supplementary material

Analysis of storage capacity change and dam failure risk for tailings ponds using WebGIS-based UAV 3D image

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Text S1. Calculation method of flood regulation storage capacity.

According to the Safety Regulation for Tailings Pond (GB39496-2020) [1] in China, flood control standards for tailings ponds during different usage stages should be determined based on their grades, as presented in **Table S5**. According to the third-grade flood control standard, the flood return period of the tailings pond was 200 years, corresponding to a design frequency of 5%. Then the required flood regulation storage capacity of the tailings pond was calculated following **Equation (S1)** to **(S5)** [2].

$$H_{24P} = K_P \times \overline{H}_{24} \quad \text{(S1)}$$

$$W_{24P} = 1000\Psi H_{24P} F \quad \text{(S2)}$$

$$S_P = H_{24P} \times 24^{(n_3-1)} \quad \text{(S3)}$$

$$Q_P = 0.278(S_P - 1)F \quad \text{(S4)}$$

$$V_T = W_{24P} \times (1 - q_m/Q_p) \quad \text{(S5)}$$

Where H_{24P} is the 24-hour rainfall with a frequency of P, mm; K_P is the simulation rate coefficient, and the value can be obtained by referring to the corresponding table; $\overline{H}_{24}$ is the average annual maximum rainfall for 24 hours, mm; W_{24P} is the total catchment flood amount for a rainfall duration of 24 hours with a frequency of P, m^3; Ψ is the 24-hour flood runoff coefficient, which is the ratio of net rainfall to the average precipitation in the basin, taking 0.8; F is the catchment area, km^2; S_P is the rainfall intensity with a frequency of P, mm/h; n_3 is the rainstorm decline index, taking 0.793; Q_P is the flood peak flow with a frequency of P, m^3/s.

Table S1. Grading standards for tailings ponds.

Grade	Whole storage capacity (10^4 m^3)	Dam height (m)
First	V≥50000	H≥200
Second	10000≤V<50000	100≤H<200
Third	1000≤V<10000	60≤H<100
Fourth	100≤V<1000	30≤H<60
Fifth	V<100	H<30

Table S2. Detailed parameters of UAV flight route.

Route	Route length (km)	Flight area (km^2)	Flight height (m)	Fore-and-aft overlap percentage (%)	Side overlap percentage (%)	UAV model	Camera model	Pixel (10^4)	Sensor size (mm)	Focal length (mm)	Equivalent focal length (mm)
I	10.80	2.55	200	80	70	Loong 2160	SONY ILCE-5100	2430	23.5	35.8	53.5
II	2.71	0.28	130	80	70	DJI Mavic2	Hasselblad L1D-20c	2000	13.2	10.4	28.4

Table S3. GSPs data.

Number	X (m)	Y (m)	Z (m)
KZ01	593985.080	2535095.037	264.512
KZ02	593832.966	2535105.805	241.455
KZ03	593684.168	2535326.455	215.248
KZ04	593587.322	2535131.905	194.234
KZ05	593584.016	2535023.109	183.351

KZ06	593421.154	2535095.335	186.707
JC01	593853.251	2535132.953	246.540
JC02	593660.056	2535051.507	192.249
JC03	593555.193	2535060.546	177.950
JC04	593356.378	2535051.365	133.310

Table S4. Results of two phases of flight operations.

Flight batch	Flight Date	Route number	Flight time (min)	Photo quantity
Phase I	8 December 2021	I	33	1315
		II	75	923
		Sum	108	2238
Phase II	3 January 2023	I	28	1310
		II	71	920
		Sum	99	2230

Table S5. Flood control standards for tailings ponds.

Grade	Flood return period (year)
First	1000~5000 or PMF[a]
Second	500~1000
Third	200~500
Fourth	100~200
Fifth	100

[a]PMF is the possible maximum flood.

Table S6. Requirements for minimum flood control dam width and minimum free height of dry tailings pond dams.

Dam grade	Minimum flood control dam width (m)	Minimum free height (m)	Dam slope ratio
First	100	1.5	
Second	70	1.0	
Third	50	0.7	<1:3
Fourth	35	0.5	
Fifth	25	0.4	

Table S7. Model coordinates of the four checkpoints, unit: m.

