*Supplementary Materials*

# Comprehensive evaluation model for urban water security: A case study in Dongguan, China

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## S1. The annual average water quality statistics

**Table S1.** The annual average water quality statistics of six major river cross-sections in Dongguan City.

| River cross section | Year (annual average) | DO (mg/L) | $COD_{Mn}$ (mg/L) | $COD_{Cr}$ (mg/L) | $BOD_5$ (mg/L) | $NH_3$-N (mg/L) | TP (mg/L) |
|---|---|---|---|---|---|---|---|
| Dongjiang South Tributary - Shatin Sisheng | 2016 | 3.76 | 3.4 | 13 | 3.4 | 1.11 | 0.22 |
| | 2017 | 3.97 | 2.9 | 12 | 3 | 1.23 | 0.15 |
| | 2018 | 3.61 | 3.3 | 12 | 2.8 | 0.658 | 0.11 |
| | 2019 | 6.1 | 3.8 | 15.2 | 4.3 | 1.20 | 0.17 |
| | 2020 | 6.5 | 4.7 | 15.8 | 2.9 | 0.58 | 0.16 |
| Dongjiang North Main Stream - Shilong North River | 2016 | 6.34 | 2 | 12 | 1.7 | 0.664 | 0.16 |
| | 2017 | 5.67 | 1.9 | 10 | 1.8 | 0.437 | 0.13 |
| | 2018 | 5.04 | 2.1 | 9 | 1.9 | 0.336 | 0.12 |
| | 2019 | 7.0 | 2.4 | 7.1 | 2.0 | 0.28 | 0.12 |
| | 2020 | 7.5 | 1.9 | 6.3 | 1.2 | 0.14 | 0.06 |
| Dongjiang South Tributary - Shilong South River | 2016 | 6.7 | 1.9 | 12 | 1.8 | 0.474 | 0.13 |
| | 2017 | 5.93 | 1.8 | 10 | 1.9 | 0.364 | 0.12 |
| | 2018 | 5.49 | 2.1 | 9 | 1.7 | 0.26 | 0.11 |
| | 2019 | 7.3 | 2.0 | 5.6 | 2.6 | 0.28 | 0.09 |
| | 2020 | 7.5 | 1.9 | 5.8 | 1.2 | 0.11 | 0.06 |
| Zhongtang Waterway - Wanjiang Water Treatment Plant | 2016 | 6.55 | 2.1 | 13 | 2.6 | 0.15 | 2.98 |
| | 2017 | 5.84 | 1.8 | 9 | 1.9 | 0.13 | 2.55 |
| | 2018 | 5.89 | 1.9 | 8.4 | 1.8 | 0.11 | 2.48 |
| | 2019 | 7.0 | 1.7 | 7.3 | 1.9 | 0.19 | 0.10 |
| | 2020 | 7.2 | 1.8 | 6.9 | 1.2 | 0.09 | 0.07 |
| Dongguan Canal-Zhangshun | 2016 | 3.86 | 5.8 | 18 | 4.5 | 2.56 | 0.4 |
| | 2017 | 4.98 | 4.1 | 17 | 3.5 | 4.46 | 0.38 |
| | 2018 | 5.82 | 4.7 | 15 | 3.6 | 2.99 | 0.31 |
| | 2019 | 4.8 | 5.2 | 17.0 | 5.0 | 6.49 | 0.30 |
| | 2020 | 5.6 | 4.3 | 16.2 | 5.4 | 3.30 | 0.15 |
| Shima River - Qiling | 2016 | 4.05 | 6.4 | 21 | 5.9 | 7.74 | 1.11 |
| | 2017 | 3.98 | 6 | 19 | 4.7 | 8.60 | 1.64 |
| | 2018 | 4.45 | 5.5 | 21 | 4.4 | 8.80 | 0.79 |
| | 2019 | 6.5 | 4.7 | 16.1 | 5.9 | 3.62 | 0.73 |
| | 2020 | 7.5 | 4.0 | 12.5 | 4.4 | 1.80 | 0.20 |

