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Conveyance Loss Modelling and Conservation Planning for Irrigation Canals – A Geo-Spatial Approach

A.A.Kulkarni, R.Nagarajan

***Abstract*— According to the FAO Aquastat 2015, in India, around 91% of water is utilized for Agriculture purpose and out of which 45% is getting lost under Farm Distribution, Irrigation Distribution and Field Application losses. During the water conveyance from Dam Headwork till Farms using irrigation canals, the seepage loss constitutes a substantial percentage of the total water transported. Currently, many irrigation projects are struggling with proper planning and managing budgets while maintaining canal system due to various conveyance losses like seepage losses, evaporation, and percolation through cracks and other damages in lined as well as earthen canals. Out of these losses, seepage loss is quite significant in most of the water conveyance systems. Seepage loss estimation from large canals is quite difficult using ponding method due to continues flow and large canal dimensions. Other methods may involve lots of field work and calculations to get the average seepage values. The indirect methods like empirical formulae and analytical equations were proved useful for computing seepage losses. This paper presents a Seepage Loss Estimation Tool developed using ArcGIS Python Script to evaluate the seepage losses at various canal sections with their prioritization for carrying out current and future operational activities. The model also assesses the potential water saving with help of "What If" scenarios by providing various remedial measures like lining which will useful for designing unlined canals. It has been seen that average 31.3% losses can be minimized by providing all canal sections with concrete as lining material.**

***Index Terms*— Irrigation Canal, Seepage Loss, Prioritization, Remediation.**

I. INTRODUCTION

It has been seen since last century, water usage has been grown more than double with an increase in the rate of population. So it can be concluded that water scarcity resulted due to both a natural and human-made activities. Though, there is adequate water available on earth which suffice requirements however it is distributed unevenly and wasted, polluted and poorly managed [18]. In addition to that, to fulfill the global food needs, crop production is likely to have to double to meet the demand by 2050 [6]. With the increase in as global population water for food and agriculture is becoming a scarce resource, and the situation is further worsened by climate change. Agriculture is by far the largest user of the world's water resources, with 70% of global freshwater withdrawals being directed to irrigation [10]. Agriculture quite relies on water which is mainly climate driven in arid and semi-arid regions and production is highly impossible in the dry season without irrigation by increase needs on smaller land areas. Irrigation agriculture is going to be important when facing the water shortage. However, by 2030, the world seems to be facing a threatening water challenge by increase in global water requirements greater than 40% than current supplies, and one-third of the world's population, mostly in developing countries, might live in areas where this deficit is larger than 50% [1]. About 6,000,000 ha of the additional area could be irrigated if seepage loss is prevented, however, seepage from canal can't be controlled completely. A well maintained canal with a 99% perfect lining minimizes about 30-40% of water seepage loss [16].

Amol Kulkarni, Research Scholar, Center for Studies in Resources Engineering, Indian Institute of Technology, Bombay, India., +91 9850415446

R. Nagarajan, Professor, Center for Studies in Resources Engineering, Indian Institute of Technology, Bombay, India

The study carried to estimate seepage losses in lined and unlined sections of canal irrigation network in Panchnadi Minor Irrigation Project. It was determined under the existing situation and the scenarios shown that conveyance efficiency was increased from 52% from 75% by providing the lining to the canal [7].

The research carried out by [15] focused on conveyance losses in irrigation systems in the developing countries as these are the main systems to supply the water for irrigation. The research was mainly focused on conveyance losses evaluation in lined and unlined tertiary channels irrigation supply system at South Asia (Pakistan/India). As per the results, in Pakistan, almost 43.5% of the water losses occur in lined watercourses and 66% losses in unlined watercourses and in India 11% of water losses occur in lined watercourses and 20-25% in unlined watercourses.