Number	Phase I			Phase II		
	$X_{1_{model}}$	$Y_{1_{model}}$	$Z_{1_{model}}$	$X_{2_{model}}$	$Y_{2_{model}}$	$Z_{2_{model}}$
JC01	593853.208	2535132.907	246.778	593853.201	2535132.815	246.668
JC02	593660.137	2535051.698	192.044	593660.039	2535051.364	192.533
JC03	593555.269	2535060.715	178.128	593555.275	2535060.539	177.757
JC04	593356.523	2535051.168	133.146	593356.476	2535051.197	133.477

Table S8. Comprehensive summary of the error calibration results of the four checkpoints, unit: m.

Number	Phase I				Phase II			
	ΔX_1	ΔY_1	ΔS_1	ΔZ_1	ΔX_2	ΔY_2	ΔS_2	ΔZ_2
JC01	0.043	0.046	0.063	−0.238	0.050	0.138	0.147	−0.128
JC02	−0.081	−0.191	0.207	0.205	0.017	0.143	0.144	−0.284
JC03	−0.076	−0.169	0.185	−0.178	−0.082	0.007	0.082	0.193
JC04	−0.145	0.197	0.245	0.164	−0.098	0.168	0.194	−0.167
Max	0.145	0.197	0.245	0.238	0.098	0.168	0.194	0.284
Min	0.043	0.046	0.063	0.164	0.017	0.007	0.082	0.128

Avg	0.086	0.151	0.175	0.196	0.062	0.114	0.142	0.193
RMSE	0.094	0.163	0.188	0.198	0.069	0.130	0.147	0.201

Table S9. Calculation parameters of design rainstorm intensity.

Flood control standard	Rainfall duration (hour)	$\bar{H}_{24}$ (mm)	C_V	C_S	K_P	H_{24P} (mm)	S_P (mm/h)
P_{200}=0.5%	24	190	0.48	3.5C_V	2.95	560.50	290.32

Table S10. Calculation results of flood regulation storage capacity.

Flood return period (year)	Flood control standard	F (km²)	W_{24P} (m³)	Q_P (m³/s)	q_m (m³/s)	V_T (m³)
200	P_{200}=0.5%	0.19	85196.00	15.28	8.50	37808.22

Table S11. Summary results of measuring minimum flood control dam width and minimum free height, unit: m.

Number	Phase I		Phase II	
	Minimum flood control dam width	Minimum free height	Minimum flood control dam width	Minimum free height
1	79.76	2.94	98.22	0.85
2	79.98	2.92	96.47	0.91
3	79.05	2.89	97.36	0.89
4	80.25	2.84	98.05	0.82
5	79.91	2.88	97.06	0.88
Average	79.79	2.89	97.43	0.87
SD	0.45	0.04	0.72	0.04

SD: standard deviation.

