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Optimizing Irrigation: Precise Canal Design and Earthwork Estimation with iCAD and CanalNETWORK

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Abstract

Irrigation can be a promising option to feed a highly growing population and thus to create a climate resilient community for a country like Ethiopia. However, irrigation projects often suffer from poor performance mainly due to knowledge gaps and technical constraints during design and implementation. Often a series of MS Excel sheets supported by manual calculations have been used as computing tool for irrigation systems and canal designing purposes. Thus, technologies shall be applied and the existing conventional processes shall be modified to improve the design of irrigation system~~s~~ components and eventually to enhance the operational performance. iCAD and CanalNETWORK are recently developed software which allow engineers to design complete irrigation systems in an all-in-one environment. The software employs a more realistic approach to capture and process topographic data, reduces human error, and automates manual operations, and as a result can deliver projects faster with improved design quality including optimized canal network and reduced constructional expenses compared to the conventional practices. Dabus Irrigation scheme of Ethiopia was used as a case study to examine the values added by the software while computing earthwork quantities. Different scenarios in this study revealed that there are substantial variations, up to 450 % m^3 of Earth volumes, between Excel computations and iCAD results for 1800m profile sample; in which the iCAD simulation was able to capture more details than the MS Excel counterpart. Among other functionalities, the software offers simplified design procedures; this feature highly favors for accurate earthwork quantity estimations, which is usually an extremely daunting task. Overall, the software can overhaul irrigation systems design process, optimize irrigation system's functionality, and contribute to food security and climate resilience in the country at large.

KEYWORDS: Canal design, Earthwork quantities, Irrigation system, iCAD and CanalNETWORK

1. Introduction

Climate and hydrological variabilities already caused adverse impact on economic development of Ethiopia. Recurrent drought and variable rainfall affect such a country where its economy mainly relies on the agricultural system. Irrigation is identified as the most prominent way to support the rainfed agricultural system of the country (MoFED, 2006; MoWR, 2002; World Bank, 2005). Irrigation increases land and labor productivity, creates climate resilience system, reduce land and natural resource degradation, and promotes to improve livelihoods with engagement of rural communities so that it enables sustainable economic growth and further enhance food security and poverty alleviation.

Ethiopia is located between 5°N and 15°N, and 35°E and 45°E covering 1.13 million km^2 area from which 99.3 % is covered with land and the remaining 0.7 % is water bodies (Awulachew et al., 2007). The country has enormous water resources and is considered as a water tower of Africa. It has 12 river basins with annual runoff estimated as 122 Billion m^3 of water and 2.6 - 2.65 Billion m^3 of groundwater potential (MoA, 20011a). The country is the second most populous country in Africa where about 85 % of it lived in rural areas depending on mostly the rainfed agricultural system (Bekele et al., 2012; Makombe et al., 2011; MoA, 20011a; MoA, 20011b).

In Ethiopia, irrigation has been practiced since ancient times whereas modern irrigation system started in 1960s in Awash valley (Awulachew et al., 2007). According to WAPCOS (1995), there are 560 irrigation potential sites on the major river basins of Ethiopia where their potential was estimated as 3.7 Million ha (Mha) from which Abbay, Baro-Akobo, Omo-Ghibe and Genale Dawa basins have principal share with 27 %, 26.5 %, 12% and 11.4 % respectively. The total irrigation potential of the country is about 5.3 Mha including the area which can be irrigated using groundwater and rainwater management (Awlachew and Ayana, 2011). Applying remote sensing technology, Chandrasekharan et al., (2021) recently revealed that the aerial coverage of croplands was estimated as 21.8 Mha, of which only 1.11 Mha were the irrigated area; accordingly, about 5% of total agricultural area that was irrigated by that year. Research conducted by Mekonnen et al. (2022) also showed that around 0.7 Mha of land used for irrigation development while only 46.8% of beneficiaries used from and 74.1 % command area was under cultivation.

Some of the existing large scale (i.e. when irrigated area covers more than 3000 ha [3, 16]) irrigation schemes in Ethiopia include Metahara Abadiy, Finchaa, and Wonji covering 8960 ha, 8,060 ha, and 5,925 ha respectively. According to the irrigation scheme performance assessment made by Awulachew and Ayana (2011), only 86.5% of schemes are operating while 74.1% of command area cultivated; and only 46.8% of the planned beneficiaries have benefited. The main constraints for the sector in the country are knowledge gaps while executing design, construction, supervision and operational management of the schemes (Awulachew et al., 2010; Getahun, 2015; Gurum et al., 2023; Haile, 2015; Kassie, 2020; Lambisso, 2008; Meja et al., 2020). On top of that, lack of available advanced technologies/software and low level technology adoption have been major challenges for the irrigation sector (Alemu, A. M., unpublished document, 2020; Amede, 2015; Berhe et al., 2022; Gebremeskel, 2015; Gebul, 2021; Gurum et al., 2019; Meja et al., 2020; Yohannes et al., 2019). Besides, the conventional Excel supported calculations has severely limited the scope of analysis possible for designs, and resulted in inferior quality products (Alemu, A. M., unpublished document, 2020). Those technical constraints cause canal siltation, sedimentation of headworks, problem of seepage, canal scouring and damage of structures. Proper design and implementation of canal and related structures will be the base to alleviate the above problems mentioned.

Although much debatable, a strong school of thought has emerged that design (approaches, processes and tools) is indeed the crux of the problem (Alemu, A. M., unpublished document, 2020; Horst, 1998; Plusquellec, 2002; Plusquellec, 2019), automating the conventional canal design processes and tools can reduce human errors, improve computational ability, and save time. iCAD and CanalNETWORK are promising software which embed various canal design approaches and suitable algorithms. The software were developed by Quanomic IT and Engineering Services PLC and validated with real life projects in collaboration with Ethiopian Construction Design and Supervision Works Corporation (ECDSWCo). It enables to design optimal canal cross sections for the requested intervals and precisely computes earthwork quantities by accounting corresponding structures such as drops, turnouts, division boxes, and head and cross regulator structures. The software handles all required hydraulic analysis automatically, and also allow the use of berms or benches in order to stabilize inclined surfaces - a difficult (often missing) analysis in conventional practice. It can also quantify earthwork volume of structures separately. The software allows interactive design with multiple data visualization and presentation features.

