water

MDPI

SUPPLEMENTARY MATERIAL

Appendix A

Mathematical equations and the scoring for Trends and Pressure Framework is shown below.

Indicator 1: Urbanization rate

$$\text{Indicator } 1 = -0.114X^2 + 1.3275X + 0.1611 \quad \text{(A1)}$$

where:

X = Urbanization rate (%); As of 2019, urbanization rate of Mongolia is 1.63% [1].

Indicator 1 = 2 (medium concern)

Indicator 2: Burden of disease

Table A1. Scoring for Burden of disease by DALY

DALY per 100'000 people	Score
0 – 20'000	0
20'000 – 40'000	1
40'000 – 60'000	2
60'000 – 80'000	3
80'000 <	4

It has been reported from World Health Organization, DALY (Disability adjusted life years) rates per 100'000 population was 42'935 [2].

Indicator 2 = 2 (medium concern)

Indicator 3: Education rate

$$\text{Indicator } 3 = -10^{-5}X^3 + 0.0012X^2 + 0.0426X + 4.3057 \quad \text{(A2)}$$

where:

X = Education rate (%); From the data of National statistics office of Mongolia, 98% of population of Ulaanbaatar completed primary education [3].

Indicator 3 = 2.3 (medium concern)

Indicator 4: Political instability (and absence of violence)

$$\text{Indicator } 4 = 4 - \left[\frac{X - (-2.5)}{2.5 - (-2.5)} \times 4\right] \quad \text{(A3)}$$

where:

X = Estimated political stability score from World Bank Indicator; Mongolia is ranked 47 among 195 countries with Political Instability was 0.82 [4].

Indicator 4 = 2.7 (concern)

Indicator 5: Water scarcity

Indicator 5 consists of three sub-indicators, and the highest score of the three sub-indicators is used as the final score for water scarcity.

Indicator 5 = 1 (low concern)

Indicator: 5.1 Fresh water scarcity

Table A2. Scoring for Fresh water scarcity by percentage of renewable fresh water resource abstracted

% of renewable resource abstracted	Score
0 – 2	0
2 - 10	1
10 - 20	2
20 - 40	3
> 40	4

Fresh water withdrawal percentage of total actual renewable water resources was 1.3% as of 2013-2017 [5].

Indicator 5.1 = 0 (no concern)

Indicator: 5.2 Groundwater scarcity

Table A3. Scoring for Groundwater scarcity by percentage of abstracted renewable ground water recharge

% abstracted renewable recharge	Score
0 – 2	0
2 - 20	1
20 - 50	2
50 - 100	3
> 100	4

According to the Groundwater development stress map, created by International Groundwater Resources Assessment Centre, annual rate of groundwater abstraction was 2-20% [6].

Indicator 5.2 = 1 (low concern)

Indicator: 5.3 Salinization and/or seawater intrusion

5.3.1 Sea water intrusion

Table A4. Scoring for Sea water intrusion

Description	Score
No seawater intrusion reported and city not prone to (future) intrusion	0
No seawater intrusion reported and city can experience intrusion in coming century	1
No seawater intrusion reported but city is prone to intrusion in the near future	2
Seawater intrusion reported	3
Seawater intrusion reported and city is particularly prone to intrusion	4

5.3.2 Groundwater salinization

Table A5. Scoring for Groundwater salinization

Description	Score
No concern	0
Low concern	1
Medium concern	2
Concern	3
Great concern	4

The highest score of the two sub-subindicators is used as the final score for salinization and/or seawater intrusion.

Seawater intrusion is not reported and city not prone to (future) intrusion due to the Mongolia is a landlocked country. Groundwater salinization in Ulaanbaatar can be not observable.

Indicator 5.3 = 0 (no concern)

Indicator 6: Flood risk

Indicator 6 consists of four sub-indicators, and the highest score of the four sub-indicators is used as the final score for flood risk.

Indicator 6 = 4 (great concern)

Indicator 6.1 Urban drainage flood

$$\text{Indicator } 5.1 = \frac{X - 31.7}{69.6 - 31.7} \times 4 \qquad \text{(A4)}$$

where:

X = Soil sealing (%); As estimation of CBF indicator 18, share of green area was approximately 3%. Therefore, share of paved area and sealed soil is high.