Currently, various irrigation projects are struggling with conveyance efficiencies due to seepage losses, evaporation, and percolation of water, cracks and other damages in lined as well as earthen canals. Out of these losses, seepage loss is quite significant in most of the water conveyance systems. Overall, the water conveyance losses from canals need to be curtailed for better performance and efficient water utilization. Seepage loss estimation from large canals is quite difficult using ponding method due to continues flow and large canal dimensions [17]. Reference [17] studied in Kim branch canal, Gujrat and seen that using brick lining, P.C.C lining, P.C.C with L.D.P.E film as lining, seepage losses can be reduced to nearly 87.68%, 99.3%, and 99.7% respectively. The seepage losses are very significant out of other conveyance losses like percolation, cracking, damaging, evaporation etc. in any irrigation system. Various methods empirical and analytical were used to estimate the canal seepage rate and were compared with field measured results. Indirect measurement methods like a Variable head test, Davis and Wilson formula, Mortiz Formula (USBR), Molesworth and Yennidunia and Pakistanian Formula were used for seepage computation at different critical sections of the study canal system. A study conducted on Kakrapar right bank canal the seepage loss calculated by different empirical formula varies from 5.19 m3/s to 1.43 m3/s [8].

The research carried out by [9] on the Dadu canal for effect of the canal lining and it has been observed the use of lining reduces the seepage loss to 40% from 50% and it has also been seen conveyance efficiency increase from 70% to 90%. The study has been also concluded that canal lining helps not only reducing seepage losses but also minimize the water logging, silting and overall cost of maintenance for canals. In addition to it, flow velocity, conveyance efficiency and cropping intensity can be increased. Authors supported the initial investments over canal lining seem to be very high, but canal lining is a sustainable step which proves to be very economical in terms of long term benefits. The permeability of the soil is the most important parameter for while estimating seepage loss e.g. canals built on clay soil is most impervious than the canals built on sandy soil. Geometric parameters like the shape and canal dimensions of the canal, depth of water table and canal bed are important for seepage loss estimation. Seepage losses increase with increase in water level in canal and also the level of water table. Sediments present in canal fills the pores in canal bed and minimize the seepage loss. Seepage losses from branches infiltrates into the ground water causes the water logging and salinity which affects surrounding land and its produce [19].

The study carried out by [3] to assess the difference between water losses from unlined (earthen) and lined canals from a particular area of Indus Basin of Pakistan. As a result, it has been observed that in the lined canals could save around 22.5% water than unlined canals. In addition to this, the lined canals assessed were in poor conditions and lining was deteriorated along few cracks on the side walls. In addition, it is also seen lining reduce the capacity of the water course due to overtopping and silting. Reference [13] conducted a study for comparing different methods for computing seepage losses in earthen water courses (unlined canals). the study conducted on earthen water course IR Qaiser minor the water loss has been estimated to 30.895%. Reference [12] compared the losses calculated experimentally by the different researcher on different canals around the world. The author have tried to review various research work and recommended an average water loss from the canal irrespective of the soil and other environmental condition.

In this paper, the empirical formulae and analytical equations were used for computing seepage losses and prioritization of its canal sections based on the seepage loss for Dudhganga Left Bank Main Canal (LBMC). The empirical formulae are more reliant on the characteristic of soil for unlined channels & lining material for lined canals as numerical parameters indicated are subject to the porousness soil composition and sort of lining material. It was also assessed that potential water saving with help of providing various conservation measures which are useful for designing unlined canals and providing a different type of lining for a reduction in seepage loss. Overall, this tool will be helpful for early planning for any maintenance work where priorities need to be decided to manage operational costs.

II. Study Area

The proposed study area is Dudhganga Basin along with its Irrigation Canal System command area in Kolhapur district in the Maharashtra state of India. The dam is situated at Asangon in Radhanagari Tehsil of Kolhapur District. Dudhganga Irrigation project is a joint venture of Govt, of Maharashtra and Govt, of Karnataka. The total irrigable command area of the project is 59933 ha which shares as 46937 ha in Maharashtra and 12996 ha in Karnataka.

