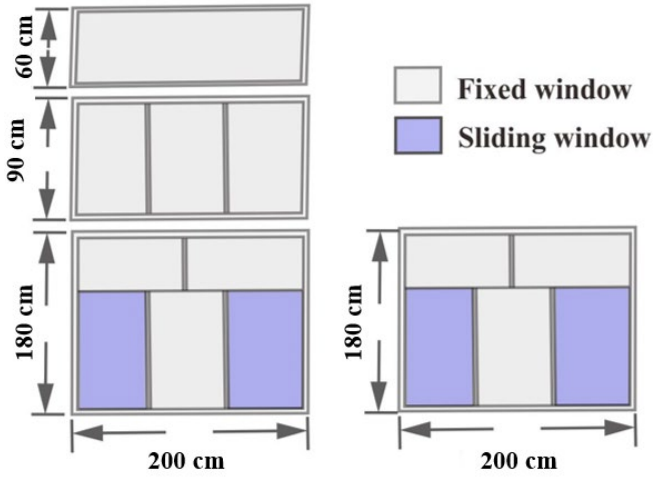
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Worker exposure to bioaerosols from sludge dewatering facilities: risks and mitigations
Supplementary Materials

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Supplementary Material Fig. 1 Type of each piece of glass in the window of Figure 1.

Supplementary Material Table 1 Detail description of the sludge dewatering facility

Serial number in the Figure 1	Item	Size or performance date
6	mixing tank	D=100 cm; H=150 cm
7	screw conveyor	L=950 cm; D=50 cm
8	horizontal screw decanter centrifuge	H=250 cm; S=2700 r/min
9	pedestal	Left: L×B×H=1050×300×15 cm Right: L×B×H=800×300×15 cm
11	motor	P=3 kw

D=diameter; L=length; W=width; H=height; S=speed; P=power.

Supplementary Material Table 2 Weather conditions during the sampling campaign

Sampling date	Item	Temperature (˚C)	Relative humidity (%)	wind speed (m/s)
Spring (two days: 28 March and 1 April)	Open window; Standing working posture	18.33±0.27	47.35±4.31	2.04±0.20
	Open window; Stooping working posture	18.24±0.69	47.61±3.64	2.17±0.30
	Closed window; Standing working posture	20. 77±1.34	41.64±3.47	—
	Closed window; Stooping working posture	20.48±0.51	40.97±2.16	—
Summer (two days: 16 June and 27 June)	Open window; Standing working posture	35.15±1.24	42.35±5.29	1.34±0.42
	Open window; Stooping working posture	35.82±1.33	42.66±3.54	1.26±0.33
	Closed window; Standing working posture	38.21±1.26	43.18±1.94	—
	Closed window; Stooping working posture	39.55±1.34	41.30±3.31	—

*Wind speed values listed for open-window conditions correspond to the two individual sampling days within each season, reported in the same order as the sampling dates indicated (spring: 28 March and 1 April; summer: 16 June and 27 June). Wind speed was not applicable under closed-window conditions.

Supplementary Material Table 3 Mean value ± SD sample concentration (CFU/m^3) for exposure to *E. coli* bioaerosol under stooping and standing working postures in spring and summer periods

Sampling date	Item	Mean value ± SD
Spring (28 March and 1 April)	Open window; Standing working posture	22.75±10.41
	Open window; Stooping working posture	24.24±6.40
	Closed window; Standing working posture	35.61±18.82
	Closed window; Stooping working posture	40.92±19.74
Summer (16 June and 27 June)	Open window; Standing working posture	25.78±19.48
	Open window; Stooping working posture	40.55±31.17
	Closed window; Standing working posture	47.29±36.80
	Closed window; Stooping working posture	20.77±11.16

*Non-detect samples were excluded when calculating mean values and standard deviations to provide conservative (worst-case) estimates, consistent with the approach described in Section 3.1.