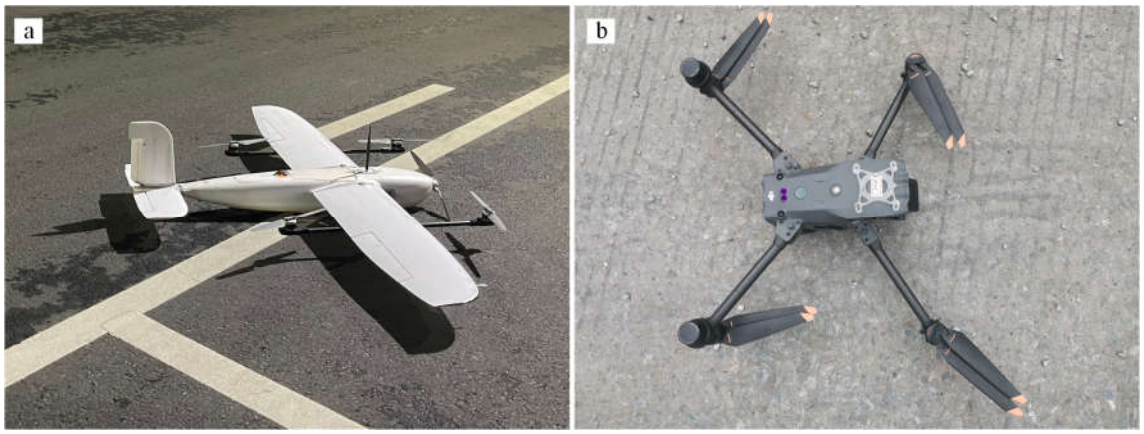
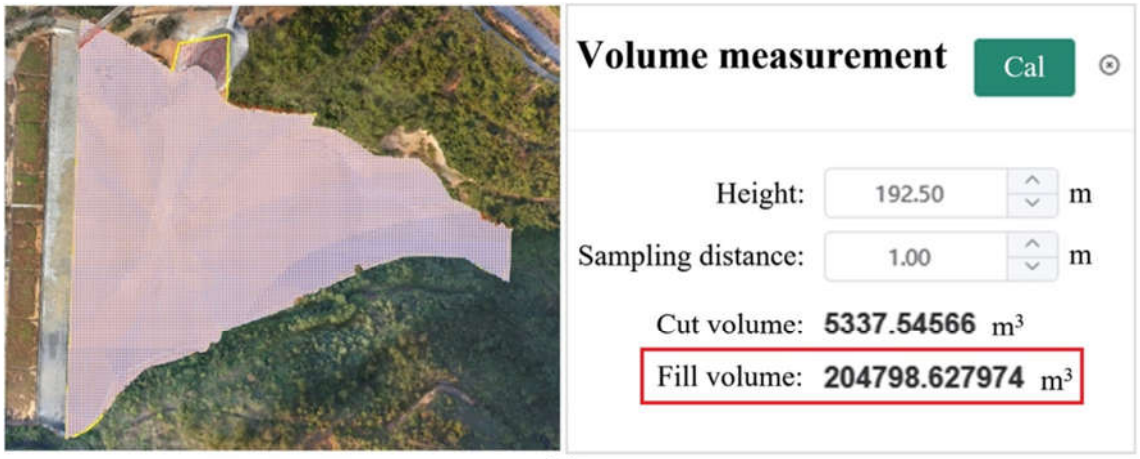
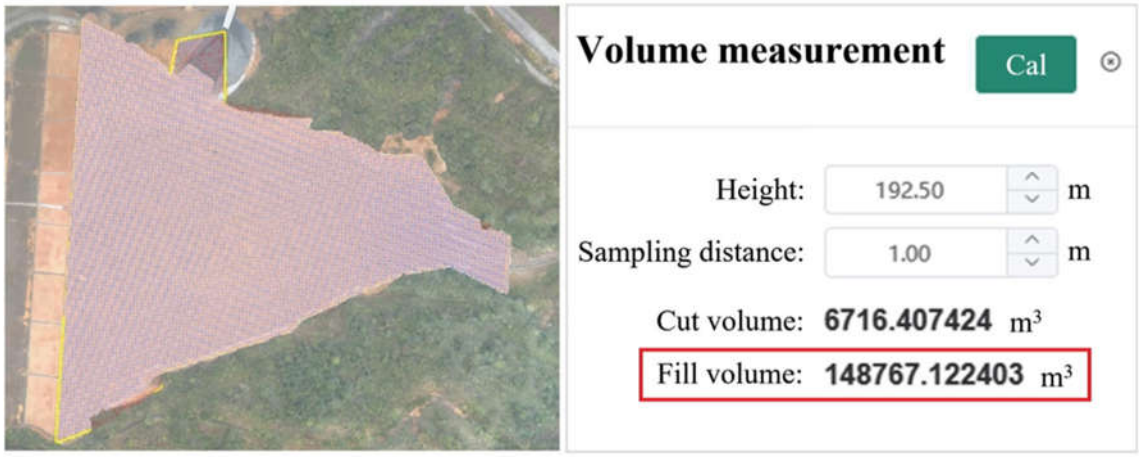


Figure S1. UAVs: (a) Loong 2160, (b) DJI Mavic2.