**Table S2.** The annual average water quality statistics of eight medium-sized reservoirs in Dongguan City.

| Reservoir | Year (annual average) | chl a ($mg/m^3$) | TP (mg/L) | TN (mg/L) | SD (m) | $COD_{Mn}$ (mg/L) |
|---|---|---|---|---|---|---|
| Dalang Town Songmushan Reservoir | 2016 | 21.73 | 0.06 | 2.10 | 0.53 | 4.6 |
| | 2017 | 9.07 | 0.06 | 1.90 | 0.58 | 3.8 |
| | 2018 | 20.02 | 0.04 | 1.82 | 0.79 | 3.7 |
| | 2019 | 21.32 | 0.04 | 1.96 | 0.73 | 4.2 |
| | 2020 | 18.74 | 0.04 | 2.20 | 0.77 | 3.5 |
| Dongcheng District Tongsha Reservoir | 2016 | 10.81 | 0.10 | 4.15 | 0.50 | 5.3 |
| | 2017 | 8.65 | 0.09 | 4.99 | 0.52 | 4.2 |
| | 2018 | 29.89 | 0.09 | 6.02 | 0.61 | 5.1 |
| | 2019 | 33.73 | 0.06 | 4.50 | 0.65 | 4.5 |
| | 2020 | 27.83 | 0.06 | 4.16 | 0.65 | 4.1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Fenggang Town Yantian Reservoir | 2016 | 6.06 | 0.06 | 1.39 | 0.62 | 2.5 |
| | 2017 | 8.53 | 0.07 | 1.42 | 0.64 | 2.5 |
| | 2018 | 13.58 | 0.06 | 1.34 | 0.82 | 2.5 |
| | 2019 | 18.55 | 0.06 | 1.39 | 0.84 | 2.4 |
| | 2020 | 16.77 | 0.07 | 1.19 | 0.76 | 2.5 |
| Huangjiang Town Huangniupu Reservoir | 2016 | 6.00 | 0.04 | 1.52 | 0.73 | 3.1 |
| | 2017 | 5.15 | 0.03 | 1.15 | 0.73 | 3.3 |
| | 2018 | 20.59 | 0.03 | 1.18 | 0.78 | 3.5 |
| | 2019 | 26.52 | 0.03 | 1.23 | 0.75 | 3.1 |
| | 2020 | 16.48 | 0.05 | 1.05 | 0.70 | 4.2 |
| Qingxi Town Maoche Reservoir | 2016 | 5.38 | 0.03 | 1.11 | 0.82 | 2.7 |
| | 2017 | 22.60 | 0.06 | 0.95 | 0.78 | 3.7 |
| | 2018 | 19.69 | 0.04 | 0.80 | 0.82 | 3.1 |
| | 2019 | 21.02 | 0.05 | 0.86 | 0.79 | 3.3 |
| | 2020 | 27.42 | 0.05 | 0.92 | 0.74 | 4.1 |
| Qingxi Town Qiyeshi Reservoir | 2016 | 6.99 | 0.04 | 1.0 | 0.78 | 2.7 |
| | 2017 | 9.10 | 0.04 | 1.07 | 0.82 | 3.0 |
| | 2018 | 16.63 | 0.04 | 0.80 | 0.85 | 3.2 |
| | 2019 | 18.36 | 0.03 | 0.87 | 0.79 | 2.9 |
| | 2020 | 12.00 | 0.03 | 0.82 | 0.81 | 2.9 |
| Houjie Town Henggang Reservoir | 2016 | 15.38 | 0.04 | 1.40 | 0.15 | 3.8 |
| | 2017 | 23.05 | 0.08 | 1.21 | 0.23 | 5.5 |
| | 2018 | 43.65 | 0.06 | 1.88 | 0.44 | 5.2 |
| | 2019 | 59.64 | 0.05 | 1.86 | 0.60 | 5.9 |
| | 2020 | 49.71 | 0.07 | 2.08 | 0.50 | 8.4 |
| Tangxia Town Xiagongyan Reservoir | 2016 | 5.69 | 0.03 | 1.19 | 0.66 | 2.9 |
| | 2017 | 4.00 | 0.06 | 0.74 | 0.79 | 2.9 |
| | 2018 | 13.37 | 0.07 | 0.79 | 0.88 | 2.8 |
| | 2019 | 18.40 | 0.02 | 0.90 | 0.85 | 2.8 |
| | 2020 | 8.42 | 0.03 | 0.75 | 0.99 | 2.8 |

