Preliminary Studies of Fecal Sludge Accumulation Rates of Dry Pit Latrines Using Kinect Based 3D Scanning Technology

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Mark Amo-Boateng
University of Energy and Natural Resources

Franklin Benjamin Afedoh
University of Energy and Natural Resources

Yakubu Elijah
University of Energy and Natural Resources

Samuel Siadey
University of Energy and Natural Resources

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Research Article

Preliminary Studies of Fecal Sludge Accumulation Rates of Dry Pit Latrines Using Kinect Based 3D Scanning Technology

Amo-Boateng M.[1,2*], Appiah-Effah E.[3], Afedoh B. F.[1], Yakubu E.[1], Siadey S.[1], Siabi E. K.[2]

Abstract
This study entails the findings of the accumulation rates of dry pit latrines in an urban community in Ghana. The results are then compared to that proposed by the World Health Organization (WHO). Over the years, studies have been conducted to get faecal sludge accumulation rates that could be internationally accepted. As a result of the discrepancies in the values obtained over the years, WHO proposed a figure (0.006m^3/person/year) which has been used since the 1950s. Our study was conducted in line with the already conducted studies but using the 3D Kinect technology with the cloud compare software. Based on our findings, we realized that the accumulation rates of dry pit latrines average 0.132m^3/person/year) in Fiapre, Ghana. This study also points out few reasons why there may have been discrepancies in the values obtained by various researchers over the years. We therefore encourage that the methods used in this study be employed in determining the accumulation rates of solids in latrines prior to their design and construction.

Keywords
accumulation rate, sanitation, KVIP, toilet pits, Kinect, 3D scanning

[1]Department of Civil and Environmental Engineering, University of Energy and Natural Resources, Sunyani, Ghana
[2]Earth Observation Research and Innovation Centre, Univeristy of Energy and Natural Resources, Sunyani, Ghana
[3]Regional Water and Environmental Sanitation Centre, Department of Civil Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
***Corresponding author**: mark.amo-boateng@uenr.edu.gh

Contents

1. Introduction

Sanitation forms part of the essential services in human life. Poor sanitation in the environment is a critical health risk and an affront to the dignity of humanity [1]. The population to use the facility is critical in the determination of the accumulation rate of the fecal sludge. Therefore, a change in the number of people to use the facility will reflect in the desludging frequency. This can lead to a number of public health problems such as the spread of diseases due to the production of strong odor and problems with flies. Others may also be the unawareness and unpreparedness to desludge the latrine. According to a monograph series on excreta disposal by the World Health Organization, many researches on the amounts of human excreta have mainly been undertaken on physiological basis, and have given some information on the extents and average figures of the amounts of excreta individuals produced. In addition, existing information on accumulation rate of fecal sludge in pit latrines are of varying reliability given that, amounts of human excreta produced may be influenced by local, cultural and religious conditions. However, in spite of the suggested values, it is recommended that controlled observations be made in each country in the modelling of accumulation rate of pit latrines [2]. Many of sanitation systems have been developed and used over the years e.g. ventilated improved pits (VIP), simple pit latrine etc. However, a distinction is made between dry sanitation systems (no water) and wet sanitation systems (require water). The accumulation rate of both dry and wet on-site sanitation systems have varying figures. This is so because the amounts of human excreta generated may be influenced by local factors which are not only physiological but may also include religious and cultural. For instance water used for ablution or other personal cleansing materials [2]. However, if it surprises municipalities when pits reach their peak and do not have the required finances, equipment and workforce in position to respond, households will fail to find for themselves access to proper sanitation facility, a state that compromises both public dignity and health [3]. Thus, this work seeks to contribute to improving environmental sanitation by accurately measuring the accumulation rates of toilet pits in Ghana. This is achieved by using Kinect based 3D scanning to determine the accumulation rate of public toilet pits and factors affecting the rate of accumulation.

