Water

Electronic Supplementary Material

Title: **Performance simulation and assessment of an appropriate wastewater treatment technology in a densely populated growing city in a developing country: A case study in Vientiane, Laos**

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Supplementary Material S1

Table S1. Number of populations in Vientiane in 2015

No.	Districts	Area (km^2)	Population (People)	Population Density (People/ km^2)	Remark
1	Chanthabuly	29	69,200	2,386	Selected study area
2	Sikhottabong	140	121,000	864	Selected study area
3	Xaysettha	147	116,900	795	Selected study area
4	Sisatanak	31	65,700	2,119	Selected study area
5	Naxaithong	1,131	75,200	67	-
6	Xaythany	916	196,600	215	-
7	Hatxaifong	258	97,600	378	-
8	Sangthong	622	29,500	27	-
9	Pakngum	646	49,200	76	-
	Total	**3,920**	**820,900**	**209**	**-**

Table S2. Analytical results of the wastewater in terms of BOD, COD and TSS concentration of the influent and effluent from a decentralized anaerobic wastewater treatment plant at Thongkhankham Village, Chanthabuly District.

Parameters	Concentration (mg/l)	
	Influent	Effluent
BOD	337	38
COD	674	96
TSS	375	8

Table S3. The water use at the household level in Laos

Items	City level	Serviced population (people)	Water use (l/cap/d)
1	Municipality	>100,000	200 - 250
2	Large city	50,000 - 100,000	120 - 200
3	Small city	20,000 - 50,000	100 - 120
4	Small town (densely populated)	4,000 - 20,000	80 - 100
5	Small town (non-densely populated)	2,000 - 4,000	60 - 80
6	community	< 2,000	40 - 60

Table S4. Population projections in 2025 and 2035 for the four study districts in Vientiane.

Year	1995	2005	2015	2025	2035
Population	266,539	334,966	372,800	425,937	479,061

Table S5. The considered weights for the four criteria for TOPSIS analysis

Experiments	Weights of criteria				$\sum_{j=1}^{n} W_j = 1$
	Land requirement	Electricity use	Sludge production	CO_2 emission	
1st Experiment	0.25	0.25	0.25	0.25	1
2nd Experiment	0.40	0.20	0.20	0.20	1
3rd Experiment	0.30	0.30	0.20	0.20	1
4th Experiment	0.20	0.20	0.40	0.20	1
5th Experiment	0.20	0.20	0.30	0.30	1
6th Experiment	0.20	0.20	0.20	0.40	1

