Scrub typhus islands in the Taiwan Area and the association between scrub typhus disease and forest land use and farm worker density: Geographically weighted regression

Pui-Jen Tsai\(^1\), Hsi-Chyi Yeh\(^1\)

Address: \(^1\)Center for General Education, Aletheia University, New Taipei 25103, Republic of China (Taiwan).

Email: Pui-Jen Tsai\(^*\) - puijentsai@gmail.com; Hsi-Chyi Yeh - yehhc123@gmail.com
\(^*\) Corresponding author
Abstract

Background: The Taiwan Area includes the main island of Taiwan and several small associated islands, which are located off the coast of Southern China. The eastern two-thirds of Taiwan’s main island are characterized by rugged mountains covered with tropical and subtropical vegetation. Western Taiwan’s main island is characterized by flat to gently rolling plains. The geographical distribution of the Taiwan Area exhibits diversity in ecology and environment, which are both under the threat of scrub typhus. This study investigates the effects of seasonal and meteorological factors on scrub typhus infection in 10 local climate regions. This study also investigates the spatial distribution of scrub typhus incidence in correlation with forest land uses and farm workers on the main island of Taiwan.

Methods: This study uses Pearson’s product moment correlation to describe the correlation between confirmed cases of scrub typhus and meteorological factors in 10 local climate regions. This study also uses geographically weighted regression (GWR), a local version of spatial regression that generates parameters disaggregated by the spatial units of analysis, to describe and map each regression point for the response variable of standardized incidence ratio (SIR)-district scrub typhus. This study also uses GWR to describe the explanatory variables of various forest land uses and farm worker densities on the main island of Taiwan in 2005.

Results: Scrub typhus endemic areas in the Taiwan Area are located in southeastern Taiwan, mountainous township areas, Pescadore Islands, Kinmen Islands, and Matou Islands. The age-adjusted standard incidence rates range from 15.6 to 185.5 per 100 000 people for males and from 9.3 to 40.4 per 100 000 people for females. These rates are higher than those for the low incidence areas in Northern Taiwan, Northwestern Taiwan, West-Central Taiwan, Southwestern Taiwan, and Northeastern Taiwan, which have age-adjusted standard incidence rates ranging from 0.5 to 1.6 per 100 000 people for males, and 0.3 to 1 per 100 000 people for females. In the Taiwan Area, the 20-24 year-old male group and 60-64 year-old female group have the highest age-specific incidence rates. The seasonal incidence of scrub typhus was 12.7% in spring (468 cases), 40.2% in summer (1488 cases), 30.2% in autumn (1115 cases), and 16.9% in winter (626 cases) showing significant seasonal differences ($\chi^2 = 704.7, p < 0.001$). In addition, the number of infectious cases in the warm season (2540 cases, 68.7%) was significantly higher than that in the cold season (1157 cases, 31.3%) ($\chi^2 = 517.4, p < 0.001$). A high infectious peak in summer was reflected in 472 cases in June and 638 cases in July, respectively. However, the high-risk groups varied in age and seasonal incidence among the 10 local climate regions. The Pescadores, Kinmen, and Matou islands, along with low-incidence areas in west-central Taiwan and Southwestern Taiwan, were significantly correlated to air temperature, but showed no significance
in endemic areas (e.g., Southeastern Taiwan and the mountainous township areas). In the GWR models, the response variable of SIR-district scrub typhus was positively and significantly associated with the farm worker and timber management area explanatory variables. In addition, the explanatory variables of recreational forest area, natural reserve area, and other purpose area showed positive and negative signs for parameter estimates in various locations of Taiwan’s main island. Negative signs of parameter estimates only appeared in the explanatory variables of the national protective area, plantation area, and clearcut area.

**Conclusion:** The results of this study indicate that the scrub-typhus type in the Taiwan Area is an island type of scrub typhus rather than the summer type of scrub typhus found in southern China. Results also show that higher SIR values for scrub typhus in the central and southern portions of the mountainous township area and Southeastern Taiwan are associated with the variables of farm worker density, timber management area, recreational forest area, natural reserve area, and other purpose area.

