Supplementary

Table S1. Comparison of model performance metrics across different mode k values (k=7, 8, 9, 10) in VMD. The bold fonts highlight the decomposition results under the optimal mode.

	K	RMSE(μg/m³)	MAE(μg/m³)	MAPE	R^2	Pearson's r
Qingdao	7	2.6909	2.0031	32.8032	0.4908	0.7433
	8	2.3057	1.6237	25.3862	0.6262	0.816
	9	**0.9191**	**0.7122**	**11.3761**	**0.9406**	**0.9781**
	10	2.3421	1.6952	27.3709	0.6143	0.8288
Rizhao	7	3.5854	2.7236	39.73	0.2189	0.7016
	8	1.6286	1.3091	22.6144	0.8388	0.9456
	9	**1.0061**	**0.7584**	**11.3494**	**0.9385**	**0.9715**
	10	1.9246	1.4341	20.7926	0.7749	0.8854
Weifang	7	3.1402	2.6379	32.85	0.7805	0.9513
	8	3.1518	2.3734	26.58	0.7789	0.9065
	9	**1.3473**	**0.9408**	**10.1221**	**0.9596**	**0.9798**
	10	2.4507	1.7839	18.9446	0.8663	0.9398
Weihai	7	1.018	0.7155	16.7215	0.858	0.9294
	8	1.5351	1.373	36.9022	0.677	0.9549
	9	2.0649	1.4667	36.7828	0.4156	0.6969
	10	**0.7856**	**0.6006**	**14.6128**	**0.9154**	**0.9675**
Yantai	7	2.817	2.1913	25.6335	0.4422	0.7763
	8	**1.1082**	**0.8517**	**10.4936**	**0.9137**	**0.9631**
	9	1.8248	1.3427	16.9423	0.7659	0.8878
	10	2.1496	1.7087	23.2055	0.6752	0.8896

Table S2. The central frequency of the intrinsic mode function (IMF) across five coastal cities.

	Qingdao	Rizhao	Weifang	Weihai	Yantai
IMF1	0.000407	0.000407498	0.000407	0.000407	0.002852
IMF2	0.062755	0.033414833	0.062755	0.05053	0.08313
IMF3	0.115322	0.087204564	0.115322	0.120212	0.134882
IMF4	0.162184	0.135696822	0.162184	0.162184	0.162184
IMF5	0.184597	0.185004075	0.219234	0.198452	0.254686
IMF6	0.254686	0.257131214	0.289324	0.255094	0.297474
IMF7	0.339446	0.348410758	0.321516	0.293399	0.359413
IMF8	0.389976	0.421352893	0.388753	0.365526	0.43643
IMF9	0.456398	0.464955175	0.465363	0.431948	-
IMF10	-	-	-	0.492665	-

Table S3. Performance comparison of different forecasting methods: RF-VMD-Seq2Seq, RF-EEMD-Seq2Seq, and RF-Seq2Seq.

		RMSE(μg/m³)	MAE(μg/m³)	MAPE	R^2	Pearson's r
Qingdao	RF-VMD-Seq2Seq	0.9192	0.7122	11.3761	0.9406	0.9781
	RF-EEMD-Seq2Seq	2.4986	1.6741	23.7581	0.561	0.903
	RF-Seq2Seq	3.1897	2.0699	28.8737	0.2846	0.6054
Rizhao	RF-VMD-Seq2Seq	1.0061	0.7584	11.3494	0.9385	0.9715
	RF-EEMD-Seq2Seq	2.0857	1.5969	24.9162	0.7357	0.8739
	RF-Seq2Seq	3.5271	2.5489	38.902	0.2441	0.5811
Weifang	RF-VMD-Seq2Seq	1.3473	0.9408	10.1221	0.9596	0.9798
	RF-EEMD-Seq2Seq	2.9947	2.2289	28.5003	0.8004	0.9224
	RF-Seq2Seq	6.6796	4.3674	51.2079	0.0071	0.4895
Weihai	RF-VMD-Seq2Seq	0.7856	0.6006	14.6128	0.9154	0.9675
	RF-EEMD-Seq2Seq	1.2288	0.7793	17.01	0.7931	0.8991

	RF-Seq2Seq	2.1992	1.4198	31.065	0.3371	0.609
Yantai	RF-VMD-Seq2Seq	1.1082	0.8517	10.4936	0.9137	0.9631
	RF-EEMD-Seq2Seq	2.0497	1.3162	14.993	0.7047	0.8765
	RF-Seq2Seq	3.4559	2.3657	26.1528	0.1605	0.5702

Table S4. Model performance indicators for predicting SO_2 concentration during COVID-19 across five coastal cities.

City	RMSE(μg/m³)	MAE(μg/m³)	MAPE	R^2	Pearson's r
Qingdao	0.9173	0.7323	12.0756	0.8286	0.9508
Rizhao	0.9085	0.6698	10.4059	0.9343	0.9683
Weifang	1.1361	0.9065	12.171	0.9135	0.9608
Weihai	0.7285	0.6079	19.6196	0.849	0.9529
Yantai	0.9787	0.8324	8.7786	0.8901	0.9663

Table S5. Model performance of different input-sequence length used for Forecasting in RF-VMD-Seq2Seq.

	RMSE(μg/m³)	*MAE(μg/m³)*	*MAPE*	*R^2*	*Pearson's r*
2	1.5663	1.3705	22.4156	0.8213	0.9747
3	1.7002	1.4161	23.1982	0.7731	0.9473
5	2.2896	1.6312	24.2254	0.589	0.8268