Supporting Information

Specificality, Quality Variation, Assessment and Treatment of Estuarine Water in the Pearl River Delta, South China

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Text S1. The comprehensive risk assessment of MCDA method

Multiple--criteria decision analysis (MCDA) is an effective tool for assessing and deciding the comprehensive risk under multi-criteria and multiple factors (Huang et al., 2011). In this study, MCDA includes stochastic weight averaging (SWA), the technique for order preference by similarity to an ideal solution (TOPSIS), fuzzy principal component analysis (FPCA) and analytic hierarchy process (AHP).

1. Simple Weights Addition (SWA)

According to the actual conditions, SWA decides the weight of each attribute. It uses linear weighted average to calculate every solution's risk value, which determines the choice of optimization solution. The mathematical formulation of the SWA is shown in Equation (S1):

$$U_i = \sum_{j=1}^{n} w_i z_{ij}{}', i = \{1, 2, \cdots m\} \quad \text{(S1)}$$

where $\mathrm{w} = (w_1, w_2, w_3 \cdots w_m)^{\mathrm{T}}$ represents the weight, and $w_i \in [0,1]$, $\sum_{i=1}^{m} w_i = 1$; z_{ij} represents the attribute.

2. Technique Order Preference Ideal Solution (TOPSIS)

TOPIS is a multi-attribute decision making method from the point of geometrical optics. The ranking is determined by its distance to the negative ideal solution (Wang 2020). The mathematical formulation of the TOPSIS is shown in Equation (S2 ~ S6):

$$A^- = \{(min(v_{ij}), j \in I^{'}), i = 1,2, \cdots m\} = (v_1^-, v_2^-, \cdots v_i^-, \cdots v_m^-) \quad \text{(S2)}$$

$$A^+ = \{(\max(v_{ij}), j \in I), i = 1,2, \cdots m\} = (v_1^+, v_2^+, \cdots v_i^+, \cdots v_m^+) \quad \text{(S3)}$$

$$S_j^- = \sqrt{\sum_{i=1}^{m} (v_{ij} - v_i^-)^2}, j = 1,2, \cdots, n \quad \text{(S4)}$$

$$S_j^+ = \sqrt{\sum_{i=1}^{m} (v_{ij} - v_i^+)^2}, j = 1,2, \cdots, n \quad \text{(S5)}$$

$$U_j = \frac{S_j^-}{S_j^+ + S_j^-} \quad \text{(S6)}$$

where v_{ij} represents the attribute value; A^- and A^+ represent the negative ideal solution and ideal solution, respectively; S_j^- and S_j^+ represent the negative ideal distance and ideal distance, respectively; U_j represents the risk value of solution j.

3. Fuzzy Principal Component Analysis (FPCA)

Principal Component Analysis (PCA) is an effective linear analysis method, which is sensitive to extreme values and missing data. To cover the shortage of the traditional PCA, Fuzzy PCA (FPCA) was used. Based on the construction of a fuzzy covariance matrix, principal component analysis can be effectively analyzed. FPCA has an advantage in solving the problem of subjective, imprecise and uncertain information to be translated into quantitative data for decision making (Du et al. 2015, Lin et al. 2006).

4. Analytic Hierarchy Process (AHP)

AHP decomposes the decision problem into a complex hierarchical framework. The order of a specific solution is affected by general goals, subgoals and assessment criteria. The solution of matrix eigenvectors is then calculated, which is the priority weight of each element in one hierarchy to one element in an above hierarchy. Finally, a weighted sum is used to recurse the final weight of each alternative to general goals. The element with the highest weight is the optimal decision (Tseng et al. 2009, Wong et al. 2008).

Table S1. Storm surges occurred in the PRD (2013 ~ 2020)

Year	**No.**	**Name**	**City**	**Direct economic loss (×10^9 dollars)**	**Occurrence time (month, day)**	**Times every year**	**National standard**
2013	1311	Utor	Jiangmen	2.09	8.13 ~ 8.15	2	GB/T 17839-2011, GB/T 17839-1999
	1319	Usagi	Huizhou	9.20	9.21 ~ 9.23	-	
2014	-	-	-	-	-	0	
2015	1522	Mujigae	Jiangmen	4.12	10.3 ~ 10.5	1	
2016	1604	Nida	Shenzhen, Zhuhai, Jiangmen, Huizhou	0.18	8.1 ~ 8.2	3	
	1622	Haima	Huizhou	1.19	10.20 ~ 10.22	-	
2017	1702	Merbok	Huizhou	0.03	6.12 ~ 6.13	-	
	1713	Hato	Guangzhou, Shenzhen, Zhuhai, Dongguan, Zhongshan, Jiangmen, Huizhou	8.09	8.22 ~ 8.23	-	
	1714	Pakhar	Zhongshan, Jiangmen	0.02	8.26 ~ 8.27	2	
2018	1822	Mangkhut	Guangzhou, Shenzhen, Zhuhai, Zhongshan, Jiangmen, Huizhou	3.72	9.16 ~ 9.17	1	
2019	-	-	-	-	-	-	-
2020	1502	Higos	Zhuhai, Huizhou, Jiangmen	0.08	8.19	1	-