## S2. The TLI correlation coefficient and calculation formula

**Table S3.** The correlation coefficient $r_{ij}$ between parameters and *chl a* and the value of $r_{ij}^2$.

| Parameters | chl a | TP | TN | SD | $COD_{Mn}$ |
|---|---|---|---|---|---|
| $r_{ij}$ | 1 | 0.84 | 0.82 | -0.83 | 0.83 |
| $r_{ij}^2$ | 1 | 0.7056 | 0.6724 | 0.6889 | 0.6889 |

*TLI(j)* is calculated as follows:

$$TLI(chla) = 10(2.5 + 1.086 \cdot ln\ chla) \tag{1}$$

$$TLI(TP) = 10(9.436 + 1.624 \cdot \ln\ TP) \tag{2}$$

$$TLI(TP) = 10(5.453 + 1.694 \cdot \ln\ TN) \tag{3}$$

$$TLI(TP) = 10(5.118 - 1.94 \cdot \ln\ SD) \tag{4}$$

$$TLI(COD_{Mn}) = 10(0.109 + 2.661 \cdot \ln\ COD_{Mn}) \tag{5}$$

**S3. TLI(Σ) sensitivity analysis**

In this study, since the weights $W_j$ of TLI are evaluated by the relative contributions of different parameters [81], the sensitivity of the weights is tested using the One-At-a-Time (OAT) [82] method as follows [83]:

(1) Calculate the weights of changes

The adjustment of specific weights is calculated according to the following formula. In this paper, the range and step of change of weights are ±100% and 5%, respectively.

$$\overline{W_j}(cr) = (1 + cr) \times W_j \tag{6}$$

where $\overline{W_j}(cr)$ is the adjusted weight of parameter $j$; $cr$ is the rate of change of the weight; and $W_j$ is the original weight of parameter $j$. The other weights are calculated as follows:

$$\overline{W_i}(cr) = W_i \times \frac{1 - \overline{W_j}}{1 - W_j} \tag{7}$$

where $\overline{W_i}(cr)$ is the weight of the other parameters, $i \neq j$; $W_i$ is the original weight of parameter $i$.

(2) Calculation of the rate of change of the results

The sensitivity of the weights was analyzed by calculating the mean of the absolute change rate (MACR) with the following formula:

$$MACR(W_j, cr) = \frac{1}{N}\sum_{k=1}^{N}\left|\frac{R_k(W_j, cr) - R_0}{R_0}\right| \tag{8}$$

The results of the sensitivity analysis of the weights are shown in Figure S1. In this sample, $COD_{Mn}$ was the most sensitive indicator, with a MACR of only 2.2% for a 30% rate of change. This indicates that the results of the evaluation are relatively robust [84].

