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Criticality in computation of volume excavated by opencast mining: some key observations

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ABSTRACT
Survey plays a vital role in computation of actual volume excavated. Precise computation of opencast excavation is of prime importance as it affects the quantity of mineral/coal and in turn economy. The paper covers the methodology encompassing the concept and procedure for estimation of volume of irregular excavated geometry by section method on varying section orientation. The same approach has been correlated with field measurement done in New Akashkinari mine of Jharia Coalfield. Susceptible aspects like type of software used, process of preparation of cross sections, position of sections, and interval between two sections are discussed to assess the cause for variation in volume computed for the same input data.

Keywords: survey, area, volume, cross section, Terrestrial Laser Scanner, Total Station

INTRODUCTION

Advent of upgraded survey and volume technique finds its place in research. Computation of volume of excavation is indispensable in mining domain especially in estimation of ore/coal removal. In some of the opencast mines, mining operation is outsourced and the payments are made based on the quantity excavated. Precise calculation of cut volume is a matter of concern both theoretically and practically to avoid discrepancies (Soole and Poropat, 2000). Furthermore, over or under excavation made by the contractor can also be monitored by regular volume measurements and consequently operation can be managed following the guidelines of mining scheme.

Method of surveying plays a vital role in volume computation (Yakar and Yilmaz, 2008). Density of measurement of 3D data of the area excavated is a key factor to it. The geometry of opencast excavation is, in general, irregular and hence measurement of slight changes in elevation in all the places is practically difficult. Survey by Total Station requires point by point measurement which is cumbersome and time consuming. Presently, many modern survey instruments are available for obtaining 3D surface data quickly (Wang et al., 2013).

Terrestrial Laser Scanner (TLS) could be applied to acquire high density point cloud for (Digital Terrain Model) DTM modelling (Sturzenegger and Stead, 2009). An implementation of laser technology helps in providing dense and precise point cloud data thereby overcoming the limitations of field measurement by traditional means like Total Station. Interferometric Synthetic Aperture Radar (InSAR) technique was used to determine surface profile of opencast mine (Paradella et al., 2015; Mura et al., 2014).

Several methods of volume computation were exercised by various researchers. Pflipsen (2007) explained the concept of the Total Station and volume calculation. Napoles and Berber (2018) proposed contour method of volume computation with newly developed formula. Labant, Staňková and Weiss (2013) used Global Navigation Satellite System (GNSS) and electronic Total Station for volumetric computation of stockpile. The application of Global Positioning System (GPS), Total Station and ground photogrammetry for the volume accuracy assessment was explained by Wajs (2015). The average difference in estimated excavation volume between Light Detection and Ranging (LiDAR) derived Digital Elevation Model (DEM) and Real Time Kinematic (RTK) GPS analysis was 19.69% for two ditches according to study conducted by Paff (2014). Jwamer et al. (2012) elaborated about precise calculation of pit excavation volume using fifth degree polynomial curve as high degree curve provides more smooth ground profile.

Present study covers the combination of GNSS, Total Station and TLS for surveying of opencast mine and the outcome of data was used for volume computation with a key focus to achieve the result close to actual.

STUDY SITE

Fig. 1: Location of New Akashkinari mine in google map

The study was conducted in New Akashkinari opencast mine of Bharat Coking Coal Limited (BCCL), Jharia Coalfield, India, for volume computation (Prakash, 2019). The mine was having a stretch of around 800 m along strike and 450 m wide. Closed traverse was conducted by Total Station around the periphery of mine to determine the geo-reference stations as shown in satellite image (Fig. 1). TLS was used for 3D scanning by setting the instrument over geo-referenced stations as shown in Fig. 2. TLS data was processed through ATLAS scan software and the plot of point cloud data is shown in Fig. 3.

(a) (b) (c)