Table S2. Saltwater intrusions occurred in the PRD (2013 ~ 2020)

Year	Emergence period (month)	Duration (day)	Highest salinity (psu)	Maximum chlorinity (mg/L)
2013	1 ~ 2, 12	1 ~ 3	1.17 ~ 9.72	2430
2014	1 ~ 3, 11 ~ 12	3 ~ 15	3.52 ~ 11.06	6122
2015	-	-	-	-
2016	10 ~ 11	-	-	1703
2017	1 ~ 3, 10 ~ 12	72 (maximum)	10.84 (highest)	6000
2018	1, 4, 9, 10 (frequently)	1 ~ 82	0.53 ~ 12.05	6658
2019	1, 11 ~ 12	1 ~ 10	875 ~ 5090 (mg/L)	5090
2020	1, 2, 11, 12	3 ~ 8	-	5758

Table S3. Red tides occurred in the PRD region (2013 ~ 2020)

Year	City	Duration (day)	Main algae	Maximum area (km^3)
2013	Shenzhen	3.18 ~ 3.25 10.13 ~ 10.25	Noctiluca, Cochlodinium geminatum	2, 6.5
	Zhuhai	11.28 ~ 12.11	Phaeocystis globsa	1.5
2014	Shenzhen	2.8 ~ 2.10, 2.27 ~ 3.3, 4.8 ~ 4.12, 4.11 ~ 4.20, 4.29 ~ 5.4, 6.18 ~ 6.25, 11.24 ~ 11.27	Heterosigma akashiwo, Akashiwo sanguinea, Gonyaulax polygramma, Noctiluca	2.5, 2, 2, 3, 1, 5, 0.05
	Zhuhai	11.30 ~ 12.1	Noctiluca	0.05
	Huizhou	4.6 ~ 4.6 4.11 ~ 4.23	Akashiwo sanguinea, Gonyaulax polygramma	8, 100
2015	Shenzhen	1.5 ~ 1.8, 8.27 ~ 9.2	Noctiluca, Cochlodium polykrikoides	0.08, 1.5
	Zhuhai	1.4 ~ 1.13, 1.28 ~ 2.5	Noctiluca, Heterosigma akashiwo	0.01, 0.07
2016	Shenzhen	2.22 ~ 3.15, 4.2 ~ 4.8, 5.3 ~ 5.10	Akashiwo sanguinea, Noctiluca	70, 5, 0.5
	Zhuhai	3.4 ~ 3.10, 4.8 ~ 4.11,	Akashiwo sanguinea, Noctiluca	70, 0.01
	Huizhou	2.17 ~ 2.29, 3.4 ~ 5.9	Akashiwo sanguinea, Skeletonema costatum	74
2017	Shenzhen	8.15 ~ 8.24	Scrippsiella trochoidea	45
	Huizhou	3.21 ~ 3.24, 8.14 ~ 8.19, 8.30 ~ 9.4, 9.13 ~ 9.15	Heterosigma akashiwo, Scrippsiella trochoidea	3, 16, 7.2, 20
2019	Shenzhen	1.30 ~ 2.6	Heterosigma akashiwo	1.50
	Huizhou	2.16 ~ 2.20	Heterosigma akashiwo	0.46
2020	Shenzhen	5.3 ~ 5.5 5.15 ~ 5.17	Heterosigma akashiwo, Skeletonema costatum Cochlodium polykrikoides	45

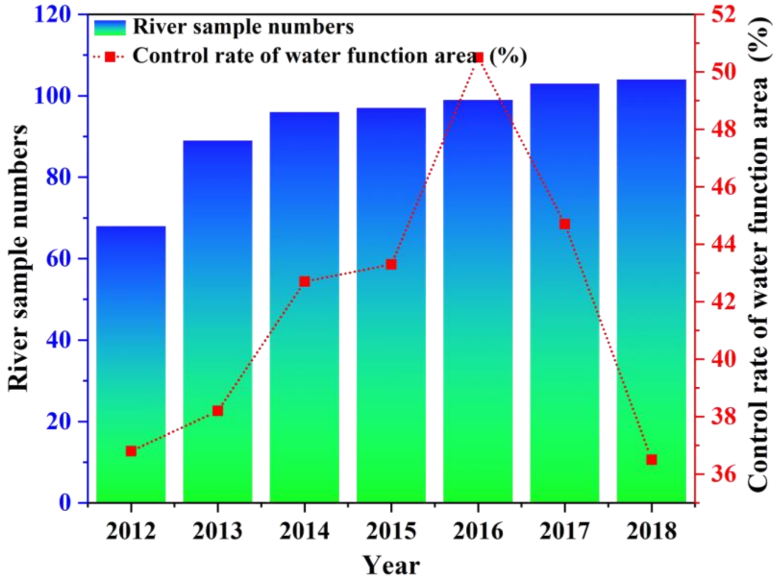

Figure S1. The water quality compliance rate in the PRD region.

