Application of Geographic Weighted Regression to Establish Average Rainfall-Altitude Functions Reflecting Spatial Variation

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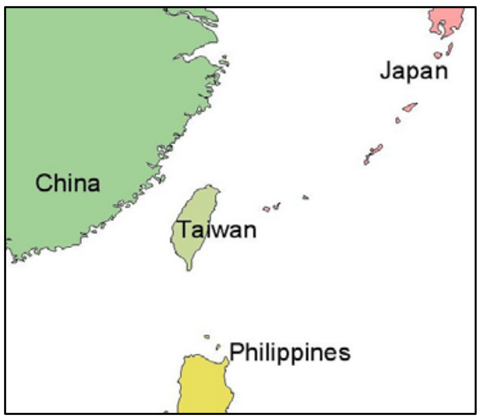
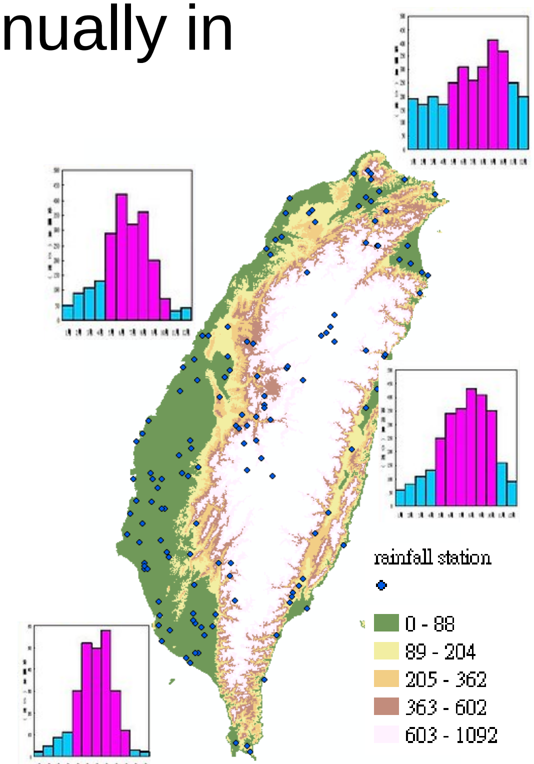
Location and Climate of Taiwan

- Taiwan is located in the East Asia and in the subtropical zone.
- Because of its geographical location, climate and topography, there is a lot of rainfall annually in Taiwan.
  - 2,515 mm/year





Introduction

Interpolations Used to Estimate Regional Precipitation

- The precipitation data that is observed by a rainfall station can only represent the precipitation of that station, but not the precipitation values of other unknown station.
- To estimate local precipitation spatial distribution, interpolations have been used by the previous researchers to carry out estimation.

Approaches to Estimate Regional Precipitation

- There are several approaches to estimate the regional average precipitation from one rainfall station's precipitation data.
- The common spatial statistical methods include
  - Arithmetical averaging method
  - Thiessen polygons method
  - Isohyetal method
  - Reciprocal-distance-weighting method
  - Reciprocal square distance interpolation
  - Kriging method.

- Ray-Shyan Wu et al. (2003) compare the above-mentioned methods, they found that there were very few differences between the results of each spatial statistical method.

Multivariate Regression Models

- Yun-hsin Chang and Sheng-Tsai Li (2007) used multivariate geological statistical method to try to interpolate the more accurate precipitation spatial distribution.
- main variables
  - rainfall station data
- auxiliary variables
  - geographical factors
    - such as elevation, gradient, and slope
- Their study indicates
  - the amount of precipitation is often affected by the terrain effect
  - the precipitation would have some variations because of different leeward and windward directions and altitude changes

Advantages and Disadvantages of Multivariate Regression Models

- Generally, precipitation function involves many spatial factors
  - elevation, gradient, and slope
- Multiple regression models
  - Advantages
    - Incorporate other factors except elevation
  - Disadvantages
    - increases the difficulty of predictor's data collection
    - have not consider the spatial variations （Platt，2004）
    - Residuals maybe have spatial autocorrelation.

Introduction

Factors of Average Annual Precipitation

- According to those previous studies, it is shown that the average precipitation increases with altitude.
- Since elevation is an important factor of precipitation, the above-mentioned studies point out that precipitation estimation often involves many spatial factors.
- Thus this study selects elevation as the independent variable, and average annual precipitation as dependent variable.

