Spatiotemporal analysis of aquifers salinization in coastal area of Yunlin, Taiwan

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1. Introduction

The groundwater resource in Choushui River Alluvial Fan is an important district of water resource. According to the Water Resources Agency, the groundwater use is 2,600 million tons, and accounts for 40% of the groundwater use in Taiwan.

The groundwater use includes:

- Irrigation
- Industrial water
- **Aquaculture**
- More than 90% tap water is from pumping groundwater

1.1 Study Area

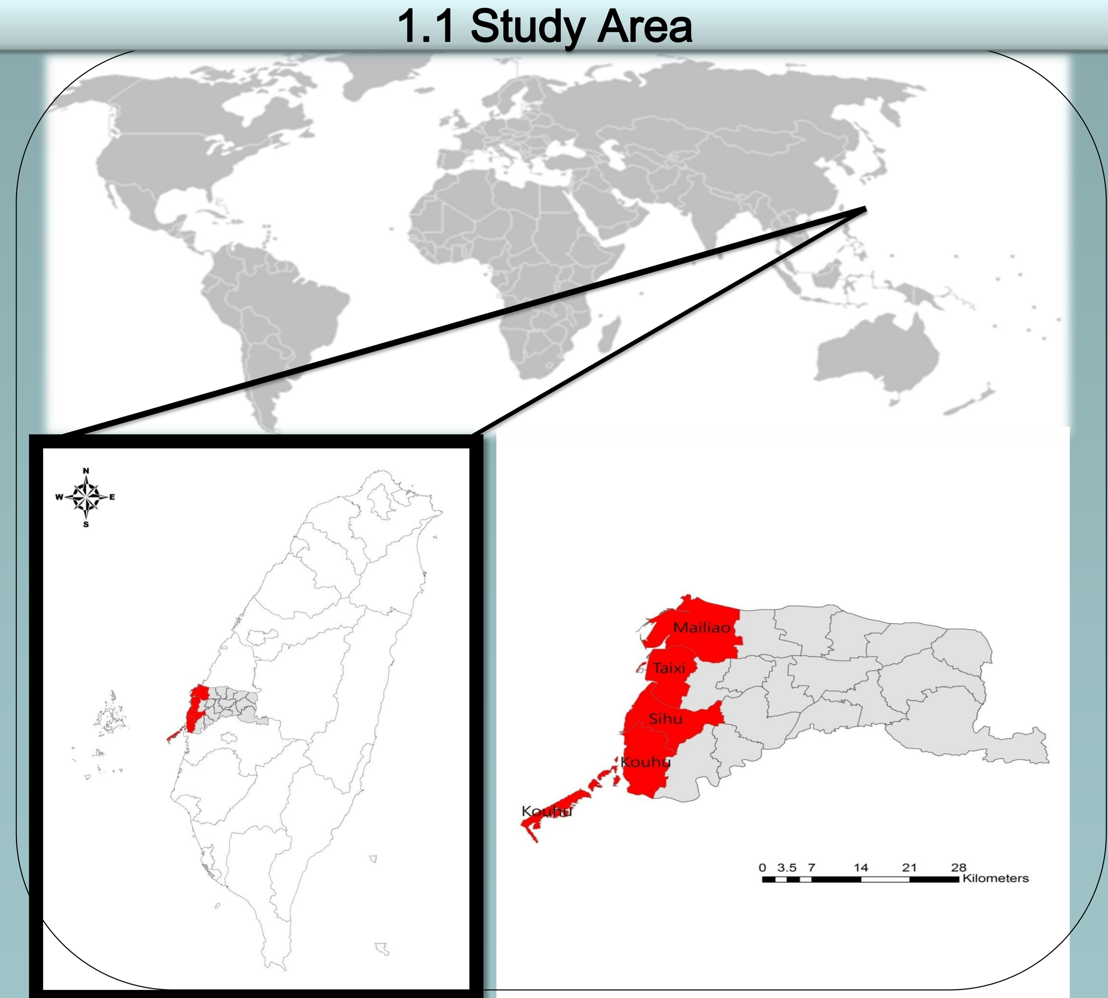
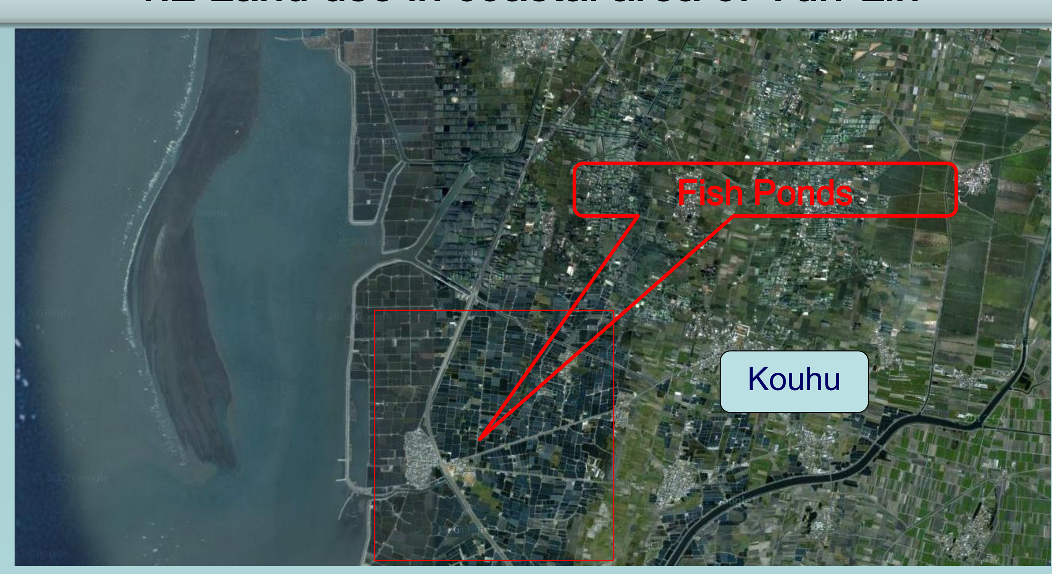


