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Determination of the Canal Discharge Capacity Ratio and Roughness to Assess Its Maintenance Status: Application in Egypt

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Abstract: Waterlogging and soil salinity issues can be handled using surface or subsurface drainage networks, soil bed elevation, and soil and crop management patterns. A properly operating and maintained drainage system is important for both rural and urban inhabitants to protect lives and property from flooding and high groundwater levels, enhance health conditions, and safeguards water purity, soil salinity, and waterlogging. It also supports and increases crop yields and consequently rural incomes. This study assessed the maintenance condition of the main surface drains (Baloza and ELFarama) located in the Tina Plain (50,000 acres) and a portion of the Southeast El-Kantara regions (25,000 acres) in North Sinai, Egypt, based on the values of the Discharge Capacity Ratio (DCR) and Manning's roughness (n). Ten measurement locations at the drain cross-section were used in the investigation. For the ELFarama Drain, the average values of n and DCR were found to be 0.029 and 86.2%, and for the Baloza Drain, they were 0.032 and 78.6%, respectively. Compared to the design values, the actual Manning's roughness was higher, indicating that the drainage canals' capacities had been reduced and that their upkeep was inadequate. In both drains, sedimentation is present and they need to be maintained, according to the hydrographic surveying results for the actual cross-sections compared to the planned cross-sections. A methodology for the channel maintenance method is presented. For removing vegetation and dredging sediment, a long-boom mechanical hydraulic excavator with a bucket is suggested and to be conducted every two years. To the results of this study, the amount of weed infestation in vegetated channels is the main factor that affects Manning's roughness coefficient value. It is now easier to calculate the proportion of weeds that are submerged in vegetated channels using echo-sound sonar technology. The DCR is an affordable and simple methodology to assess the channel maintenance status for sustainable agriculture.

Keywords: water resources; canal roughness; sedimentation; vegetation management; Egypt

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1. Introduction

Vegetation is a crucial factor from the perspective of catchment hydrology [1–3] as interception of raindrops, evapotranspiration, and infiltration are factors to take into account in surface and subsurface water balance. In terms of ecology and habitat, riparian vegetation is crucial and makes a considerable contribution to biodiversity. In fact, vegetation creates microenvironments that can house creatures and insects beneficial for farming and keeps pollutants and fertilizers from getting into streams. Due to how it affects the landscape, it also has a significant recreational impact [4]. Waterlogging and soil salinization issues are brought on by seepage from unlined canals, over-salinized groundwater inundation, and the use of ineffective irrigation techniques [5,6]. Since waterlogging and soil salinization issues are the root cause of anaerobic conditions and the growth of hydrophilic weeds, which result in nutrient shortages in the root zone, a sizable share of agricultural output declines in soggy soils worldwide [7,8]. However, it should be mentioned that a variety of programs and tactics have been employed to tackle these problems. For instance, the application of surface or subsurface drainage networks [9–11], soil bed elevation [12], and soil and crop management strategies [13,14].

In Egypt, the main causes of soil salinity issues are inadequate irrigation, shallow groundwater, and seawater intrusion [15,16]. Therefore, in the Delta, hard clay soil is the most prevalent soil-type [17,18].

More than 82% of Egypt's canals and drains are severely overrun by aquatic weeds of various types, making aquatic weeds the principal issue in open channels [19,20]. This percentage is expected to increase due to the recent change in water quality and the fall in actual water depths in the majority of Egyptian canals and drains. The three primary types of aquatic weeds are those that are submerged, floating, and ditch bank weeds. Open channels are most negatively impacted by aquatic weeds that are submerged. Worm infestation has two main effects: it increases flow resistance and reduces conveyance capacity [21].

Adequate drainage system operation and maintenance protects the resource base for food production, sustains and increases yields and rural incomes, protects irrigation investment, serves rural and urban residents as well as industrial activities, protects human lives and assets against flooding and high groundwater levels, improves health conditions, and protects the water quality [22,23]. Irrigation and drainage networks require periodic monitoring of size, water discharge, sedimentation, vegetation, water quality, and biodiversity to satisfy their high efficiency [24–26].

Vegetation management activities increase hydraulic efficiency and bank erosion protection. According to Wu et al. [27], the kind and distribution of vegetation in open channel cross-sections have an impact on velocity profiles due to plant drag, which significantly increases flow roughness. Five degrees of retardance for vegetated waterways were developed by Chow [28].

According to Han et al. [29], vegetation in open channels is a crucial design element. It has various impacts based on the type of vegetation and has an impact on the local water depth and the water velocity profile. Wan Yusof et al. [30] concluded that there is a significant association between Manning's roughness coefficient and drag coefficient in vegetated channels based on an experimental analysis employing natural vegetation to discover the relationship. Also, Pu et al. [31] concluded that the vegetation in open channels acts as a flow obstacle, which creates turbulence that alters the distribution of flow velocity and water depth as well as sedimentation in the canal cross-section.