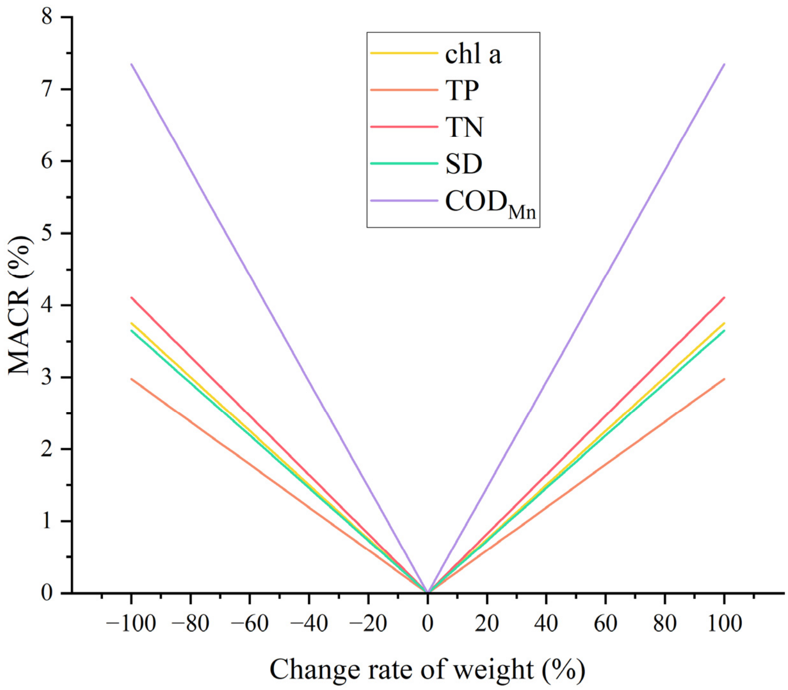


**Figure S1.** The sensitivity analysis of TLI weights.

## S4. The grey prediction model accuracy test formula

(1) Average relative percentage error *Φ* [85]

$$\varphi_i = \frac{\left| x_i^{(0)} - \hat{x}_i^{(0)} \right|}{x_i^{(0)}} \tag{9}$$

$$\Phi = \frac{1}{n}\sum_{k=1}^{n} \varphi_i \tag{10}$$

where $x_i^{(0)}$ is the true value and $\hat{x}_i^{(0)}$ is the predicted value.

(2) Variance ratio *C*

$$S_1 = \sqrt{\frac{\sum_{i=1}^{n} (x_i^{(0)} - \overline{x}^{(0)})^2}{n-1}} \tag{11}$$

$$S_2 = \sqrt{\frac{\sum_{i=1}^{n} (\Delta_i^{(0)} - \overline{\Delta}^{(0)})^2}{n-1}} \tag{12}$$

$$C = \frac{S_2}{S_1} \tag{13}$$

where $S_1$ is the mean squared deviation of the original series and $S_2$ is the mean squared deviation of the error term.

(3) Minor probability *p*

$$p = P(|\Delta_i^{(0)} - \overline{\Delta}^{(0)}| < 0.6745 \times S_1) \tag{14}$$

**S5. The WSI evaluation indicators and grading standards**

**Table S4.** Dongguan WSI evaluation indicators and grading standards.

| Index | 2016 | 2017 | 2018 | 2019 | 2020 | grade I | grade II | grade III | grade IV | grade IV |
|---|---|---|---|---|---|---|---|---|---|---|
| D1 | 72028 | 78637 | 84708 | 90696 | 92176 | 73856 | 57906 | 41956 | 26005 | 10055 |
| D2 | 35.47 | 35.49 | 39.21 | 43.98 | 46.52 | 300 | 200 | 100 | 50 | 25 |
| D3 | 2968.16 | 3618.19 | 3914.38 | 4192.78 | 4477.91 | 4800 | 2400 | 1200 | 600 | 300 |
| D4 | 4132 | 4220 | 4243 | 4250 | 4262 | 1000 | 1750 | 2500 | 3250 | 4000 |
| P1 | 24.8 | 22.1 | 20.2 | 15.2 | 15 | 10 | 20 | 30 | 40 | 50 |
| P2 | 4.47 | 4.69 | 3.90 | 4.01 | 2.96 | 5 | 10 | 25 | 40 | 55 |
| P3 | 7845 | 8235 | 8250 | 8250 | 8340 | 6000 | 7500 | 9000 | 10500 | 12000 |
| P4 | 1070.28 | 1047.73 | 956.98 | 786.70 | 758.47 | 400 | 450 | 500 | 550 | 600 |
| P5 | 209 | 206 | 210 | 208 | 166 | 150 | 180 | 220 | 250 | 300 |
| P6 | 106.18 | 99.64 | 102.01 | 111.31 | 107.42 | 10 | 20 | 30 | 80 | 130 |
| S1 | 335.04 | 202.08 | 228.88 | 236.63 | 190.96 | 1000 | 750 | 500 | 250 | 150 |
| S2 | 15.8 | 28.4 | 27.1 | 21.4 | 30.6 | 10 | 20 | 30 | 40 | 50 |
| S3 | 1.57 | 1.59 | 1.38 | 0.98 | 0.63 | 0.35 | 0.63 | 1.00 | 1.58 | 2.20 |
| S4 | 49.92 | 50.53 | 51.70 | 51.49 | 51.63 | 30 | 50 | 60 | 70 | 90 |
| S5 | 2493.1 | 1696 | 1857.1 | 1935.3 | 1635.5 | 2500 | 2000 | 1500 | 1000 | 500 |
| I1 | 47.71 | 46.98 | 53.59 | 35.86 | 43.20 | 70 | 40 | 15 | 5 | 3 |
| I2 | 3643 | 4201 | 4677 | 5922 | 5482 | 500 | 1625 | 2750 | 3875 | 5000 |
| I3 | 457 | 523 | 587 | 741 | 668 | 100 | 325 | 550 | 775 | 1000 |
| I4 | 62.41 | 60.30 | 60.20 | 60.90 | 59.60 | 90 | 75 | 55 | 35 | 20 |
| R1 | 96.2 | 94.1 | 94.5 | 99.5 | 96.2 | 90 | 70 | 50 | 30 | 10 |
| R2 | 1.56 | 2.11 | 2.22 | 4.43 | 4.4 | 5 | 4 | 3 | 2 | 1 |
| R3 | 89.7 | 72.4 | 66.3 | 81.5 | 78.2 | 50 | 60 | 70 | 80 | 90 |
| R4 | 14.2 | 12.7 | 12.9 | 12 | 11.8 | 8 | 10 | 12 | 14 | 16 |