Objectives

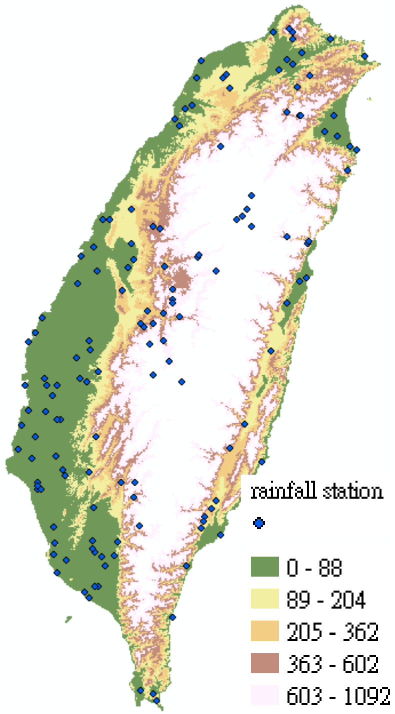
- The objectives of this research are to establish the relationship between annual precipitation and elevation, while considering the spatial variations and solving the problems of spatial autocorrelation in residuals.

Method

- Global Regression Model
  - ***OLS*** (Ordinary Least Squares)
- Examine the spatial autocorrelation of residuals
  - ***Moran's I index*** is used to detect spatial autocorrelation in the residuals
  - If standardized ***Moran's I Z(I)*** <1.96 , residuals have no spatial autocorrelation
  - If standardized ***Moran's I Z(I)*** >1.96, residuals have spatial autocorrelation
- In order to solve the problem of residual with spatial autocorrelation, we use ***GWR Model*** (Geographically Weighted Regression) to modify.

Data Collection

- Precipitation and elevation data resource
  - Central Weather Bureau
  - Hydraulic Engineering Office.
- Data recorded different period data
  - Choose the data which has least 30 years rainfall data. (World Meteorology Organization ,WMO)
  - 715 stations in total
- Arranged as average annual precipitation.



Taiwan Topographic Chart

Method

Results of Global Regression Model

- model $$y = \beta_0 + \beta_1 x_1 + \varepsilon$$

y is the average annual precipitation（mm）

x_1 is the elevation（m）

β_0 、β_1 are the regression coefficients

ε is the residual

R^2=0.15

Table 1 global[a] regression analysis results of average annual precipitation（n=705）

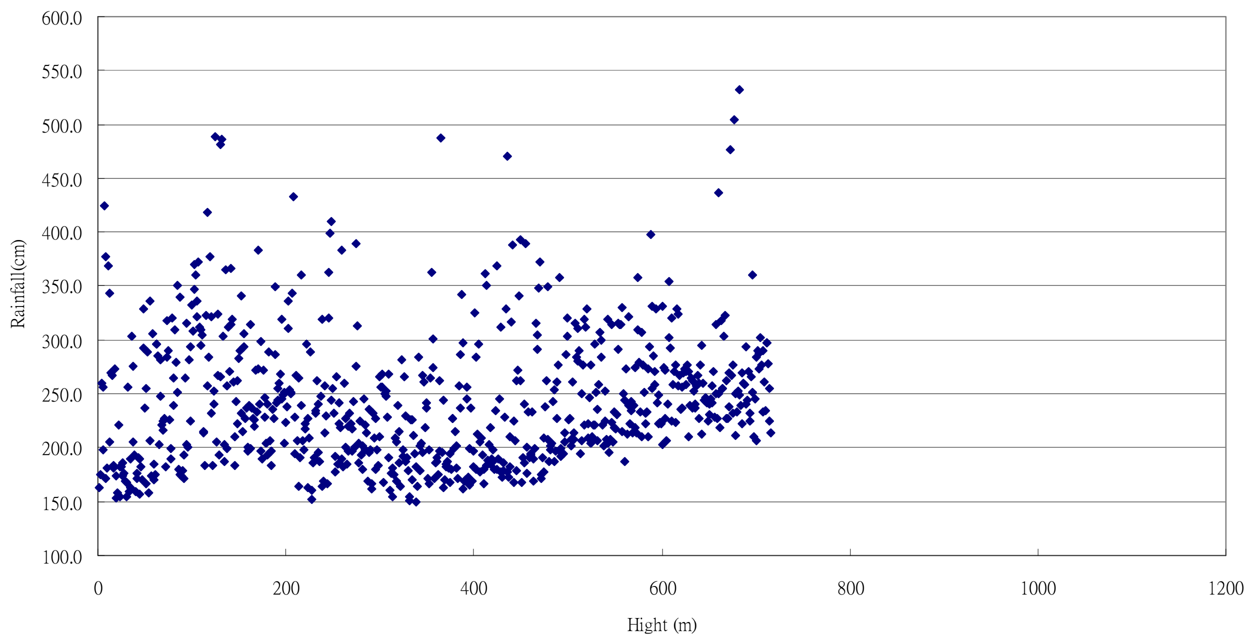
Parameter	Estimate	Std Estimate	Std Err	T	P-Value
Intercept	228.46	2.46	2.471	92.801	0.0001
Elevation	0.0417	0.004	0.0036	11.441	0.0001