Indicator 6.1 = 4 (great concern)

Indicator 6.2 Sea level rise

Table A6. Scoring for Sea level rise by percentage of urban affected area with sea water

Urban area affected (%)	Score
0 – 5	0
6 - 10	1
11 - 20	2
21 - 40	3
41 - 100	4

The area which is being affected by 1-meter sea level rise, when without any flood protection. Mongolia is a landlocked country, and Climate Central reported that Mongolia is one of the countries will be unaffected during 6 meters sea level rise.

Indicator 6.2 = 0 (no concern)

Indicator 6.3 River peak discharges

Table A7. Scoring for Sea level rise by percentage of urban affected area with river water

Urban area affected (%)	Score
0 – 5	0
6 - 10	1
11 - 20	2
21 - 40	3
41 - 100	4

The area which is being affected by 1-meter river level rise, when without any flood protection. 6-10% of Ulaanbaatar territory will be affected during 1 meter river level rise [7].

Indicator 6.3 = 1 (low concern)

Indicator 6.4 Flood risk due to subsidence

Table A8. Scoring for Flood risk due to subsidence

Score	Description
0	No infrastructure damage, no flood risk
1	Low/medium infrastructure damage expected, no major increase in flood risk expected
2	Experienced infrastructure damage and medium infrastructure damage expected or <0.50m subsidence by 2100 in a substantial area of the city
3	Serious experienced infrastructural damage or < 1m subsidence by 2100 in a substantial area of the city
4	Serious experienced infrastructure damage, Imminent flooding/ < 2m subsidence by 2100 in a substantial area of the city

Land subsidence risk can be not clear determined in Ulaanbaatar. However, low or medium infrastructure damage expected and cannot be major factor of flood risk.

Indicator 6.4 = 1 (low concern)

Indicator 7: Water quality

Indicator 7 = 2.2 (medium concern)

Indicator 7 consists of two sub-indicators, and the highest score of the two sub-indicators is used as the final score for water quality.

Indicator 7.1 Surface water quality

$$\text{Indicator 7.1} = \frac{100 - WQI}{25} \quad \text{(A5)}$$

Water quality index of Mongolia was 45, as reported on Environmental Performance Index [8].

Indicator 7.1 = 2.2 (medium concern)

Indicator 7.2 Biodiversity

$$\text{Indicator 7.2} = \frac{100 - Water\ (impact\ on\ ecosystems)}{25} \quad \text{(A6)}$$

Biodiversity in the aquatic ecosystem was evaluated as 57.55 [8].

Indicator 7.2 = 1.7 (medium concern)

Indicator 8: Heat risk

$$\text{Indicator } 8.1 = 4 - \left[\frac{\%\ green\ area - 16}{(48 - 16)} \times 4\right] \quad \text{(A7)}$$

$$\text{Indicator } 8.2 = \left[\frac{Number\ of\ combined\ tropical\ nights\ and\ hot\ days}{50}\right] \times 4 \quad \text{(A8)}$$

The arithmetic average of sub-subindicators is an overall score for Heat risk.
Number of combined tropical nights (>20 °C) and hot days (>35 °C) in the period of 2071 – 2100 can not be estimated. Based on data of meteorological station in the period of past 50 years, the combined number was less than 50. Share of green area was less than 16%.

Indicator 8 = 2 (medium concern)

Indicator 9: Economic pressure

$$\text{Indicator } 9 = 4 - \left[\frac{X - 514.7}{(59231.2 - 514.7) \times 4}\right] \quad \text{(A9)}$$

where:
X = GDP per capita per year (US$); GDP per capita was 4100 USD as of 2018 [9].

Indicator 9 = 3.9 (great concern)

Indicator 10: Unemployment rate

$$\text{Indicator } 10 = 0.0002X^3 + 0.0173X^2 + 0.5077X - 0.8356 \quad \text{(A10)}$$

where:
X = Unemployment rate (%); Unemployment rate was 7.6% in Ulaanbaatar, as of 2018 [3].

Indicator 10 = 2 (medium concern)

Indicator 11: Poverty rate

$$\text{Indicator } 11 = -0.0001X^2 + 0.0404X + 1.1686 \quad \text{(A11)}$$

where:
X = Poverty rate (% less than 2US$ a day); As World Bank reported, percentage of population living less than 2 USD a day in Mongolia was 0.1% [10].