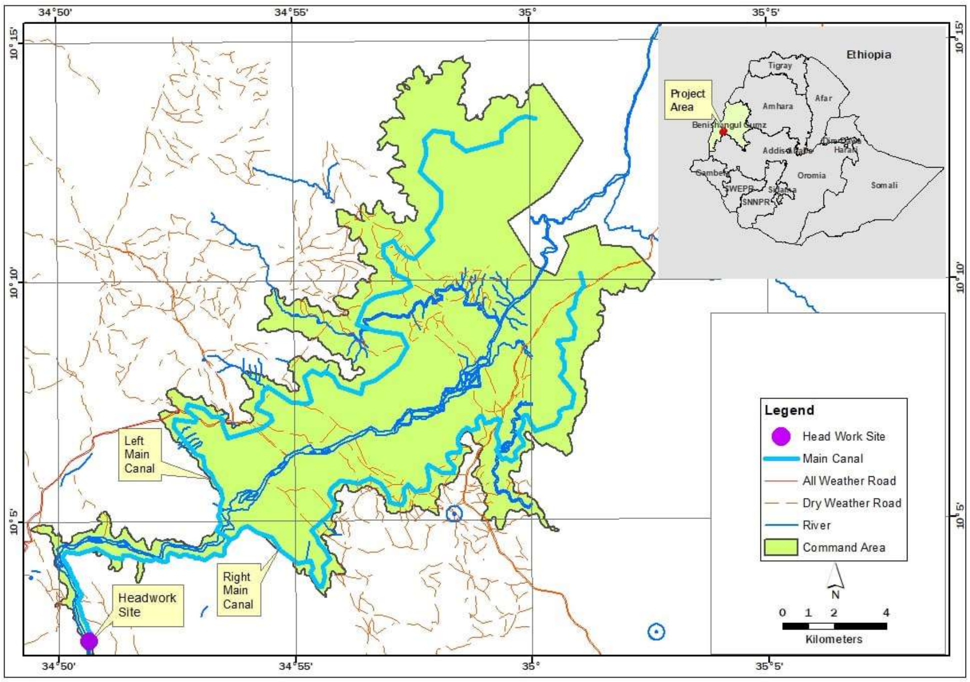
On the other hand, the conventional practice uses a series of MS Excel spreadsheets as the main design and analysis tool. It is prone to manual input error in data processing and inserting formulae. It also comes with a maximum limit for data handling, and limited data visualization for interactive design. Only one longitudinal profile data taken at the center of canal alignments is used for design, when in practice data away from the centerline (or transverse profile) is also an important consideration. It requires to create and manage as many sheets as the number of canals designed, making the process prone to error. From a quality assurance point of view, creating and maintaining controlled versions is not implemented - mostly because data and formulae need fine tuning from user to user - making it difficult to ensure engineers are using the correct/up-to-date version all the time.

Compared to the conventional practice, therefore, iCAD and CanalNETWORK software offer a purpose-built environment that can reduce errors, increase accuracy of design outputs, and save time. Unlike the MS Excel based process, it uses 3D profile data, and also provides multiple data visualization and presentation features. It also has the added advantage of working simultaneously together with AutoCAD - on one hand eliminating the need to use other interim software tools for data processing and exchange, and on the other allowing automatic export of detailed publication drawings.

This research work considered the case of Dabus Irrigation Scheme, a real project designed at the ECDSWCo, aiming to capture the benefits of using appropriate/purpose-built technologies while designing canals in general, and earthwork computation in particular. The scheme was designed using conventional method by accounting only the elevations of the centerline of the canal for computing earthwork volumes. The Dabus project enables to show the improvements achieved through the use of iCAD and Canal Network software because of its undulating terrain features.

2. Study Area Description

The Dabus irrigation and drainage scheme lies in Benishangul-Gumuz, Ethiopia (Figure 1). Its Left Bank Main Canal (LBMC) stretches 39.98 km with undulating terrain including gorges and hills, ideal for demonstrating differences in earthwork estimation methods (conventional vs. iCAD software). The canal starts at 1004.5m above sea level with a discharge of 8.7 m^3/s and irrigates 9,421 ha. Around 14.9 km require geo-membrane lining, while the rest utilize earthen material. This study focuses on the unique challenges of the LBMC's terrain and how iCAD software can improve earthwork estimation accuracy compared to conventional methods.



Source (Geospatial sub-process of ECDSWCo.)

Figure 1: Location map of Dabus irrigation scheme

The gorges in the canal run about 17 m deep, whereas the hills elevated up to 8 m high as shown in Figure 2. The canal is operated gravitationally while there are also night storages in tertiary canals. Dabus is a large-scale irrigation scheme and has a very long canal; therefore small errors while quantifying earthwork quantities in a segment can accumulate and result in excessive under/over estimation of quantities.

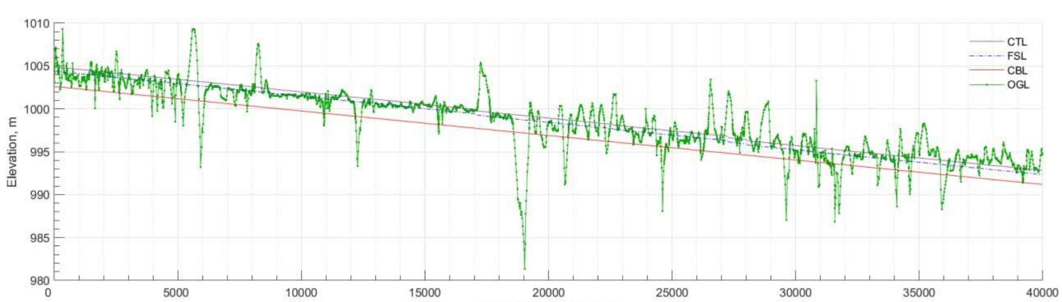


Figure 2: Longitudinal profile of Dabus left main canal also showing designed canal profiles. Where: OGL: Original Ground Level (i.e. original bare earth surface elevation at centerline of intended canal), CBL – intended Canal Bed Level, FSL - Full Supply Level, & TBL - canal Top Bank Level