[a]Average regression result of the whole study area

Results

Residual Plot – Global Regression

- The figure shows the residuals plot for global regression.
- The residuals is randomly distributed about the mean without any noticeable pattern.



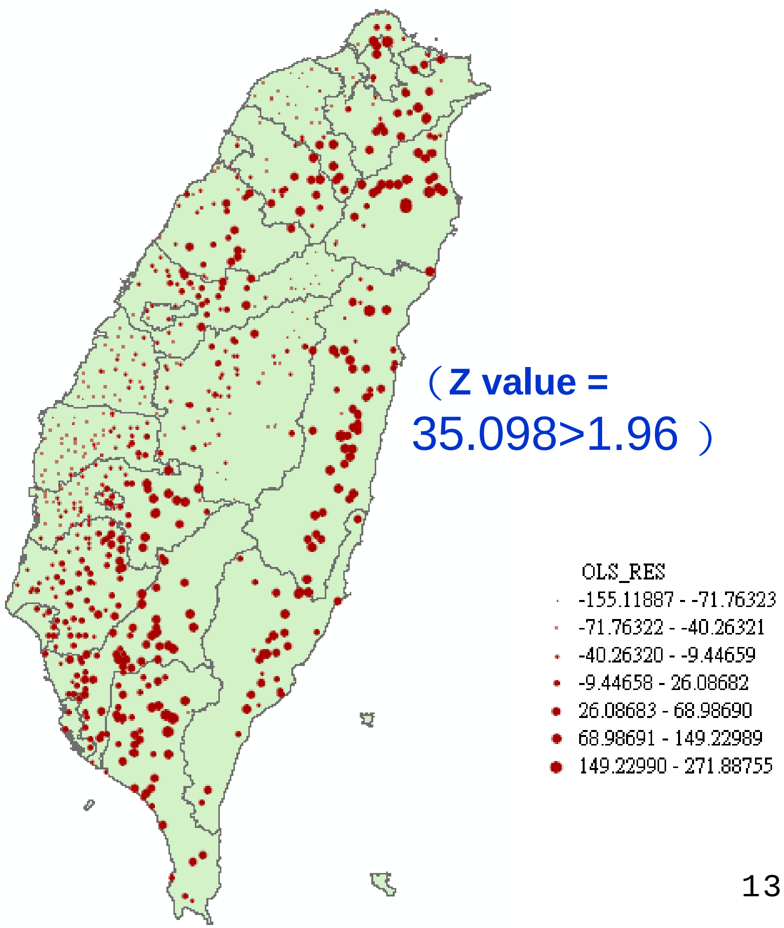
Results

OLS Spatial Autocorrelation Test

- Then all data were geo-referenced with coordinates, and were tested for spatial autocorrelation.
- The resulting Moran’s I = 0.15675, and （Z(I) = 35.098078>1.96）

implying that the residuals had spatial autocorrelation, violating the assumption of linear regression.

- Therefore, GWR was applied to modify the model.



（**Z value =** 35.098>1.96 ）

Results

GWR Model

- Model

$$y_i = \beta_0(u_i, v_i) + \beta_1(u_i, v_i) \cdot x_i + \varepsilon_i$$

y_i is average annual precipitation of point i （mm）

x_i is the elevation of point i （m）

(u_i, v_i) is the coordinates of the ith point in space

$\beta_0(u_i, v_i)$, $\beta_1(u_i, v_i)$ is therealization of the continuous function at point i

