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Research Article

Hydrospatial Modelling and Simulations for Assessing the Irrigation Canal Conveyance Losses

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Since last few decades, the extensive underutilization has been found in canal irrigation. This issue constitutes the serious lacuna in irrigational planning which often depicts the major problem about optimal water use. As per FAO Aquastat 2015 records for India, out of 91% of water utilized for agriculture purpose, 45% is getting lost under different types of conveyance losses from dam headworks till farms. The conveyance losses constitute the seepage and evaporation losses. Out of these, seepage is a quite significant loss in most of the water conveyance systems. Estimating conveyance losses using physical methods is quite difficult and involves lots of field work and calculations, whereas empirical and analytical methods will not accommodate site condition of respective study area. This study attempted to assess the conveyance loss of Dudhganga Right Bank Main canal with the help of a hydraulic model built on a spatial platform and verified with flow-monitoring events. The hydrospatial model was simulated to understand the canal behaviour and evaluate the conveyance losses. The results show Dudhganga Right Bank Main canal has average 39.96% water conveyance loss.

1. Introduction

Global agricultural production is heavily dependent on irrigation; however, it has been seen that efficiencies of irrigation systems are often amazingly low. Regional patterns in beneficial irrigation efficiency are found, which are an indicator showing water consumption in crop productivity; due to differences in these features, South Asia and sub-Saharan Africa have the lowest value (less than 30%), while Europe and North America have the highest values (greater than 60%). Present irrigation efficiencies are mostly seen below 50%, as diverted water is considerably lost in the conveyance system or through inefficient farm applications [1].

India is one of the small numbers of countries in the world provided with plenty of land and water resources. The estimated average rainfall is more than 4000 km^3, which is distributed spatially over 329 mha and helps cultivation in 165.3 mha [2]. The southwest monsoon controls the Indian climate and mostly receives its water. Approximately 60 percent of Indian arable land is dependent on rain , and it becomes reason of low productivity, low income, and low employment with high rate of poverty [3, 4]. As per FAO Aquastat 2015 [5], in India, approximately 91% of available water is utilized for agriculture purpose, which is quite high compared to municipal and industrial sectors, out of which approximately 45% of water is lost during its conveyance from the head of canal till it reaches the agriculture fields. According to the Indian Standard, the water loss from unlined canals in India varies from 0.3 to 7.9 m^3/s per 10^6 of wetted surface and about 6,000,000 ha of additional area could be irrigated if this loss gets prevented. Canal irrigation is a major conveyance system for delivering water for agriculture in the alluvial plains of India; however, the conveyance loss from irrigation canals constitutes a substantial percentage of the usable water [6]. However, seepage from canal cannot be controlled completely. A well-maintained canal with a 99% perfect lining minimizes about 30–40% of water seepage loss [7].

Currently, various irrigation projects are struggling with water loss during its conveyance due to seepage losses, evaporation, 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. The evaporation loss in irrigation networks is generally not taken into consideration because it is only 0.3% of total stream loss, whereas major portion of 98.37% is due to seepage [7]. It is one of the major problems for Ministry of Irrigation and Water Resources that about 80% of the water conveyance system length is passing through the silt and clay soil. It affects water surface profiles, slope, discharge, and water level [8]. The research carried out by Sultan et al. [9] focused on conveyance losses in irrigation systems in the developing countries as these are the main systems to supply water for irrigation. The research was mainly focused on conveyance losses evaluation in the lined and unlined tertiary channel irrigation supply system in South Asia (Pakistan/India). As per the results, in Pakistan, almost 43.5% of the water losses occurs in lined watercourses and 66% losses in unlined watercourses, and in India, 11% of water losses occurs in lined watercourses and 20–25% in unlined watercourses.

The water conveyance losses from canals need to be curtailed for better performance and efficient water utilization, and accurate estimation is quite important to propose solutions and prioritize the maintenance activities. The water loss estimation from large canals is quite difficult using physical methods like ponding method and involves lots of field work and calculations, whereas empirical and analytical methods will not accommodate site condition of the respective study area [10]. The simulation of water flow in irrigation canals may divulge the management deficiencies and support managers to find solutions to overcome those. These models can be used as suitable tools by incorporating all levels of canal distribution network with their dynamic parameters and model-control structures like gates, orifices, and other hydraulic parameters [11].