Indicator 11 = 1.2 (low concern)

Indicator 12: Inflation

$$\text{Indicator } 12 = 0.0025X^3 - 0.0744X^2 + 0.8662X + 0.0389 \quad \text{(A12)}$$

where:
X = Inflation rate (%); Inflation rate was 3.5% as a Mongolian statistical information service reported [3].

Indicator 12 = 2.3 (medium concern)

Appendix B

Mathematical equations and the scoring for City Blueprint Framework is shown below.
Indicator 1: Secondary wastewater treatment
Secondary waste water treatment: process generally involving biological treatment with a secondary settlement or other process, with a Biological Oxygen Demand (BOD) removal of at least 70% and a Chemical Oxygen Demand (COD) removal of at least 75% [11].

$$\text{Indicator } 1 = \frac{X}{10} \quad \text{(B1)}$$

where:
X = Percentage of population connected to secondary sewage treatment; 41% of total population of Ulaanbaatar is connected to secondary sewage treatment [12].

Indicator 1 = 4.1

Indicator 2: Tertiary wastewater treatment

Tertiary waste water treatment: treatment of nitrogen or phosphorous or any other pollutants affecting the quality or a specific use of water (microbiological pollution, colour, etc.) [11].

$$\text{Indicator 2} = \frac{X}{10} \quad \text{(B2)}$$

where:
X = Percentage of population connected to tertiary sewage treatment; 0% of total population of Ulaanbaatar is connected to tertiary sewage treatment [13]. Recently, any kind of tertiary waste water treatment process is not existent.

$$\text{Indicator 2} = 0$$

Indicator 3: Groundwater quality

$$\text{Indicator 3} = \left[\frac{X}{X+Y}\right] \times 10 \quad \text{(B3)}$$

where:

X = Number of groundwater samples of 'good chemical status'
Y = Number of groundwater samples of 'poor chemical status'
We took data from the measurement of mechanical and chemical components of groundwater by Water Supply and Sewerage Authority in Ulaanbaatar [13], and compared with Mongolian National Standard 6148:2010 "Water quality. Maximum limit of substance contaminating the ground water" that is an official standard for groundwater in all municipalities of Mongolia. Number of groundwater samples with good chemical status was 33 and with poor chemical status was 0.

$$\text{Indicator 3} = 10$$

Indicator 4: Solid waste collected

$$\text{Indicator 4} = \left[1 - \frac{X - 136.4}{689.2 - 136.4}\right] * 10 \quad \text{(B4)}$$

where:
X = kg/cap/year of collected solid waste; The lowest and highest 10% produced solid waste of all countries that are available is taken. This respectively 136.4 kg/cap/year and 689.2 kg/cap/year; 408.82 kg/cap/year solid waste was produced in Ulaanbaatar, as of 2017 [14].

$$\text{Indicator 4} = 5.1$$

Indicator 5: Solid waste recycled

$$\text{Indicator 5} = \left[\frac{\%\text{ recycled or composted}}{100 - \%\text{ used for incineration with energy recovery}}\right] \times 10 \quad \text{(B5)}$$

In Ulaanbaatar, 5.5% of total collected solid waste is recycled and does not have any factory or system to use solid waste for energy recovery [14].

$$\text{Indicator 5} = 0.06$$

Indicator 6: Solid waste energy recovery

$$\text{Indicator 6} = \left[\frac{\%\text{ incineration with energy recovery}}{100 - \%\text{ recycled or composted}}\right] \times 10 \quad \text{(B6)}$$

As mentioned on Indicator 5, any factory or system that uses solid waste as the energy resource is not existing.

$$\text{Indicator 6} = 0$$

Indicator 7: Access to drinking water

$$\text{Indicator 7} = \frac{X}{10} \quad \text{(B7)}$$

where:
X = Percentage (%) of total urban population with access to potable drinking water; In Ulaanbaatar, there are general 2 types of living areas, which are apartments and "Ger area". Ger area is an area

with Ger, traditional nomadic accommodation, without any connection to central pipelines for drinking water supply and waste water sewerage system. Pit latrines are used in Ger area, and drinking water is carried from water kiosks or wells [15]. We considered people in ger area are accessible for potable drinking water, even though they have to carry. This is the uniqueness of nomadic lifestyle in modernized city. 99% of total population of Ulaanbaatar have access to potable drinking water [16].