2. Materials and Methods

2.1 Study Area

Fiapre is located in the Sunyani West District in the Bono Region of Ghana. On the map of Ghana, it has co-ordinates of 7°22’00" 2°21’00"W and shares borders with the regional capital, Sunyani. The people of Fiapre are known for agriculture as their main occupation whiles others occupations such as; civil service, teaching, and private businesses also play a vital role. In addition, majority of the people use the public toilets, and some own their private toilet facilities mostly the KVIP. Fiapre has two private universities; Ideas University College and Catholic University College of Ghana. GN Bank, Capital Rural Bank as well as Drobo Community Bank Limited which serve as financial institutions have their branches at Fiapre [4]. It also has one of the top female Senior high schools in the region called, Notre Damme Senior High School.

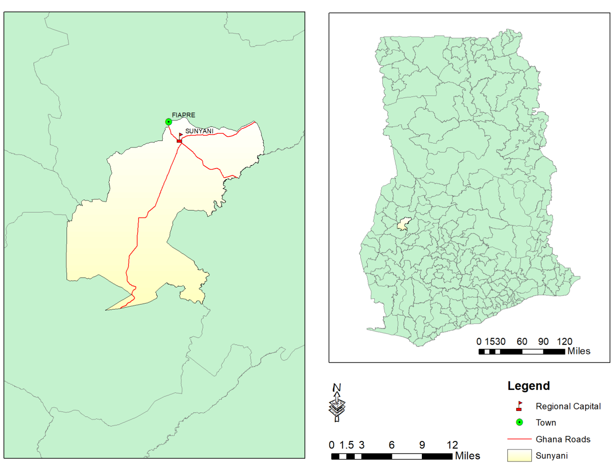

Figure 1. Location of study area

Figure 2. Front-view of the public toilet pit

Figure 3. Back-view of the toilet pit

2.2 B. Kinect V2 3D Scanning

The Kinect v2 device (contact free controller) is a multi-sensory peripheral designed by Microsoft for Xbox gaming console. It comprises of a color camera, a depth camera that supports both spatial and color information recognition about a filmed scene, a four-microphone array that provide full body 3D motion capture, as well as voice and facial recognition support [5]. The technique of attaining 3D information via an input device and processing it to a virtual 3D model is called 3D reconstruction and Kinect Fusion can be used for this purpose [6]. The depth sensor allows the estimation of the 3-dimensional coordinates of the points of a surface, using projected light patterns and the camera system. The depth camera system processes live data of many coordinates into a rebuilt 3D model in real-time [7]. The Kinect depth sensor employs structured light principle to enable the rebuilding of virtual 3D surfaces described by point clouds and defined by three dimensional coordinates (x, y and z). A structured light scanning system projects different light patterns, or structures, and captures the light as it falls onto the scene. It then uses the data about how the patterns appear after being distorted by the scene to eventually recover the 3D geometry [8].

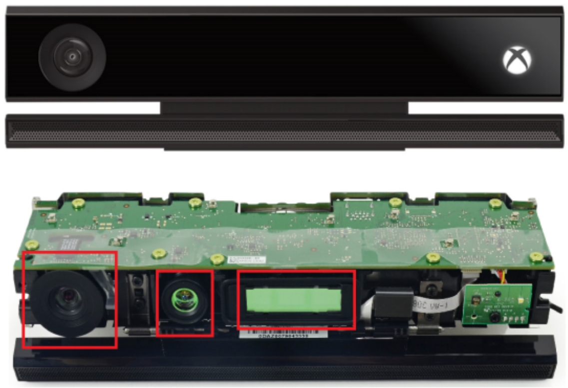

Figure 4. Kinect v2 sensor

2.3 Data Processing

Cloud Compare is an open-source point cloud analysis package that was developed for processing and comparing dense point cloud data, visualizing and data analysis. It has applications in civil engineering, manufacturing (quality control) and can also be used for distance computation (cloud-mesh or cloud-cloud, Nearest Neighbor Distance), point registration (ICP), Geometric features estimation (density, curvature, roughness, geol. plane orientation), Statistics estimation (spatial chi-squared test), etc. [13]. Using the 2D volume computation, the volume of accumulated in a period is calculated. This is obtained when two of the scanned 3D images are loaded into the software, aligned to each other and analyzed. In order to obtain our results, the Kinect device was used to scan each pit to generate mesh. In computing the volume of accumulated sludge in each pit, the Cloud Compare software was used to align the first 3D scan (base reference) to the next scan (final) which are similar and 1000000 points sampled from the mesh. With this alignment and due to the accumulation of the fecal sludge over the 4-day period, a gap is formed between the two 3D scans. Using the 2D volume computation, the volume between the two 3D scans is computed.