The Figure 1 shows the location of the Dudhganga Irrigation Canal Command Area. Dudhganga Major Irrigation Project site is situated approximately 65 Km from Kolhapur. The study area is bounded by North latitude 16° 7′ to 16° 37′ and East longitude 73° 53′ to 74° 20′.

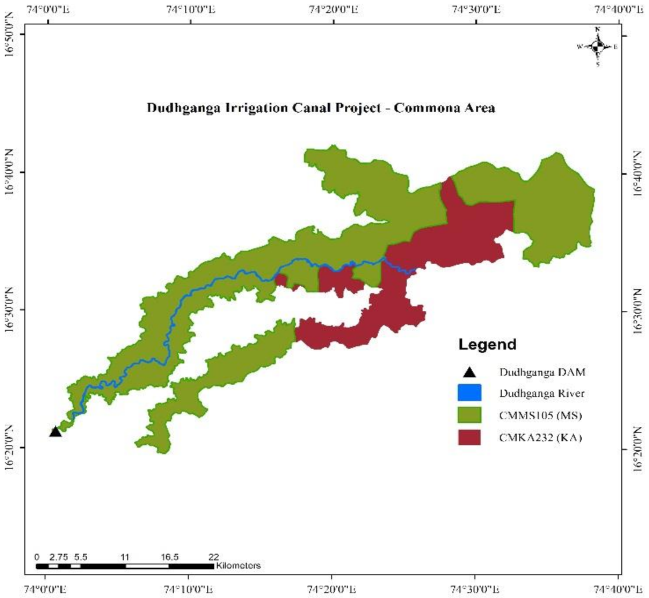

Fig. 1 – Location of Dudhganga Irrigation Canal Project - Command Area

The project benefits to Kolhapur district of Maharashtra state and Belgaum district of Karnataka state. The total culturable command area of the project is 81,092 hectare and Annual Irrigation is 81975 hectare. A combined canal off taking from the dam and bifurcating into left bank canal system 200 Km long and right bank canal system 201 Km long together with branches in the Panchganga and Vedganga Valley to provide irrigation, partly by flow and partly by lift [5].

III. METHODOLOGY

Seepage loss is quite dominant way of water loss though any canal system and its exact estimation is very complex process. However, forecasting of seepage is quite important for effective operations planning and better irrigation management. Seepage rates can be measured using field techniques and other estimating methods. However current study have used the empirical formulae and analytical methods to estimate the seepage losses from unlined and lined canal sections with reference to their design conditions in terms of materials, dimensions and discharges.

Reference [1] has discussed in his book that many factors known to have definite effects on seepage rate are and few Characteristics of the soil of the canal bed strata like texture, porosity, permeability, length of time the canal in operation - canal age, top width and wetted perimeter of the canal, canal dimensions/geometry, depth to ground water, depth of the water in canal, temperature of the water and soil, sediment load in the canal, salinity of water and soil etc. Number of soil properties and qualities are important to the design, operation, and management of irrigation systems, including water holding capacity, soil intake characteristics, permeability, soil condition, organic matter, slope, water table depth, soil credibility, chemical properties, salinity and pH [20]. In case of lined canals, lining material laid resist seepage of water. Ideally, lining should stop seepage loss however it gets damaged along with time. Damage like cracks develops along the perimeter due to various reasons like weeds growth, construction defects, quality of lining material etc. [17].

The cut-off (canal design) data acquired from Dudhganga Irrigation Canal Division, the Dudhganga LBC is combination of lined and unlined sections. Following empirical formulae and analytical methods used for estimating seepage loss.