Fig. 2: 3D scanning by TLS at different location

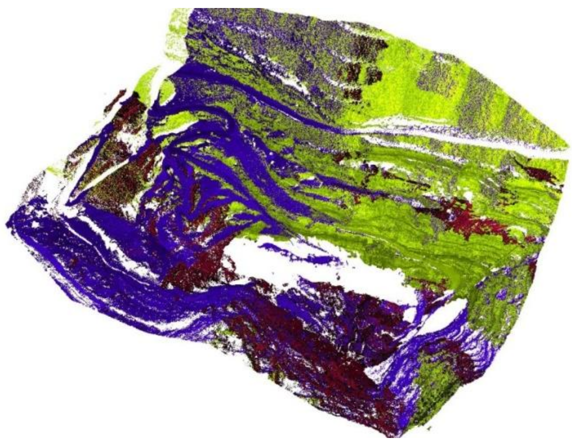
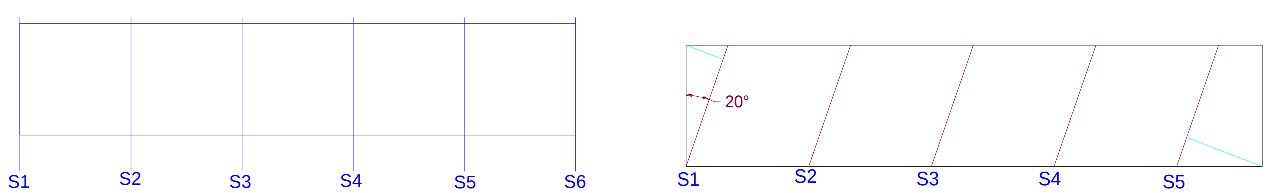


Fig. 3: Plot of point cloud data

METHODOLOGY

The volume computation was exercised using cross section method. Cross sections are generally prepared perpendicular to the centerline. Sometimes attaining a proper orientation of centreline and cross section becomes difficult due to irregular shape of opencast mine. This concept makes a way to revisit into the process of volume computation. Thus, experiment was conducted to examine the variation in volume by altering the orientation of cross sections. The concept has been framed based on known dimension and the same has been implemented for irregular shaped opencast mine for correlation perspective.

A known volume of 1000 m^3 cuboid of dimension 10 x 50 x 2 m has been considered for better comprehension. Volume was computed by making sections perpendicular and at 70^o to longer axis of cuboid respectively as shown in Fig. 4.



(a) Vertical section (b) Sections at 20^o from the vertical

Fig. 4: Sections at different orientation

Volume was computed using Trapezoidal Rule, expressed as:

$$V = D/2\{A_1 + A_n + 2(A_2 + A_3 + \ldots + A_{n-1})\} \quad (1)$$

Where, V = volume (m^3)

D = common distance between two sections (m),

A_1 = area of first section (m^2),

A_n = area of last section (m^2) and

A_2 to A_{n-1} = area of intermediate sections (m^2).

The area before S1 and after S5, i.e., left out terminal parts not covered by section lines, were calculated separately and multiplied with their heights to compute the left out edge volumes as shown in Fig. 5. The details of computed volume for different sectional orientation are given in Table 1.

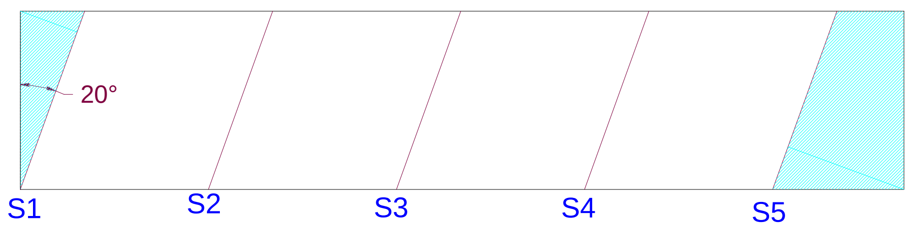


Fig.5: Area computation beyond section boundary

Table 1: Volume computation at different orientation of sections

Parameters	Vertical section to longer axis	Section at 20° from the vertical
No. of full sections	6	5
No. of partial sections	0	0
Area of each full section	20 m^2	21.2836 m^2
Volume for full section	1000 m^3	851.344 m^3
Volume at edge	0 m^3	148.657 m^3
Total Volume	1000 m^3	1000.001 m^3

It is evident from Table 1 that variation in volume of cuboid calculated by different sectional orientation which was negligible. Slight variation in volume may be anticipated for irregular geometry in real ground condition primarily due to improper coverage at the ends/edges.

VOLUME COMPUTATION

Volume computation is done by various standard methods like cross sectioning (Trapezoidal, Simpson-based, cubic spline and cubic Hermite formula) (Yanalak, 2005). The use of cross section method for the calculation of volume was extensively described by Michalcak (1990). As the volume can be computed by various approaches, deciding the most precise one is a critical factor.

Classical cross sectioning method like trapezoidal, Simpson and average formula was described by Yanalak, 2005. Trapezoidal Rule, an average of left- hand and right-hand Riemann, provides accurate approximation in comparison to normal averaging. The result obtained by the trapezoidal rule is not affected because the boundary between the ordinates is considered straight. There is no limitation to this rule and can be applied to any number of ordinates. In the present study, volume computation was done using cross section method applying trapezoidal rule, as it is being commonly practiced in Indian coal mines.

