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Research paper

Vegetation growth impacts conveyance efficiency of irrigation canals - a geo-drone approach

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Abstract

In spite of canals are most important conveyance systems for delivering water for irrigation in the alluvial plains of India, many irrigation canal projects are suffering from massive growth aquatic plants along the canal sides known as aquatic weeds and siltation along canal bed. Aquatic weeds are unwanted plants playing a very important role in different eco-systems and many of them cause enormous direct and indirect losses. The losses include interference with the cultivation of crops, loss of biodiversity, loss of potentially productive lands, loss of grazing areas and livestock production, erosion following fires in heavily invaded areas, choking of navigational and irrigation canals and reduction of available water in water bodies. Also, it has been found that it severely reduces the flow capacity of irrigation canals thereby reducing the availability of water to the farmers. The vegetation on bottom and sides of the canal increases the roughness resulted into a decrease in velocity which further leads to silt deposition on canal bed which affects the canal functions. The complexity of these situations has resulted in a need for identification of impact of weeds on the hydraulic efficiency of canals. For accurate identification of weeds, low altitude drone survey becomes an innovative solution than other conventional methods. This study captured vegetation along the canal using the drone images and estimated roughness shows, the reduction in conveyance efficiency by 21.90% compared with design data.

Keywords: *Conveyance; Drone; Efficiency; Roughness; Weeds.*

1. Introduction

Different irrigation schemes did not satisfy the net irrigation demand even though the available water is adequate, due to high losses at storage, during conveyance, and reduction in efficiency due to damage into hydraulic parameters like cross-section area, perimeter, roughness and design velocity. Identifying the level of damage and knowing what improvements can be made are essential in making most effective use of vital water resource. As available water resources become scarcer, more emphasis is given to the efficient use of irrigation water for maximum economic return and water resources sustainability [7]. Water conveyance loss consists mainly of operation losses, evaporation and seepage into the soil from the sloping surfaces and bed of the canal. The seepage loss in the irrigation canals accounts for the major portion of water conveyance loss (98.37%) while approximately 0.3 percent of the total stream is lost due to evaporation [1]. The damage to the canal hydraulic parameters triggers to seepage losses, therefore, the assessment of the potential cause of canal hydraulic inefficiency is vital for the sustainable functionality of irrigation schemes [6].

Aquatic weeds may be defined as upsetting or unsightly plants growing where they are not wanted. These plants are either adapted to continuous supplies of water or are at least tolerant to water-logged soil conditions for substantial periods of time. Weed problems quite dominant particularly in a topic area, since the high year-round temperatures boost plant growths and curtail the lifecycle of plants. This impacts on the large accumulation of organic material releasing nutrients further stimulate more growth. Mostly seen, irrigation and drainage systems are constructed with unlined earth canals, with relatively slow flow velocities to prevent excessive erosion (usually in the places of 0.5 m/s) often contain slow moving or stagnant water. Such distribution systems and the drainage canals are favorite places for growing aquatic weeds. The wide range of adaptation to varying amounts of water and the impossibility of sharply distinguishing between aquatic and terrestrial environments makes it difficult to precisely define an aquatic plant. The level of this problem in irrigation canal is a replication of lack of consideration of potential growth aquatic weeds in canals while designing the canal system as well as the poor maintenance [4].

In India, many rivers, irrigation canals and water bodies are blocked by the extensive growth of aquatic weeds which results in huge direct losses. Although there isn't a precise estimate of the losses caused by aquatic weeds however it is estimated that the submerged aquatic weeds cause 50% to 60% loss of water of the cultivable water in Assam, Bihar, Madhya Pradesh, Orissa, Uttar Pradesh and West Bengal. Several irrigation projects in India are in danger of destruction by the massive growth of aquatic weeds in dam reservoirs e.g. Tungabhadra in Karnataka, Nagarajan Sagar project in Andhra Pradesh and Kakki and Idikki reservoirs in Kerala are in alarming situations due to the severe growth of aquatic weeds. It has been also reported that aquatic weeds had cut the flow of water by 80% in the canals system [8].