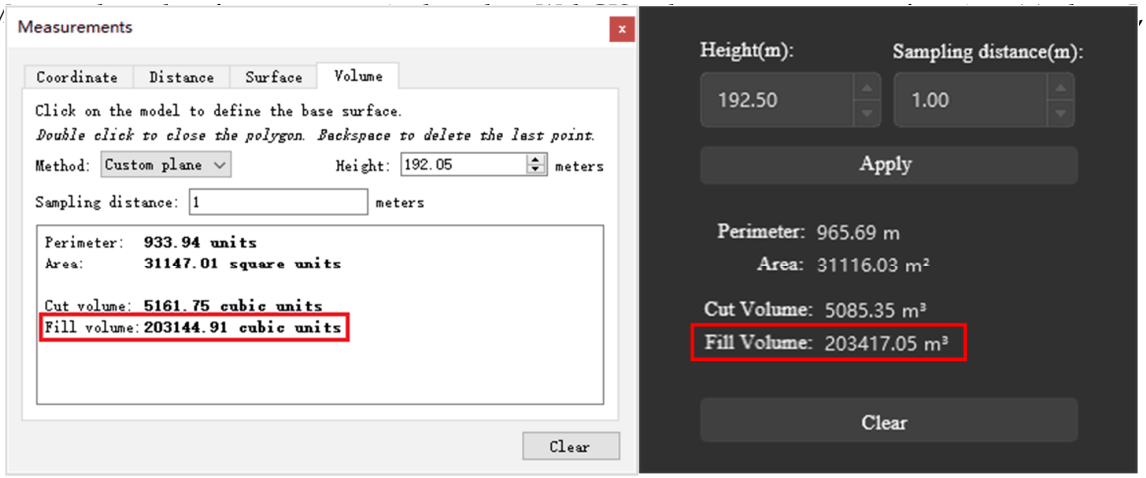

Volume measurement
Cal
Height: 192.50 m
Sampling distance: 1.00 m
Cut volume: 5337.54566 m³
Fill volume: 204798.627974 m³

(a)

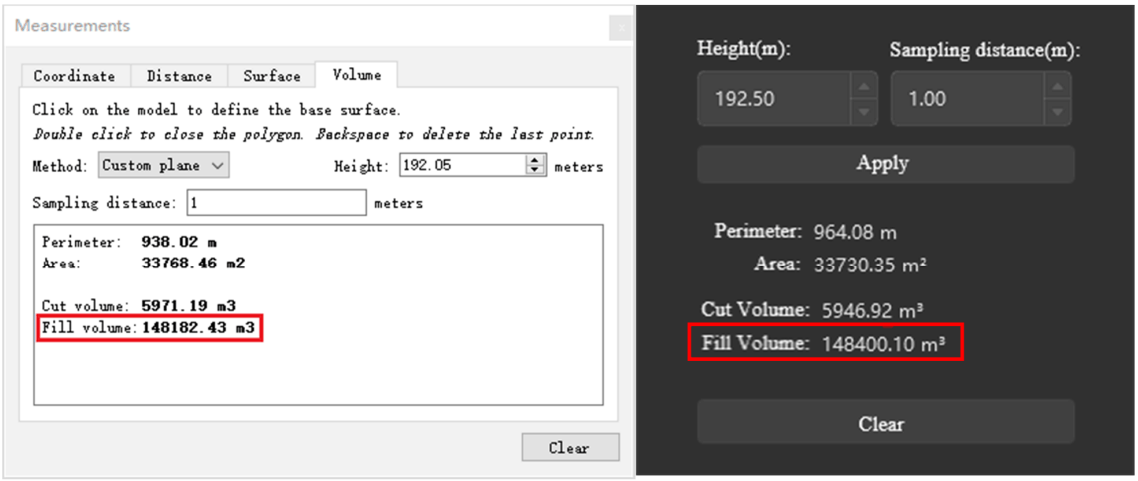

Volume measurement
Cal
Height: 192.50 m
Sampling distance: 1.00 m
Cut volume: 6716.407424 m³
Fill volume: 148767.122403 m³

(b)

Figure S3. M , (b)