Supplementary Material Table 4 Aerosol respirable ratio (%) for exposure to *E. coli* bioaerosols referring to on-site workers when exposing to sludge dewatering facility

period	Sampling date	Item			
		Open window; Standing working posture	Open window; Stooping working posture	Closed window; Standing working posture	Closed window; Stooping working posture
Spring	28 March	1.00	0.67	1.00	0.79
		0.89	0.83	0.93	0.89
		0.88	0.92	0.87	0.72
	1 April	0.63	0.33	0.75	1.00
		1.00	0.83	1.00	0.86
		0.83	1.00	0.93	0.64
Summer	16 June	1.00	0.93	1.00	1.00
		1.00	0.93	1.00	1.00
		0.91	0.97	0.97	1.00
	27 June	1.00	0.60	1.00	1.00
		1.00	1.00	0.60	1.00
		0.25	0.50	1.00	1.00

Supplementary Material Table 5 Exposure limit of acceptable exposure concentration (CFU/m^3) for exposure to *E. coli* bioaerosols based on the health risk level of the U.S. EPA annual infection risk by reverse-quantitative microbial risk assessment referring to on-site workers when exposing to sludge dewatering facility

	Item	wearing mask						no–mask					
		male			female			male			female		
		2.5th percentile quantiles	mean value	97.5th percentile quantiles	2.5th percentile quantiles	mean value	97.5th percentile quantiles	2.5th percentile quantiles	mean value	97.5th percentile quantiles	2.5th percentile quantiles	mean value	97.5th percentile quantiles
Spring	Open window; Standing working posture	2.34	5.46	11.50	2.95	6.88	14.50	0.09	0.14	0.20	0.12	0.18	0.26
	Open window; Stooping working posture	2.54	7.20	15.90	3.20	9.07	20.10	0.10	0.18	0.33	0.12	0.23	0.41
	Closed window; Standing working posture	2.24	5.07	10.90	2.83	6.39	13.70	0.09	0.13	0.18	0.11	0.16	0.23
	Closed window; Stooping working posture	2.34	5.50	12.50	2.95	6.93	15.70	0.09	0.14	0.20	0.12	0.18	0.26
Summer	Open window; Standing working posture	2.65	8.17	19.20	3.34	10.30	24.20	0.10	0.20	0.39	0.13	0.26	0.49
	Open window; Stooping working posture	2.43	6.25	13.40	3.06	7.88	16.80	0.10	0.16	0.24	0.12	0.20	0.31
	Closed window; Standing working posture	2.33	5.76	12.00	2.93	7.25	15.10	0.10	0.14	0.21	0.12	0.18	0.27
	Closed window; Stooping working posture	1.88	4.30	9.13	2.37	5.42	11.50	0.08	0.11	0.15	0.10	0.14	0.18

The 2.5th and 97.5th percentile values represent conservative estimate in worst-case condition and optimistic estimate in best-case condition,

respectively.

Supplementary Material Table 6 Exposure limit of acceptable exposure concentration (CFU/m^3) for exposure to *E. coli* bioaerosols based on the health risk level of the WHO disease burden by reverse-quantitative microbial risk assessment referring to on-site workers when exposing to sludge dewatering facility

	Item	wearing mask						no–mask					
		male			female			male			female		
		2.5th percentile quantiles	mean value	97.5th percentile quantiles	2.5th percentile quantiles	mean value	97.5th percentile quantiles	2.5th percentile quantiles	mean value	97.5th percentile quantiles	2.5th percentile quantiles	mean value	97.5th percentile quantiles
Spring	Open window; Standing working posture	0.52	1.19	2.53	0.66	1.50	3.19	0.02	0.03	0.04	0.03	0.04	0.06
	Open window; Stooping working posture	0.56	1.60	3.67	0.71	2.02	4.63	0.02	0.04	0.07	0.03	0.05	0.09
	Closed window; Standing working posture	0.49	1.11	2.35	0.62	1.40	2.97	0.02	0.03	0.04	0.03	0.04	0.05
	Closed window; Stooping working posture	0.53	1.20	2.57	0.66	1.52	3.24	0.02	0.03	0.04	0.03	0.04	0.06
Summer	Open window; Standing working posture	0.60	1.81	4.26	0.75	2.28	5.37	0.02	0.05	0.09	0.03	0.06	0.11
	Open window; Stooping working posture	0.55	1.34	2.92	0.70	1.69	3.68	0.02	0.03	0.05	0.03	0.04	0.07
	Closed window; Standing working posture	0.53	1.23	2.71	0.67	1.55	3.42	0.02	0.03	0.05	0.03	0.04	0.06
	Closed window; Stooping working posture	0.42	0.92	1.95	0.53	1.16	2.46	0.02	0.02	0.03	0.02	0.03	0.04

The 2.5th and 97.5th percentile values represent conservative estimate in worst-case condition and optimistic estimate in best-case condition, respectively.