Plant growth depends on many factors such as light, temperature, nutrient levels in the water column and streambed sediments, and hydrologic regime. Bed roughness for artificial and natural channels is affected by several factors such as the shape of a canal, silting and scouring, vegetation, canal irregularity, obstruction, seasonal change, bed load, and suspended material [32]. A numerical model was developed to evaluate the state of canal maintenance based on the canal carrying capacity ratio (DCR) [33]. The DCR is defined as the actual capacity of the selected canal over its designed capacity.

The Nile Delta of Egypt is a fertile cultivated area that depends on surface irrigation for cultivated crops; recently, the soil salinity rates were raised to 30% [34,35]. As reported, [14], in Egypt's Nile West Delta, soil salinization degrees according to Russian classification were at 71%—non-saline, 10.5%—slight saline, 9%—moderate saline, 3.8%—strongly saline, and 5.7%—very strongly saline in the investigated area. The El-Salam Canal Project for reclamation and cultivation of 260 thousand hectares in the North East of Egypt is considered to be the Delta extension [36,37]. It consisted of two phases; phase one lies in the Nile West Delta to the west of the Suez Canal for an area that served 220 thousand acres. On the other hand, phase two lies east of the Suez Canal for an area that served 400 thousand acres at the North Sinai Development Project (NSDP) [38]. This project faced waterlogging and salinity problems and solved them by constructing subsurface and surface drainage networks [37].

The objective of this work was to apply the DCR method to assess the channel maintenance status for sustainable agriculture. The Baloza and ELFarama surface drains in the NSDP, North Sinai Egypt, were used as a case study. To achieve this objective (i) the studied drains were described and the water levels and channel roughness were collected and investigated, (ii) the actual velocities during the maximum water level period were measured in the field, (iii) the actual Manning's roughness coefficient (n) was determined and compared with the literature, (iv) hydrographic surveying to measure the drains actual cross-sections was carried out, (v) surveying for vegetation was also carried out, and (vi) a methodology for the channel maintenance method was determined.

2. Materials and Methods

2.1. Study Area

Egypt's Nile West Delta is located between the latitudes of 30.33° and 31.166° N and longitudes of 31.5° and 32° E. The Nile West Delta elevations range from 1 to 50 m above the main sea level [39]. The soil's texture ranges from sand to clay, with clay content increasing nearer the center of the Nile Delta and declining toward the delta's boundaries and the desert [40]. Fluvio-marine flats and river terraces are the two dominant terrain types in the region east of the Nile Delta. Additionally, the primary geomorphic units of the East Nile Delta are as follows: clay flats in the north, gypseous flats in the northwest of Ismailia, and historic river terraces with sandy soils in the south-west and east of El-Sharkia and the governorate [41]. The Nile West Delta experiences arid and semiarid weather [42]. Additionally, it has meteorological characteristics such as significant daily temperature swings between the lowest and highest temperatures. The temperature varies greatly between summer and winter, with an average yearly temperature of roughly 22 °C [42–44]. Additionally, 33.3 mm of rainfall precipitates on average throughout the winter months [41].

The studied surface drains Baloza and ELFarama are located in the Tina Plain region at the borders of the Egypt's Nile West Delta as shown in Figure 1. El-Sheik Gaber Canal is the main feeder for the NSDP, the annual water resource for the NSDP is 4.5 km^3. The canal starting from Suez Canal extended to the east with a length of 86.5 km; the canal was lined with gabions to protect and stabilize inside slopes in the Tina Plain region (clay soils) for 24.5 km. The remaining length is lined with plain concrete in the Romanna, Rabaa, and Bir EL-Abd regions (sandy soil). The topography of the Tina Plain region is flat with mean elevations of 1.0 m above mean sea level, and the predominate soil type is clay.

The area served by the drains is 75,000 acres, which has been operated and maintained by the Sector for Irrigation, Water Resources, and Infrastructures at North Sinai (SIWRI) Ministry of Water Resources and Irrigation (MRWI) since 1998. Potatoes, wheat, beans, tomatoes, and sugar beet are the major crops grown besides poplar trees. About 55,000 acres are served by the Baloza Drain, which is 17.480 km long, 2.0 m wide at the entrance, and 10 m wide at the outlet, with corresponding water levels of 1.22 m and 1.97 m and has an inside slope of 1 to 3. There is a pump station at 3.500 km from the drain outlet that pumps the irrigation drainage water into a 3.0 km long carrier channel that empties into the Suez Canal. On the other hand, about 20,000 acres are served by the ELFarama Drain, which is 20 km long, 3.0 m wide at the entry and 7.0 m wide at the outflow, with corresponding water levels of 4.17 m and 4.52 m, and has an inside slope of 1 to 3. A pump station is located at 3.500 km from the drain outlet and pumps drainage water into a 3.0 km long carrier channel that empties into the Suez Canal. According to [45], the soil classification for the studied drains is shown in Table 1.

Figure 1. Location of the studied drains and the hydrographic survey cross-sections.

Table 1. Soil classification for the studied drains.