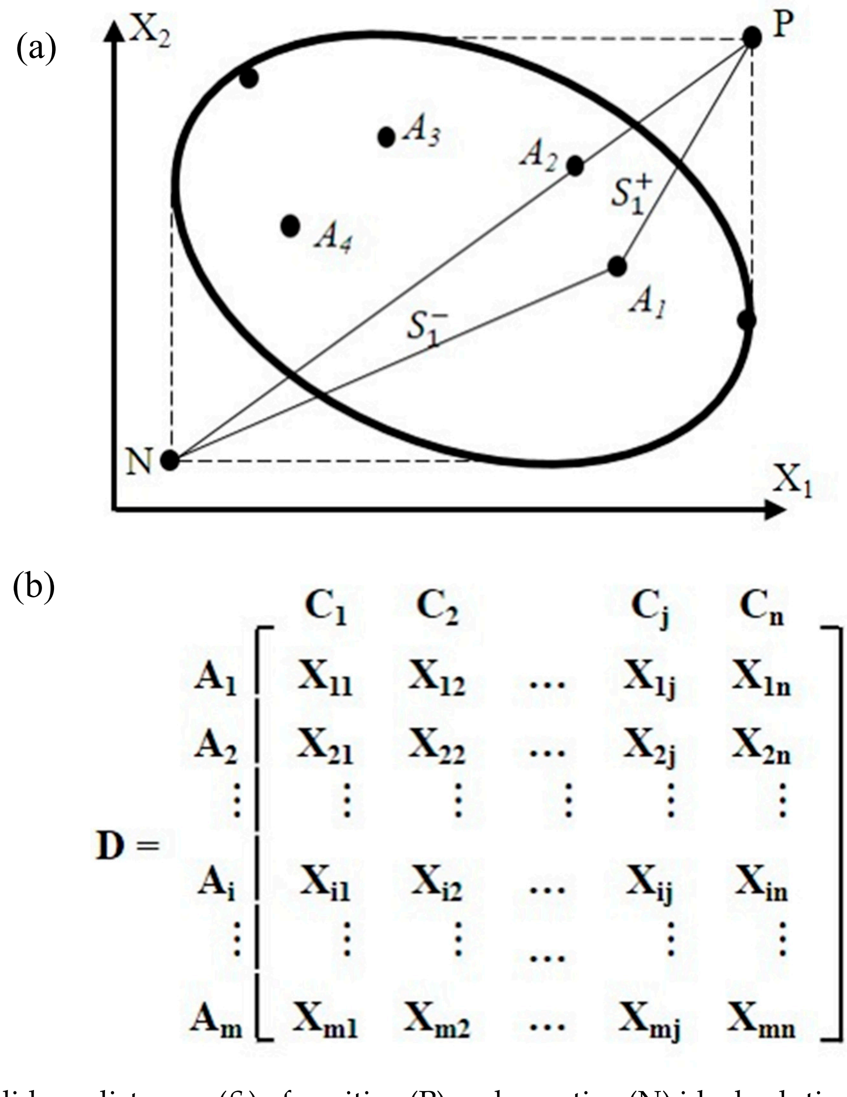

Figure S1. (a) Euclidean distances (S_i) of positive (P) and negative (N) ideal solution from alternatives (A_i), and (b) decision matrix of TOPSIS with "m" alternatives associated with "n" criteria

Supplementary Material S2. Estimation of the four criteria for the optimized wastewater treatment system using TOPSIS analysis

1. Land requirement

The land requirements are calculated from the design footprint of each tank.

Table S6. Land requirement of each technology

Technology	Amount of WWTP (WWTPs)	Land requirement (m^2/plant)	Total Land requirement (m^2)
①	②	③	④=②*③
On-site 1	96 000	2.06	197 760
On-site 2	96 000	1.57	150 720
DEWATS 1	1 920	16.16	31 027
DEWATS 2	1 920	18.87	36 230
CEWATS 1	2	16 006.50	32 013
CEWATS 2	2	10 990.50	21 981

Note: For CEWATS, an additional 50% more land requirement is added for transport infrastructure, pumping station, etc. based on the Laos government wastewater treatment design

2. Energy use

2.1 On-site system and DEWATS

For on-site systems and DEWATS, the electricity use is for aeration which is calculated from the oxygen requirements of 2 kg O_2 / kWh [1].

Table S7. Electricity use of on-site systems and DEWATS

Technology	Q (m^3/d)	O_2 required (kg/d)	Electricity use factor (kg O_2/kWh)	Electricity use (kWh/d)	Number of WWTP (WWTPs)	Total electricity use (kWh/d)
	①	②	③	④=②*③	⑤	⑥=④*⑤
On-site I	1	0.15	2	0.3	96 000	28 800
On-site II	1	0.33	2	0.66	96 000	63 360
DEWATS I	50	6.78	2	13.56	1 920	26 035
DEWATS II	50	13.94	2	27.88	1 920	53 530

2.2 CEWATS

1) The electricity use of the sewage collection system for CEWATS II is estimated of 20,768 kWh/d for two of the WWTPs as follows, based on the main pipeline system.