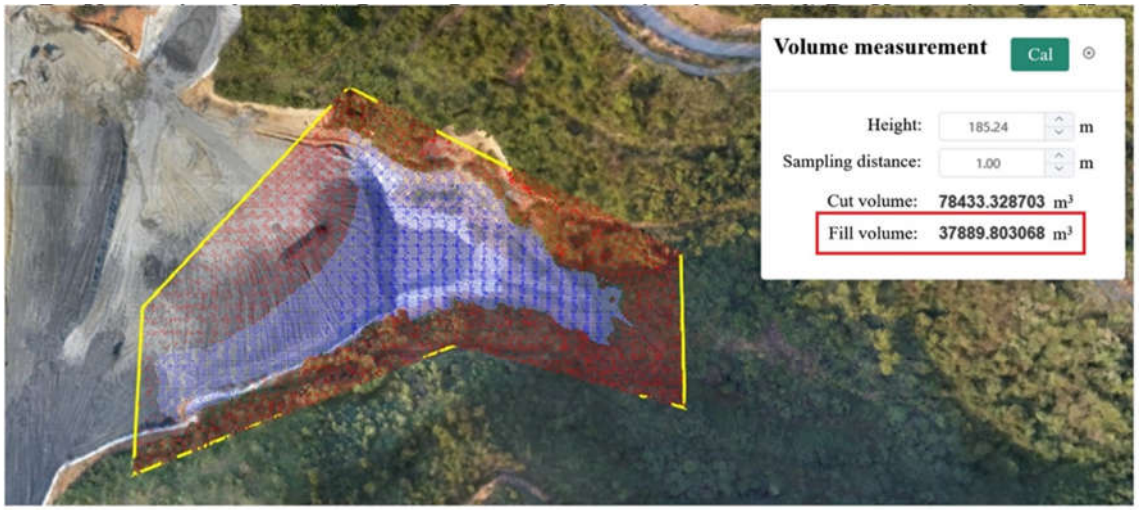
(a) **(b)**



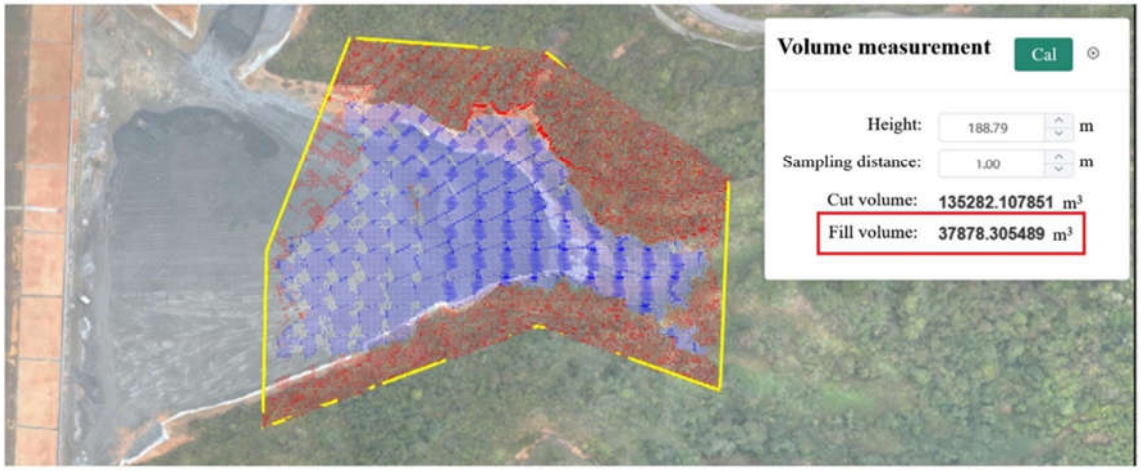
(c) **(d)**

phase II.