Drain	Km	Sample Location	Soil Classification			Soil Type
			Sand (%)	Silt (%)	Clay (%)	
ELFarama	0.25	Bed	4.02	88.75	10.23	Silty clay
	7.5	Right bank	59.59	32.18	8.23	Silty sand
	15.0	Right bank	16.67	75.10	8.23	Silty clay
	19.5	Bed	20.41	71.36	8.23	Silty clay
Baloza	0.3	Bed	98.50	1.5	-	Sandy
	7.3	Right bank	99.69	0.31	-	Sandy
	13.3	Right bank	99.27	0.73	-	Sandy
	17.3	Bed	98.29	1.71	-	Sandy

2.2. Research Methodology

Figure 2 shows a flow chart for the research methodology. Therefore, (1) the studied drains were described and the design (projected) water levels, bed width, bed slope, and channel roughness ($n_{projected}$) were collected, (2) the actual velocities during the maximum water level period were measured, (3) the actual Manning's roughness coefficient (n_{actual}) is determined, (4) the canal Discharge Capacity Ratio (DCR) is estimated, and (5) a methodology for the channel maintenance method was selected.

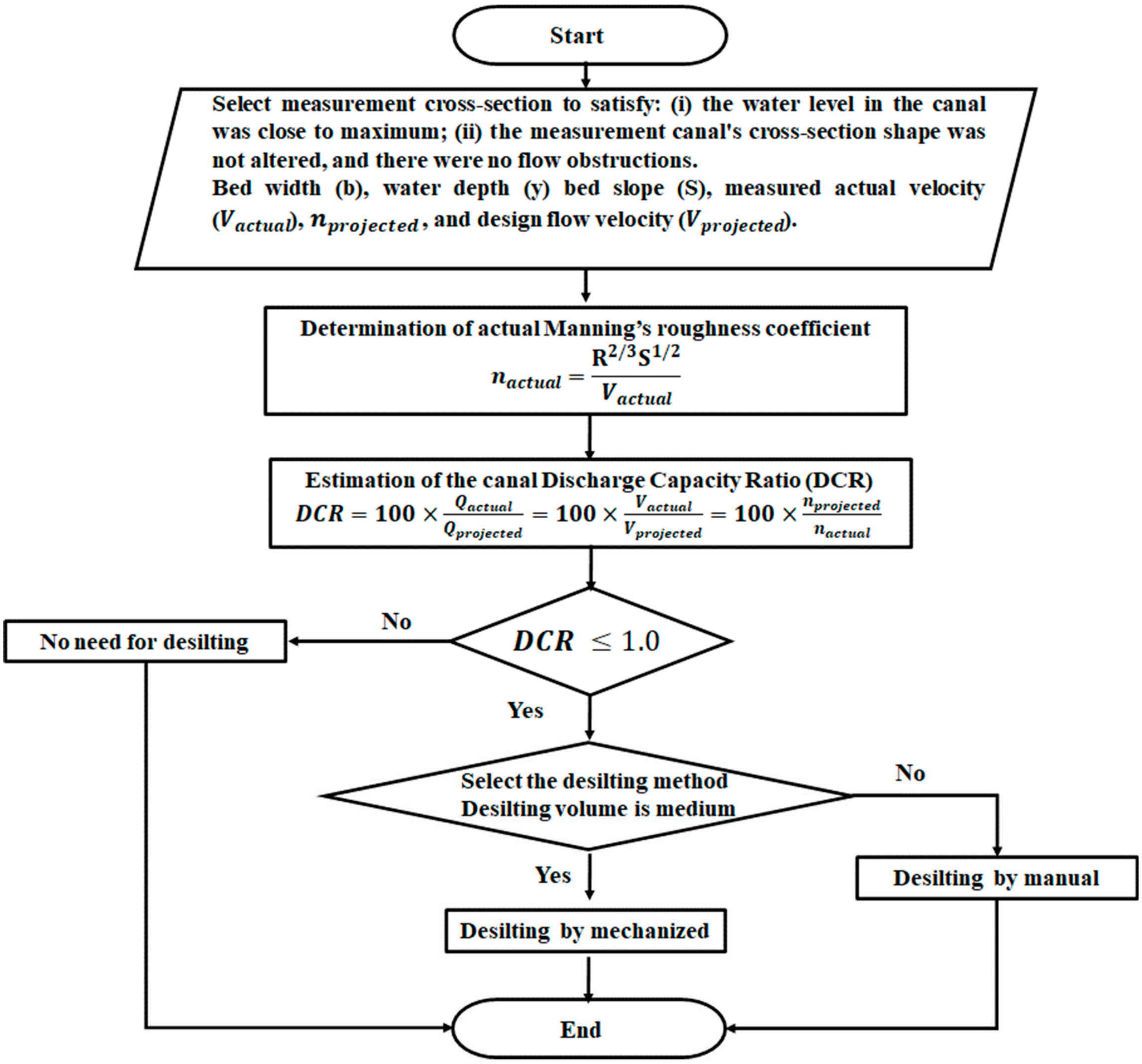

Figure 2. Flow chart for the research methodology.