1. Bioaerosol concentration analysis

The method of positive-hole correction was used to revise overlapping colonies by Eq. (1) (Andersen, 1958).

$$Pr=N\cdot\left[\frac{1}{N}+\frac{1}{N-1}+\frac{1}{N-2}+\cdots+\frac{1}{N-r-1}\right] \quad (1)$$

Where *Pr*, *r*, and *N* represent the modified colonies, sampling colonies, and number of sieve pore at each stage of the Anderson six-stage cassette impactor, respectively.

The samples concentrations (C_{sample}) during the field sampling campaign were calculated using Eq. (2).

$$C_{sample}=\frac{P_r\times 1000}{t\times Q} \quad (2)$$

Where C_{sample} is the measured bioaerosols concentration (CFU/m³), *t* is the sampling time (min), and *Q* is the sampling flow rate (L/min).

According to the Anderson six-stage cassette impactor, the ratio of the particles size distribution (*W*) was calculated using Eq. (3).

$$W=\frac{Csample(n)}{Csample(total)}\times 100\% \quad (3)$$

Where *W* is the ratio of bioaerosol sample concentration from the each stage (stage 1-6) to all the six stages of the Andersen six-stage cascade impactor (%), *Csample(n)* is the sample concentration of 1 to 6 of Andersen six-stage cascade impactor. *Csample(total)* is the sample concentration of all bioaerosol particles.

2. Reverse-QMRA

(1) Hazard identification

The indicator pathogen of concern in this study was *E. coli* bioaerosols emitted from sludge dewatering facility in a WWTP (Xu et al., 2020; Gollakota et al., 2021).

(2) Risk characterization

Risk characteristics were determined using two authoritative and widely used health risk levels: the U.S. EPA annual infection risk (10^{-4} pppy) and WHO disease burden (10^{-6} DALYs pppy).

Based on the risk level of the U.S. EPA annual infection risk, the probability of acceptable daily infection risk ($P(d)_{inf}$) was estimated in Eq. (4) (Haas et al., 2014).

$$P(d)_{inf}=1-(1-P_y)^{\frac{1}{n}} \quad (4)$$

Where P_y is the acceptable annual infection risk (pppy), and n is exposure frequency in one year (Table 1).

Based on the risk level of the WHO disease burden, the probability of acceptable annual infection risk (P_y) was estimated in Eq. (5) and Eq. (6) (Busgang et al., 2018; Havelaar et al., 2015).

$$P(a)_{ill}=\frac{DB}{HB} \quad (5)$$

$$P_y=\frac{P(a)_{ill}}{P_{ill/inf}} \quad (6)$$

Where $P(a)_{ill}$ is the acceptable annual probability of illness risk (pppy), DB is the disease burden (DALYs pppy), HB is health burden (DALYs/case) (Table 2) and $P_{ill/inf}$ is the specific conditional probability of illness given an infection (Table 2).

(3) Dose–response models

The beta-Poisson dose–response model was used to calculate the acceptable exposure dose for *E. coli* bioaerosol. Eq. (7) and Eq. (8) calculated the acceptable exposure dose (d) (Haas, 2015).

$$d=\beta((1-P(d)_{inf})^{-\frac{1}{\alpha}}-1) \quad (7)$$

$$\beta=\frac{D_{50}}{2^{\frac{1}{\alpha}}-1} \quad (8)$$

Where α and β are the beta-Poisson dose–response model parameters, and $D50$ is a derived quantity calculated from α and β and reported in Table 2 for reference. **(4) Exposure assessment**

According to the Anderson six-stage cassette impactor, the aerosol respirable ratio (IR) was calculated using Eq. (9).

$$IR=\frac{Csample(3-6)}{Csample(1-6)}\times 100\% \quad (9)$$

Where IR is the ratio of bioaerosol sample concentration from the 3-6 to 1-6 of the Andersen six-stage cascade impactor (%), $Csample\ (3\text{-}6)$ and $Csample\ (1\text{-}6)$ is the sample concentration

of respirable (3-6 stages of Andersen six-stage cascade impactor) and all bioaerosol particles (1-6 stages of Andersen six-stage cascade impactor), respectively.

The exposure limit (EL) benchmark of acceptable exposure concentration (C) was calculated according to Eq. (10) (Jahne et al., 2015).

$$C=\frac{d}{Br\times T\times IR\times(1-F_{PPE})} \quad (10)$$

Where Br is breathing rate of exposure population (L/min), T is exposure time in an exposure (working) day (h), IR is bioaerosol respirable ratio, and $FPPE$ is the removal fraction by equipping personal protective equipment. The values of these four input variable parameters were shown in Table 2.

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