A. *Empirical Formulae*

- **Davis and Wilson Formula**

These authors suggest the following formula for the estimation of seepage in lined and unlined canals (UPWSRP Guidelines, 2010)

$$\mathbf{S = [0.45*C*h^{1/3}/(4*10^6+3650*V^{1/2})]*P*L*10^6}$$

where:
S is the seepage, in m3/sec,
h is the water depth, in m,
V is the flow velocity in the canal, in m/s,
P is wetted perimeter in m,
L is length of canal section in m,
C is a numerical coefficient whose value depends on the type of soil or lining

- **Mortiz Formula (USBR Method)**

The USBR utilizes the following formula for estimating seepage from unlined canals (Koradiya et al., 2014),

$$\mathbf{S = 0.2 * C * (A)^{1/2}}$$

where:
S is the seepage in ft^3/s /mile of canal,
A is the wetted area of canal in (ft^2),
C is a constant whose value depends on the type of soil,

Following are the recommended values for the coefficient “C”:

For sake of simplicity, above formula is converted into metric units and further simplified as below,

$$\mathbf{S = 0.0117 * C * (A)^{1/2} * L}$$

where:
S is the seepage in m^3/s per canal section,
A is the wetted area of canal in (m^2),
L is the length of canal section in Km.

- **The Egyptian Formula**

Following is a formula adopted for design by the Egyptian Department of Irrigation (Singh et al., 2013):

$$\mathbf{S = C * L * P * R^{1/2}}$$

where:
L is the canal length in km,
R is the hydraulic radius in m = (A / P),
P is the wetted perimeter in m,
A is the wetted surface area in m^2
C is a numerical parameter whose value varies from 0.0015 for clay to 0.0030 for sandy soils.

- **India - Punjab State Formula**

As per UPWSRP Guidelines (2010), in Punjab, the following formulae have been reported as recommended for the estimation of seepage losses in irrigation canals:

For unlined canals:

$$\mathbf{S = 1.90 * Q^{0.0825}}$$

For lined canals:

$$\mathbf{S = 0.35 * Q^{0.056}}$$

where, in both formulas:
S is the seepage losses, in m3/s per million m^2 of wetted perimeter
Q is the discharge in the canal, in m3/s

B. Analytical Methods

- **Molesworth and Yennidunia Equation**

Deduced analytical formulae to estimate seepage losses which are written as follows (Mowafy, 2001);

$$\mathbf{S = as * Q}$$

where:
S : the seepage loss in m3/s/km;
$as = 0.375*10^{-4}/(R^{1.166}*i^{0.5})$
Q is the discharge in the canal, in m3/s
R is the hydraulic radius in m = (A / P),
P is the wetted perimeter in m,
A is the wetted surface area in m^2
i : the bed slope

- **Seepage Function by Swamee et al.**

The seepage analysis for these canal sections can be done based on equations derived from Swamee et al (2000). The seepage loss from a canal in open channel flow conditions is limited and maximum when the potential difference is very large and it happens when water levels is quite below. The steady seepage loss from unlined open canal and damaged lined canal in consistent and isotropic permeable media can be expressed as equation below,

$$q_s = ky_nFs$$

where,
q_s = Seepage discharge per unit length of canal (m^2/s)
k = Coefficient of permeability (m/s)
y_n = Normal depth of the flow in the canal (m)
F_s = Seepage function of channel geometry (dimensionless)

The seepage function can be estimated for specific canal conditions or dimensions. It is quite difficult and inconvenient to estimate the seepage loss from the existing and in design canal conditions due to unknown implicit state variables and improper fundamentals required.

The Swamee et al (2000) simplified the numerical methods for easy estimation of seepage loss for various design sections. For trapezoidal section the seepage function is given by equation below,

$$F = \left(\{[\pi (4 - \pi)]^{1/3} + (2m)^{1/3}\}^{(0.77+0.462m)/(1.3+0.6m)} + (b/y)^{(1+0.6m)/(1.3+0.6m)}\right)^{(1.3+0.6m)/(1+0.6m)}$$

where,
m = Side Slope,
b = Width of Canal
y = Depth of flow

The canal sections were created in GIS and design data was attributed provided by Irrigation Department, Kolhapur. The seepage analysis was done for Dudhganga Left Bank Canal and seepage loss for each was estimated. The results would be helpful to designing the lining for under construction unlined canal sections. Table 1 show the seepage loss estimated for each reach of Dudhganga Left Bank Canal at their design conditions.