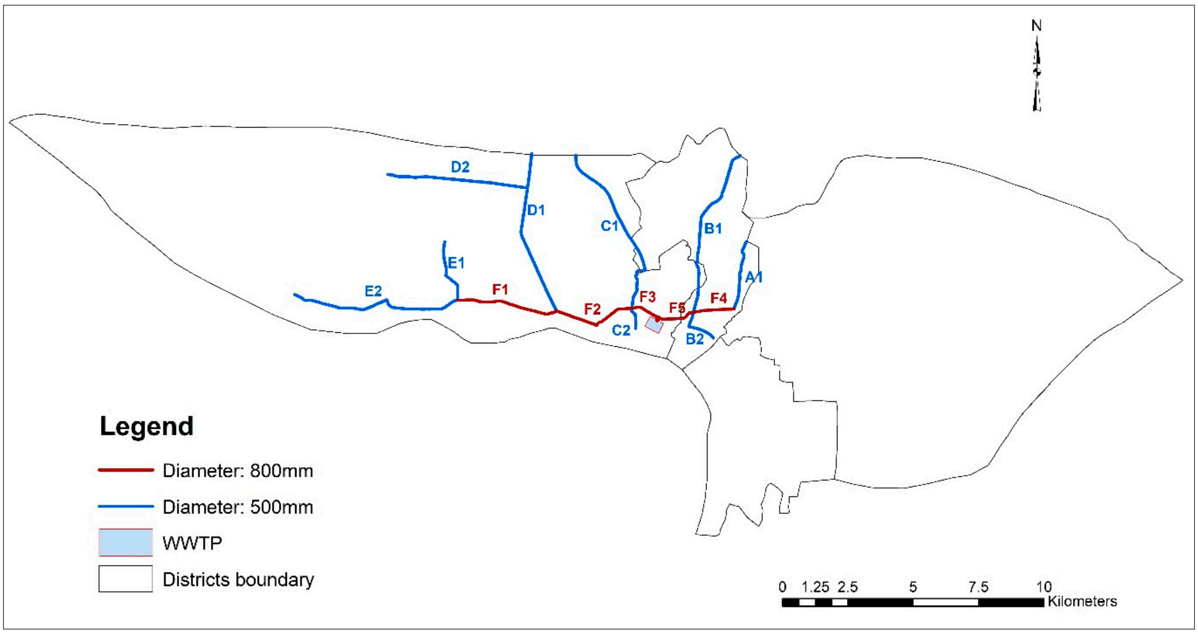

Figure S2. Main pipeline system in the study area

The power requirement is calculated [2] as,

$$P = \frac{Q \times H \times g \times p}{\text{Pump Efficiency}} \quad \text{(Eq.S1)}$$

$$H = H_S + H_D \quad \text{(Eq.S2)}$$

where, P: power (w), Q: flowrate (m^3/s), H: total head loss (m), g: acceleration due to gravity (m/s^2), p: density of water (kg/m^3), H_S: static head loss (m), H_D: dynamic head loss (m).

Hazen Williams' formula is

$$H_D = H_f + H_{fittings} \quad \text{(Eq.S3)}$$

$$H_f = 10.666 \times C^{-1.85} \times D^{-4.87} \times Q^{1.85} \times L \quad \text{(Eq.S4)}$$

where, H_f: friction head loss (m), L: pipe length (m), D: pipe diameter (m), $H_{fittings}$: head loss of fittings (m), C: friction coefficient (130-150).

Table S8. Calculating dynamic head loss

Pipe No.	Length	Water flow		Diameter	Cross section	Velocity	Velocity coefficient	H_f	$H_{fittings}$	H_D
	(m)	(m^3/d)	(m^3/s)	(m)	(m^2)	(m/s)		(m)	(m)	(m)
①	②	③	④=③ /(24x3,600)	⑤	⑥=3.14x(⑤ /②)^2	⑦=④/ ⑥	⑧	⑨ =(Eq.4)	⑩=⑨x25%	⑪=⑨+⑩
A1	2,658	2,661	0.031	0.5	0.196	0.157	130	0.163	0.041	0.203
B1	6,654	8,942	0.103	0.5	0.196	0.527	130	3.836	0.959	4.795
B2	1,625	1,957	0.023	0.5	0.196	0.115	130	0.056	0.014	0.070
C1	7,085	6,498	0.075	0.5	0.196	0.383	130	2.263	0.566	2.829
C2	840	585	0.007	0.5	0.196	0.034	130	0.003	0.001	0.004
D1	6,367	5,340	0.062	0.5	0.196	0.315	130	1.414	0.354	1.768
D2	5,403	8,511	0.099	0.5	0.196	0.502	130	2.843	0.711	3.554
E1	2,465	4,854	0.056	0.5	0.196	0.286	130	0.459	0.115	0.574
E2	6,663	9,122	0.106	0.5	0.196	0.538	130	3.986	0.996	4.982
F1	3,897	13,976	0.162	0.8	0.503	0.322	130	0.520	0.130	0.650
F2	3,181	27,827	0.322	0.8	0.503	0.641	130	1.519	0.380	1.898
F3	1,122	34,910	0.404	0.8	0.503	0.804	130	0.815	0.204	1.019
F4	1,570	2,661	0.031	0.8	0.503	0.061	130	0.010	0.002	0.012
F5	1,434	13,560	0.157	0.8	0.503	0.312	130	0.181	0.045	0.226
F_{WWTP}	73	48,470	0.561	1	0.785	0.714	130	0.033	0.008	0.041
Total										22.6

Table S9. Calculating power requirement

Q		H_s	H_D	H_{total}	*p*	g	Pump Efficiency	*P*		
m^3/d	m^3/s	m	m	m	Kg/m^3	m/s^2	%	w	Kw	Kwh/d
①	②=① /(24*3600)	③	④	⑤=③+④	⑥	⑦	⑧	⑨=(Eq.1)	⑩=⑨/1000	⑪=⑩*24
48,000	0.556	37	22.6	59.6	1000	9.8	75	432,652	432.65	10,384

Therefore, the power requirement for sewage collection system is 10,384 Kwh/d. The power requirement for sewage collection system for 2 WWTPs is, therefore, 20,768 Kwh/d

2) The electricity use of aeration and pumping for CEWATS II is calculated as follows.

