agriculture, and irrigated agriculture contributes 56% of all food grain production [1]. Agriculture is the backbone and the primary source of livelihood for over 75% of the population of India, and its contribution is about 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 can be explained simply as an electrical engineer controls voltage and amperage, the irrigation/hydraulic engineer controls pressure and discharge in a piped system, and water level and flow in a free-flow canal. This is the double problem of canal hydraulics [2]. In irrigation canal scheduling, an optimal scheduling of flow through the supply canal as per requirement of farmers is planned, considering the constraints in canal irrigation system. Sustainability of irrigated agriculture depends on the efficient operation and management of a canal irrigation system [3, 4]. One of the most important management strategies is to supply a maximum amount of water to the scheduled irrigation canals and to remove the surplus water through the drainage system [5]. However, traditional canal irrigation management problems include less capacity than the peak demand of water distribution system, irregular delivery rates, with low irrigation efficiency and uniformity. One of the major reasons for the low performance of canal irrigation system is the inaccurate water distribution due to the lack of monitoring system for water delivery [6,7]. In several cases, the irrigation networks are found to be extensively degraded, and large conveyance losses cause reduced amount of water delivered at the field. Therefore, it becomes inevitable to precisely estimate the irrigation demand and compare it with the actual water supplies to maintain and balance 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 gauges 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 is generally measured at the delivery points in order to assess the canal irrigation water delivery [8] and accurate monitoring and management are needed in order to prevent unscheduled use of water [9, 10]. 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 makes implementation and monitoring of irrigation efficiencies difficult. Therefore, it is observed that external performance objectives such as crop production, water supply, and water delivery capacity are mainly considered at the main/branch canal level. 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 [11, 12]. Irrigation system performance describes the effectiveness of the physical system and operation decision to deliver irrigation water from a water source [13]. In canal irrigation projects, the performance of water delivery system is evaluated based on different performance indicators such as adequate, dependable, efficient and equitable fashion [14].

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 [15]. It shows that the farmers at the tail end must be compensated for the seepage loss. It is 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 [16]. 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 incorporate 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 [17], 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. Application and management of surface-water and groundwater without compromising quality and quantity of the water resources and in a optimum manner as per the required irrigation demand is known as conjunctive use [18]. Conjunctive-application has been the most suitable alternative for optimum utilization of available land and water resources [19-29]. A thorough review is presented below for four important components *viz*., (a) crop water requirement, (b) performance indicators, and (c) Canal water Distribution system and (d) conjunctive use, affecting the overall system performance for optimal application of water and for maximum annual return as discussed below.

Crop Water Requirement

The original form of adjustment factor c was analyzed with help of 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 [30]. Neutron probe was used and lysimeter measured Evapotranspiration (ET) data was acquired at different crop growth stages to assess the total water requirements of different crops for an entire growing season. In the study seasonal crops such as wheat, corn, broad beans, millet, cowpea, okra and eggplant and forage crops such as alfalfa, blue panic grass, rhodes grass and Sudan grass were included .The field experiments were conducted at the Research Farm of King Abdul-Aziz University, Hoda Al-Sham, Makkah area. It was found in the study that crop water requirements was varying from 303 to 727.8 mm in seasonal crops and was varying from 436.7 to 1821.94 mm in forage crops. Moreover, Crop Water Productivity (CWP) of summer season crops (1.478 kg/m^3) was observed higher than that of the forage crops (1.079 kg/m^3) and winter season (0.942 kg/m^3) crops. The corn crop showed the lowest value of CWP as 0.794 kg/m^3, while the okra crop showed highest value of 1.724 kg/m^3[31]. Remote sensing and FAO 56 crop water model were used for estimating crop water requirement for paddy crop in the main branch canal of Bhadra, which is situated in a command area of Karnataka state, 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 Indian Remote Sensing (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 [32]. The Principal Component Analysis (PCA) and Geographically Weighted Regression (GWR) were combined to estimate the spatially distributed water requirement for the winter wheat in North China while the effect of the macro and micro topographic and 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 factors affecting spatial variation the regression coefficients were analyzed. It was observed in the study that the co-linearity can be effectively reduced when PCA is applied to process all of the affecting factors. A strong variability in space was observed in the regression coefficients of GWR. The evaluation index of the proposed method was found to be more efficient than the widely used Kriging method [33].The various methods for estimation of evapotranspiration were Evaluated to predict water requirement of soybean and wheat crops for nine selected districts of Madhya Pradesh under vertisols. Four methods (Penmann Montieth, Hargreaves, SCS-Blaney-Criddle and Thornthwaite) for estimation of reference evapotranspiration (ET_0) were compared for assessing their predictive capability for Bhopal and Indore districts using meteorological data. All these methods were applied as per the availability of the climatic data for estimation of evapotranspiration. Reference evapotranspiration was estimated by using Penmann-Montieth method for two districts (i.e., Bhopal and Indore) in which solar radiation data were available and Hargreaves method for remaining seven districts (i.e., 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 that was installed at Central Institute of Agricultural Engineering, Bhopal. The study revealed that out of the four methods, Hargreaves method estimated ET_0 values with minimum deviation (4.24%) for Bhopal District as compared to Penmann-Monteith. The crop water requirement estimated by Penmann-Monteith method for soybean and wheat crops was in close agreement (-2.58% and 9.26% deviation) with the observed 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 preferred for estimation of crop 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 [34]. The readily available pan evaporation data was used to estimate the ET_0 for hot and humid region of West Bengal considering the factor of pan coefficient (K_P) depending on fetch, wind speed, and relative humidity. The soil moisture depletion method was applied for estimation of ET_C for the tossa jute crop. The ratio of ET_C to ET_0, called the crop coefficient (K_C), was calculated on weekly basis for irrigation scheduling of jute in a hot and humid region of West Bengal [35]. The net irrigation water requirement was estimated for different crops in Limbasi branch canal command area of Mahi Right Bank Canal (MRBC) project, situated in Gujarat, India. The Hargreaves-Samani approach for estimation of reference crop evapotranspiration (ET_0) was used with thirteen years of available data. The ETc and net irrigation requirement (NIR) for *kharif, rabi* and summer season crops 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 and 564.7, respectively and summer crops paddy and bajri were 851.1 and 619 mm, respectively [36]. Mehran model was applied 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 [37].