The Geographic Information System (GIS) is base for hydrospatial modelling because of its abilities and effective functionalities to store, retrieve, analyse, manipulate, and display large volumes of spatial digital data and to create maps. It accommodates all the geometric and hydrodynamic data like base width, top width, side slope, full supply depth, cross-sectional area, design discharge, etc., in the hydraulic model. The model verification with the help of a set of measured data should efficiently be used to simulate the existing canal conditions. This helps to understand the canal management shortcomings which impact the canal performance and further possible improvements.

Hydrospatial modelling based on the Geographical Information System (GIS) is used to carry out basic analytical processes for a given set of spatial features. The hydrospatial modelling is to be able to study and simulate spatial objects or events that occur in the real world and facilitate performance assessment using key performance indicators. This formulates criteria-based alternatives, comparing the data, evaluation models, analysis, and results in a user-specified format. Hydraulic models built with hydrodynamic data offer limitless opportunities for performance improvement of the irrigation systems through simulating and observing the flow in a large and complex canal distribution network using different design and management scenarios [12].

2. Study Area

2.1. Right Bank Main Canal of Dudhganga Irrigation Canal System. The Right Bank Main Canal (RBC) of Dudhganga Irrigation Canal System in Kolhapur district in the state of Maharashtra, India, has been used as the study area. The Dudhganga Dam (also known as Kalammawadi Dam) is located across Dudhganga River near Asangaon village in Radhanagari Tehsil of Kolhapur district. The Dudhganga Major Irrigation Project is an interstate project and the benefits are shared by the Governments of Maharashtra and Karnataka states. In total, 59,993 ha is the designed irrigation potential share between 46,937 ha in Maharashtra and 12,996 ha in Karnataka. The study area is located around 65 km away from Kolhapur and bounded by north latitude 16°7′ to 16°37′ and east longitude 73°53′ to 74°20′. The command area of the Dudhganga Irrigation Project is 772 sq. km and receives rainfall ranging from 6980 mm to 3170 mm per year from west to east.

Figure 1 shows the Right Bank Main Canal with 24 km length with 4 lined reaches. The Right Bank Main Canal is diverted from the Left Bank Main Canal at 3.29 km from headworks. The Right Bank Main Canal is lined with partially stone masonry and cement concrete material with 96 structures including bridge crossings, gates, tunnels, flumes, weirs, etc. The designed canal bed levels ranges from 581.111 m (upstream) to 574.616 m (downstream), maintaining 1 : 6000 bed slope. The designed canal width is 3.6 m with depth ranging from 2.99 m to 3.06 m. Designed discharge of the canal ranges between 23.089 cumecs and 21.520 cumecs [13].

2.2. Existing Condition of Right Bank Main Canal. The extensive filed work has been carried out through site visits, and it has been observed that the lining is degraded at various sections due to cracks. The unlined canals have seen issues of soil instability at many sections where erosion resulted in siltation. Maybe due to sudden changes in velocity, along with side slopes, canal bed also got scoured, which caused stagnant water pools. It has also been observed that side slope is covered with aquatic plants/vegetation even if the sections are lined. Weeds are found on side slope surfaces with considerable silt deposition on the canal bed. Figure 2 shows the existing condition of the Dudhganga Right Bank Main Canal at the selected sections.

From Figure 2, it is clearly seen that the study canal is degraded badly and the issues like siltation on canal bed, degraded lining, ponding due to bed scoring, and weeds on