3. Results

The results of the Kinect 3D image scan of the toilet pits are shown in the figures and tables below. Figure 5a shows the true image taken with a digital camera of one of the toilet pits. Figure 5b shows the mesh image captured by the Kinect 3D sensor of the same image.

Also, Figure 6 shows the images captured of Pit A for the 1^{st}, 4^{th}, 8^{th}, and 12^{th} day. The mesh images were initially captured with the Kinect v2 sensor. Cloud points were then generated, aligned and registered using the Cloud Compare software. This was then used to compute the difference in volume using the 2.5D volume

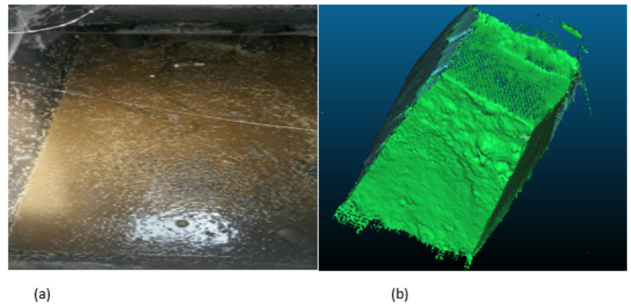

Figure 5. (a) True image; and (b) 3D mesh generated from Kinect v2 sensor

tool (also found in the Cloud Compare software). Cloud points generated and the differences in volumes for each of the pits is shown in Appendix A of this paper. The relative height of each of the pits for day 1, 4, 8, and 12 fell between 1.163 and 1.876 (see fig 6). The total volume of accumulated sludge for the period 1, 2 and 3 were 0.52, 0.29 and 0.64m^3 respectively (see table 1).

4. Discussion

From Table 2, the annual rate of accumulation for each period varies. This is reasonable because, the number of users of the facility has an effect on the mass and composition of fecal sludge at any given time. This is consistent with the findings of [11] who noted that fluctuations in the rates of accumulation may be attributed to the number of users of a certain latrine. Moreover, the relative population and the disposal of household waste into pits can affect the volume of accumulation across pits. For instance, the study of [3] revealed that settlement patterns such as dense urban settlement as well as soil composition can affect the volume of accumulated sludge in a pit. Despite attaining higher annual rates of accumulation in this study (See table 1), the study of [3] revealed similar discrepancies after sampling 100 latrines in the Limpopo Province in South Africa. Seven out of the 100 latrines attained over 0.08 m^3/person/year annual accumulation rate whereas eight attained less than 0.02 m^3/person/year annual accumulation rate. There was no explanation by the authors on the discrepancies, however, the lower accumulation rate can be related to small number of users than believed due to variation in the number of people in a household over the testing period, less inorganic material disposal into pits, higher degradation rate, variations in water table levels amongst others. The study reveals 0.132m^3/person/year (see table 2) as an average annual accumulation rate. This is 45% more than the 0.06m^3/person/year recommended rate. According to a study by the World Health Organization in 1950, they recommend that 0.04m^3/person/year be used for wet pits and where solid anal cleansing material are used. 0.06m^3/person/year be used dry pits, but there should be a 50% added volume where there is the usage of large amounts of anal cleansing materials (grass, stones etc.) [9]. However, despite the fact that many countries use these figures as guidelines, WHO emphasizes that pit filling rates should be developed for each country.