The flowchart shows in the Figure 2 describes the approach used for estimating the seepage loss while developing the Seepage Loss Estimation Tool as backend process. The methodology consist of soil texture for unlined canals and lining material for lined canals while assigning the coefficient of permeability for calculating seepage loss using empirical formulae and analytical equations. Based on the seepage loss canal reaches/sections got prioritized as low, medium and high classes.

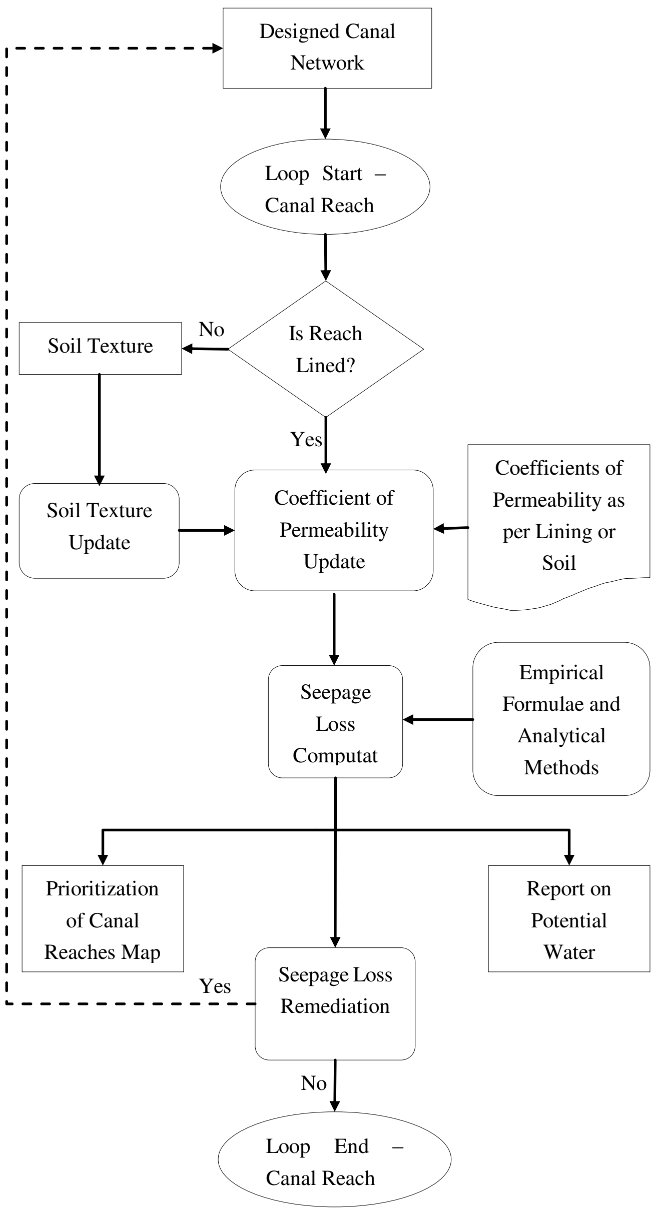

Fig. 2 – Geo-Spatial Approach for Conveyance Loss Modelling and Conservation Planning

IV. Results

Dudhganga Canal Division No.1 shared the cutoff statement for Left Bank Canal which ranges from 0Km to 76Km. Cutoff data consist of hydrodynamic information about the main canal like Chainage, Calculated Discharge, Length, Bed Width, Side Slope, Bed Slope, Full Supply Depth (FSD), Velocity, Manning's Constant and B/D Ratio. Figure 3 shows the various canal reaches along with the cutoff data. Dudhganga LBC is consisting of 13 reaches with different lengths with respective calculated discharge data.