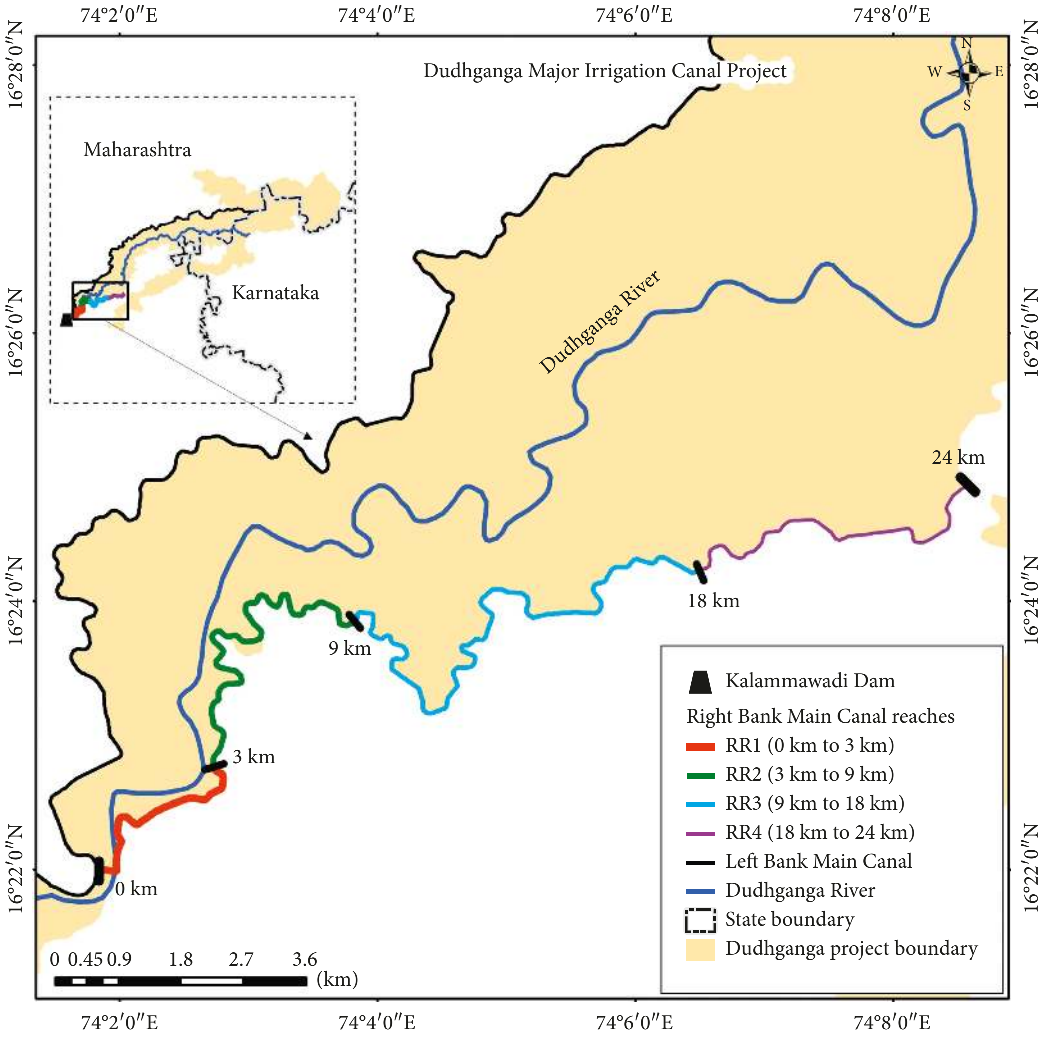


Figure 1: Location of Dudhganga Irrigation Right Bank Main Canal.

(a) (b)

Figure 2

the side slopes were identified, which eventually make an effect on the wetted area, velocity, and other hydraulic parameters. The stone with large diameter was found on the bed that may be dislodged from the sides or flown from upstream. Similarly, it has been seen in case of weeds on sides at lower levels.

3. Materials and Methods

3.1. Hydrospatial Model Build and Verification. The spatial and nonspatial data related to Dudhganga Irrigation Right Bank Canal were created using ArcGIS 10.4 software package. Database creation was the preliminary task involved in the conversion of various data sources into spatial formats. Considering the overall study, the database creation and canal model build is very critical part as far as accuracy of the results was considered. The canal design information usually known as the cutoff data acquired from Dudhganga Irrigation Canal Division used to build the canal model. The spatial model was built with the cutoff data shared by Dudhganga Irrigation Canal Division No. 1, which have all hydrodynamic information of the canal design. Initially, the design model was built and then the existing model was replicated by substituting the existing canal information to represent the current conditions.