2.3. Hydrographic Surveying for the Studied Drains

Measurement points were selected according to the following criteria: (1) the water level in the canal was close to maximum; (2) nothing happened to change the water levels while measurements were being taken; and (3) the cross-section geometry of the drainage canal being measured was not deformed and did not cause any obstruction to flow (no vegetation). The study was carried out according to these criteria at ten measurement points, five points on the ELFarama Drain, and five points on the Baloza Drain. A series of 18 cross-sections along the examined drains were chosen in accordance with the existing vegetation and hydraulic structures in order to examine the changes in the drains' cross-section with respect to the specified cross-sections (Figure 1). The selected reaches were measured three times in one year, at the beginning of February, August, and February in the next year, using an echo sounder and total station survey equipment to gauge the rates of sedimentation. Additional information about the hydrographic survey is available in [46]. The actual cross-sections were compared to the ones that were intended, and the annual rate of sand accumulation as a percentage of the intended cross-section area during the six months was calculated. The actual drain velocity is measured as follows: the canal cross-section at the measurement point was first divided into subsections (4 subsections were selected), and velocity values were measured for each subsection by the two-points method, using a propeller current meter calibrated by the hydraulic laboratory at the National Water Research Center, Egypt. Then, the average measured velocity was calculated according to the area of each subsection provided. This was checked by measuring flow depths while measurements were being performed.

2.4. Determination of Manning's Roughness Coefficient (n)

Manning's roughness (n) actual values were determined at the selected measurement points on the studied main drains using Manning's velocity Equation (1):

$$n = \frac{R^{2/3}S^{1/2}}{V_{actual}} \quad (1)$$

where R is the hydraulic radius (m), S is the channel bed slope (m/m), and V_{actual} is the measured velocity in (m/s). The value of V_{actual} was defined as the average velocity at the measurement points on these drains.

The value of S for each canal was taken from SIWRI records. In order to evaluate the physical condition of the drains included in the study, values of n obtained were compared with the design values of n in Table 2, which were selected from SIWRI and MRWI records.

Table 2. Projected values of Manning roughness for ELFarama and Baloza drains with no vegetation [45].

Manning's Roughness (n) ELFarama Drain	Manning's Roughness (n) Baloza Drain	Canal Condition
0.025	0.028	(Best exceptional (projected))
0.028	0.031	Good
0.031	0.034	Fair
0.035	0.037	Bad

2.5. Estimation of Discharge Capacity Ratio (DCR) for the Studied Drains

The ideal ratio of DCR would be one to one. Estimation of Discharge Capacity Ratio (DCR) for the studied drains is displayed in Equation (2):

$$DCR = 100 \times \frac{Q_{actual}}{Q_{projected}}\% = 100 \times \frac{V_{actual}}{V_{projected}}\% = 100 \times \frac{n_{projected}}{n_{actual}}\% \quad (2)$$

where DCR = Discharge Capacity Ratio (%); Q_{actual} = actual canal discharge capacity in m^3/s; $Q_{projected}$ = projected canal discharge capacity in m^3/s; V_{actual} = actual water velocity in m/s; $V_{projected}$ = projected water velocity in m/s; n_{actual} = actual Manning's roughness coefficient; and $n_{projected}$ = projected Manning's roughness coefficient.

In applying this indicator, flow measurements were carried out during the month of August in the summer season for the selected section, where conditions for designated water levels (maximum levels) for unchanged channel cross-sections with no vegetation and sediment deposition existed (field design cross-section). Further, assuming that for the field design cross-section, the canal slope values in Manning's velocity equation were the same as the designed values. With these conditions, the second part of the DCR equation was obtained from the first part. In the DCR equation, the value of n_{actual} indicates that values were obtained from a previous Manning's equation. The value of n designed was based on the value of $n_{projected}$ = 0.028 for the Baloza Drain and $n_{projected}$ = 0.025 for the ELFarama Drain as observed in the drainage system planning in SIWRI and MRWI (Table 2). Values of Manning's roughness coefficient (n) and DCR along with the values of other hydraulic parameters, such as flow average velocity (V), wetted perimeter (P), cross-section (A), and hydraulic radius (R), were used in the calculations. These parameters were obtained at the ten measurement points determined for ELFarama and Baloza Drains. The impact of weed infestation on the hydraulic efficiency and other hydraulic parameters of vegetated channels was investigated through a number of experiments.