3. Methodology

3.1 Materials

This research aims to emphasize how important the choices of appropriate methodologies and principles for performing canal design using the case of earthwork calculations. Computations of earthwork volumes are made based on the geometry of canal sections and profile data. The canal geometry is obtained from the intended capacity of the Manning equation, which is an open channel uniform flow function, was used to calculate design capacity of the canal in both conventional and iCAD solutions, Equation (1). The equation accounts flow velocity, flow area and channel bed slope in order to determine channel discharge.

$$Q = VA = \left(\frac{1.00}{n}\right) AR^{2/3}\sqrt{S} \quad \text{...........Eqn. 1}$$

Where Q stands for discharge in m^3/s, V is channel velocity in m/s, A is cross-sectional area of flow in m^2, R is hydraulic radius in m, and n stands for surface roughness. For the segments considered in this case study, the slide slope of the canal has been set as 1:1.5 (V:H) and manning roughness coefficient, 'n' as 0.0250 has been considered for unlined sections while 'n' = 0.015 for geo-membrane lined sections. In addition, a freeboard of 0.5m, a cut slope of 1.75H:1V and fill slope of 2H:1V is used beyond the canal top width. CanalNETWORK allows to model actual stability provisions for canals in deep cut and fill conditions. A value of 2H:1V and 3H:1V, respectively, with a 2.0m wide bench is used (Figure 6). Finally, identical design bed level was used (Figure 2) for both methods for the entire length of the canal route. Combining this information, complete canal geometry can be obtained at any desired station.-

Profile data is the other input for earth work computation. The surface elevation data of Dabus scheme was generated from both land surveying and earth observation data. The profile data is obtained by extracting elevations at specific increments along the canal alignment. The same incremental distance of 50m was used in both methods. The conventional method extracted elevation data along the centerline of canal alignment. The iCAD/CanalNETWORK software extracted elevations at the same 50m increment, and included offset locations 50 meters to the left and to the right of the centerline (Figure 11).

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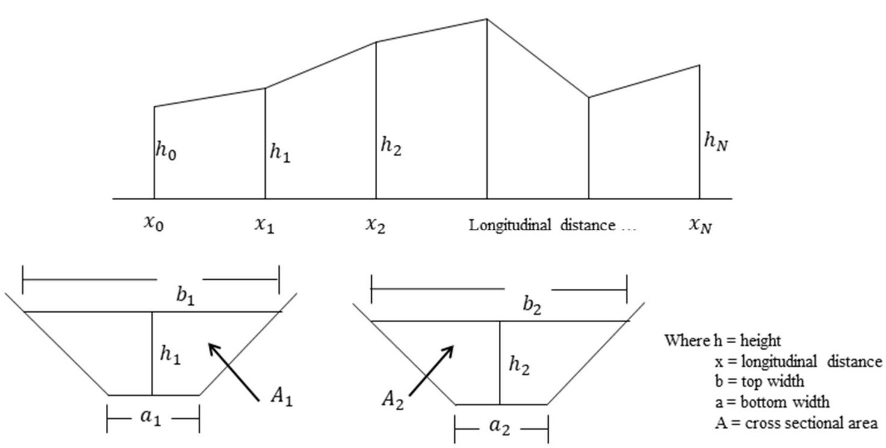


Figure 3: Trapezoidal assumptions for calculating earthwork volumes

With the complete canal geometry and profile data available, volume calculation can be carried out in the software. Both the conventional method & CanalNETWORK software employ Eqn. 2. The trapezoidal approach computes earthwork volumes by integrating sequences of cross-sectional areas determined with specific separation distance longitudinally (Figure 3).

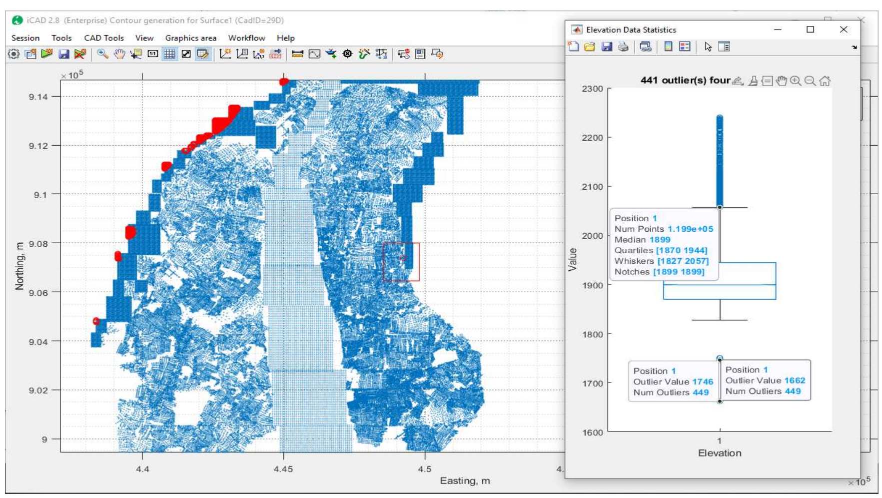
$$V = \frac{1}{2}\sum_{n=1}^{N}(x_{n+1} - x_n)\ [A_{n+1} + A_n] \quad \text{....(Eqn. 2)}$$

Where V represents volume (m^3), N stands for number of cross-section, $x_{n+1} - x_n$ is distance between two consecutive cross sections (m) and $A_{n+1} + A_n$ is the area (m^2) of cut and/or fill at consecutive sections.

Note that the two major differences in profile data and canal geometry creation are summarized below (Table 1). The use of transverse profile data (instead of assuming perfect flat ground laterally) and the ability to represent actual construction conditions for high fill or deep cut conditions (instead of assuming constant slope) will make significant difference for precise earth volume estimations.