Indicator 7 = 9.9

Indicator 8: Access to sanitation

$$\text{Indicator } 8 = \frac{X}{10} \tag{B8}$$

where:
X= Percentage (%) of total urban population with access to proper sanitation facilities; 41% of total population of Ulaanbaatar is living in apartments with water supply and waste water removal [12].

Indicator 8 = 4.1

Indicator 9: Drinking water quality

$$\text{Indicator } 9 = \frac{X}{Y} \times 10 \tag{B9}$$

where:
X = Total number of samples meeting standards
Y = Total number of samples
Water Supply and Sewerage Authority in Ulaanbaatar analyses drinking water and shows results by every seasonal period [13] and compare with Mongolian National Standard 0900:2018 "Environment, Health protection, Safety, Drinking water. Hygienically requirements, assessment of the quality and safety". Total number of samples meeting corresponding standard was 33 and total number of samples was 33.

Indicator 9 = 10

Indicator 10: Nutrient recovery

$$\text{Indicator } 10 = \frac{A}{B} \times \frac{\%\ secondary\ WWT\ coverage}{100} \times 10 \tag{B10}$$

where:
A = Wastewater treated with nutrient recovering techniques at the wastewater treatment plants (Mm^3/year)
B = Total volume of wastewater passing the wastewater treatment plants (Mm^3/year)
Central wastewater treatment plant in Ulaanbaatar treats 160'000 – 170'000 m^3 wastewater per day. This means 58.4 M m^3 wastewater is treated per year [17]. However, current wastewater treatment plant works without any nutrient recovery process.

Indicator 10 = 0

Indicator 11: Energy recovery

$$\text{Indicator } 11 = \frac{C}{D} \times \frac{\%\ secondary\ WWT\ coverage}{100} \times 10 \tag{B11}$$

where:
C = Total volume of wastewater treated with techniques to recover energy (Mm^3/year).
D = Total volume of wastewater treated in wastewater treatment plants (Mm^3/year).
Current wastewater treatment plant in Ulaanbaatar works without any energy recovery techniques.

Indicator 11 = 0

Indicator 12: Sewage sludge recycling

$$\text{Indicator } 12 = \frac{C + D}{A} \times \frac{\%\ secondary\ WWT\ coverage}{100} \times 10 \tag{B12}$$

where:

A = Dry weight of sludge produced in wastewater treatment plants serving the city
C = Dry weight of sludge thermally processed
D = Dry weight of sludge disposed in agriculture
Information about volume of sludge in Ulaanbaatar is not clear. Therefore, we asked about it from the Central Wastewater Treatment Plant in Ulaanbaatar, as they informed, about 1000 m^3 wet sludge is produced per day, and it dries by itself in the open space. After sludge dried, it is dumped in land fill.

Indicator 12 = 0

Indicator 13: Energy efficiency wastewater treatment
A self-assessment is applied for this indicator.

Table B1. A self-assessment meaning with corresponding indicator score

Indicator score	Assessment
0	no information is available on this subject
1	limited information is available in a national document
2	limited information is available in national and local documents
3	the topic is addressed in a chapter in a national document
4	the topic is addressed in a chapter at the national and local level
5	a local policy plan is provided in a publicly available document
6	as 5 and the topic is also addressed at the local website
7	plans are implemented and clearly communicated to the public
8	as 7 plus subsidies are made available to implement the plans
9	as 8 plus annual reports are provided on the progress of the implementation and/or any other activity indicating that this is a very high priority implemented at the level of the local
10	as 9 and the activity is in place for = 3 years

Central wastewater treatment plant in Ulaanbaatar works without any kind of energy efficiency techniques.

Indicator 13 = 0

Indicator 14: Stormwater separation

$$\text{Indicator } 14 = \frac{B + C}{A + B + C} \times 10 \quad \text{(B13)}$$

where:
A = Total length of combined sewers managed by the utility (km)
B = Total length of stormwater sewers managed by the utility (km)
C = Total length of sanitary sewers managed by the utility (km)
Total length of stormwater sewers managed by the utility was 180 km [18] and total length of combined sewers managed by the utility was 297.9 km [17], as of 2018.

Indicator 14 = 3.7

Indicator 15: Average age sewer

$$\text{Indicator } 15 = \frac{60 - X}{60 - 10} \times 10 \quad \text{(B14)}$$

where:
X = Average age sewer; The maximum and minimum age of the system is taken. These respectively 60 years and 10 years; The first sewerage system in Ulaanbaatar was built in 1963, then it is extending until now. The latest sewerage extension work was finished a year before last year, and maintenance is carried out every year [13]. We took a maximum is 55 years, and a minimum is 2 years, then 28.5 years as an average age of the sewerage system in Ulaanbaatar.