Preparation of plan and sections

The location of section preparation and the quantity of sections are defined mainly by the plan. Surface plan was prepared based on the outcome of the TLS data (Fig. 6). The easting coordinates ranging from 78460 to 79290 were taken into consideration for preparation of vertical sections which is not exactly perpendicular to the centreline. Another set of sections were made at 10 m intervalperpendicular to centreline (Fig. 7).

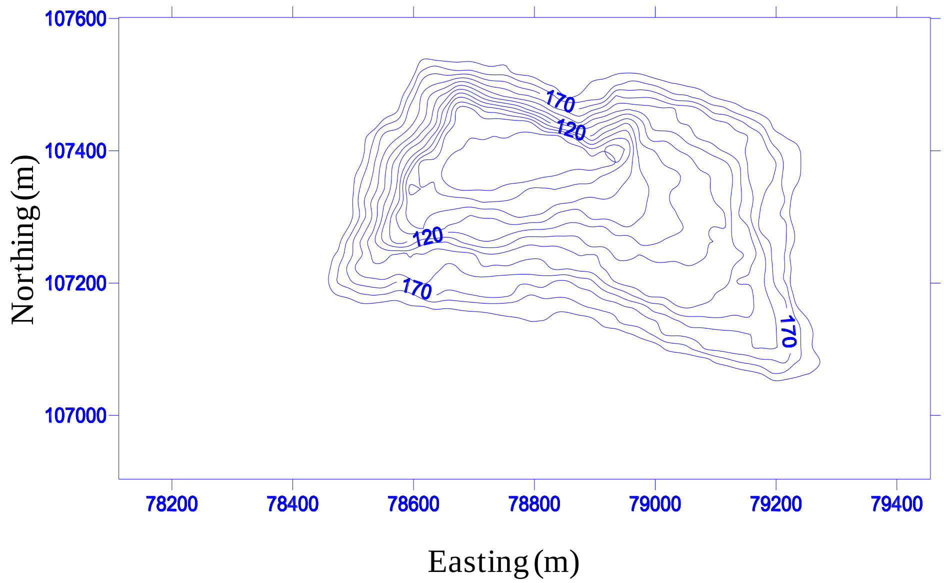


Fig. 6: Opencast mine shown by contour lines

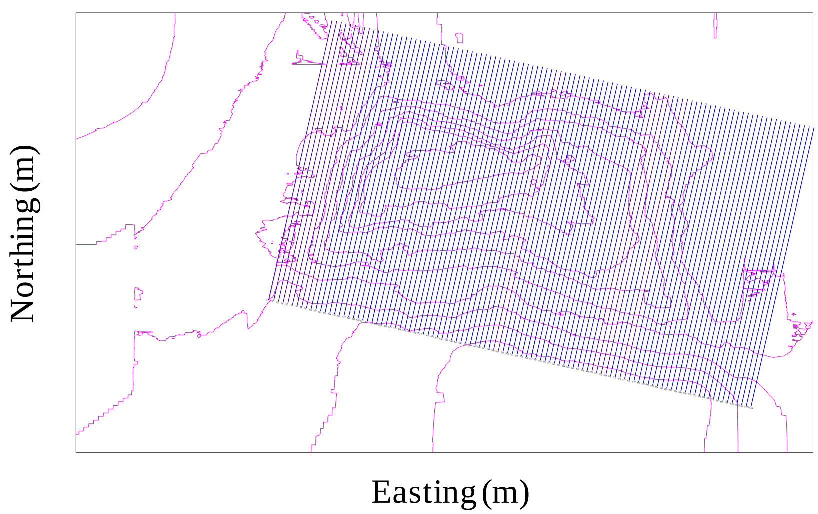


Fig. 7: Section lines perpendicular to centreline

Area of each cross section has to be obtained for computation of volume of any irregular mass of earth work. The area of each section was computed in AutoCAD.

The accuracy of surface profile of any excavated area close to actual primarily depends on closures and number of measurements onx, y, z coordinates. Proper coverage of profile deviation is essential. The accuracy of the area of each section depends on the precision of the sectional profile. Hence, profile was prepared by generating data at 1 m intervalalong each section from the interpolated DTM for vertical section, while CivilCAD software was used to generate sections perpendicular to centerline as it was not feasible to generate data for inclined planes due to software limitation. Section of one of the profiles is shown in Fig. 8.