There is a wide range of open channel simulation software packages which can handle canal flow simulation. The basic difference between those tools are the size of the irrigation network handling the simulations in one run and managing the type of flow running through the canals. Few tools handle only steady flow and some of them handle both steady and unsteady flow types. In this study, both the spatial models were imported into InfoWorks as open channel along with the nonspatial database. As shown in Figure 3, the InfoWorks hydrospatial model was built including trapezoidal cross-section profile with dimensions, bed levels, roughness data, and outlet points with offtake flow as specified by canal department.

The hydrospatial model was verified with different flow survey events collected during frequent field visits for different flow period. During the field visits, velocity and depth were measured at identified site locations along the canal reaches. At every site location, the canal cross sections were divided into five equal subsections, and velocity and depth at each subsection have been measured. Velocity was measured with the help of Propeller Type Water Current Meter (RK-01), and depths were measured with the help of wadding rod with 6-inch marking on it as specified by the FAO [14]. Average depth, wetted area, and other canal parameters were calculated and further used for discharge calculation using the area-velocity method at each site locations. The flow survey data in comma separated file format were imported into InfoWorks as measured data for model verification.

3.2. Estimation of Conveyance Loss Using Verified Hydrospatial Model. It is very important to measure water loss during its conveyance correctly for better management. There are two direct methods mostly used to measure the conveyance loss in the irrigation canals, inflow-outflow method, and ponding method [15]. In this study, conveyance loss was determined by the inflow-outflow method by using the measured data field survey work as this method is more suitable for long canals having few diversions.

To determine the conveyance losses by the inflow-outflow method, the following equation was used:

$$Q_{\mathrm{Loss}} = Q_{\mathrm{In}} - Q_{\mathrm{Out}} + Q_{\mathrm{Int}} - Q_{\mathrm{Div}}, \tag{1}$$

where Q_{Loss} is the conveyance/transmission losses (m^3/s), Q_{In} is the inflow to the reach (m^3/s), Q_{Out} is the outflow from the reach (m^3/s), Q_{Int} is the intervening inflow (m^3/s), and Q_{Div} is the total of diversions from the reach (m^3/s).

With the help of equation (1), all links in the verified model were analyzed to estimate the conveyance loss for each reach. Verified model links were part of canal reaches where existing conditions were modelled. Reach-based conveyance loss was calculated as the final output.

4. Results

4.1. Hydrospatial Model Build and Simulation. Due to nonavailability of canal flow data at Dudhganga Canal Division, carrying out flow surveys was absolutely essential for the study. Depending on canal maintenance days from irrigation department, between April 2017 to May 2017 and November 2017 to March 2018, field data were measured and used for model verification for simulated results. To increase the accuracy of model predictions, periodical flow monitoring, assessment of physical conditions, and model calibrations need to be carried out. The simulated and measured depth, flow, and velocity graphs for four flow measurement locations, FM1 to FM4, along the Right Bank Main Canal are shown in Figure 4.