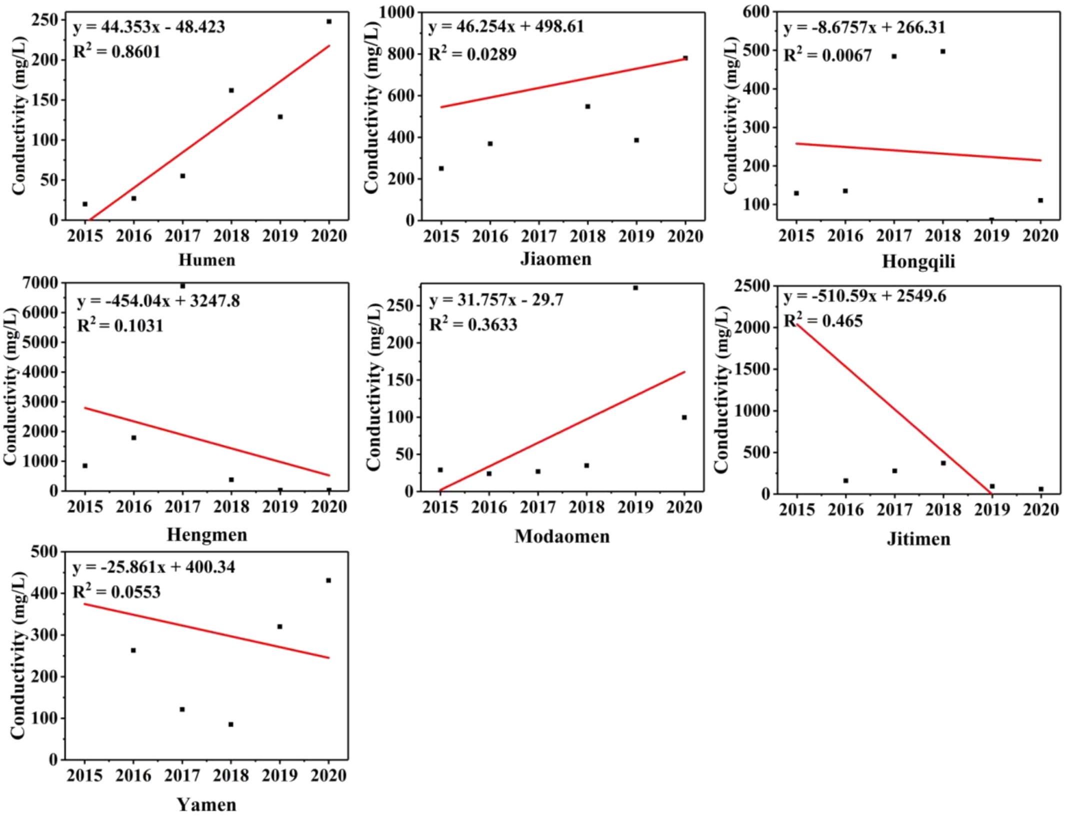

Figure S2. The fitted equations for variation trend of conductivity in spatial distribution.

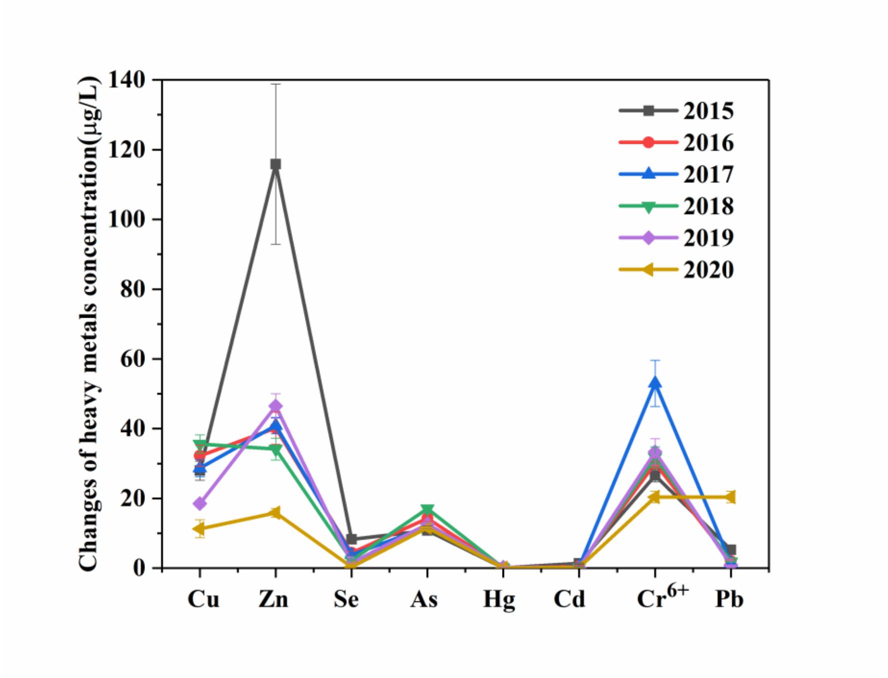

Figure S3. Variations of heavy metals concentration in the seven estuaries from 2015 to 2020.

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