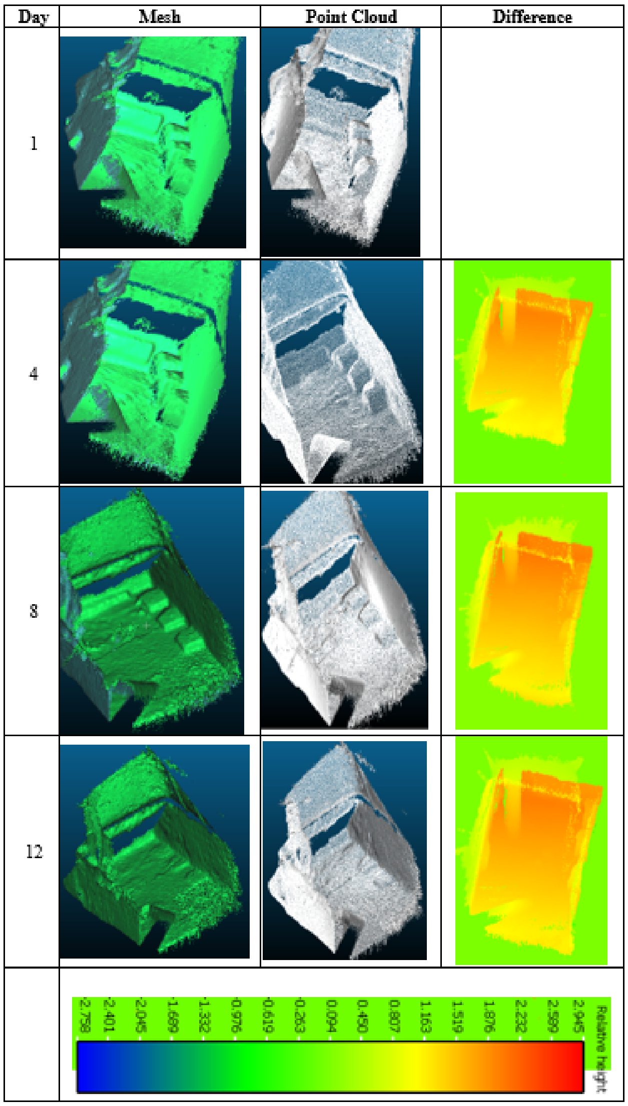

Figure 6. Kinect 3D scanning at day 1, 4, 8 and 12

The higher average annual accumulation rate could be attributed to the fact that, the study was not conducted over a long period, and use of a single study area. For instance, studies such as [11], [3] and [12] conducted their studies in more than one location. Also, if the study was to use factors considered in the study of [12] such as the variance in topography, population density, groundwater levels, soil composition, flood vulnerability, swamps etc. the estimated average annual accumulation rate could have been more. However, Still et al. noted that non-fecal matter disposal into pits may result in doubling the

Table 1. Volume of accumulated sludge in each period

Volume of accumulated sludge in each period (m3)			
Pits	**Period 1 (day 1 – day 4)**	**Period 2 (day 4 – day 8)**	**Period 3 (day 8 – day 12)**
A	0.052	0.026	0.063
B	0.028	0.008	0.036
C	0.129	0.104	0.158
D	0.059	0.064	0.056
E	0.104	0.008	0.099
F	0.054	0.006	0.059
G	0.017	0.023	0.047
H	0.039	0.027	0.061
I	0.025	0.01	0.035
J	0.013	0.014	0.028
Total volume	**0.52**	**0.29**	**0.642**

average fill rates of pits and may be the cause of higher accumulation rate than expected in many South African municipalities. This may be another cause of higher accumulation rate in this study since the pit contained other non-degradable materials other than anal cleansing materials. In countries like Ghana, the pit serves as the only practical and safe place to dispose hazardous substances such as disposable nappies, broken glass or sharp metals etc. or materials which could not be easily burned [10]. This however increases the rate of accumulation rate of the pit, but during the design and construction of the pit, they must be taken into consideration. Therefore, the approach used in this study cannot be liable for the higher estimate average annual accumulation rate since a single site was used. Conclusions can only be made after applying this approach to several study areas.