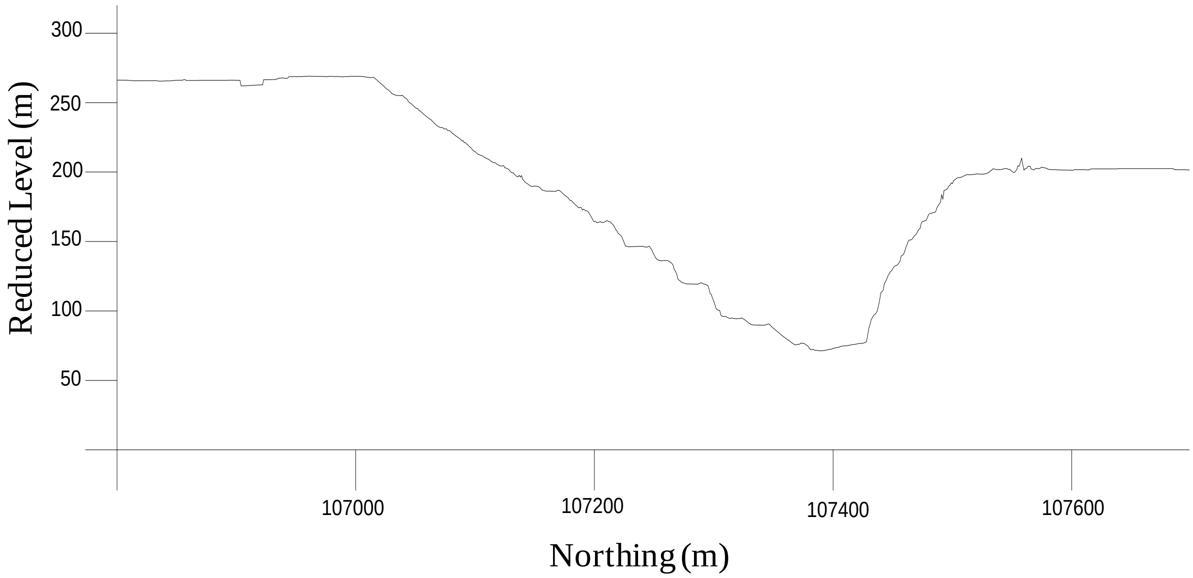


Fig. 8: Sectional view of one of the profiles

For computation of volume of earth work, sectional area of each cross-section has to be obtained. The area of each section was computed through AutoCAD. Topographical data is generally taken as datum. However, in the present study, 200mRL was considered as datum for computation of quantity of excavation as only single measurement was taken in the mine (Fig. 9).The quantity of excavation was computed on the portion below 200mRL shown by hatch lines in Fig. 10.