Mohamed and El-Samman [19] developed an equation to forecast the value of Manning's roughness coefficient in the vegetated channel based on measured parameters, such as weed infestation percentage and water surface slope, using a physical model and laboratory study. The Manning roughness coefficient in vegetated open channels was calculated using two straightforward formulas as follows [Equations (3) and (4)]:

$$\frac{n_v}{n_o} = 0.089W_{inf} + 1.037 \quad (3)$$

$$\frac{n_v}{n_o} = 0.067W_{inf} + 240.43S + 0.969 \quad (4)$$

where n_v is the Manning roughness coefficient of vegetated open channel, n_o is the Manning roughness coefficient of non-vegetated open channel, S is the water surface slope, and W_{inf} is the percentage of weed infestation in open channel determined using Equation (5):

$$W_{inf} = \frac{Weeds\ area\ of\ the\ channel\ cross-section}{Total\ area\ of\ the\ channel\ cross-section} \quad (5)$$

2.6. Monitoring the Aquatic Weeds

A survey to measure the type of vegetation and the area of infection for the studied drains was carried out using a total station survey device; additional details on the hydrographic survey are provided. However, employing conventional variables like topography, overstory, and soils has proven to be quite challenging when attempting to construct spatial projections of plant cover or density in open channels [46]. LiDAR (Light Detection and Ranging) is an active remote-sensing technology that could be utilized to produce estimates to solve this problem. LiDAR can estimate the terrain, understory vegetation, and three-dimensional forest structure, including the canopy structure. LiDAR is a surveying technique that calculates the amount of time it takes for a laser light pulse to return after reflecting off of the ground or other solid objects. An image of the forest in three dimensions is produced by these laser returns. In their efforts to manage the vegetation in open streams' forests effectively and sustainably, researchers, conservationists, and forest managers have benefited greatly from this skill. Numerous forest structural characteristics, such as canopy height and cover [47–49], basal area, and tree density [50], as well as understory structure, may be accurately and robustly estimated using LiDAR.

3. Results

3.1. Maintenance Status for the ELFarama and Baloza Drains

The hydrographic surveying results showed that the flow velocities in ELFarama Drain are low ranging from 0.38 to 0.41 m/s, while for the Baloza Drain flow velocities ranged from 0.3 to 0.41 m/s. Values of n for the ELFarama Drain ranged from 0.028 to 0.03 with an average of 0.029, while n for the Baloza Drain ranged from 0.031 to 0.033 with an average of 0.032. The DCR value for the ELFarama Drain was calculated as 83.3–88.5%, with an average of 86.2%. The DCR value for Baloza Drain was calculated as 85.5–89.6%, with an average of 87.6%. Table 3 summarizes the hydraulic parameters used in the calculation of velocity, water depth, n, and DCR at the ELFarama and Baloza Drains. Values of n for the ELFarama Drain, when compared with the design rate, are located "between fair and bad" ($0.033 < n < 0.037$) (Table 2). This also has an adverse effect on the discharge capacity ratio (DCR < 100%). In this way, designed water transmission capacities are reduced by an average of 13.8% (DCR = 86.2%). While the Baloza Drain results indicated a fair canal condition (n = 0.032). This also has an adverse effect on the discharge capacity ratio (DCR < 100%).

Table 3. Hydraulic parameters used in the calculation of n_{actual}, and DCR at ELFarama and Baloza Drains.

Drain Name	Measurement Section Location (km)	A (m^2)	P (m)	R (m)	y (m)	S (m/m)	V_{actual} (m/s)	n_{actual}	DCR (%)
ELFarama Drain	0.180	19.21	17.25	1.114	1.62	0.00012	0.41	0.029	87.1
	2.600	15.97	15.25	1.048	1.62	0.00012	0.4	0.028	88.5
	7.450	14.35	14.25	1.008	1.62	0.00013	0.4	0.029	87.2
	11.150	12.25	13.11	0.934	1.52	0.00015	0.39	0.030	83.3
	16.600	9.74	11.66	0.835	1.37	0.00016	0.38	0.030	84.7
	Average				0.4	0.00014	0.40	0.029	86.2
Baloza Drain	1.600	31.34	22.46	1.4	1.97	0.00011	0.42	0.031	89.6
	4.300	20.19	17.26	1.17	1.78	0.00012	0.38	0.032	87.5
	7.500	16.72	15.56	1.07	1.67	0.00012	0.35	0.033	85.5
	11.200	9.52	11.54	0.82	1.35	0.00014	0.32	0.032	86.4
	15.300	6.91	9.72	0.71	1.22	0.00014	0.3	0.031	89.2
	Average				0.35	0.00013	0.35	0.032	87.6

Note: A, cross-section area; P, wetted perimeter; V_{actual}, actual velocity (measured in the field); y, water depth; S, channel slope; n_{actual}, Manning's coefficient; and DCR, discharge capacity ratio.

The results obtained from the study showed that the general state of maintenance of the studied drains is not good concerning roughness and water conveyance capacity. It was determined that roughness is caused by factors such as increased silting and vegetation.

3.2. Drain Cross-Section Area Deformation

According to the hydrographic survey findings, for the ELFarama Drain, the critical sedimentation reach was between kilometer 0.250 and kilometer 2.250, where the sedimentation accumulation rate was 11.8% of the designed cross-section area, and between kilometer 14.950 and kilometer 19.50, where it ranged between 10.55 and 12.64% of the designed cross-section area. The estimated total annual sedimentation in the ELFarama Drain was 34,369 m^3. For the Baloza Drain, the critical sedimentation reach was between kilometer 0.300 and kilometer 3.300, where the sedimentation accumulation rate was 7.74% of the designed cross-section area. For the ELFarama Drain, the estimated total annual sedimentation was 29,153 m^3, with rates ranging from 9.64 to 7.51% of the designed cross-section area. The windblown fine sands from the northwest during the month of March are to blame for the rising sedimentation rates for the stated reaches [51,52].