Fig. 1. Yun-Lin is located in the middle of Taiwan, and in the southern part of the Choushui River alluvial fan. It is bordered by the Taiwan Strait to the west, the Central Mountain to the east, the Choushui River to the north, and the Peikang River to the south.

1.2 Land use in coastal area of Yun-Lin



Data source: Google

2. Objectives

- To build the BME model with observations in 1992~2004, and then to compare with observation in 2005
- To construct a Baysian Maximum Entropy model that realizes the coastal aquifer salinization in different seasons (wet & dry) from 1992~2005.
- To predict the aquifers salinization. (e.g. 2006)

3. Approach

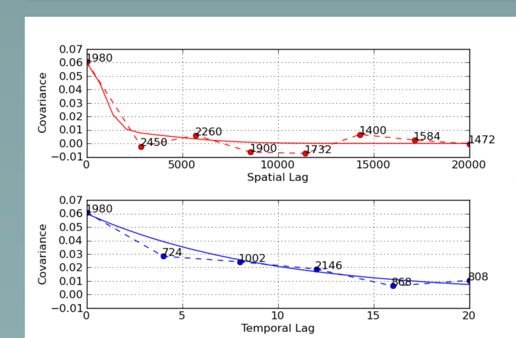


Fig. 2. Fitted water quality data.

Normalization

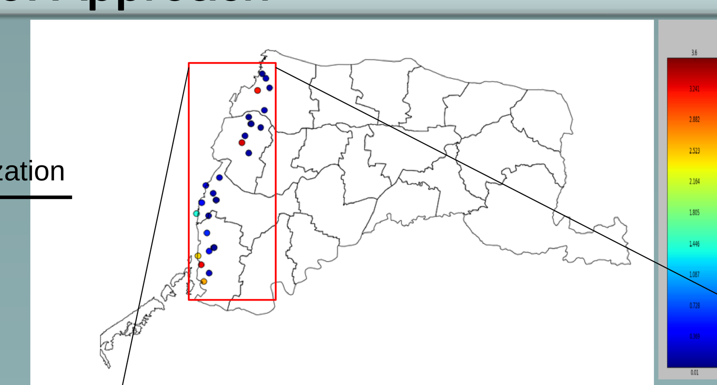


Table 1. Water quality observation from 1992~2005

Parameters	Samples	Max	Minimum	Average
Chlorine (mg/L)	275	55100	432	15989.35
Conductivity (μs/cm)	281	14560	10	4400.085
Patassium (mg/L)	280	8158	55	2496.757
Sodium (mg/L)	280	560	1	123.7389