**Keywords**
scrub typhus, climate, farm worker, forest land uses, geographically weighted regression
Background

Scrub typhus is caused by *Orientia tsutsugamushi* (*Rickettsia tsutsugamushi*), a tiny (bacteria-sized) parasite belonging to the family Rickettsiaceae. Under the microscope, rickettsiae are either rod-like (bacilli) or spherical (coccis) in shape. As intracellular parasites, they live only within the cells of other animals. *Orientia tsutsugamushi* lives primarily in mites belonging to the species *Leptotrombidium* (*Trombicula*) *akamushi* and *Leptotrombidium deliense* [1]. Scrub typhus infects approximately one million people annually, and a billion more are estimated to be at risk [2-3]. Because the disease is limited to eastern and southeastern Asia, India, northern Australia, and adjacent islands, it is also commonly referred to as tropical typhus. Scrub typhus is endemic to a part of the world known as the “tsutsugamushi triangle,” which extends from Northern Japan and far-eastern Russia in the north, to Northern Australia in the south, and to Pakistan and Afghanistan in the west [1, 4]. The infection is transmitted to man and rodents by various species of infective trombiculid mites that feed on lymph and tissue fluid rather than blood. The mites are small (0.2-0.4 mm) and can only be seen through a microscope or magnifying glass. The mites have a 4-stage life cycle: egg, larva, nymph, and adult. The larval stage is the only stage that can transmit the disease to humans and other vertebrates. The tiny chiggers (mite larvae) attach themselves to the skin. During the process of obtaining a meal, the larvae may either acquire the infection from, or transmit it to, the host. In regions where scrub typhus is a constant threat, a natural cycle of *Orientia tsutsugamushi* transmission occurs between mite larvae and small mammals (e.g., field mice and rats). Humans enter the cycle of rickettsial infection only accidentally [5].

The seasonal occurrence of scrub typhus varies with the climate in different countries, and occurs more frequently during the rainy season. Forest clearings, riverbanks, and grassy regions provide optimal conditions for the infected mites to thrive. These small geographic regions are high-risk areas for humans, and have been called scrub-typhus islands [1]. The occurrence of scrub typhus is frequently related to temperature, and occasionally to rainfall [2, 6-8]. The relationship between the incidence of scrub typhus and climate reflects the responses of chiggers to the environment [2]. Taiwan is situated between the world's largest continent (Asia) and largest ocean (Pacific). The Tropic of Cancer running across its middle section divides the island into two climates: the tropical monsoon climate in the south, and subtropical monsoon climate in the north. The latitude, topography, ocean currents, and monsoons of Taiwan lead to high temperature and humidity, massive rainfall, and summer tropical cyclones, which characterize the climate of Taiwan. According to the Köppen–Geiger climate classification system, the 4 main climate types in Taiwan include a Monsoon and
Trade-Wind Coastal Climate in the south, Mild, Humid Climate in the north, Wet-Dry Tropical Climate in the west, and Temperate Rainy Climate with Dry Winter in mountain areas [9]. Higher risk of scrub typhus infection was reported in the Matuo Islands (Lienchiang County), Kinmen (Kinmen County), Pescadore Islands (Penghu County), and endemic clusters in Southeastern Taiwan (plain townships in Hualien County and Taitung County) and mountainous township areas on the main island of Taiwan [10-13]. The main island of Taiwan and several small associated islands, such as the Pescadore, Kinmen, Matuo, Little Liuchiu, Green, and Orcid islands, exhibit geographical isolation and variations in climate type and ecological environments. However, these factors remain poorly understood. Specifically, it is not clear how local climate affects scrub typhus incidence, or how the geographical distribution of forest land use and farm worker density affects the frequency of human infection.

This study investigates the effects of the meteorological factors in local climate regions on seasonal scrub-typhus incidence. We also used spatial statistic, geographically weighted regression (GWR), to study the spatial distribution of the standardized incidence ratio (SIR)-district scrub typhus and its correlation with 8 environmental and socioeconomic factors in Taiwan’s main island in 2005.
Methods

Study area and local climate regions

This study focuses on the main island of Taiwan and surrounding islets (Pescadores, Kinmen, Matou), but excludes single isolated islands (e.g., Little Liuchiu, Green, and Orchid islands). The study area includes 365 local administrative government areas, including 5 main urban areas, 2 secondary urban areas, 178 rural townships, and 54 aboriginal townships in lowland and mountainous regions. Following a 2002 Ministry of the Interior report, urban areas are defined as regions with at least one metropolitan center, and they can include neighboring cities and townships that share socioeconomic activities. Main urban areas are defined as those with a population exceeding one million: Taipei-Keelung, Kaohsiung, Taichung-Changhua, Jhongli-Taoyuan, and Tainan. Secondary urban areas are defined as those with a residential population ranging from 0.3 to 1 million (e.g., Hsinchu and Chiayi).