3.3. Vegetation Infection

The Baloza Drain has a 28–30% weed infection ratio at the reach from kilometer 0.00 to kilometer 3.30, a 36% weed infection ratio at the reach from kilometer 3.30 to kilometer 5.50, a 27% weed infection ratio at the reach from kilometer 5.50 to kilometer 7.0, and a 22% weed infection ratio at the reach from kilometer 7.00 to kilometer 15.30. The extant vegetation included Phragmites australis, Cyperus articulates, and Ceratophyllum demersum. The existing vegetation in the ELFarama Drain between kilometer 0.00 and kilometer 2.60 consisted of Phragmites australis, Cyperus articulates, and Ceratophyllum demersum, with a weed infection ratio of 0.28–30%. There was a 35% weed infection ratio at the reach from kilometer 2.60 to kilometer 7.45, a 20% weed infection ratio at the reach from kilometer 7.45 to kilometer 11.15, and a 19% weed infection ratio at the reach from kilometer 11.15 to kilometer 16.6. The vegetation in Egypt's Damietta branch of the River is an expansion of the plant diversity in the studied drains [53,54].

4. Discussion

4.1. Comparison between the Literature and the Measured DCR for ELFarama and Baloza Drains

Applying Equations (3) and (4) developed by Mohamed and El-Samman [19] to forecast the value of Manning's roughness coefficient in the vegetated channel was based on the measured parameters, weed infestation percentage, and water surface slope. The results show an average Manning's roughness coefficient in the vegetated channel for the ELFarama and Baloza Drains of 0.27 and 0.03, respectively. Table 4 summarizes a comparison between the literature and the measured DCR for ELFarama and Baloza Drains.

Table 4. Comparison between the literature and the measured DCR for ELFarama and Baloza Drains.

Drain Name	Measurement Section Location (km)	W_{inf} (%)	S (m/m)	Projected (n_o)	DCR According [19]				DCR Current Study
					n_{v1} Equation (3)	n_{v2} Equation (4)	DCR1 (%)	DCR2 (%)	DCR (%)
ELFarama Drain	0.180	28	0.00012	0.025	0.027	0.027	94.2	92.2	87.1
	2.600	30	0.00012	0.025	0.027	0.027	94.0	92.1	88.5
	7.450	35	0.00013	0.025	0.027	0.027	93.6	91.6	87.2
	11.150	20	0.00015	0.025	0.026	0.027	94.8	92.0	83.3
	16.600	19	0.00016	0.025	0.026	0.027	94.9	91.9	84.7
	Average	26.4	0.00014	0.025	0.027	0.027	94.3	92.0	86.2
Baloza Drain	1.600	28	0.00011	0.028	0.030	0.030	94.2	92.4	89.6
	4.300	36	0.00012	0.028	0.030	0.031	93.5	91.7	87.5
	7.500	27	0.00012	0.028	0.030	0.030	94.2	92.3	85.5
	11.200	22	0.00014	0.028	0.030	0.030	94.6	92.1	86.4
	15.300	20	0.00014	0.028	0.030	0.030	94.8	92.2	89.2
	Average	26.6	0.00013	0.028	0.030	0.030	94.3	92.2	87.6

Note: W_{inf}, the percentage of weed infestation in open channel given by Equation (5); S, water surface slope; n_o, Manning roughness coefficient of non-vegetated open channel (projected); n_{v1}, Manning roughness coefficient of vegetated open channel calculated by Equation (3); n_{v2}, Manning roughness coefficient of vegetated open channel calculated by Equation (3); DCR1, discharge capacity ratio for n_{v1}; DCR2 discharge capacity ratio for n_{v2}; and DCR, discharge capacity ratio for current study.

The maintenance problem picture gives the idea that the responsibility and corresponding institutions should be specified explicitly before decisions on a finance strategy are made. These problems are complicated in Egypt by the division between the main irrigation system, outflow command, and drainage. Determining the farmers' participation, or alternatively, the extent of government engagement in funding as well as in duties for execution and control of maintenance at the outflow command level and in downstream drainage would be crucial subjects [55,56].

Additionally, the particular climate, soil, and hydrological conditions are important. For instance, the kind and rate of growth of the plants may be influenced by the soil and climate. In some regions, vegetation regeneration is particularly quick, which necessitates frequent upkeep.

There are many different types of vegetation in some ecosystems, while only one dominates in others. While desilting is hardly ever necessary in some locations where the irrigation water is clear, in others it is substantially silt-loaded and necessitates periodic desilting. There are some maintenance variations between peat, clay, and sandy environments in the Netherlands. Different alluvial, loamy, or clay soil may exist in the Egypt Delta [57,58].