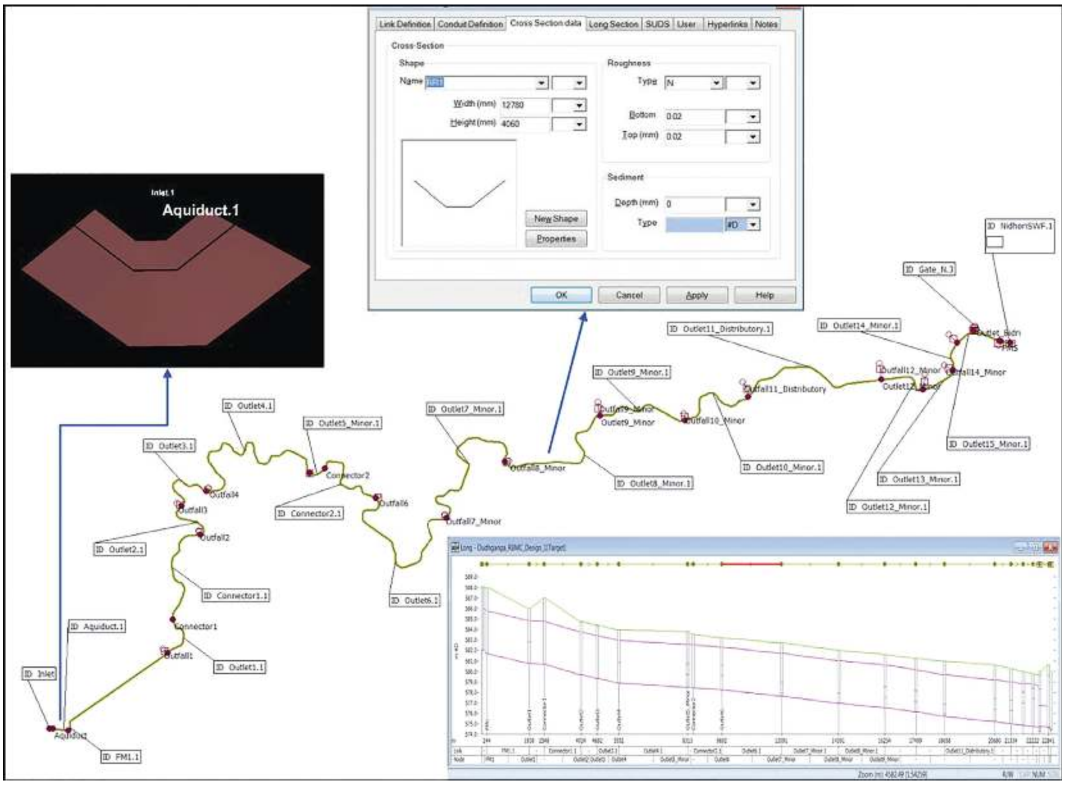
4.2. Estimation of Conveyance Loss of Dudhganga Right Bank Main Canal. The verified hydrospatial model sections were analyzed for inflow of 450 cusec, and conveyance loss was estimated with the help of equation (1). Figure 5 shows the percent conveyance loss estimated for each reach of Dudhganga Right Bank Canal. Reach RR2 is predicting high conveyance loss.

In addition to this, the verified model was also simulated for different inflows of 815 cusec (design), 750 cusec, 650 cusec, 550 cusec, and 450 cusec (inflow during flow measurement), and it predicts lower conveyance losses for higher inflows as shown in Figure 6.

5. Conclusion

The Dudhganga Irrigation Right Bank Main (RBC) Canal was modelled in ArcGIS and InfoWorks with hydrodynamic (cutoff data) parameters. Overall, the study observed the following conclusions:

(i) The Dudhganga Right Bank Main Canal was found in highly degraded condition, devastated with unwanted dense vegetation (aquatic weeds), cracks in canal lining, fractures on sides, and silt deposition on bed slope at different reaches. Overall, these hydraulic changes resulted in considerable conveyance performance. Reach RR2 predicted higher conveyance loss than other reaches.