In any irrigation canal system, maintaining the limiting velocity of the flowing water is an important parameter for appropriate functioning and expected the performance of the canals. The velocity more than permissible results in scouring and erosion of the canal however velocity less than permissible impacts on silt deposition as well as helpful for the growth of unwanted plants. The velocity of the water is dependent mostly on roughness factor of material it is flowing, is roughness is less more would be velocity and vice versa. The roughness of the canal bed and sides is depending on the surface material and it's been seen loose material from movable bed has more roughness than the rigid boundary. The Manning's roughness coefficient for an ideally finished earthen canal is 0.016 to 0.020 [2] which is been normally considered while designing the canals. Vegetation reduces the effective flow area and increases the roughness. Vegetation growth is more pronounced in clear water; however, the nutrients in water with sediment may help the growth of weeds. The degree of obstruction by vegetation is highly variable and depends upon the type, height, density and flexibility of the vegetation, submerged or un-submerged conditions, water level, and flow velocity [3].

Historically, weed detection involved manual crop scouting and inspection. Such approach deemed greatly inefficient and time-consuming for farmers managing vast arable lands. Satellite images available freely won’t help much because of its low resolution and high-resolution images sometimes not viable due to its cost. With the advent of drones and advanced data analysis, weed detection can now be done in a seamless and sophisticated manner. Aerial drones provide high-resolution images which can be used as orthophotos in GIS. Introducing these georeferenced images into mapping software allows for accurate measurements, and this is used for survey and monitoring projects. For weed surveys, the aerial perspective allows detecting weeds that cannot be seen from ground level.

2. Study area

2.1. Left bank main canal of dudhganga irrigation canal system

The proposed study area is Left Bank Main Canal (LBC) of Dudhganga Irrigation Canal System in Kolhapur district in the Maharashtra state of India. The Kalammawadi dam is situated on the Dudhganga River at Asangon in Radhanagari Tehsil of Kolhapur District. Dudhganga Irrigation project is a joint venture of Government of Maharashtra and Government of Karnataka. The project is proposed to irrigate an area of 59933 ha (ICA). (46937 ha in Maharashtra and 12996 ha in Karnataka) partly by flow and partly by lift. The study area 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′. The total area of the Dudhganga Command is 722 Sq. Km and receives rainfall from predominantly from South-West monsoon ranges from 6980mm to 3170mm West to East.

The project benefits to district Kolhapur of Maharashtra and district Belgaum of Karnataka with Cultural Command Area (CCA) 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].

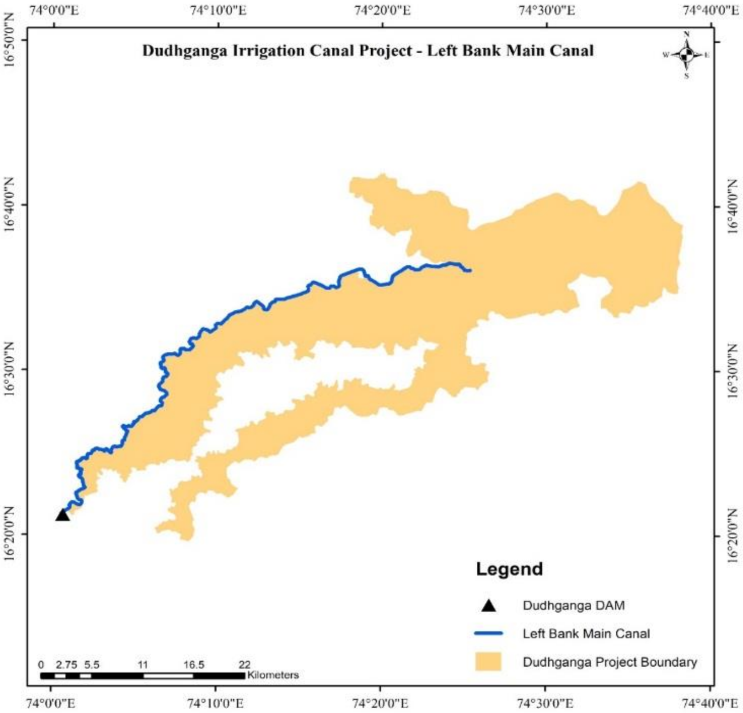

Fig. 1: Location of Dudhganga Left Bank Main Canal.