Any maintenance policy needs a choice between two options. With or without reliable cost and benefit information, this decision may be taken based solely on political or national economic considerations. More specifically, the problem is impacted by a number of things. Examples include maintenance procedures, methodologies, and physical circumstances. The work's quality, and hence the frequency needed, are influenced by the methods utilized, but so are the prices [59].

Because an increase in roughness reduces the canal's capacity, it gives rise to operating problems with regard to sufficiency and flexibility. The fact that an important part of the irrigation area's crop pattern is cotton means that irrigation is concentrated in specific periods. At these times, the reduction in canal capacity due to roughness increases the problem of insufficiency in canal capacity [60]. Surface roughness has an impact on water transmission since it sits at the soil-atmosphere interface. Surface roughness can improve infiltration, reduce overland flow, and store water in puddles. It may also have an impact on the direction, depth, and speed of overland flow. Surface roughness can exhibit a variety of characteristics as a result of field activity and rainfall, and this causes its impact on water transport to change across time and space. This variability and its time-consuming measurement contribute to the complexity of determining roughness effects. However, a correlation between surface roughness parameters and water transfer can be seen [61].

4.2. Assessment of the Hydraulic Roughness and Vegetation Management

From a spatial and temporal perspective, riparian vegetation, especially that found along floodplains, exhibits quite varied properties. The hydraulic and hydrological models need to effectively account for these properties. Traditional ground-based monitoring is frequently impractical since it takes a lot of time and money [62], especially for huge areas and inaccessible areas. Remote sensing, which has advanced significantly over the past few decades and has seen an increase in use in the environmental field, presents new prospects. The use of remote sensing in fluvial investigations has been discussed in few papers [63,64], with a focus on mapping riparian vegetation and estimating biomechanical parameters [65]. From multispectral satellite data, Forzieri et al. [66] proposed a method to estimate vegetation height and flexural rigidity for herbaceous patterns as well as plant density, tree height, stem diameter, crown base height, and crown diameter of high-forest and coppice consociations for arboreal and shrub patterns (SPOT 5). The method is created in four consecutive steps: (1) five land cover classifications are derived from the classification of pixel surface reflectance: mixed arboreal, shrubby, herbaceous, bare soil, and water habitats; (2) data transformation based on principal component analysis of the original multispectral bands and use of only the first principal component since it explains a lot of variances; (3) identification of significant correlation structures between the main components and biomechanical properties; (4) use of the principal component analysis of the original multispectral bands to transform the data; and (5) determination, estimation, and validation of the simple tri-parametric power law relationship between the normalized principal component and the biomechanical characteristics. By comparing the vegetation hydrodynamic maps with simulated water stages, it is demonstrated that they can also accurately reflect the comparable Manning's roughness coefficient.

Although the vegetation's vertical structure cannot be determined from satellite photos, its spatial variability can be determined. Information on the three-dimensional structure of vegetation is available because of LiDAR technology. Terrain-based (TLS), airborne (ALS), and mobile (MLS) platforms all use Laser Scanning (LS). A realistic representation of the forest canopy and ground elevations is provided by the Aerial Laser Scanner (ALS), which creates a digital terrain model and a digital surface model. The tree heights are determined by the variation between the digital surface model and the digital terrain model. In order to calculate the total plant area of herbaceous vegetation and the vertical distribution of the total plant area of foliated woody vegetation at various levels of submersion, Jalonen et al. [67] used multistation TLS in both field and laboratory circumstances. Using airborne LiDAR data, Forzieri et al. [68] created a model to pinpoint specific tree locations, crown limits, and plant density. It requires a preliminary calibration stage based on a basic additive multiple attribute decision-making algorithm. One of the first to offer some instances of managing vegetation in both man-made and naturally occurring trapezoidal-shaped channels were Phillips and Tadayon [69]. The design discharge for the canal in full-grown vegetation conditions would flood nearby areas, according to simulation results from the Hydrologic Engineering Center's River Analysis System (HEC-RAS) program. Instead, simulations under post-vegetation maintenance settings that included only partial removal of the vegetation show that the intended discharge would stay inside the channel.

Verifying whether the design flow has the ability to lay over bushes was a recurring theme in a few of the examples. If this happened, the accompanying roughness component was regarded as insignificant and was not taken into account when calculating the Manning coefficient. Additionally, a minimum of 30 cm of freeboard above the planned sea surface height was taken into account. This freeboard's function is to reduce risk by adding a margin of safety. Phillips and Tadayon [69] have discussed how having the vegetation randomly scattered is more aesthetically pleasing, but maintaining the trees and bushes grouped together may create a better habitat environment for wildlife.