Table 1: Summary of approaches considered in Conventional and iCAD/CanalNETWORK

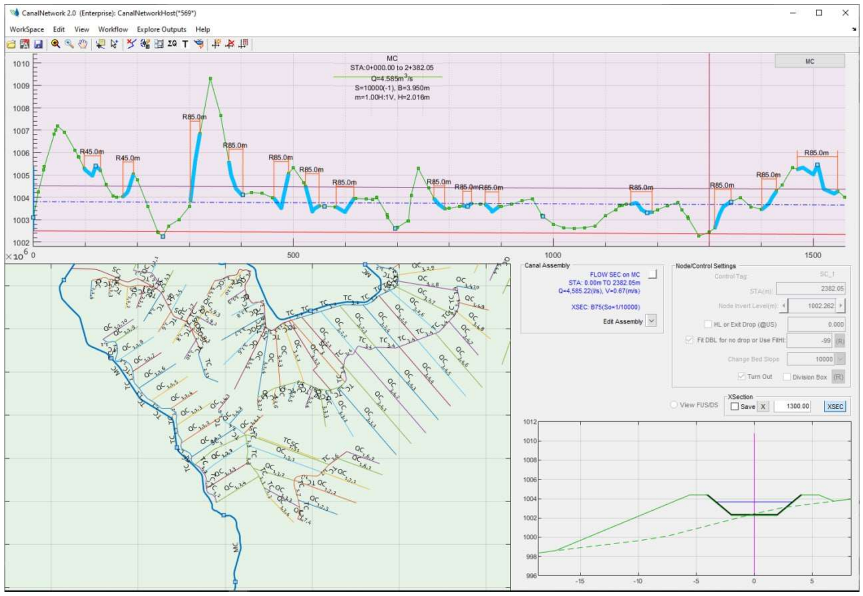
Data Description	Conventional Method	iCAD/CanalNETWORK Software
Profile Data	Centerline only, assumes perfect flat ground in transverse direction	100m wide strip data at 5m interval, capturing variation in transverse direction
High fills/deep excavation	accepts only one slope for all heights	Allows multiple benches and slopes for stability



Source (Quanomic IT & Engineering Services PLC)

Figure 4: iCAD Software interface, showing topographic data preprocessing for surface modeling, and subsequent profile extraction

iCAD is a modular application built for surface data processing, hydraulic design and analysis tasks; for example it is used for rating curve development, diversion weirs and embankment dams (Plusquellec, 2002). CanalNETWORK is a specialized application to design and analyze a network of canals in one environment (Plusquellec, 2002). Both iCAD and CanalNETWORK leverage computational geometry and work together with AutoCAD to create a real computer aided design environment for the engineers. Figure 4 and 5 describe the user interface of iCAD and CanalNETWORK.



Source (Quanomic IT & Engineering Services PLC)

Figure 5: CanalNETWORK user interface

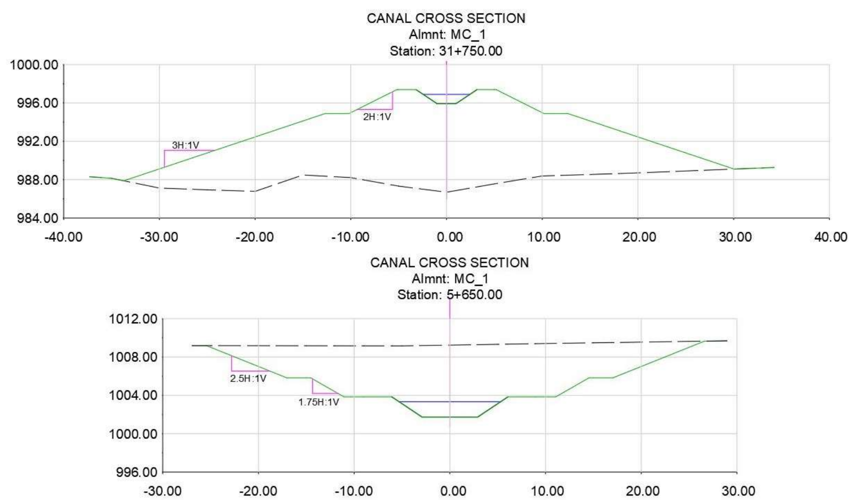


Figure 6: Sample cross sections with berm (upper plot - deep cut & lower plots - fully fill section)

4. Results and Discussions

In this section, results will be described and explained. It includes design parameters such as hydraulic parameters and it will discuss clearing & earthwork computations of Dabus canal derived using different methods, conventional versus iCAD. The design parameters are used as initial input to estimate corresponding clearing and earthwork quantities.

4.1 Hydraulic parameters

Both conventional method and iCAD software applied manning's equation to determine hydraulic parameters including bed width, flow area, wetted perimeter, hydraulic radius, flow velocity and bed width to depth ratio. The hydraulic parameters stated in Table 2 are similar for both conventional and iCAD computations.