Left Bank Main Canal is having 76 Km length with total 13 lined and unlined sections/reaches. Currently lined till 41 Kms from dam headworks with partially stone masonry and cement concrete material and rest is still unlined. It consists of around 276 structures including flumes, bridge crossings, weirs, gates, tunnels etc. Headworks is getting controlled with manual gates. Canal upstream level starts at 583.58m and downstream level ends at 560.8m with the total head of 22.78m. Canal designed with bed width ranges from 10.31m to 4.3m and depth ranges from 4m to 2.85m. Designed discharge of the canal ranges between 74.825 Cumecs to 23.3 Cumecs.

2.2. Existing condition of left bank main canal

The frequent site visits have been carried out along the along the canal and observed the canal lining degradation at various sections and also seen cracks in the side slope linings. In case of unlined canals, issues with soil stabilization found in many sections are eroded resulting in siltation. Maybe due to sudden changes in velocity, in unlined canal sections, along with side slopes, canal bed also got scoured which caused stagnant water pools. It has been also observed that side slope is covered with aquatic plants/weeds in both lined and unlined sections. Weeds are found on side slope surfaces as well as on the canal surfaces. Photograph 1 shows the existing condition of the Dudhganga left bank main canal at the lined section and unlined section respectively.

Photograph 1: Low Altitude Drone Image for Interpretation of Weeds, Siltation and Cracks.

From photograph 1, it is clearly seen that due to siltation and excess weeding on the side slopes the canal dimensions which will impact the wetted area and result in velocity. There are large diameter stones found along the bed of the canal those may be slipped from the side slopes or traveled from upstream. Maybe due to high velocity along with aquatic plants these stones traveled all the way through bifurcation gates.

3. Methodology

3.1. Estimation of existing hydraulic characteristics

Irrigation canals transport water from the source to the farmers' fields. The discharge is the volume of water that is transported each second. The more fields that are served by a canal, the more water has to be transported. The rate at which water is transported by a canal is called its discharge, and the maximum discharge that any canal can transport is canal capacity. The method consists of estimating the average flow velocity (V), and measuring the area of the cross-section, called the 'wetted cross-section' (A).
The discharge (Q) can be calculated by the following equation 1:

$$Q = V * A \tag{1}$$

Where:
Q is the Discharge in m^3/s;
V is the Average Flow Velocity in m/s; and
A is the Area in m^2 of the Wetted Cross-section.
Manning's formula is most frequently used for estimating flow velocity as shown in equation 2. The results of Manning's formula, an indirect computation of stream flow, have applications in flow management, in flooding studies.

$$V = 1/n * (R)^{2/3} * (S)^{1/2} \tag{2}$$

Where:
V = mean velocity flow, in meters per second
R = hydraulic radius, in meters = A/P (Cross Section Area/Wetted Perimeter)
S = Bed slope, in meters per meter.
n = Manning's roughness coefficient.
Roughness coefficient n, represent the resistance to water flows in the canal. The roughness of the side slopes and canal bed is depending on the surface material and it's been seen loose material from movable bed has more roughness than the rigid boundary.
The roughness due to surface irregularities caused by a type of material, construction method, aging of the side slopes, rain cuts, bank sliding, maintenance, etc. The Manning's roughness coefficient (n) changes from base value considered during canal design. The changed roughness coefficient value gets changed which reflect the existing conditions which increase resistance to the velocity and further to flow. These conditions are based effects of obstructions by weeds along with weed density at its full growth which are derived by [2] of weed (vegetation) a correction to be added to Manning's 'n' in terms of Weed Factors as given in Table 1.
It is a simple way to incorporate the effect of weed is given by Chow (1983), who has suggested a classification of vegetation and a correction to be calculated to the Manning's n in terms of weed factor. The weed factor is defined as it is a ratio of roughness including weed factor to roughness without weed factor (initial roughness).
The actual roughness (Chow's n) can be calculated using Chow's weed factor using equation 3 as below which shows the roughness due to weeds.