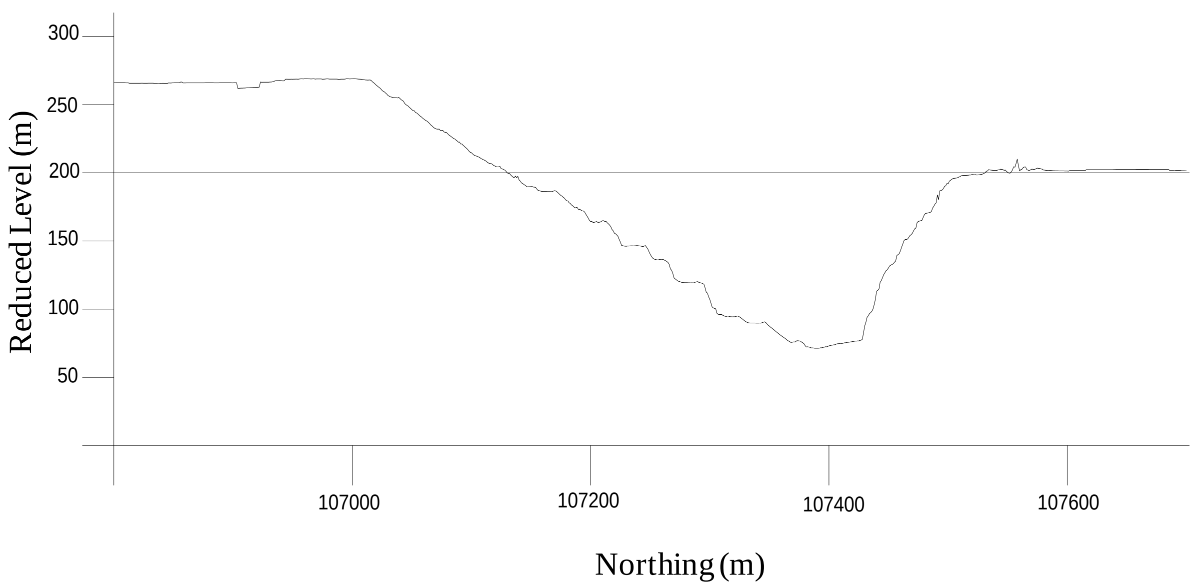


Fig. 9: Datum line for area computation

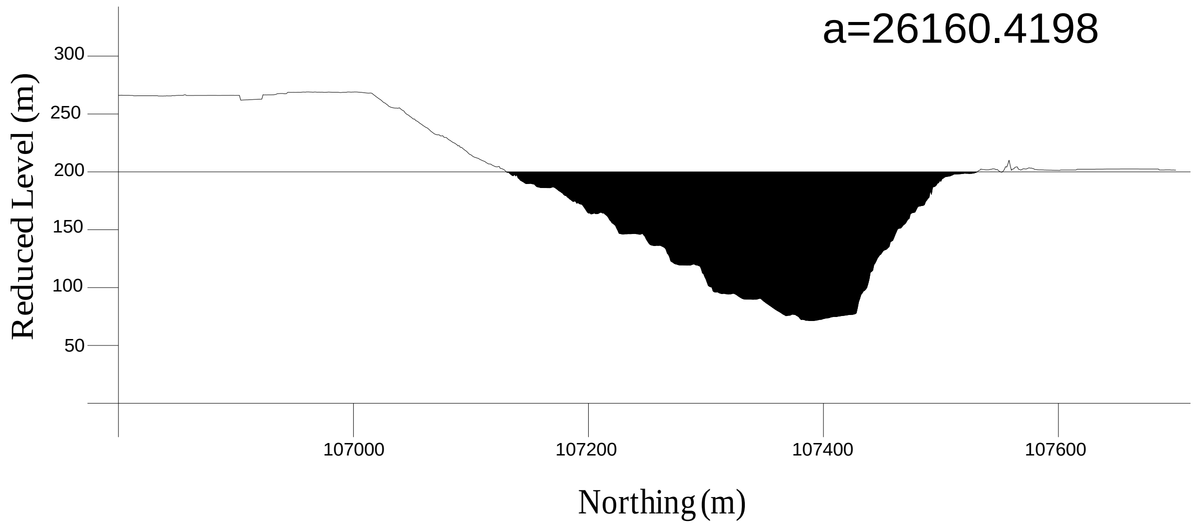


Fig. 10: Area computation below datum

Calculation of volume

The volume was computed using trapezoidal rule for both the conditions (vertical and inclined sections). 76 sections were made in inclined direction (perpendicular to centreline) and the volume computed was 16672566.453 m^3. 84 vertical sections were developed covering the entire area and the volume obtained was 16699241.620 m^3. Volume computed by ATLAScan software considering the altitude reference plane as 200 m (Fig. 11) amount to 16609589.093 m^3.