Table 2: Hydraulic parameters of Dabus left main canal

Chainage		Required Q	Roughness Coefficient	F.S.D	Bed width	Side slope	Bank width	Flow area	Wetted perimeter	Hydraulic radius	Flow velocity	B/D	Irrigated area
From	To	m^3/s		m	m		m	m^2	m	m	m/s		ha
0	650	8.67	0.03	1.63	6.09	1.50	5.00	13.88	11.96	1.16	0.62	3.75	6192.43
650	2200	8.67	0.02	1.22	6.09	1.50	5.00	9.70	10.50	0.92	0.89	3.75	6192.43
2200	2382	8.67	0.03	1.63	6.09	1.50	5.00	13.88	11.96	1.16	0.62	3.75	6192.43
2382	5357	8.32	0.03	1.61	5.94	1.50	5.00	13.43	11.74	1.14	0.62	3.69	5944.38
5357	6050	8.08	0.02	1.20	5.82	1.50	5.00	9.13	10.14	0.90	0.89	3.66	5773.07
6050	6156	8.08	0.03	1.59	5.82	1.50	5.00	13.07	11.56	1.13	0.62	3.66	5773.07
6156	7500	8.08	0.03	1.59	5.82	1.50	5.00	13.07	11.56	1.13	0.62	3.66	5348.54
7500	8000	8.08	0.02	1.20	5.82	1.50	5.00	9.13	10.14	0.90	0.89	3.66	5773.07
8000	8779	8.08	0.03	1.59	5.82	1.50	5.00	13.07	11.56	1.13	0.62	3.66	5773.07
8779	11000	7.49	0.03	1.56	5.54	1.50	5.00	12.27	11.16	1.10	0.61	3.56	5348.54
11000	11622	7.49	0.02	1.17	5.52	1.50	5.00	8.56	9.76	0.88	0.87	3.56	5348.54
11622	12750	7.44	0.02	1.17	5.52	1.50	5.00	8.52	9.74	0.87	0.87	3.55	5315.09
12750	14330	7.44	0.03	1.55	5.52	1.50	5.00	12.21	11.13	1.10	0.61	3.55	5315.09
14330	17000	6.96	0.03	1.52	5.29	1.50	5.00	11.55	10.79	1.07	0.60	3.47	4972.34
17000	17105	6.96	0.02	1.26	4.37	1.50	5.00	7.87	8.91	0.88	0.88	3.47	4972.34
17105	17571	4.68	0.02	1.04	3.97	1.50	5.00	5.75	7.72	0.74	0.81	3.02	3345.29
17571	20013	4.57	0.02	1.02	3.97	1.50	5.00	5.64	7.67	0.74	0.81	2.99	3262.04
20013	22200	4.47	0.02	1.01	3.97	1.50	5.00	5.56	7.62	0.73	0.81	2.97	3195.27
22200	22650	4.47	0.03	1.34	3.97	1.50	5.00	7.99	8.79	0.91	0.56	2.97	3195.27
22650	23800	3.89	0.03	1.28	3.63	1.50	5.00	7.10	8.24	0.86	0.55	2.83	2777.44
23800	24700	3.89	0.02	0.97	3.63	1.50	5.00	4.93	7.13	0.69	0.79	2.83	2777.44
24700	27100	3.89	0.03	1.28	3.63	1.50	5.00	7.10	8.24	0.86	0.55	2.83	2777.44
27100	27266	3.89	0.02	1.06	2.99	1.50	5.00	4.84	6.81	0.71	0.80	2.83	2777.44
27266	28019	2.52	0.02	0.92	2.25	1.50	5.00	3.36	5.58	0.60	0.75	2.43	1798.21
28019	30554	1.73	0.02	0.79	1.99	1.50	5.00	2.49	4.82	0.52	0.69	2.13	1233.23
30554	31400	1.57	0.02	0.74	1.99	1.50	5.00	2.28	4.64	0.49	0.69	2.06	1122.49
31400	35184	1.57	0.03	0.96	1.99	1.50	5.00	3.30	5.46	0.61	0.48	2.06	1122.49
35184	37073	1.55	0.03	0.96	1.97	1.50	5.00	3.26	5.42	0.60	0.47	2.05	1105.08
37073	39984	1.50	0.03	0.95	1.93	1.50	5.00	3.18	5.35	0.59	0.47	2.03	1072.97

4.2 Comparison of Earthwork Quantities

The quantity of earthwork volume for Dabus irrigation scheme for the left main canal obtained using iCAD/ CanalNETWORK software and conventional method are presented in Table 3. iCAD calculates the earthwork quantities in a more advanced way as it embeds more reliable approaches (see section 3). Consequently, the values computed through conventional method and iCAD software for the Dabus left main canal has been compared (Table 3).

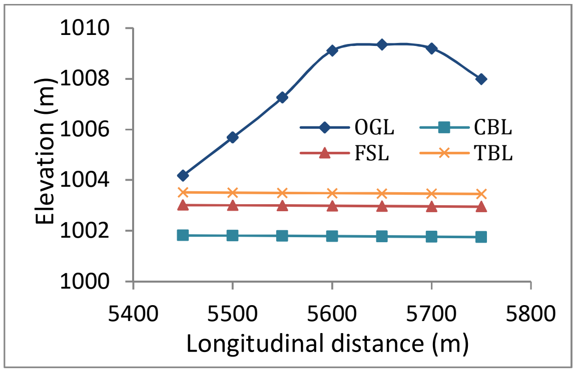
Table 3: Summarized earthwork quantities computed using iCAD and Conventional method

No.	Description Left Bank Main Canal (LBMC) with total length of 39.98 km	Unit	iCAD software	Conventional method	Difference
1	Excavation of existing formation to designed Canal Bed Level or foundation level of Canal Lining as per design specifications	m^3	337,433.90	322,280.01	15,153.90
2	Clearing of existing formation to a depth of **10CMs** under earth fills	m^2	1,301,317.61	915,577.65	385,739.96
3	Fill works on cleared existing formation to designed finish level corresponding to canal top level or top of foundation level, as per design schedule; and adequately compacted as per specifications	m^3	1,392,471.45	694,132.03	698,339.42

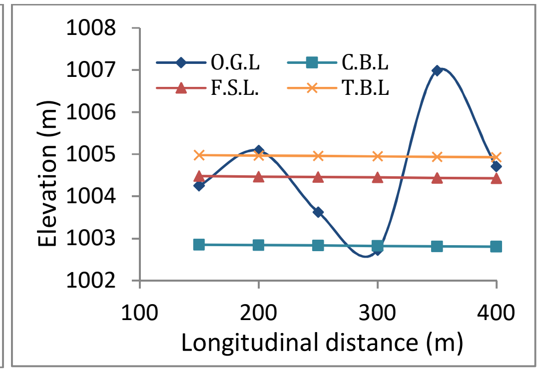
The values estimated for excavation work in iCAD increased by 4.7% while fill works was increased by 100 % from values calculated in the conventional method (Table 3). The volume variations occurred mostly due to considering/ignoring of the whole topographical profile of the design area. In addition, canal sectional areas with berms obviously have higher top width than normal trapezoidal section as it uses more length in transverse direction to stabilize side slope. As a result, clearing areas determined in iCAD has increased by 42 % from corresponding value calculated using the conventional method.

The main drawback of conventional method is developing trapezoidal cross section and computing cut/fill volumes as if elevation of ground surface in transverse direction is perfectly horizontal. This assumption can be possible when a terrain is flat. However, when the terrain has hillsides, gorges or undulating surfaces, considering constant ground level is not appropriate; rather taking into account actual ground surface elevations and considering berms (when required) in the design process are vital.