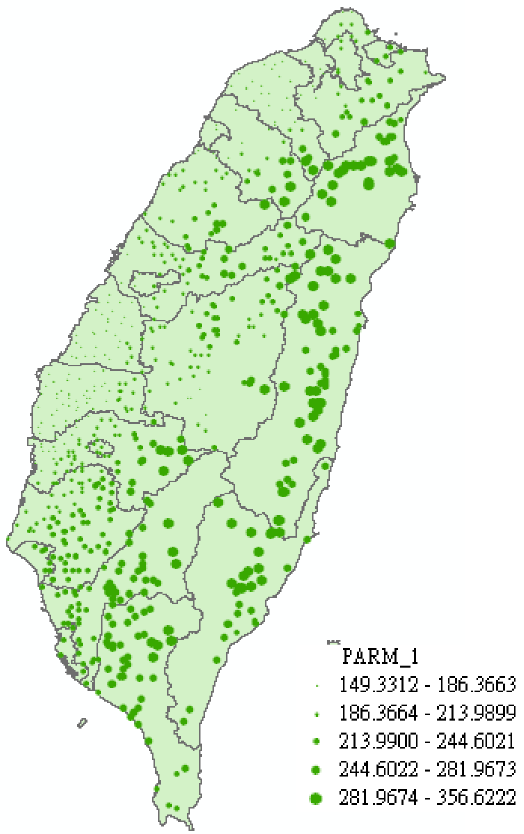
ε_i is the residual of point (u_i, v_i)

- R^2 increased from 0.15 (OLS) to 0.78 (GWR)

Results

Spatial Variations of Intercepts

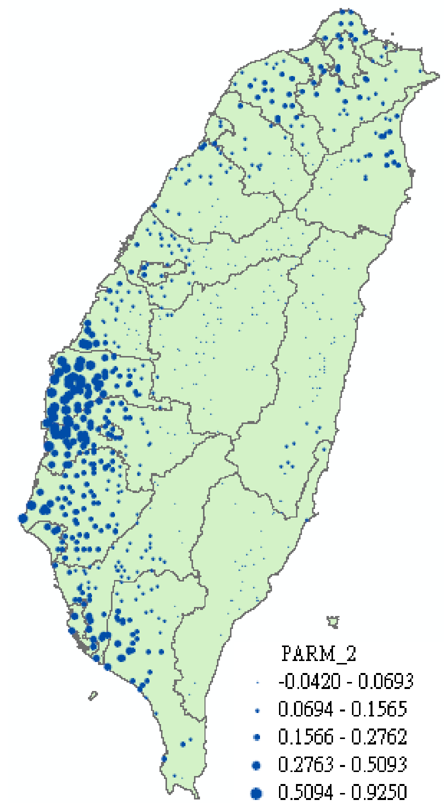
- The intercept of central mountain area of study area is greater than western plain area
- It means that the basic precipitation of mountain area is higher than the plain.
- The precipitation of Central and Southern Taiwan is higher than the plain of Northern Taiwan.



Results

Spatial Variations of Elevation Coefficients

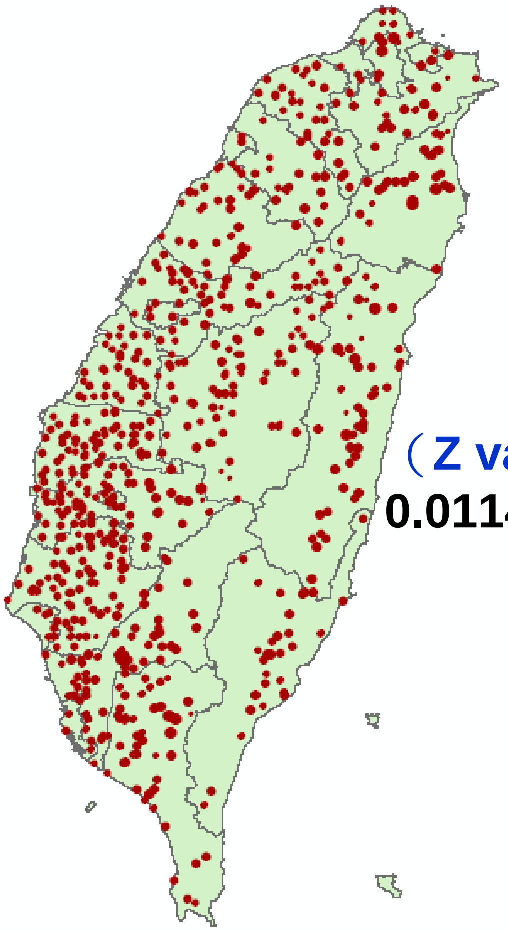
- Elevation regression coefficients of western plain area are higher than central mountain area.
- It means that when elevation is increased by 1 unit, the average annual precipitation of western plain area would increase more than the central mountain area.
  - Especially the plain areas from Central and Southern Taiwan
    - such as Yunlin, JiaYi, Tainan, and Kaohsiung
    - when elevation is increased by 1 unit, the average annual precipitation would increase more.