Figure S4. Measured results of storage capacity based on two software: (a) ContextCapture Viewer for phase I, (b)

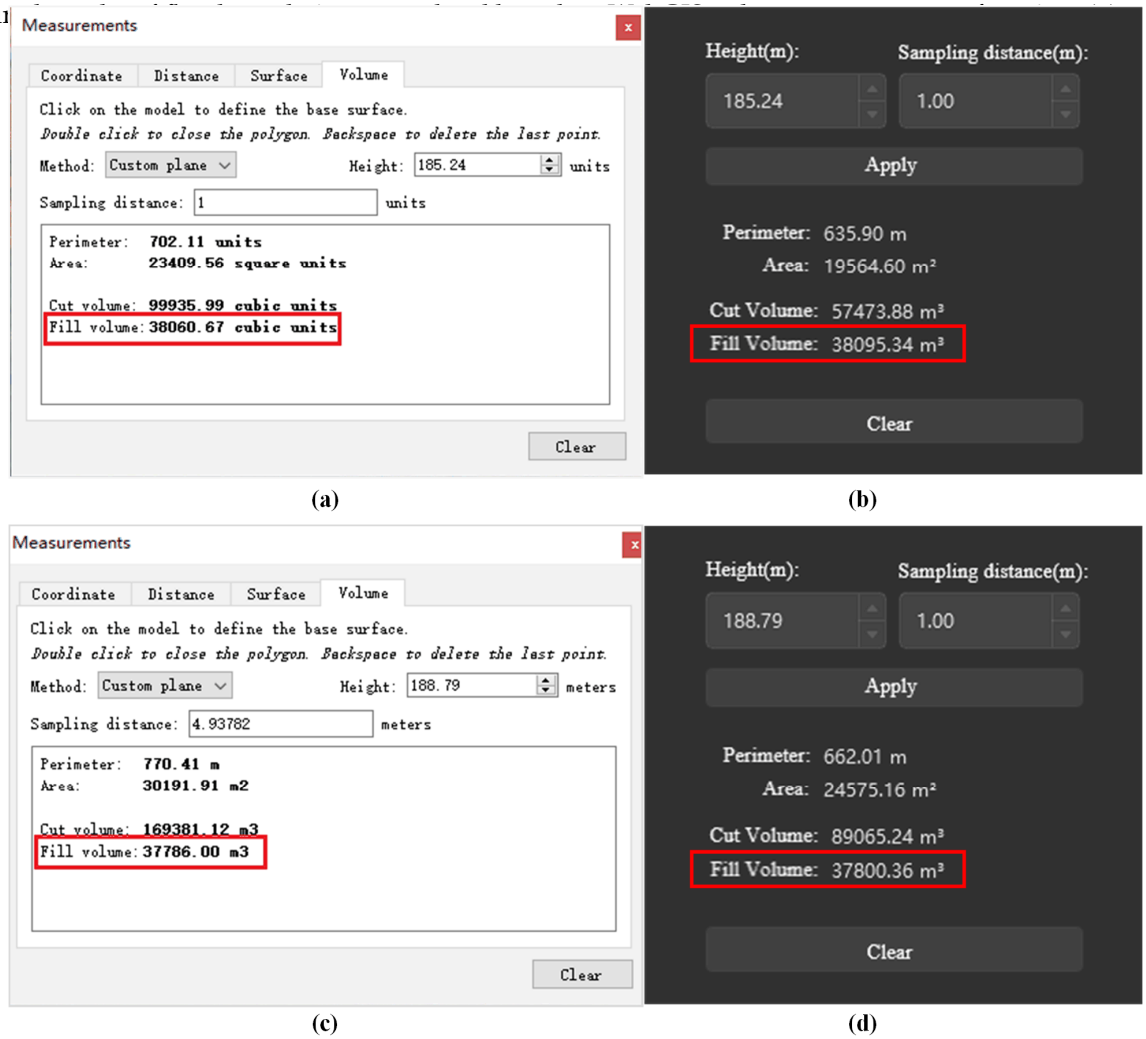


(a)



(b)

Figure S5. Measu



phase I, (b) phase II.

Figure S6. Measured results of flood regulation water level based on two software: (a) ContextCapture Viewer for phase I, (b) DasViewer for phase I, (c) ContextCapture Viewer for phase II, (d) DasViewer for phase II.

Reference

1. *GB 39496-2020*; Safety Regulation for Tailings Pond. State Administration for Market Regulation, Standardization Administration: Beijing, China, 2020.
2. Guangdong Hydrological Station. *Guangdong Storm Runoff Check Calculation Chart*; Guangdong Storm Runoff Check Calculation Chart: Guangdong, 1991.