Indicator 15 = 6.3

Indicator 16: Water system leakages

$$\text{Indicator } 16 = \frac{50 - X}{50 - 10} \times 10 \quad \text{(B15)}$$

where:
X = Water system leakages (%); Water system leakage in Ulaanbaatar was 16% [13].

Indicator 16 = 6.8

Indicator 17: Operating costs recovery (ratio)

$$\text{Indicator } 17 = \frac{X - 0.33}{2.34 - 0.33} \times 10 \quad \text{(B16)}$$

where:
X = Operating cost recovery is illustrated as a ratio between total annual operational revenues and total annual operating costs; Of the operating cost recovery ratio for all countries available the highest and lowest 10% are averages and used as minimum and maximum value to rescale the operating cost recovery ratio to a score between 0 and 10 points. The minimum and maximum are respectively 0.33 and 2.34.
Water Supply and Sewerage Authority in Ulaanbaatar works with charge for supplying water and removing wastewater, as its financial report of 2017 total annual operational revenue was 49'428.7 million tugrugs (an official currency of Mongolia) and total annual operating cost was 58'993.6 million tugrugs [13].

Indicator 17 = 2.6

Indicator 18: Green space

$$\text{Indicator } 18 = \frac{X - 16}{48 - 16} \times 10 \quad \text{(B17)}$$

where:
X = Share of blue and green area (%); From the data of 367 European cities, the average of the lowest 10% is taken as minimum (16%) and the average of the highest 10% is taken as maximum (48%); Approximately 3% of the total area of Ulaanbaatar is urban green area [19].

Indicator 18 = 0

Indicator 19: Climate adaptation
A self-assessment is applied for this indicator same as Indicator 13.
Several official documents and programs were developed on climate adaptation in Mongolia such as "National Program on Climate Change" approved on January 06, 2011, "Green Development Policy" approved on June 13, 2014, Mongolian national law on "Energy saving" approved on November 26, 2015, "National Energy Saving Program" is implementing from 2018 until 2022 [20].

Indicator 19 = 5

Indicator 20: Drinking water consumption

$$\text{Indicator } 20 = \frac{X - 45.2}{266 - 45.2} \times 10 \quad \text{(B18)}$$

where:
X = m^3/person/year drinking water consumption; The minimum is for Rotterdam at 45.2 m^3/person/year. The maximum is for Kiev at 266 m^3/person/year.
Depending on the water source, water consumption is different in Ulaanbaatar. Dwellers in apartments which are connected to the central water supply system are using 167 litre per person a day, while dwellers in Ger area are using 8 litre per person a day [12]. Taking average of this consumption can make a mistake, so we added these meanings and converted into m^3/person/year unit.

Indicator 20 = 9.1

Indicator 21: Climate robust buildings
A self-assessment is applied for this indicator same as Indicator 13 and 19.

In addition to the documents and programs mentioned on Indicator 19, project "Energy saving of the buildings" MON/09/301 is being implemented, and Energy saving centre of Ulaanbaatar is working.

Indicator 21 = 3

Indicator 22: Management and action plans

A self-assessment is applied for this indicator same as Indicator 13, 19 and 21. This indicator is based on the application of the concept of Integrated Water Resources Management (IWRM) in the city. Integrated Water Resources Management Plan of the Tuul River is developed and Ulaanbaatar city is being included in this plan [21].

Indicator 22 = 5

Indicator 23: Public participation

$$\text{Indicator } 23 = \frac{(0.6573 \times Y - 22.278) - 5}{53 - 5} \times 10 \quad \text{(B19)}$$

where:

Y = Rule of law score; As one of the World Bank governance indicators, rule of law score of Mongolia was 46.6.

Indicator 23 = 0.7

Indicator 24: Water efficiency measures

A self-assessment is applied for this indicator same as Indicator 13, 19, 21 and 22; Water efficiency concepts are written on Mongolian Law on Water [20].

Indicator 24 = 5

Indicator 25: Attractiveness

A self-assessment is applied for this indicator same as Indicator 13, 19, 21, 22 and 24.

Indicator 25 = 2

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