Using the Köppen–Geiger climate classification, this study divides the study area into 10 distinct climate regions (Fig. 1). Meteorological data were collected from 24 local meteorological stations. The climate data for the mountainous township area (29 mountain aboriginal townships) were collected from local meteorological stations and coordinates such as Alishan (23.5083° N, 120.8134° E). In addition to the mountainous townships area, the remaining 336 local administrative government areas were divided into other 9 climate regions. The climate region data for Northern Taiwan (e.g., Taipei City and County, and Keelung City) were collected from local meteorological stations such as Tamsui (25.1649° N, 121.4489° E), Keelung (25.1329° N, 121.7406° E), Anbu (25.1827° N, 121.5292° E), and Taipei (25.0377° N, 121.5138° E). The climate region data for Northwestern Taiwan (e.g., Taoyuan County, Hsinchu City and County, and Miaoli County) were collected from local meteorological stations such as Hsinchu (24.8281° N, 121.0142° E). The climate region data for West-central Taiwan (e.g., Taichung City, Changhua County, and Nantou County) were collected from local meteorological stations such as Wuqi (24.2565° N, 120.5234° E), Taichung (24.1456° N, 120.684° E), and Sun Moon Lake (23.8814° N, 120.9082° E). The climate region data for Southwestern Taiwan (e.g., Tainan City, Chiayi City and County, Yunlin County, Kaohsiung City, and Pingtung County) were collected from local meteorological stations such as Chiayi (23.4961° N, 120.4326° E), Tainan (22.9932° N, 120.2049° E), Kaohsiung (22.5663° N, 120.3158° E), and Hengchun (22.0037° N, 120.746° E). The climate region data for Northeastern Taiwan (e.g., Yilan County) were collected from local meteorological stations such as Yilan (24.7636° N, 121.7561° E), and Su-ao (24.5972° N, 121.8571° E). The climate region data for Southeastern Taiwan (e.g., Hualien County and Taitung County) were
collected from local meteorological stations such as Hualien (23.9752° N, 121.6135° E), Taitung (22.7522° N, 121.1547° E), Chenggong (23.0978° N, 121.3728° E), and Dawu (22.3558° N, 120.9036° E). The climate region data for the Pescadore Islands (e.g., Penghu County) were collected from local meteorological stations such as Penghu (23.565° N, 119.5636° E), and Dongjidao (23.2572° N, 119.6678° E). The climate region data for the Kinmen Islands (e.g., Kinmen County) were collected from local meteorological stations such as Kinmen (24.4074° N, 118.2893° E). The climate region data for the Matou Islands (e.g., Lienchiang County) were collected from local meteorological stations such as Matou (26.1695° N, 119.9231° E). Meteorological factors in monthly observations (e.g., surface temperature, precipitation, relative humidity, atmospheric pressure, number of wet days, and sunshine duration) were obtained from the Taiwan Central Weather Bureau [14].

**Confirmed cases of scrub typhus**
The information on confirmed cases of scrub typhus was obtained from the Notifiable Infection Diseases Statistics System and Infection Diseases Database, Taiwan Centers for Disease Control (CDC) [15]. Scrub typhus is a notifiable disease in Taiwan. Blood samples from patients with suspected scrub typhus symptoms are generally collected and sent to the Taiwan Centers for Disease Control (CDC) for laboratory diagnosis. Samples are labeled positive for scrub typhus based on a positive real-time polymerase chain reaction (PCR) test or the detection of OT-specific antibodies based on the indirect immunofluorescence assay (IFA) (4-fold increase in OT-specific immunoglobulin M (IgM) or IgG antibody in paired sera).