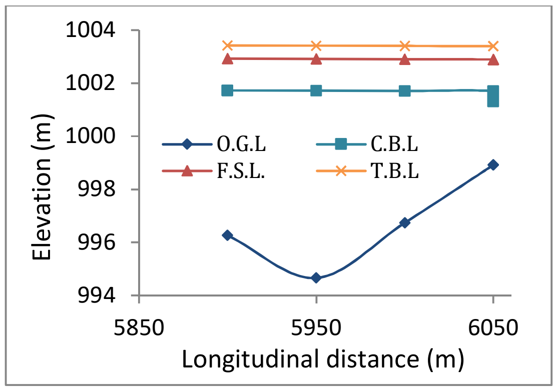
Three scenarios were also formulated from Dabus left main canal in order to show clearly how the volume estimations vary when the canal has deep cut, fully fill, or partial fill & partial cut (Figure 7). Scenario-1 has a deep cut segment with chainage from 5+450m to 5+750m, Scenario-2 was bounded between 5+900m to 6+050m and was fully fill section, and Scenario-3 has partially fill and partially cut portion lie in between 0+150m to 0+400m. In every 50m interval of longitudinal distance, a new cross sectional area was calculated both in conventional and iCAD solutions.



a) Scenario – 1



b) Scenario - 2



c) Scenario - 3

Figure 7: Longitudinal profiles of different scenarios

In Scenario-1, the canal has only deep cut sections. Total of seven cross sectional areas were considered in this scenario. Applying methodologies stated in section 3, cross sectional areas and corresponding volumes were determined both in iCAD and conventional method (Table 4). As shown in the table, there is a clear quantity difference. For instance, if we take the cross sectional area at 5+500m (Figure 8), iCAD provided berm to stabilize sides of the trapezoid which resulted 33.5 m^2 areal increment. Similarly, the other six cross sections developed by iCAD have larger areas and consequently caused higher volumes. Eventually, for the 300m deep cut segment of the canal, 13136.7 m^3 volume difference was observed in between the two approaches.

Table 4: Result comparisons for 300m fully cut section of Dabus main canal

Chainage (m)	**iCAD software**		**Conventional method**		**Difference**	
	Area of cut (m^2)	Volume (m^3)	Area of cut (m^2)	Volume (m^3)	Area of cut (m^2)	Volume (m^3)
5450.0	36.51	--	22.17	--	14.33	0.00
5500.0	78.47	2874.3	45.03	1680.1	33.43	1194.2
5550.0	130.94	5235.1	76.49	3038.1	54.45	2197.0
5600.0	183.61	7863.5	123.06	4988.7	60.55	2874.9
5650.0	183.94	9188.6	129.93	6324.7	54.01	2863.9
5700.0	170.24	8854.4	126.06	6399.7	44.18	2454.7
5750.0	112.23	7061.7	94.32	5509.3	17.91	1552.4
TOTAL		41077.5		27940.5		13136.9

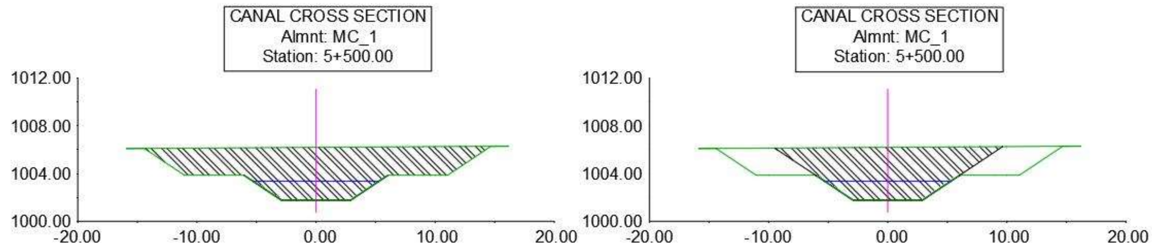


Figure 8: Deep cut sections in iCAD (left plots) and convectional method (right plots)

In Scenario-2, the 150 m length of Dabus canal was completely filled. As shown in Table 4, there are 4 sections in between 5+900m and 6+050m. If we consider section at 5+900m, the area of fill calculated using conventional method is lower than corresponding iCAD values (Table 5 and Figure 9). Conventional method always considers only the height of the centerline of the canal with referring to the Original Ground Level (OGL) parallel to it. As a result, the method missed the probable filling quantity which can occur when the terrain is inclined in the transverse direction. Likewise, the other three sectional areas computed using conventional method has different values.

Table 5: Result comparisons for 150m fully fill section of Dabus main canal

Chainage (m)	**iCAD software**		**Conventional method**		**Difference**	
	Area of fill (m^2)	Volume (m^3)	Area of fill (m^2)	Volume (m^3)	Area of fill (m^2)	Volume (m^3)
5900.0	261.03		212.48		48.55	0.00
5950.0	251.99	12825.40	284.01	12412.45	-32.03	412.95
6000.0	194.58	11164.20	191.89	11897.68	2.69	-733.48
6050.0	95.13	7242.68	109.48	7534.22	-14.35	-291.55
TOTAL		31,232.28		31,844.35		612.08

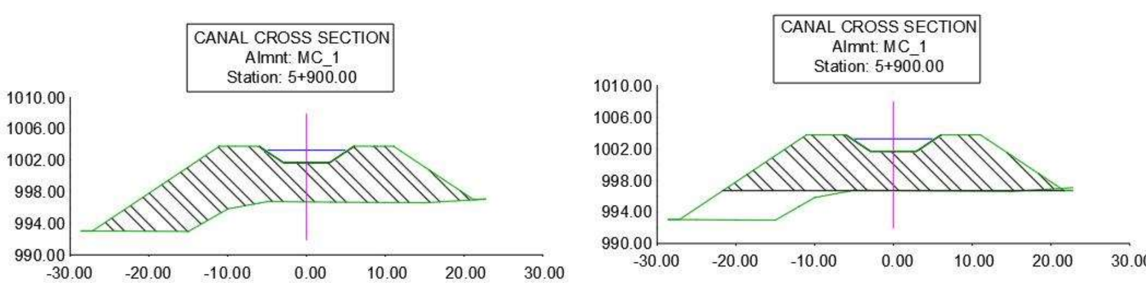


Figure 9: Fully fill sections in iCAD (left plot) and convectional method (right plot)

In Scenario-3, both fill and cut processes practiced for 250 m length of the canal. In this part of the canal, the terrain has a very high inclination along the transvers direction. It shows boldly how the assumptions considered in the conventional method influence the precision of the results. Figure 10 shows at station 0+300 m. Both fill and cut areas were significantly lower in the conventional method, resulting from flat terrain assumption. A closer look at Table 6 shows the area of fill missed at 0+200 (Table 6).