Spatiotemporal analysis

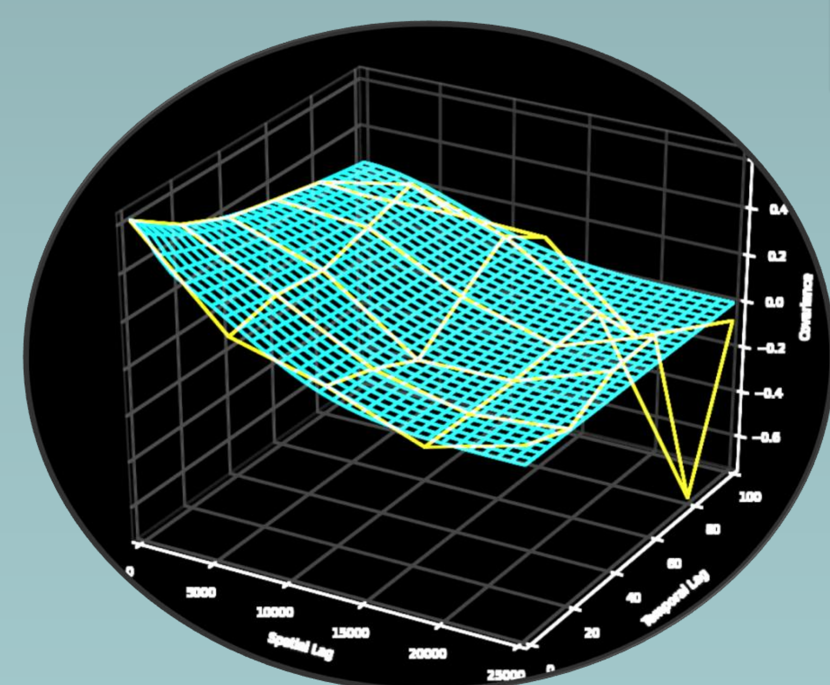


Fig. 3. The analysis of spatiotemporal covariance.

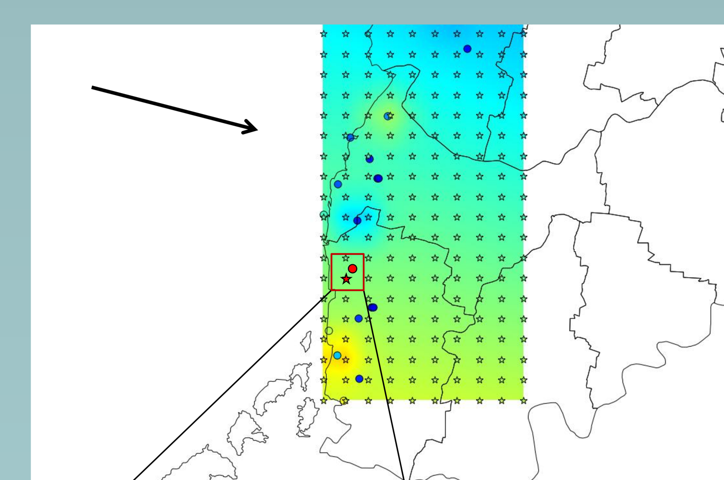


Fig. 4. Estimation by Spatiotemporal BME model by dry season. (average values in 1992-2004)

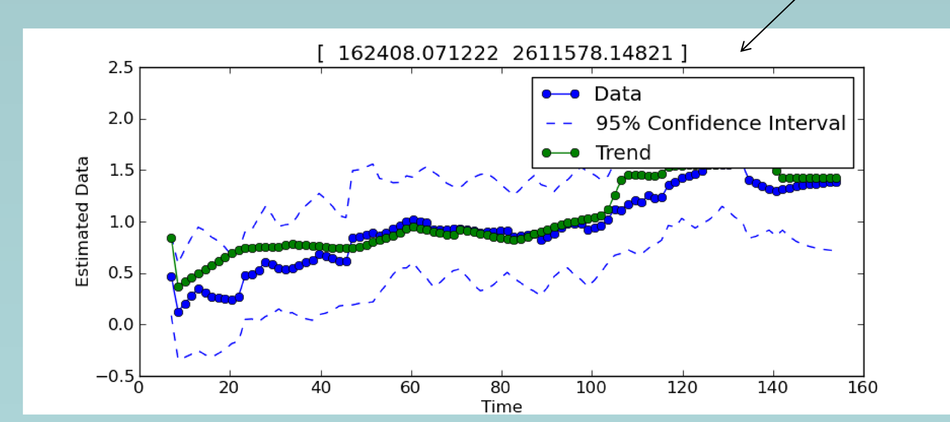


Fig. 5. The trend of estimation and field data in 95% confidence interval.