$$\text{Chow's } n = \text{Weed Factor} * \text{Initial Roughness} \tag{3}$$

Table 1: Weed Factor for Different Types of Vegetation at Full Growth (Derived from Chow's (1983) Suggested N for Vegetation)

Category	Description	Weed Factor
Low	• Dense growth of flexible turf grass (h/hg =2–3) • Supple seedling tree switches (h/hg =3–4)	1.25–1.5
Medium	• Turf grasses (h/hg =1–2) • Stemmy grasses, weeds or tree seedlings (h/hg =2–3) • Brushy growth, moderately dense	1.5–2.5
High	• Turf grasses (h/hg =1) • Willow or cottonwood trees 8–10 years old • Bushy willows	2.5–3.5
Very High	• Turf grass (h/hg =0.5)	3.5–6.0

3.2. Comparing estimated and measured conveyance

Depending on canal maintenance days from irrigation department, during September 2015 to May 2016, frequent field visits have been carried out to measure the canal velocity and depth. The canal reaches LR1 to LR4 were selected for the data measurements. The end of each reach, field measurements were carried out. The canal cross section was divided into 5 equal parts and 5 readings of velocity and depth at each location have been measured.
Velocity was measured with help of current meter as specified by the FAO method and depths were measured with help of wadding rod with 6 inches marking on it. With help of water depth, the wetted area has been calculated. With help of calculated wetted area and average velocity, discharge was calculated at starting (Qin) and ending point (Qout) of the study section. The conveyance efficiency for canal reach was calculated with the equation 4 where the ratio of the volume of water delivered at the downstream end to the volume of water released at the upstream end of the canal section.

$$E_c = (V_d+V_2) / (V_c+V_1) * 100 \tag{4}$$

Where
E_c = conveyance efficiency;
V_c = volume of water at upstream canal end (m3);
V_1 = inflow, if any, from other sources within the section (m3);
V_d = volume of water delivered to the farmer (at the downstream end of the section) (m3);
V_2 = non-irrigation deliveries from the conveyance system (m3).
The Manning's roughness coefficient n has been estimated using equation 2, with help of the data measured for conveyance parameters like velocity, wetted are, and wetted perimeter during the field survey. The comparison was done between the roughness factor used while design, calculated using measured data and estimated using Chow's weed factor. This comparison would show how well Chow's method suitable for this study.

4. Results

Dudhganga Left Bank Main Canal first four sections were analysed based on the velocity calculation based on roughness factor. Due to dense vegetation (aquatic weed) on the side slope of the canal sections and silt deposition on canal bed affected to the conveyance efficiency.

The Manning's n corrected with help site condition as per values are given by Chow (1983) for weed factor. However, both of these n values show, due to exiting conditions of the canal, roughness is increased and velocity has been decreased considerably. The Figure 2 shows the comparison between design n, measured n and Chow's n.

Table 2: Dudhganga Left Bank Canal System – Computed and Designed Conveyance Efficiency at Different Locations along the Main Canal

At Km	Velocity (m/s)		Manning's n		Discharge (m3/s)		Conveyance Efficiency	
	Design	Existing	Design	Existing	Design	Existing	Design	Existing
HW	1.654	1.158	0.020	0.025	73.63	34.90	-	-
1.80	1.213	0.910	0.020	0.021	73.59	30.58	0.999	0.876
3.29	1.120	0.784	0.020	0.024	49.95*	21.61**	0.993	0.707
12.3	1.120	0.672	0.020	0.024	48.44*	11.78**	0.979	0.545
(Source for Design Data – Dudhganga Canal Division No. 1)								
* Design discharge 23.089 m3/s diverted to Right Bank Main Canal								
** No water released to RBC during field survey carried out				Canal Conveyance Efficiency			0.99	0.71