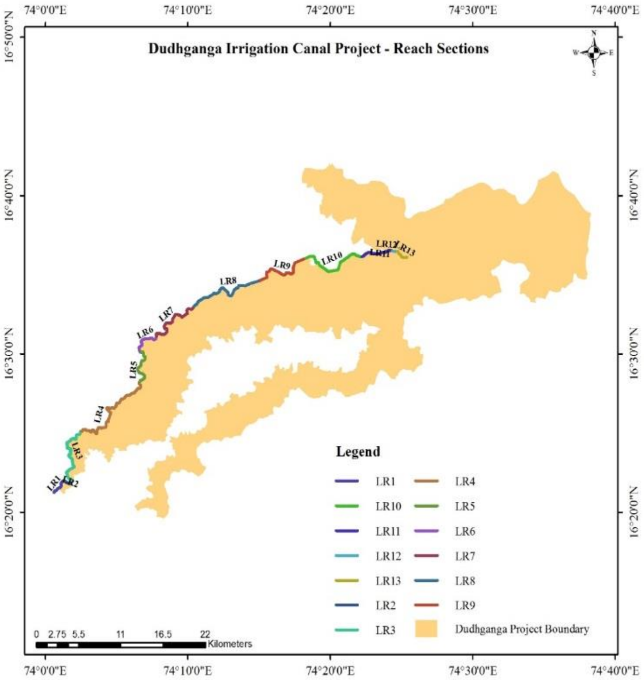

Fig. 3 – Dudhganga Left Bank Main Canal – Reaches/Sections

Figure 4 show the user interface of the Seepage Loss Estimation Tool has been built using Python Scripting on ArcGIS platform to compute the seepage loss for each canal section as per the methodology proposed. User has to input the canal network in terms of shapefile or feature layer with the canal information. Figure 5 is showing seepage losses using different method with various model conditions. Based on results, canal reaches were prioritized for conservation planning as shown in Figure 6.

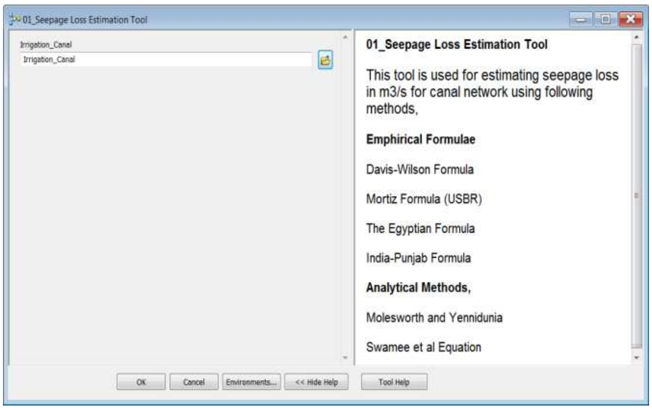

Fig. 4 – User Interface of the Seepage Loss Estimation Tool

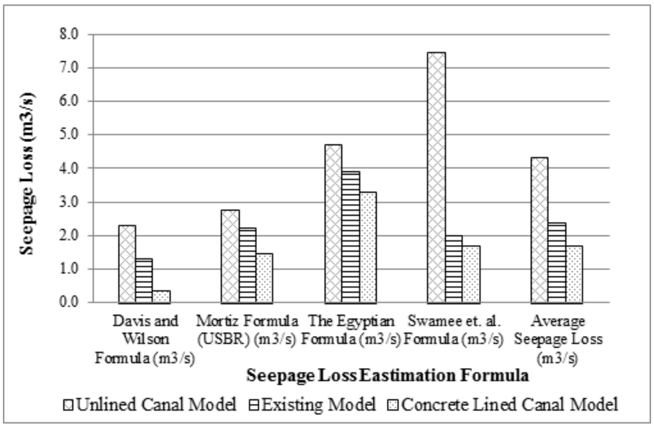

Fig. 5 – Dudhganga Canals - Comparison of Seepage Losses Estimated using Different Methods