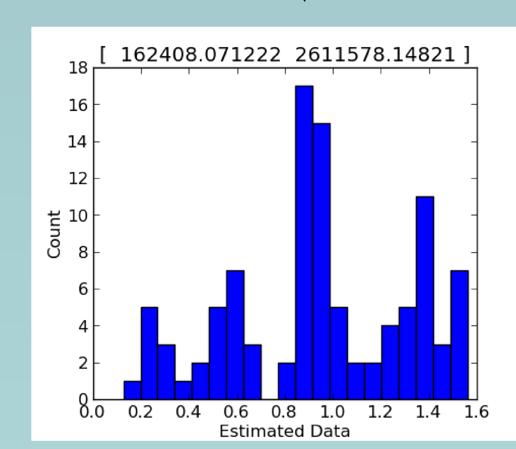


Fig. 6. Histogram of the estimates, which is close to the Gaussian Distribution

4. Results

Verification

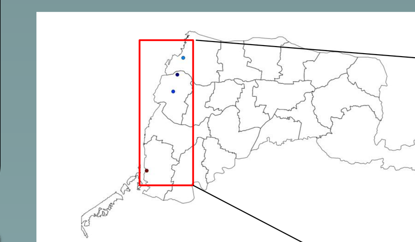


Fig. 7. The observation in Mialia, Taixi and Kouhu.

Fig. 7. Observation (2005)

X	Y	Observation
161957.6	2607624	2.71724417
167683.5	2624763	0.545915977
168607.7	2628389	0.090109671
169881.8	2632076	0.731961534

Fig. 8. Estimates (2005)

X	Y	Estimates
161837.9	2607414	3.149122
166969.8	2624072	0.501278
168110.3	2628237	0.091414
169820.9	2632401	0.703529

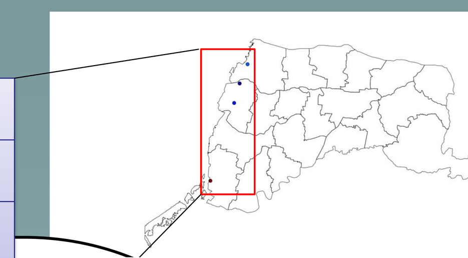


Fig. 8. The choices of estimates in Mialia, Taixi and Kouhu.

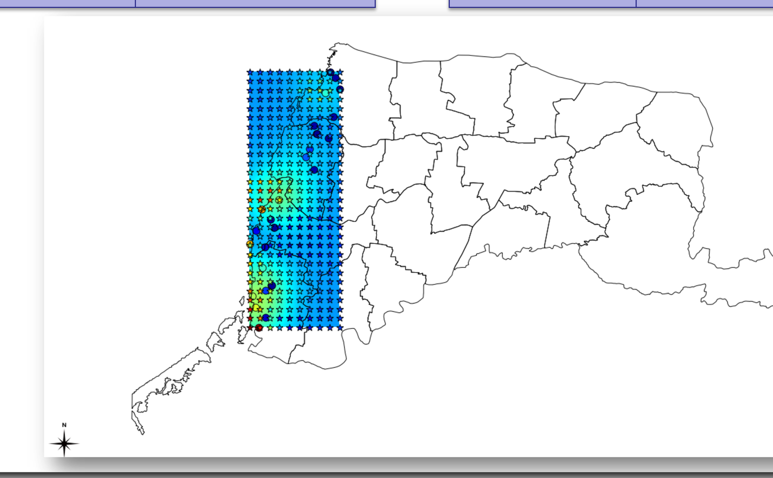
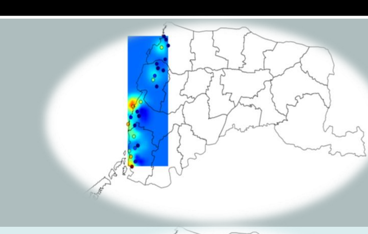
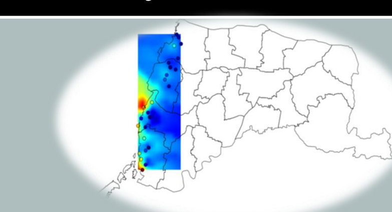
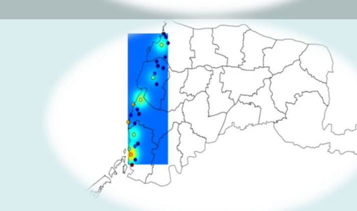
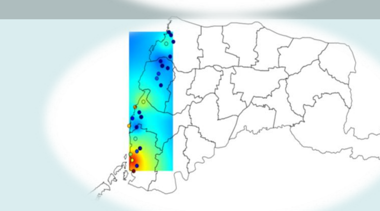
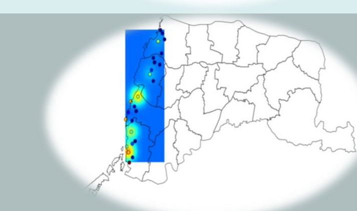
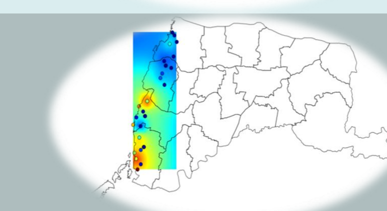