Performance Indicators

The performance of a rehabilitated and turned over flow based minor irrigation project with respect to irrigation, agriculture and institutional aspects were assessed. The overall performance of irrigation system was good, however, some of the short comings were observed due to inadequacy of irrigation water availability in dry season and high spatial variation in water distribution. In the study secondary storage reservoir in each outlet command was conceptualized and field tested for augmenting the irrigation system. 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 [10]. 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 [38].

Canal Water Distribution System

A model was developed for ensuring 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 [5]. Multi-dimensional problems such as technical, socio-economic, hydrologic and hydraulic, managerial, institutional and financial in Patna Canal Command under Sone Canal System in India were analyzed. These issues were related to allocation, distribution and utilization of released water in canal command. The issues related to lack of frequent communication and dialogue among water users were also discussed. 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. It was found in the study 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, agricultural water management, canal system maintenance, etc [39]. It was proved that canal scheduling is an important activity that significantly influence on 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. The proposed tool was considered very efficient tool for management of canal irrigation water for optimal canal irrigation scheduling [40]. The canal irrigation water supply was simulated for Best Management Practices (BMP) using Soil and Water Assessment Tool (SWAT) considering water balance methods in an irrigated watershed. 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 km^2 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 [41]. Three modules were proposed 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. Water allocation among several crops, and intra-seasonal irrigation scheduling were presented for optimal water delivery, showing the applicability of the proposed integrated approach [42]. The model HYDRUS-1D was applied and coupled with the FAO-56 dual crop coefficient approach (dual Kc), to simulate the water and salt movement processes. Field experiments were conducted 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 [43]. Analysis of canal network flows was emphasized for proper distribution of crop water requirements. A hydraulic model for irrigation canal flow was developed using Storm Water Management Model (SWMM) tool in a rice field in the Daesan District 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 [44].

Conjunctive Water Use

An Irrigation Scheduling Model (ISM) was developed for predicting actual crop yield under full and deficit depths of irrigation. The crop yield obtained by the ISM under different irrigation management strategies was used in the Linear Programming Optimization Model (LPM) to optimize and allocate the land and water resources under 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. In the study it was proposed that cropping area should be given priority, followed by the market price and cost of cultivation [45]. A dynamic programming approach was developed 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 [29]. The variation was found in conjunctive water management practices, groundwater productivity and crop profitability in Chuharkana irrigation sub-division in Punjab.The physical and questionnaire based data were collected 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. Electrical Conductivity (EC), Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) were measured to evaluate groundwater quality. Results showed prevalence of surface and groundwater use for irrigation. It was found in the study that area under conjunctive use was decreased from 76.6% at head to 46% at tail due to decreased canal water supply towards tail. Area irrigated only from groundwater was found to be increased from 20% to 54% from head to tail. It was observed in the study that groundwater quality was decreasing from head to tail in terms of EC, SAR and RSC. Groundwater use efficiency for wheat crop was relatively higher at the head, whereas there was no significant effect on rice crop.[46].

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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Author Contributions

DEEPAK KUMAR[ABCDE], M. K. Tiwari[AC], D. K. Vyas[AC]

A	Study Design
B	Literature Search
C	Review Interpretation
D	Manuscript Preparation
E	Editing

Abbreviations and Symbols

GDP	Gross Domestic Product
ET	Evapotranspiration
ET_0	Reference Evapotranspiration
CWP	Crop Water Productivity
IRS	Indian Remote Sensing
PCA	Principal Component Analysis
GWR.	Geographically Weighted Regression
K_P	Pan coefficient
K_C	Crop Coefficient
M RBC	Mahi Right Bank Canal
NIR	Net Irrigation Requirement
CBIO	Crop Based Irrigation Operation
BMP	Best Management Practices
SWAT	Soil and Water Assessment Tool
GA	Genetic Algorithm
SWMM	Storm Water Management Model
ISM	Irrigation Scheduling Model
LPM	Linear Programming Optimization Model
EC	Electrical Conductivity
SA R	Sodium Adsorption Ratio
RSC	Residual Sodium Carbonate
%	Percentage
&	And
@	At the rate
±	Plus minus
ºC	Degree Celsius
Et al	And other
Etc	And so on

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