Table 2. Determination of annual accumulated rate

	Period 1 (day 1 – 4)	Period 2 (day 4 – 8)	Period 3 (day 8 – 12)
Sludge volume (m3)	0.52	0.29	0.642
Average users	310	300	380
Daily Accumulation rate (m3/person/day)	0.0016774	0.0009667	0.0016895
Annual Accumulation rate in a year (m3/person/year)	0.1530645	0.0882083	0.1541645
Average annual accumulation rate (m3/person/year)	**0.132**		

5. Conclusions

The accumulation rate of fecal matter is required for the construction of pit latrines and due limited data, the WHO upon several observations of the varying figures, recommended the 0.06 m^3/person/year and 0.04 m^3/person/year for dry and wet pit respectively. However, by harnessing the Kinect 3D scanning technology in modelling the accumulation of the public toilet facility within a 12-day period provided a figure of 0.132 m^3/person/year. This value is relatively bigger when compared to the recommended value. Since factors such as the variance in topography, population density, groundwater levels, soil composition, flood vulnerability, swamps have a direct effect on the accumulation rates, we recommend the use of many study areas and longer period (years) to verify and validate the approach used and accumulation rates for individual communities.

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6. Appendix

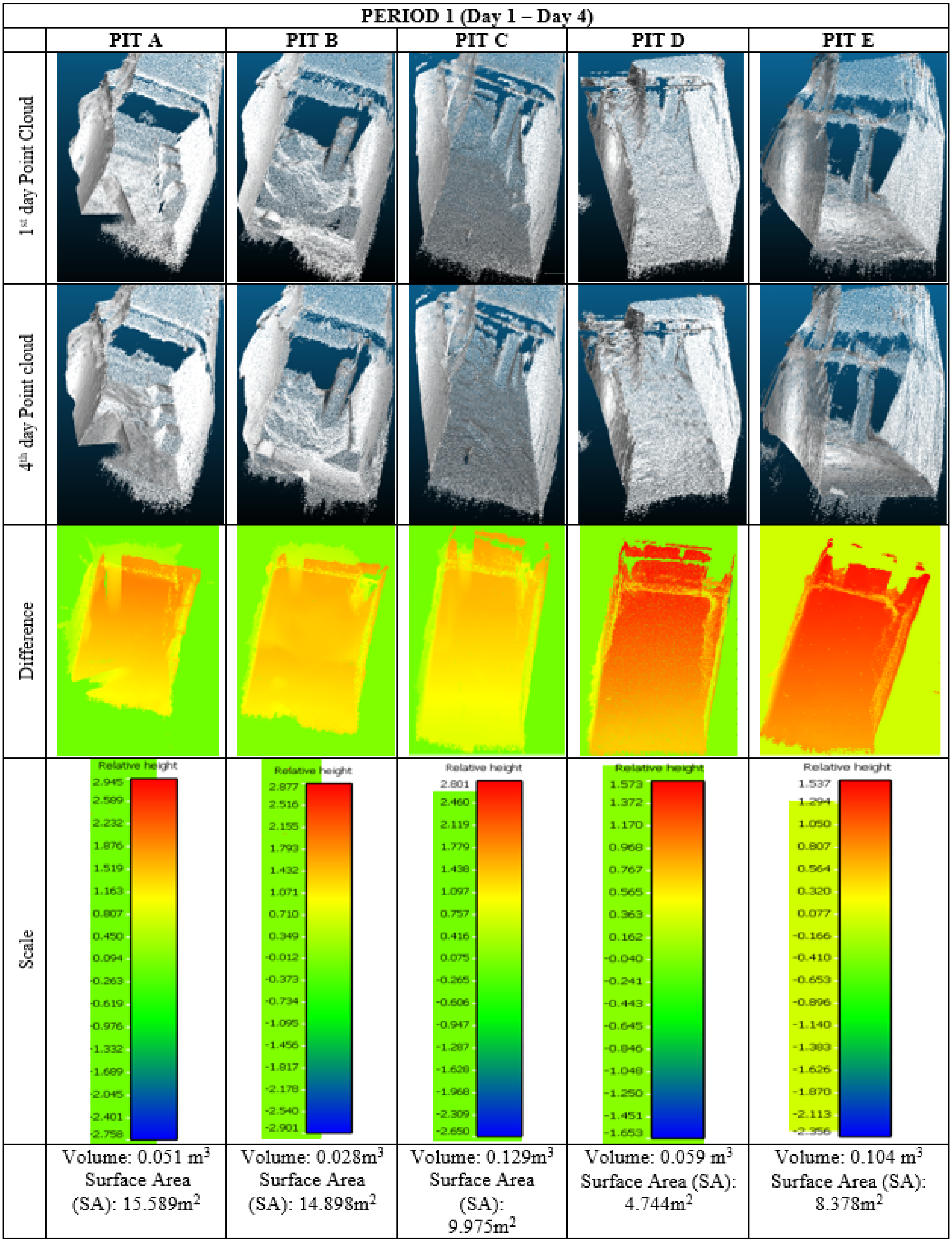
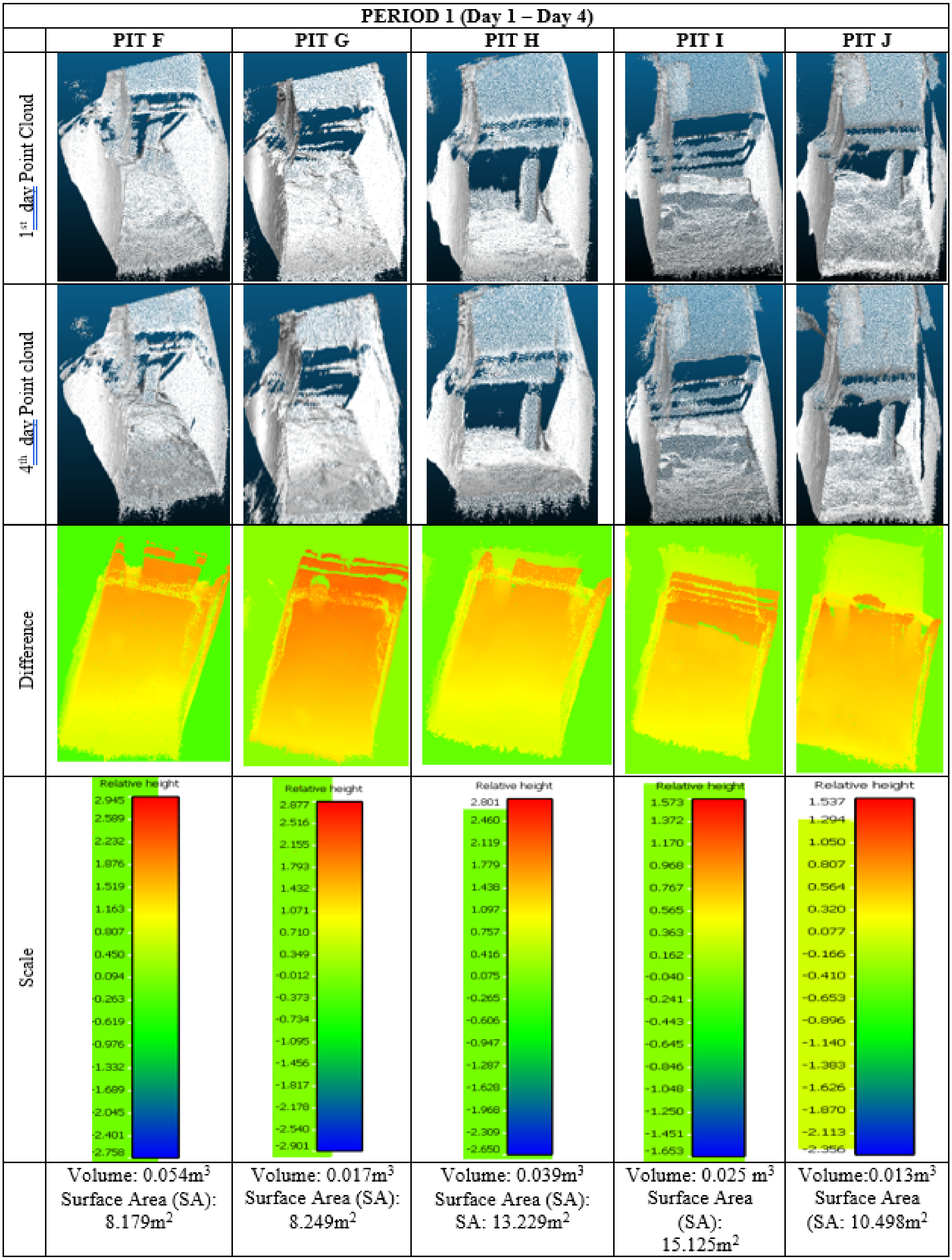