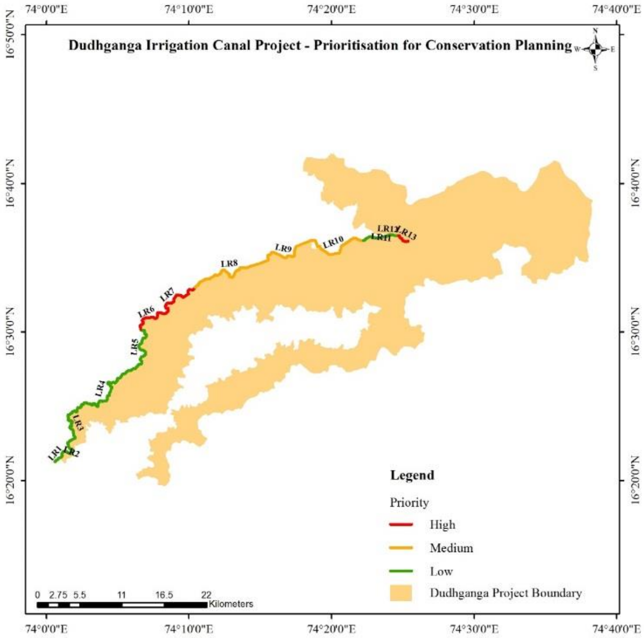

Fig. 6 – Dudhganga Left Bank Main Canal – Prioritization for Conservation Planning

V. Conclusion

The minimum seepage loss occurred at LR1 to LR5 sections which are lined and maximum seepage losses occurred at sections LR6, LR7, LR8 and LR13 which are unlined.

The results of computed seepage losses by empirical formulae, Davis and Wilson Formula predicts least seepage loss and Egyptian Formula predicts most seepage loss.

The seepage calculated by these methods needs to be verified with seepage determined by any of the direct methods in the field. The verified method with field method could be used for designing the unlined sections of the Dudhganga Irrigation Canal Network.

Canal sections LR6, LR7 and LR13 needs immediate attention to address the significant seepage losses. Different measures needs to be applied to conserve the losses like lining. Seepage losses considerably minimized by using concrete lining as solution. Average 31.3% losses can be minimized by providing all canal sections with concrete as lining material.

Considering canal operation schedules for 60days, approximately 4.017 Mm3 water can be saved by providing concrete lining to all canal sections. With the water saved, considering Wheat production, additional 1004 Ha Wheat can be cultivated.

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ABOUT THE AUTHORS

Amol Kulkarni, GISP, CGeog (GIS), FRGS, Amol Kulkarni is Lead GIS Analyst with MWH now part of Stantec (ResourceNet) India Pvt. Ltd, India, having more than 13 years' experience in Remote Sensing and GIS applications in various core engineering fields including Water Resources, Water/Wastewater Modelling, Watershed Management, Flood Risk Management, Irrigation Canal Loss Management, Forestry and Ecology etc. Along with his current job, Amol is pursuing his Doctorate in Philosophy (PhD) as an external student from India's premier institute, Indian Institute of Technology (IIT) Bombay. He is carrying out his research in developing geo-spatial model to analyze the conveyance losses and optimize the irrigation canal network.

Prof. R. Nagarajan, Professor R. Nagarajan, is with Center of Studies in Resources Engineering, Indian Institute of Technology, Bombay, India. He obtained his Masters and Doctoral degrees from Indian Institute of Technology, Bombay. He was with Asian Institute of Technology, Bangkok and Aston University, Birmingham, UK. His areas of research interest include the application of satellite remote sensing and Geospatial information attributed to natural resources assessment, monitoring, environmental assessment and natural and man-made disaster and assessment. His current activities are on the water demand and supply and water stress assessment in the present and anticipated climatic conditions of villages as well sub-basins of Krishna River, over the semi-arid region of Peninsular India.

Recent years, his focus is on the formation, sustenance and probable outburst of Glacier Lakes in the western Himalayas. He has completed several research projects and contributed publications in the journals as well as books.