Fig. 9. Using field data (1992~2004) to predict the coastal salinization in 2005.

Conditions of salinization in different seasons (wet & dry)

Table 4. Salinization in Yun-Lin coastal area among different seasons (wet: 5~10; dry: 11~4)

Wet Season	Years	Dry Season
	*1996*	
	*2001*	
	*2005*	

Prediction 2006

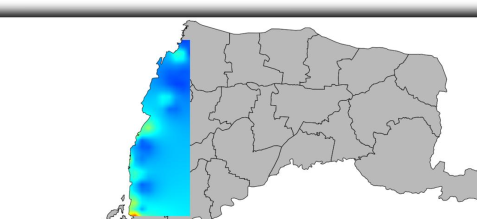


Fig. 10. The estimation of dry season in 2006

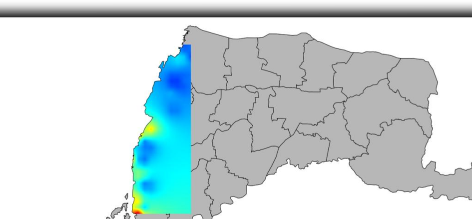


Fig. 11. The estimation of dry season in 2006

5. Conclusions

- BME model can predict the future salinization intrusion based on existing observations.
- This model identifies the spatial seriousness of salinization among wet seasons and dry seasons.

3.1 About BME

- Bayesian maximum entropy, BME. It is the one of modern spatiotemporal modeling and mapping methods. It can be automatically integrated non-linear estimation techniques and non-Gaussian probability density function theory. BME model can not only deal with the different data types but also uncertainty information.
- The theory is as followed:

$$\begin{Bmatrix} \int d\chi (g-\bar{g})\, e^{\mu^T g} = 0 \\ \int d\chi \zeta_S\, e^{\mu^T g} - A f_K(X_p) = 0 \end{Bmatrix}$$

- **Outline of the BME solution of the groundwater transfer law in light of site-specific information:**

Groundwater transfer law (General Knowledge Base) → BME

Water quality collections (Specificatory Knowledge Base) → BME

BME → $f_k(s)$, $s \in$ Domain → $T(s)$, $\sigma_r^2(s)$, $s \in$ Solution domain

$$P_{KB}[\chi_1 \le \chi_{p_1} \le \chi_1 + d\chi_1, \chi_2 \le \chi_{p_2} \le \chi_2 + d\chi_2, \dots, \chi_k \le \chi_{p_k} \le \chi_k + d\chi_k] = f_{KB}(p_1, p_2, \dots, p_k)\, d\chi_1 d\chi_2 \dots d\chi_k$$

6. References

[1] Christakos, G. (1990), A Bayesian maximum entropy view to the spatial estimation problem, Math. Geol., 22(7), 763– 777.
[2] Christakos, G. (1991), Some applications of the Bayesian maximumentropy concept in geostatistics, in Maximum Entropy, and Bayesian Methods, edited by W. T. Grandy Jr. and L. H. Schick, pp. 215–229, Kluwer Acad., Norwell, Mass.
[3] Christakos, G. (1992), Random Field Models in Earth Sciences, Academic, San Diego, Calif. Christakos, G. (2000), Modern Spatiotemporal Geostatistics, Oxford Univ. Press, New York.
[4] Yu, H.-L., and G. Christakos (2005), Porous media upscaling in terms o mathematical epistemic cognition, SIAM J. App. Math., 66(2), 433– 446.

Process

Data collection & Normalization → Kernel smoothing method → Estimate the sequence of data → Residual Calculation → Calculate covariance residual → Particle swarm optimization → Estimate covariance model → BME method → Unknown residual estimation (e.g. mean, variance) → Results