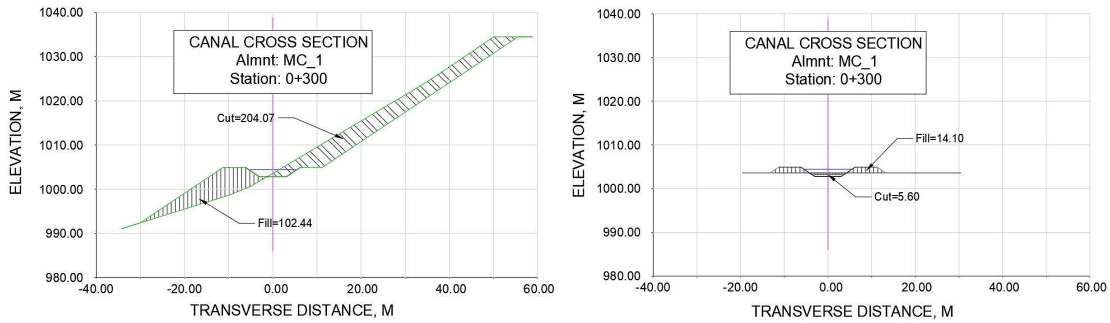


Figure 10: Partially cut & fill sections in iCAD (left plots) and conventional method (right plot)

Table 6: Result comparisons for 250m partially cut & partially fill section of Dabus main canal

Chainage (m)	iCAD software		Conventional method		Variations	
	Area of cut (m^2)	Area of fill (m^2)	Area of cut (m^2)	Area of fill (m^2)	Area of cut (m^2)	Area of fill (m^2)
150.0	19.26	21.66	11.43	8.90	7.83	12.76
200.0	89.39	26.70	21.21	0.00	68.18	26.70
250.0	23.53	76.87	5.78	18.66	17.76	58.20
300.0	204.07	102.44	5.60	14.10	202.26	64.72
350.0	241.05	17.13	51.56	0.00	189.50	17.13
400.0	42.20	59.32	17.09	2.32	25.11	57.00
	Volume of Cut (m^3)	Volume of Fill (m^3)	Volume of Cut ((m^3)	Volume of Fill (m^3)	Volume of Cut (m^3)	Volume of Fill (m^3)
150.0	-	-	-	-	-	-
200.0	2,716.3	1,209.0	816.0	2,22.5	1,900.3	986.5
250.0	2,823.0	2,589.3	674.8	4,66.5	2,148.3	2,122.8
300.0	5,690.0	4,482.8	284.5	8,19.0	5,405.5	3,663.8
350.0	11,128.0	2,989.3	1,429.0	352.5	9,699.0	2,636.8
400.0	7,081.3	1,911.3	1,716.3	58.0	5,365.0	1,853.3
TOTAL	29,438.5	13,181.5	4,920.5	1,918.5	24,518.0	11,263.0

Additional three segments named as segment_01, segement_02 & segment_03 were also considered as shown in the Figure 11 in order to understand about the impact of transverse profile consideration in volume estimation. The segments are selected based on elevation variability in transverse profile and each represents high, medium and low elevation variabilities respectively (Table 7).

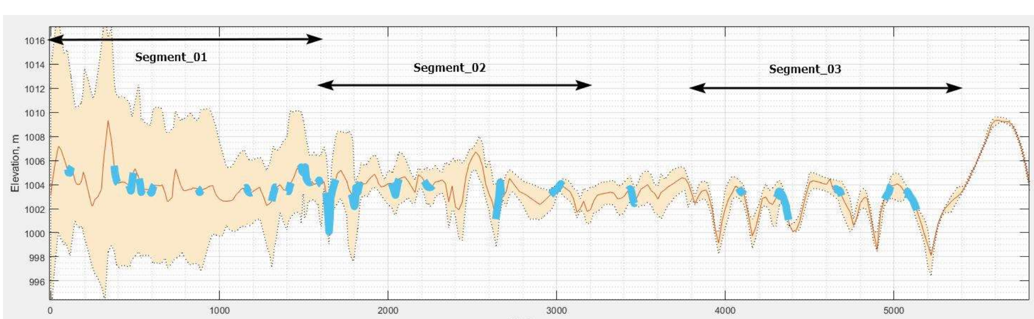


Figure 11: Band profile view of segement_01, segement_02 and segement_03 with offset distance 20m left and right from the centerline, at 2.5m resolution

Note that solid orange line indicates center line profile of the canal while thick blue marks indicate curve locations along the alignment of the canal.

Table 7: Summary of ground level elevation in segement_01, segement_02 and segement_03

Segment	**Station**		**Transverse variation of ground level elevation for each segment**		
	Start (m)	End (m)	Maximum difference (m)	Minimum difference (m)	Mean (m)
Segment_01	0	1600	23.8	3.68	10.83
Segment_02	1600	3200	10.27	0.543	3.365
Segment_03	3800	5400	3.76	0.186	1.54

Then, the earthwork volumes were computed for these segments applying both conventional and iCAD methods considering 50m offset distance in the transverse direction. The result revealed that segement_01 has highest variations both in fill and cut volumes reaching up to 556 % and 250 % respectively (Table 8). Whereas, segement_03 which has lower elevation difference in the transvers section resulted relatively lower variations (Figure 12). The results indicate that considering transverse profile while computing earthwork volume is vital and results significant difference in volume estimations. In addition, iCAD significantly reduces design time and enables comparisons of various canal routings/networks in very short time and thus supports engineers to select optimal canal route/network. It also provides detail design parameters in one click and has good visualization option.