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Depth (mm) 0
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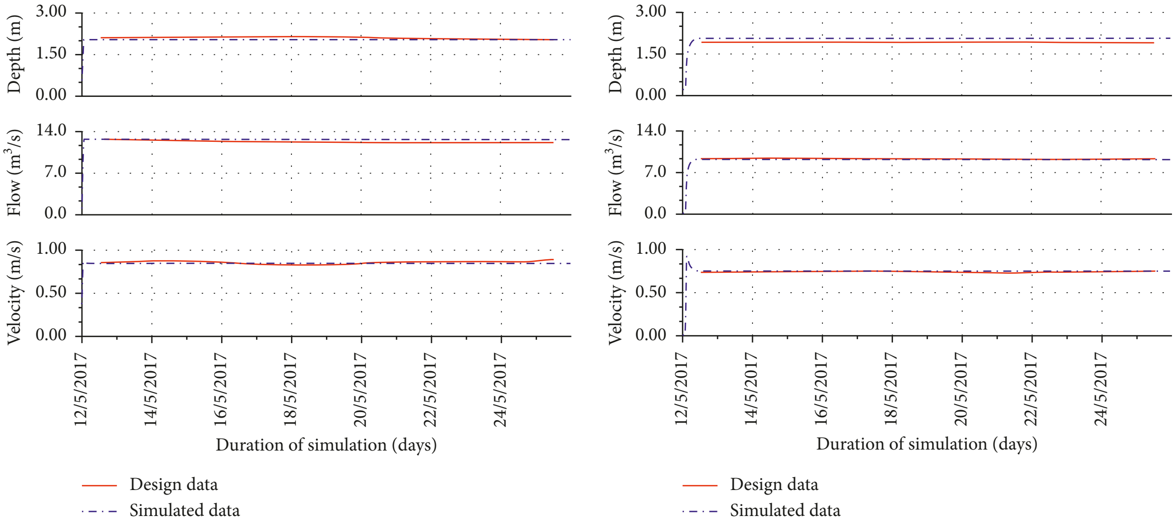
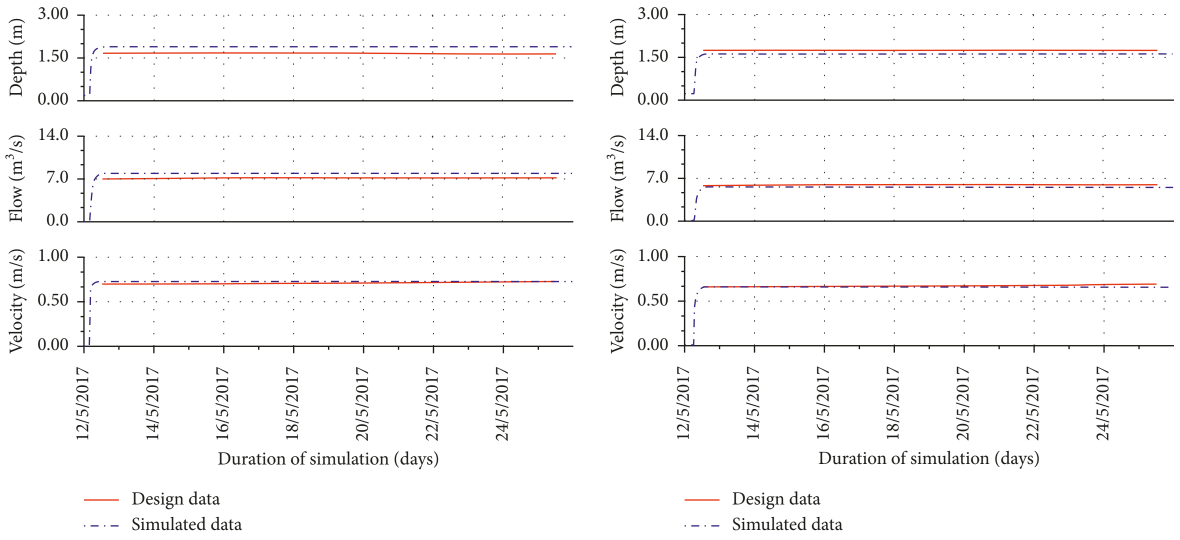
Figure 3: Hydrospatial model build of Dudhganga Right Bank Main Canal.



(a) (b)

Figure 4: Continued.



(c)

(d)

Figure 4: Graphs of simulated vs. measured data for flow-monitoring (FM) locations. Flow survey location (a) FM1 (0.4 km) simulated at inflow 450 cusec, (b) FM2 (9 km) simulated at inflow 450 cusec, (c) FM3 (16.8 km) simulated at inflow 450 cusec, and (d) FM4 (24 km) simulated at inflow 450 cusec.

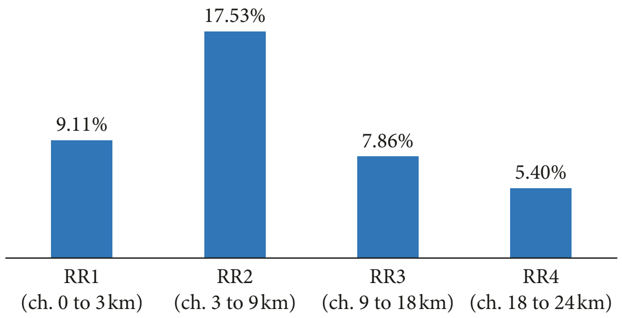


Figure 5: Estimated conveyance loss for each reach of Dudhganga Right Bank Main Canal.