PERIOD 1 (Day 1 – Day 4)
PIT A
PIT B
PIT C
PIT D
PIT E
1st day Point Cloud
4th day Point cloud
Difference
Scale
Relative height
2.945 2.589 2.232 1.876 1.519 1.163 0.807 0.450 0.094 -0.263 -0.619 -0.976 -1.332 -1.689 -2.045 -2.401 -2.758
Relative height
2.877 2.516 2.155 1.793 1.432 1.071 0.710 0.349 -0.012 -0.373 -0.734 -1.095 -1.456 -1.817 -2.178 -2.540 -2.901
Relative height
2.801 2.460 2.119 1.779 1.438 1.097 0.757 0.416 0.075 -0.265 -0.606 -0.947 -1.287 -1.628 -1.968 -2.309 -2.650
Relative height
1.573 1.372 1.170 0.968 0.767 0.565 0.363 0.162 -0.040 -0.241 -0.443 -0.645 -0.846 -1.048 -1.250 -1.451 -1.653
Relative height
1.537 1.294 1.050 0.807 0.564 0.320 0.077 -0.166 -0.410 -0.653 -0.896 -1.140 -1.383 -1.626 -1.870 -2.113 -2.356
Volume: 0.051 m³ Surface Area (SA): 15.589m²
Volume: 0.028m³ Surface Area (SA): 14.898m²
Volume: 0.129m³ Surface Area (SA): 9.975m²
Volume: 0.059 m³ Surface Area (SA): 4.744m²
Volume: 0.104 m³ Surface Area (SA): 8.378m²

Figure 7


PERIOD 1 (Day 1 – Day 4)
PIT F
PIT G
PIT H
PIT I
PIT J
1st day Point Cloud
4th day Point cloud
Difference
Scale
Relative height
2.945 2.589 2.232 1.876 1.519 1.163 0.807 0.450 0.094 -0.263 -0.619 -0.976 -1.332 -1.689 -2.045 -2.401 -2.758
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2.801 2.460 2.119 1.779 1.438 1.097 0.757 0.416 0.075 -0.265 -0.606 -0.947 -1.287 -1.628 -1.968 -2.309 -2.650
Relative height
1.573 1.372 1.170 0.968 0.767 0.565 0.363 0.162 -0.040 -0.241 -0.443 -0.645 -0.846 -1.048 -1.250 -1.451 -1.653
Relative height
1.537 1.294 1.050 0.807 0.564 0.320 0.077 -0.166 -0.410 -0.653 -0.896 -1.140 -1.383 -1.626 -1.870 -2.113 -2.356
Volume: 0.054m3 Surface Area (SA): 8.179m2
Volume: 0.017m3 Surface Area (SA): 8.249m2
Volume: 0.039m3 Surface Area (SA): SA: 13.229m2
Volume: 0.025 m3 Surface Area (SA): 15.125m2
Volume:0.013m3 Surface Area (SA: 10.498m2

Figure 8