Table 8: Earthwork volume comparison by segment

Segment	**V_c (iCAD)**	**V_c (Conv. method)**	**Difference of V_c (%)**	**V_c (iCAD)**	**V_f (Conv. method)**	**Difference of V_f (%)**
Segment_01	74272	13346.6	556.49%	66149	26418.4	250.39%
Segment_02	22676	18943.1	119.71%	28106	20036.7	140.27%
Segment_03	11639	12578.2	92.53%	57951	50055	115.77%

where V_c and V_f represent volume of cut and fill respectively

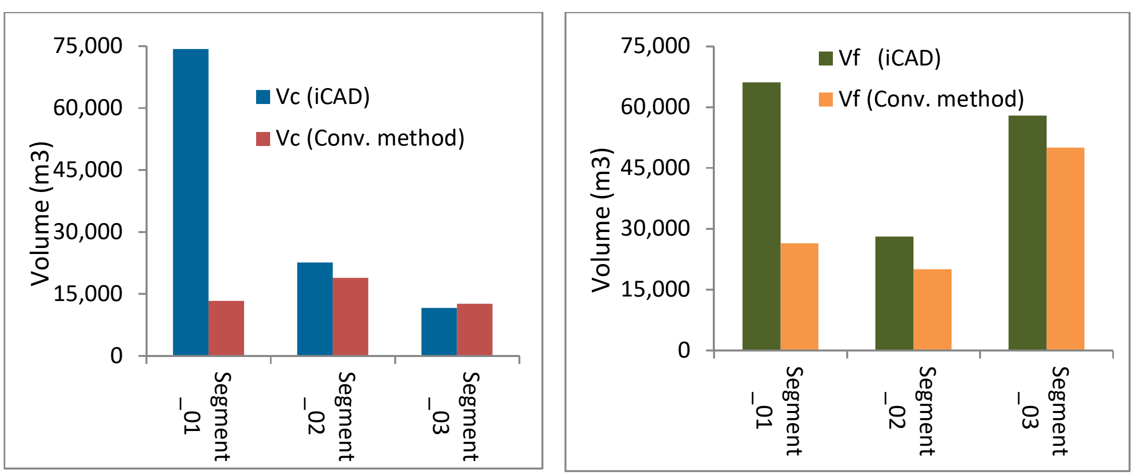


Figure 12: Earthwork volumes for deep cut segment (left plot) & fully fill segment (right plot)

4.3 Discussions

More than 85% of the Ethiopian population lives in rural areas and uses agriculture as a main source of income (Makombe et al., 2017; Mengistie & Kidane, 2016; Plecher, 2020; Wendimu, 2021). According to International Trade Administration (2022), agriculture is refereed as the most promising option in order to improve the economy of the country. The country has abundant water resources and potential sites for irrigation and its development (Assefa et al., 2019; Worqlul et al., 2015; Worqlul et al., 2015). However, irrigation is not largely practiced relative to the possible irrigable land that the country has. On top of that, the irrigation sector has been facing various challenges including low technology adaptation, inadequate technical capacities, poor operational and management processes. In this regard, iCAD is able to enhance design process by automating manual operations, embedding realistic approaches and providing good user interface/visualization system.

As mentioned, iCAD employed more advanced approach than the conventional computational practices and thus was capable to provide more precise results. The results described in the analysis section showed significant quantity difference between iCAD and conventional earthwork volume and clearing area estimations. For instance, iCAD estimated values of excavation work, fill work and clearing areas of Dabus left canal are higher by 4.7, 100 and 42% respectively than the correspondent values determined using conventional method. In addition, Scenarios which embedded segments with high, medium and low variation in transverse profile also showed that substantial significant earthwork volume deviations were occurred between conventional and iCAD computations. The conventional method is highly vulnerable to error due to ignorance of transverse profile of the area.

All the preceding analyses indicate that iCAD provides more precise result, save time and good-user interface (Alemu, A. M., unpublished document, 2020; Woldemichael et al., unpublished document, 2022). It embeds more realistic approach and enables to represent the actual scenarios. It also considers elevation data across the transvers direction which the conventional method doesn’t. Contrary to iCAD, the conventional method doesn’t take berms or benches into account for both cut and fill conditions. The software automatically generate canal-cross-section drawings at selected station or at specified increments within a few seconds. This reduces design time and save efforts which possibly spend on drawing preparation. The software is more user friendly and provides in one click either detail or summarized BOQ (Bill of Quantity) reports in presentable form. Therefore, using appropriate technologies, such as iCAD and CanalNETWORK, for canal design will enhance the practicability of designed canal as well as the feasibility of intended irrigation scheme.

Despite the positive returns of irrigation developments, various researches showed that irrigation can modify hydrological processes, cause erosion, deteriorate water quality, cause salinity, and affect ecosystem (Geleta et al., 2023; Mequanent et al., 2021; Ruffeis et al., 2008; Ulsido et al., 2014). According to Mujere and Chanza (2023), these impacts may arise either during project construction, implementation or decommissioning. Chen et al. (2020) also stated that irrigation development has notable carbon footprint released during their life time. The negative implications of irrigation projects which can be created during construction & then implementation phases can be alleviated by proper designing of irrigation systems including canal network. Consequently, estimating earthwork quantities precisely enhance to determine the exact amount of excavated and/or filled earth materials and thus results efficient resource utilization. Therefore, it contributes for environmental sustainability of irrigation projects.

5 | CONCLUSIONS

Dabus irrigation scheme was used as a case study in order to show the importance of adopting new technologies for designing irrigation canals. In the study, earthwork quantities were determined and compared applying conventional method, which embeds series of Excel spreadsheets, against the correspondent values of iCAD software. Various scenarios were considered in the study in order to show clearly where and how the variations came from. In scenario-1 where only deep cut sections considered, iCAD accounted berms in side of the canal segment to stabilize side slope whereas the conventional method did not. As a result, earthwork volume observed in conventional methods was 53% underestimation compared to iCAD computation.

Besides, when the canal has fully fill sections, as was the case in scenario-2, earthwork volumes estimated in both ways vary, by about 2%, due to the simplified assumption considered in the conventional method; whereas the software favors to represent the entire topographical profile of the design area. Another scenario that indicated maximum elevation difference transversally by 23.8 m also revealed that earth volumes computations in iCAD and conventional methods vary up to 550% and 250% in fill and cut quantities respectively. Such variations which are not represented in conventional design practice could result in poor project budgeting, work variations, lengthy contractual issues during construction, and in general low project execution efficiency.

The software, iCAD, improves quality, reduces design time and provides a decent user interface. Employing this software while designing canal and its related structures will favor for more realistic results than the conventional method. It also reduces human error hence it automates manual operations. Overall, the software has a strong potential to improve the existing design practices, impacting construction and thus will enhance for achieving the highest operational efficiency of irrigation systems.

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