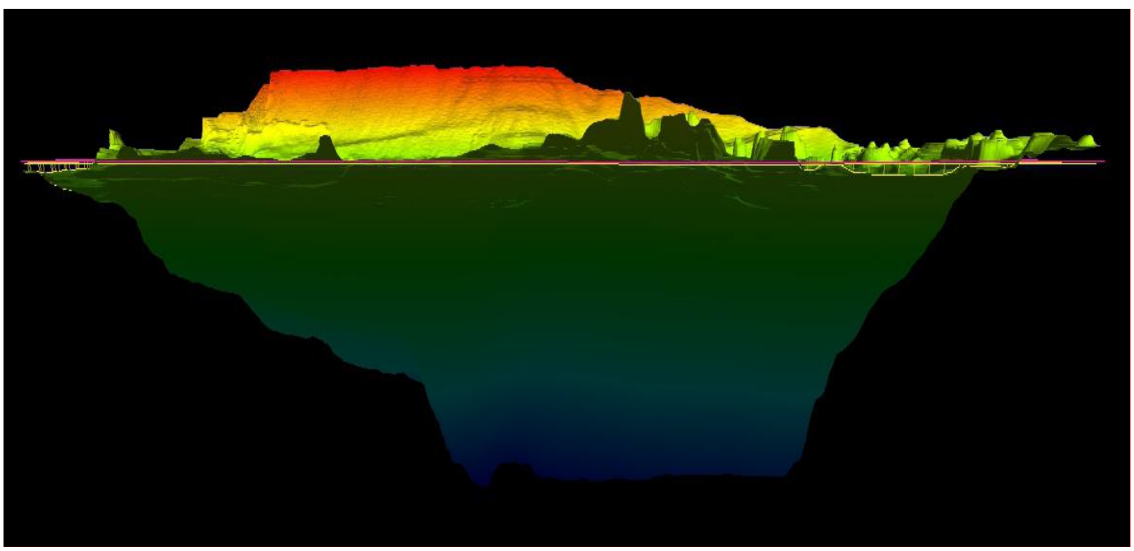


Fig. 11: Volume computation by ATLAScan with reference plane as 200 m

The deviation in volume was compared with respect to the standard measurement procedure i.e. for sections developed perpendicular to the centre line as depicted in Table 2.

Table 2: Comparison of computed volume

Item	Method	Volume (m^3)	Difference from A	Percentage deviation with respect to A (%)
A	Section perpendicular to centreline	16672566.453		
B	Vertical Section	16699241.620	26675.167	0.160

C	ATLAScan software	16609589.093	62977.360	0.378
	Average volume	16660465.722		

The maximum percentage deviation of 0.378% in volume may probably be due to influence of irregular geometry of opencast profile and methodology of computation.

FACTORS INFLUENCING VOLUME

Critical appraisal was made based on the study draws several factors to influence the volume computation of opencast excavation as illustrated in this section.

Number of geo-reference stations

The number of geo-reference stations fixed in the field is governed by the geometry and shape of the topography/ land to be surveyed. Plot of the surveyed area should be chock-a-block with point cloud data points. The portion not surveyed is easily noticeable by the absence of plots of point cloud data. Survey of such areas can be undertaken by establishing additional geo-reference stations at suitable locations. This may lead to establishment of a good number of geo-reference stations at short intervals for a small area which may affect the closing error and 3D data determination. Thus, for such terrain thorough reconnaissance survey should be conducted to have minimum possible geo-reference stations covering entire area to be surveyed.

Profile of cross section

The profile of cross section is a sensitive aspect for computation of ultimate volume. Sections were prepared by two approaches, i.e., by CivilCAD software and by manual means. The data were generated at 1m interval using Surfer software for preparing sections by manual approach through AutoCAD. The methodology of data interpretation and preparation of section is likely to affect the profile of the cross section.

Interval between cross sections

The accuracy of computed volume reduces if the distance between the gridlines is high (Crawford, 2008). The geometry of the excavated earth is also crucial in deciding the interval between cross sections. Hence, the position of sections should be maintained close enough as per the accuracy requirement of the project.

Location of each cross section

The volume of excavation will vary on shifting the position of sections as the surface profile of opencast excavation is of uneven geometry.

Computation of volume beyond extreme section boundaries

Sections at the excavation interface, where length of sectional profile reduces, should be computed separately. The orientation of cross section does not affect volume much as observed in the study. However, marginal variation was observed due to improper computation at the edges beyond the first and last sections. This variation accords a clue on the error encountered beyond the boundary ends of the sections, i.e., outside section A1 (first) and An (last), till the edge of cut. Hence, preferential attention needs to be paid to diminish such errors.

Software computation

Each software has its own entity with inbuilt program for DTM generation and volume computation. Prior to the modeling of the surface profile, all the noise or unwanted points need to be carefully eliminated. This, in turn, helps in enhancing the precision of the volume computation. Although the algorithms used by particular programs can easily make mistakes. One of the problems that can appear is that overlapping and intersecting “faces/triangles” produce mistakes in volume calculation (Molnar and Domozi, 2017).

CONCLUSION

Accuracy of field survey is the essence of estimating excavated volume. Methodology of computation is the major prospect affecting volume estimation. The basic approach for evaluating precise computation depends on proper coverage of area of extent. Volume computation of any excavation of irregular geometry can be conducted by establishing the direction of sectional plane to any orientation irrespective of perpendicularity to centreline but proper care should be taken to cover the extent of earth excavation fully. Marginal deviations were observed in volume computation by different approaches. Process of calculation is accountable for variation in volume and hence estimation of volume should be in an organized manner. The influence of irregular geometry of opencast profile affects the overall volume of excavation.

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Conflict of Interest

The authors declare that there are no conflicts of interests.

Peer-review

External peer-review was done through double-blind method.

Data and materials availability

All data associated with this study are present in the paper.

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