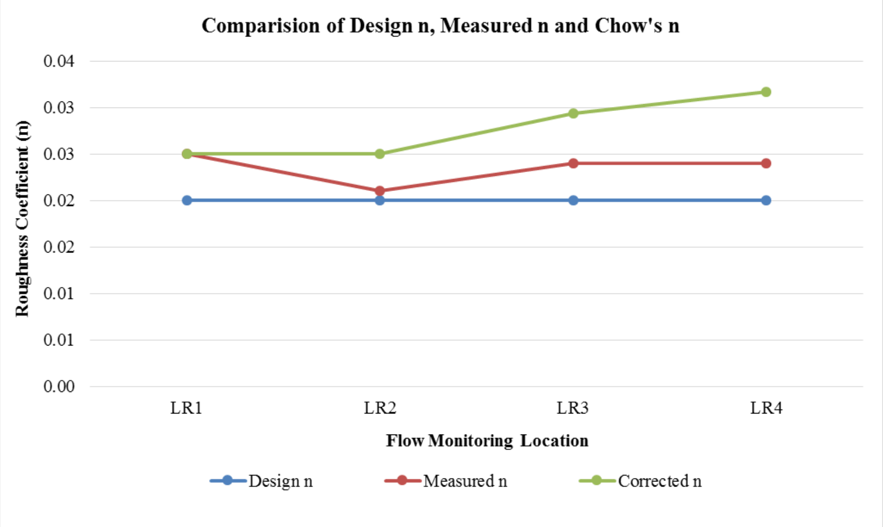

Fig. 2: Comparison of Design N, Measured N and Chow's Method N.

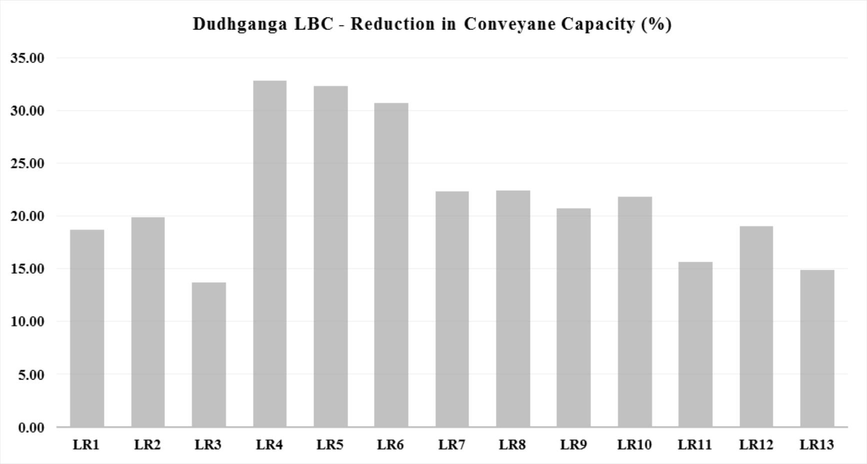

Fig. 3: Reduction in Conveyance Capacity (%) for Dudhganga LBC.

Each section of Left Bank Main canal had issues with aquatic weeds with variable densities along with other issues which affect the canal functioning. After using the corrected Manning's roughness values based on Chow's weed factor, overall 21.90% reduction observed in canal conveyance capacity. The Figure 3 shows the percent change in conveyance capacity comparing with a design capacity for each reach. Reach LR4 has a maximum reduction in conveyance capacity as 32.82%.

5. Conclusion

After two field visits, it has been observed that Left Bank Main Canal including lined reaches are highly devastated with unwanted dense vegetation (aquatic weeds). The considerable amount silt deposition found at different reaches especially for unlined canals silt deposition affected canal geometry and induce surface irregularities.

The images captured using Drone survey become a sophisticated way to analyses the canal degradation like weeds, siltation, and cracks. Further to this, it is useful to estimate the impact of these degraded hydraulic parameters on overall canal performance.

The reduction in conveyance capacity of the canal would impact on overall canal performance as well as irrigation scheduling as compared to canal design criteria. It has been that canal conveyance capacity is quite sensitive to corrected roughness factor based on weeds on canal side slopes and on canal bed. With the increase in roughness factor based on aquatic weeds, average canal conveyance capacity is reduced by approximately 21.90%, which would require serious attention and further investigation of canal behavior for different water release scenarios.

The analysis carried in this study will help canal managing group to plan their maintenance work based on the results estimated for each reach. The study shows, the sections LR4, LR5, and LR6 should be planned for maintenance on priority.

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