Spatial Autocorrelation Test for GWR

- The testing result demonstrates that the Moran's I = **0.0313** , and （Z(I) = 0.011460 <1.96）

the residual with spatial autocorrelation was already modified



（Z value= 0.011460<1.96）

Results

Discussions

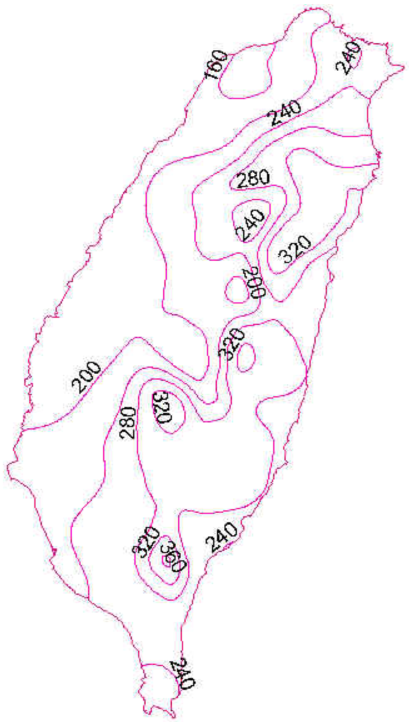
Coefficient Range

- From the results of GWR model , it is known that the intercept coefficient range is 149 – 356, and the elevation coefficient range is -0.042 – 0.925.

- In order to understand the spatial variations of intercept and elevation regression coefficients , contour lines for intercept and elevation regression coefficients are drawn respectively.

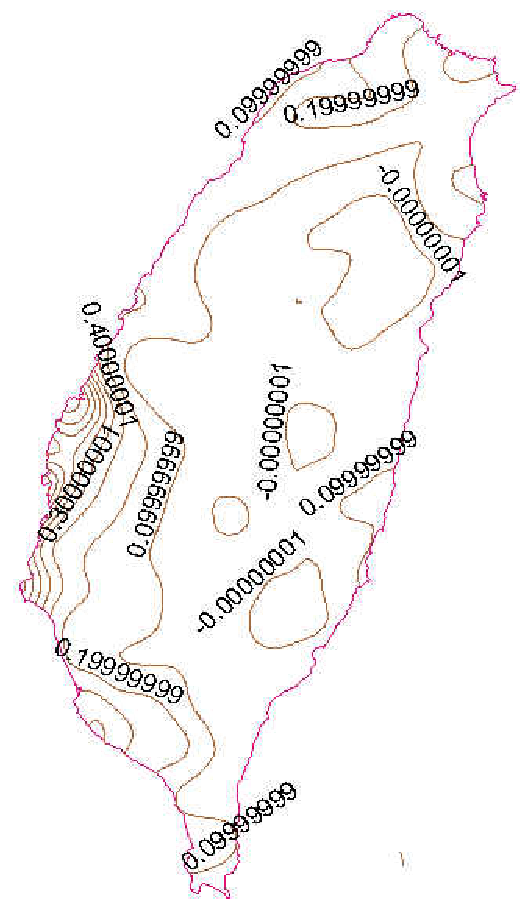
Contour map of Intercept Coefficients

- From the isohyet distribution of intercepts showed that
  - the density of central mountain area is higher, namely the precipitation variations in the mountain area are greater.



Contour Map of Elevation Coefficient

- From the isohyet distribution of elevation regression coefficients, we are able to know that
  - the elevation regression coefficients in southwest plains have greater variations
  - namely the increase of every 1 unit of elevation, the average annual precipitation from southwest plains would increase more.
- The variations of central mountain area's elevation regression coefficients are not great
  - means the influence of elevation factor towards central mountain area is smaller.



Conclusions and Suggestions

R^2 Values

- Global regression model
  - R^2=0.15
- GWR
  - R^2 increased to 0.78

Discussions

Conclusions

- This study
  - considers spatial variations
  - corrects the spatial autocorrelation of residuals from traditional regression model.
- Compare to the traditional method of using multivariate regression analysis
  - GWR regression model that uses less parameters and spatial factors can also be considered.

Discussions

Conclusions

- This study
  - discusses the average influence of elevation towards average annual precipitation
  - GWR model is used to further discuss the spatial variations of elevation towards average annual precipitation simultaneously.

Suggestions

- This study
  - focuses on the relationship between average annual precipitation and elevation.
  - not yet examined any temporal variations
- It suggests that
  - the prospective direction can focus on temporal variations.
  - Besides, the spatial distribution of intercept and elevation regression coefficients could also be applied to the study of meteorological divisions further.

Thanks for Your Attention

~/Comments and Questions