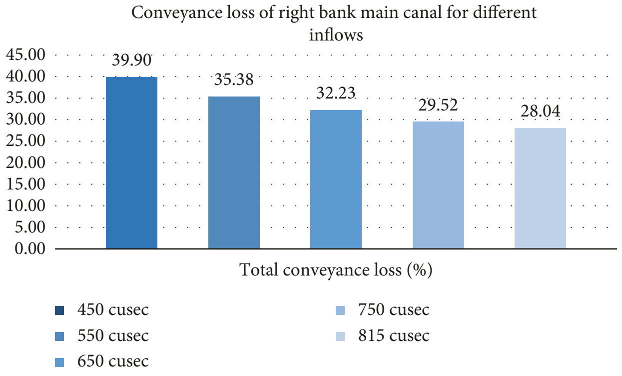


Figure 6: Estimated conveyance loss for different canal inflows.

(ii) Simulations (with present situation) of canal flow were carried out for different canal inflows: 450, 550, 650, 750, and 815 cusec. There is 39.90%, 35.38%, 32.23%, 29.52%, and 28.04% of conveyance loss at 24 km, respectively. The same canal was showing this behaviour for different inflows may be due to shallow depths for low water release.

(iii) The hydrospatial models verified with measured data are useful to simulate real-time user-defined conditions and scenarios for analyzing performance indicators. It has an edge over the conventional applications in a way that it incorporates a greater level of optimization to assist the process of decision-making in a very flexible way.

Data Availability

The Dudhganga Irrigation Canal-related data used to support the findings of this study are included within the article. The data related to existing condition of canal data including canal degradation, dimensions, flow survey, hydraulic model, and verification of model used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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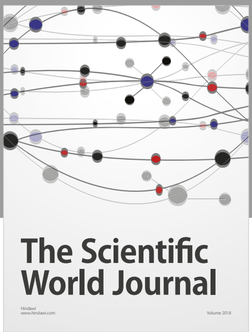
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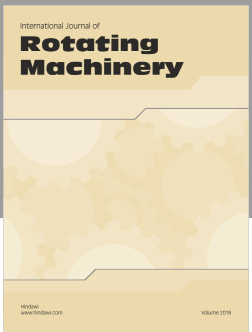
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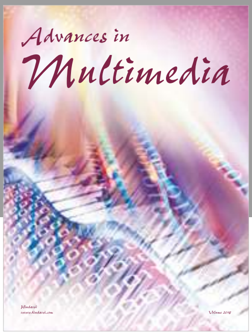
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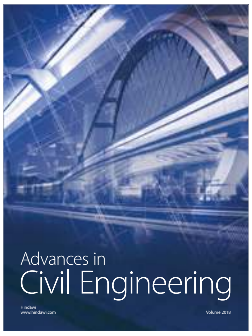
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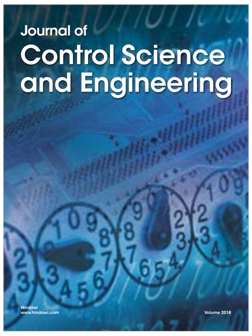
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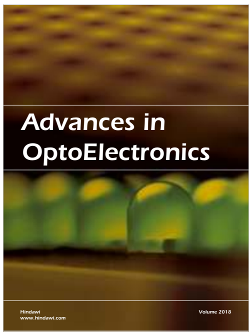
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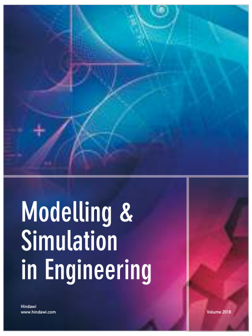
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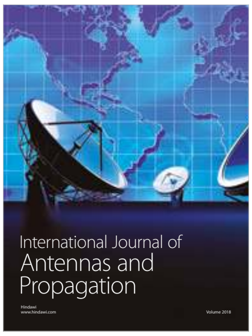
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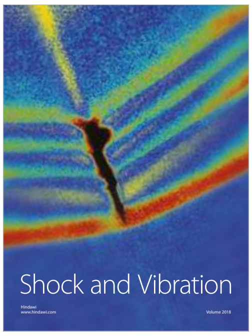
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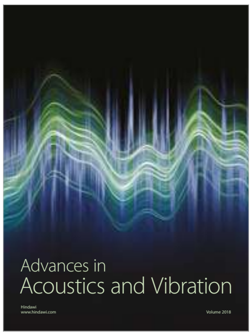
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