The grading standards are mainly based on the following:

1. National or local standards, including the Environmental quality standards for surface water (GB3838-2002), the Guidelines for prevention and treatment of eutrophication in important lake and reservoir water sources in the Guangdong-HongKong-Macao Greater Bay Area (T/CWEC25-2021), the Technical Criterion for Ecosystem Status Evaluation (HJ192-2015), the Technical guidelines for river and lake health assessment (SL/T793-2020), and the Standard for water loss control and assessment of urban water distribution system (CJJ92-2016);
2. Research results of relevant references [56,57,86];
3. National or Guangdong indicator ranking, from the Guangdong Statistical Yearbook 2021 and the China Green Low Carbon City Index Report 2021.

**S6. The classification criteria for the decoupling states**

**Table S5.** The classification criteria for the decoupling states.

| Decoupling status | | Division | Significance |
|---|---|---|---|
| I | Strong decoupling | $\Delta P$ or $\Delta SI < 0$, $\Delta D$ or $\Delta R > 0$, $DI_t < 0$ | Socio-economic drivers (or response measures, the same below) increase while water security pressures (or water and ecological status, the same below) become worse |
| II | Weak decoupling | $\Delta P$ or $\Delta SI > 0$, $\Delta D$ or $\Delta R > 0$, $0 < DI_t < 0.8$ | The improvement rate of water security pressures is obviously smaller than the increase rate of socio-economic drivers |
| III | Expansive coupling | $\Delta P$ or $\Delta SI > 0$, $\Delta D$ or $\Delta R > 0$, $0.8 < DI_t < 1.2$ | The improvement rate of water security pressures is approximately equal to the increase rate of socio-economic drivers |
| IV | Expansive negative decoupling | $\Delta P$ or $\Delta SI > 0$, $\Delta D$ or $\Delta R > 0$, $DI_t > 1.2$ | The improvement rate of water security pressures is obviously bigger than the increase rate of socio-economic drivers |
| V | Strong negative decoupling | $\Delta P$ or $\Delta SI > 0$, $\Delta D$ or $\Delta R < 0$, $DI_t < 0$ | Water security pressures improve while socio-economic drivers decrease |
| VI | Weak negative decoupling | $\Delta P$ or $\Delta SI < 0$, $\Delta D$ or $\Delta R < 0$, $0 < DI_t < 0.8$ | The deterioration rate of water security pressures is obviously smaller than the decrease rate of socio-economic drivers |
| VII | Recessive coupling | $\Delta P$ or $\Delta SI > 0$, $\Delta D$ or $\Delta R > 0$, $0.8 < DI_t < 1.2$ | The deterioration rate of water security pressures is approximately equal to the decrease rate of socio-economic drivers |
| VIII | Recessive decoupling | $\Delta P$ or $\Delta SI > 0$, $\Delta D$ or $\Delta R > 0$, $DI_t > 1.2$ | The deterioration rate of water security pressures is obviously bigger than the decrease rate of socio-economic drivers |