Table S10. Electricity requirement for aeration [1]

Technology	Q (m³/d)	O_2 required (kg/d)	Electricity use factor (kg O_2/kWh)	Electricity use (kWh/d)	Amount of WWTP (WWTPs)	Total electricity use (kWh/d)
	①	②	③	④=②*③	⑤	⑥=④*⑤
CEWATS II	48 000	11 144	2	22 288	2	44 576

- The power requirement calculation is based on (Eq.S1)

Table S11. Power for returning activated sludge.

Q (m³/d)	Tank (Chamber)	Flowrate (m³/d)	Return activated sludge (%)	(m³/d)	(m³/s)	H (m)	g (m/s²)	p (kg/m³)	E (%)	(W)	P (kWh/d)	Pump (amount)	Total (kWh/d)
①	②	③=①/②	④	⑤=③*④	⑥=⑤/(24*3600)	⑦	⑧	⑨	⑩	⑪=Eq.S1	⑫=(⑪/100)*24	⑬	⑭=⑫*⑬
48,000	8	6 000	20	1 200	0.01	5	9.81	1000	75	454	21.8	8	174.4

Therefore, 2 WWTPs = 174.4 kWh/d x 2 = 348.8 kWh/d

Table S12. Total electricity use for CEWATS II

Sewage collection system (kWh/d)	Aeration (kWh/d)	Return activated sludge (kWh/d)	Total electricity use (kWh/d)
①	②	③	④=①+②+③
20 768	44 576	348.8	65 693

3. Sludge production

Sludge production is calculated from the sedimentation of TSS in a WWTP that produces sludge that contains 50% TSS [3].

Table S13. Sludge production

Technology	Q (m³/d)	Inf. TSS (mg/l)	Eff. TSS (mg/l)	TSS removed (kg/d)	Percent of Sludge (% of TSS)	Sludge production (kg/d)
	①	②	③	④=①*((②-③)/1000)	⑤	⑥=④*⑤
On-site I	1	375	37.9	0.34	50	0.17
On-site II	1	375	37.0	0.34	50	0.17
DEWATS I	50	375	33.1	17.10	50	8.55
DEWATS II	50	375	31.8	17.16	50	8.58
CEWATS I	48 000	375	27.9	16 660.80	50	8330.4

Table S14. Sludge production for CEWATS II

Technology	Q (m³/d)	Inf. TSS (mg/l)	Eff. TSS (mg/l)	TSS removed (kg/d)	Percent of Sludge (% of TSS)	Sludge (kg/d)	Return sludge (%)	Sludge production (kg/d)
	①	②	③	④=①*((②-③)/1000)	⑤	⑥=④*⑤	⑦	⑧=⑥*0.8
CEWATS II	48 000	375	27.1	16 699.20	50	8349.6	20	6679.68

Table S15. Total sludge production

Technology	Sludge production (kg/d)	Number of WWTP (WWTPs)	Total sludge production (kg/d)
	①	②	③=①*②
On-site I	0.17	96 000	16320
On-site II	0.17	96 000	16320
DEWATS I	8.55	1 920	16416
DEWATS II	8.58	1 920	16473.6
CEWATS I	8330.4	2	16660.8
CEWATS II	6679.68	2	13359.63

4. CO_2 emission

The CO_2 emission from electricity use in Asia, excluding China, in 2015 is 672 g CO_2 /kWh [4].

Table S16. CO_2 emission

Technology	Electricity use (kWh/d)	CO_2 emission factor (kg CO_2/KWh)	CO_2 emission (kg/d)
	①	②	③=①*②
On-site I	28 880	0.672	19 407
On-site II	63 360	0.672	42 578
DEWATS I	26 035	0.672	17 496
DEWATS II	53 530	0.672	35 972
CEWATS I	20 768	0.672	13 956
CEWATS II	65 693	0.672	44 146

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