**Data management**
The Ministry of the Interior provided the demographic data used in this study [16]. The age-adjusted standard incidence rates were calculated with a direct adjustment using the global population in 2000 as the standard population [17]. The age-adjusted standard incidence rates from 2000–2010 were calculated based on the 11-year incidence rates weighted by the number of people each year. The global and local climate region’s results showed the level of scrub typhus infection for males and females in Taiwan. Farm worker density and forest land uses (e.g., timber management area, recreational forest area, national protective area, natural reserve area, plantation area, clearcut area, and other purpose area) were served as socioeconomic and environmental factors, respectively. The information of socioeconomic and environmental factors was provided by the 2005 Agricultural, Forestry, Fishery, and Husbandry census [18]. The SIR of scrub typhus was calculated for each township and used them as the response variable in the GWR model. The
GWR model used the following explanatory variables: percentage of farm labor and the land share ratio of timber management area, recreational forest area, national protective area, natural reserve area, plantation area, clearcut area, and other purpose area.

**Geographically Weighted Regression**

The GWR model is an extension of the traditional standard regression framework that estimates local, rather than global, parameters [19]. It is a type of local statistic that can produce a set of local parameter estimates demonstrating how a relationship varies over space. This makes it possible to examine the spatial pattern of the local estimates to gain a better understanding of possible hidden causes for this pattern [20]. Conversely, a traditional regression method, such as ordinary least squares (OLS), is a type of global statistic that assumes the relationship under study is constant over space, and therefore assumes that the parameter is the same for the entire study area.

An OLS model can be defined as follows:

\[ y = \beta_0 + \sum_{i=1}^{p} \beta_i x_i + \epsilon \]

where \( y \) is the response variable, \( \beta_0 \) is the intercept, \( \beta_i \) is the parameter estimate (coefficient) for the explanatory variable \( x_i \), \( p \) is the number of explanatory variables, and \( \epsilon \) is the error term.

The GWR model allows local, rather than global, parameters to be estimated for the study area. Thus, the GWR model rewrites the OLS model as follows:

\[ y_j = \beta_0 (u_j, v_j) + \sum_{i=1}^{p} \beta_i (u_j, v_j) x_{ij} + \epsilon_j \quad (1) \]

where \( u_j \) and \( v_j \) are the coordinates for each location \( j \), \( \beta_0 (u_j, v_j) \) is the intercept for location \( j \), and \( \beta_i (u_j, v_j) \) is the local parameter estimate for the explanatory variable \( x_i \) at location \( j \).

The weight assigned to each observation is based on a distance decay function centered on observation \( i \).

The estimator for the GWR model is similar to the weighted least squares (WLS) global model, except that the weights are conditioned on the location \( u \) relative to the observations in the data set, and hence change for each location. The estimator takes the following form:
\[ \hat{\beta}(u) = X^\top W(u)X^{-1} X^\top W(u)y \]  

Equation (2)

W(u) is the square matrix of weights relative to the position u. A particular location can be indexed \((u_j, v_j)\) in the study area. \(X^\top W(u)X\) is the geographically weighted variance-covariance matrix, and \(y\) is the vector of the value of the response variable.

The W(u) matrix contains the geographical weights in its leading diagonal and zero in its off-diagonal elements.

\[
\begin{bmatrix}
w_1(u) & 0 & 0 & 0 \\
0 & w_2(u) & 0 & 0 \\
0 & 0 & \ldots & 0 \\
0 & 0 & 0 & w_n(u)
\end{bmatrix}
\]

Equation (3)

In the area in which this study was conducted, the sample points produced by the polygon centroids were not regularly placed, but were clustered. A convenient way to implement the adaptive bandwidth specification is to select a kernel that allows the same number of sample points for estimations. The weight can then be calculated using the specified kernel and setting the value for any observation whose distance exceeds the bandwidth to zero. The bisquare function is as follows:

\[
w_i(u_j, v_j) = \left(1 - \left(\frac{d_i(u_j, v_j)}{h}\right)^2\right)^2
\]

Equation (4)

where \(w_i(u_j, v_j) = 0\) when \(d_i(u_j, v_j) > h\). The term \(h\) represents a quantity known as the bandwidth. This is a near-Gaussian function with the useful property of the weight being zero at a finite distance.

The bandwidth was chosen by minimizing the Akaike information criterion (AIC) score, and calculated as follows:

\[
AIC_c = 2n \log_\ell(\hat{\sigma}) + n \log_\ell(2\pi) + n \left(\frac{n + tr(S)}{n - 2 - tr(S)}\right)
\]

Equation (5)

where \(tr(S)\) is the trace of the hat matrix. The AIC method has the advantage of accounting for the fact that the degrees of freedom may vary among models centered on different observations. The optimal bandwidth was determined by minimizing the corrected AIC, as described by Fotheringham et al., 2002 [20]. GWR models produce a set of local regression results, including local parameter estimates and the local
residuals, that can be mapped to demonstrate their spatial variability.