According to Luhar and Nepf [70], the most efficient mowing patterns for lowering hydraulic resistance are those that produce less interfacial area per channel length (for example, a single continuous cut on one side of the channel). With regard to a gravel–cobble river in California, Abu Aly et al. [71] examined how vegetation affected flow rates, depths, and the size of the flooded areas for flows between 0.2 and 20 times the bankfull discharge (BFQ). They examined a section of the water flow that was 28.3 km long with a mesh of 1–3 m using a two-dimensional finite volume model (SRH-2D) that solves the vertical-mediated Reynolds equations. They used LiDAR data to determine the height of the vegetation in each cell using the method devised by Katul et al. [72] described above to estimate the Manning coefficient. For a flow of four times the BFQ, they were able to accomplish an increase in the mean water depth of 7.4% and a drop in the mean velocity of 17.5% when compared to the case of no vegetation; these values grow to 25% and 30%, respectively, for a flow rate of 22 times the BFQ. The model also demonstrates how vegetation strongly channels the flow; in fact, flow is diverted away from densely vegetated places and the gap between the mid-channel and bank velocities widens. According to the model's findings, Benifei et al. [73] demonstrated that removing the high vegetation (trees) inside the flooding area with a return period of two years and preventing the establishment of bushes (5-year-old trees) results in the most efficient flood management approach.

4.3. Procedure for Channel Maintenance Method

Six steps are important for performing channel maintenance for the purpose of achieving sustainable agriculture.

Step 1: Describe the associated geometry and characteristics of the Egyptian canal

The geometry of the cross-section, the bed slope of the reach, and the type of vegetation, which define the roughness coefficient, are identified for all the major watercourses in Egypt using data from the national database for the Egyptian Ministry of Water Resources and Irrigation (MWRI). Although it is understood that local information, when accessible, may provide more trustworthy and accurate inputs, the national database is used to obtain these data.

Step 2: Describe maintenance scenarios (comprising sediment and vegetation management)

Procedures are established to assess the potential management scenarios and the variations they cause on the features of the watercourse utilizing the parameters of the watercourse and existing advice [23].

Step 3: Determine the conveyance capacity of each maintenance scenario

A hydraulic model such as HEC-RAS is used to estimate the conveyance capacity based on the cross-section, roughness, and slope of the watercourse as calculated in Step 1. Both roughness coefficients and cross-sectional area are primarily affected by the management of the sediment and vegetation, respectively.

Step 4: Compute the impact of maintenance

To calculate the effects of maintenance, the variance in the main channel's conveyance capacity (reported as a percentage) is used. To provide a quick and accurate way to gauge the effects of maintenance activities, this parameter is approximated for all watercourses.

Step 5: Attribute benefits to various lengths of watercourses

Applying a streamlined hazard attribution methodology to watercourses, river lengths of 50 m are given characteristics in the floodplain that could make them candidates for channel maintenance. It should be assumed that the closest watercourse will most likely cause flooding in every given impact cell since we do not know which length of a watercourse would cause flooding. There are presumptions made regarding the flooding extension.

Step 6: Detecting the ideal management option

The likelihood of the characteristics in a watercourse length having the highest impact on conveyance management and highest benefits connected with the watercourse is used to determine the best maintenance option. The MWRI data are used to estimate the price of vegetation maintenance work, which is measured in pounds per square meter. The benefits to costs ratios are used to select the preferred maintenance option for a given channel, and in the case of dredging, the option with the highest ratio is chosen. However, it is impossible to state the cost of the works at the national level due to the significant variations depending on the site's features. The disposal of materials off-site, which may have significant variances, must also be taken into account when estimating the cost of this type of job. In this study, we propose a maintenance schedule for the investigated drains that calls for the use of a hydraulic excavator with a long boom to remove vegetation and silt from the most exposed sections every two years (Table 5).

Table 5. Suggested maintenance program for the studied surfaces drains.

Drain	Maintenance Type					
	Sedimentation Removal			Vegetation Removal		
	Procedure	Machine	Annual Removal Rate	Procedure	Machine	Annual Removal Rate
ELFarama and Baloza	Mechanical	Long-boom mechanical hydraulic excavator with bucket for sediment dredging	Every two years	Mechanical	Long-boom mechanical hydraulic excavator with bucket for sediment dredging	Every two years

5. Conclusions

The key factor that determines the value of Manning's roughness coefficient is the percentage of weed infestation in vegetated channels. By using echo-sound sonar equipment, it is now simpler to determine the percentage of weeds that are submerged in vegetated channels. Average actual Manning's roughness values of 0.029 were found for the ELFarama Drain, and 0.032 for the Baloza Drain, which are greater than the design n values of 0.025 and 0.028, respectively. Siltation and weed and algal growth all served to increase this roughness. The fact that the actual roughness was higher than the designed values meant that canal capacities were reduced. The study found that this reduction-averaged value is 13.8% (DCR = 86.2%) for the ELFarama Drain and 12.4% (DCR = 87.6%) for the Baloza Drain. In addition, the hydrographic surveying results showed high measured annual sedimentation volumes for the ELFarama Drain and Baloza surface Drains. Vegetation surveying results showed that the ELFarama and Baloza Drains have average weed infection ratios of 30%. It is suggested to utilize a long-boom mechanical hydraulic excavator with a bucket for clearing vegetation and dredging sediments. The DCR is a simple tool for evaluating the state of channel maintenance for sustainable agriculture.

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