This study uses the Benjamini-Hochberg (B-H) procedure to control the false discovery rate, which modifies the significance level for each test consistently. This procedure was used to determine the significance of parameter estimates produced by the GWR model. Thissen et al. (2002) proposed a quick and easy method for calculating the B-H procedure false discovery rate using Microsoft Excel [21]. The B-H approach controls the FDR by sequentially comparing the observed p value for each of a family of multiple test statistics (in order from largest to smallest) to a list of computed B-H critical values \([pB-H(i)]\). The critical value on the list is determined for each test statistic, and indexed by \(i\) by linear interpolation between \(\alpha/2\) (for the largest observed p value) to \((\alpha/2)/m\), where \(m\) is the family size (for the smallest of the p values). Because the last value is the Bonferroni critical value, the reason for the gain in the power of B-H relative to the Bonferroni approach is clear; The B-H approach compares only the smallest of the \(m\) observed p values to the Bonferroni critical value. All of the other p values are calculated using less stringent criteria. The local parameter is estimated to be significant if the p value is less than the B-H critical value; otherwise it is deemed non-significant [21].

The Pearson product moment correlation was calculated using SPSS 12, whereas ArcMap 9.3 was used to map GWR.
Results

Incidence rates of scrub typhus in 10 local climate regions

Table 1 presents a summary of the age-adjusted incidence rates for the 10 local climate regions between 2000 and 2010 in the Taiwan Area. These results show that all incidence rates related to 9 local climate regions for males were higher than those for females, except for the Pescadore Islands. Gender ratios, defined as the ratio of males to females, generally ranged from 1 to 2, but increased to 2.98 in the Kinmen Islands, and occasionally exceed 6 (e.g., the Matou Islands).

Sex and age distributions in 10 local climate regions

Results show that 3892 cases of scrub typhus infections were confirmed in the Taiwan Area from 2000 to 2010, (e.g., the main island of Taiwan, Pescadore Islands, Kinmen Islands, and Matou Islands). A single group of 20-24 age range for males and one group of 60-64 age range for females were higher than other age groups in the Taiwan Area. The confirmed male cases exceeded the confirmed female cases ($\chi^2 = 301.9, p < 0.001$). Figure 2a shows the results. In Northern Taiwan, 3 age groups of males (20-24, 50-54, and 60-69 year-olds) and one group of females (55-69 year-olds) showed a higher incidence of scrub typhus than the other age groups. The male confirmed cases exceeded the female confirmed cases ($\chi^2 = 29.4, p < 0.001$). Figure 2b shows the results. In Northwestern Taiwan, 3 age groups of males (20-24, 40-44, and 65-69 year-olds) and one group of females (40-54 year-olds) showed a higher incidence of scrub typhus than the other age groups. The number of confirmed cases was not significantly different between males and females ($\chi^2 = 8.7, p = 0.003$). Figure 2c shows the results. In West-central Taiwan, 2 age groups of males (20-24 and 50-64 year-olds) and one group of females (50-69 year-olds) showed a higher incidence of scrub typhus than the other age groups. The male confirmed cases exceeded the female confirmed cases ($\chi^2 = 19.8, p < 0.001$). Figure 2d shows the results. In Southwestern Taiwan, 2 age groups of males (20-24 and 45-64 year-olds) and one group of females (50-69 year-olds) showed a higher incidence of scrub typhus than the other age groups. The male confirmed cases exceeded the female confirmed cases ($\chi^2 = 49.4, p < 0.001$). Figure 2e shows the results. In Northeastern Taiwan, 3 age groups of males (35-39, 65-69, and >85 year-olds) and 2 age groups of females (50-59 and 70-74 year-olds) showed a higher incidence of scrub typhus than the other age groups. The number of confirmed cases was not significantly different between males and females ($\chi^2 = 3.7, p = 0.056$). Figure 2f shows the results. In Southeastern Taiwan, 2 age groups of males (45-49 and 55-69 year-olds) and one age group of females (55-74 year-olds) showed a higher incidence of scrub typhus than the other age groups. The male confirmed cases exceeded the female confirmed cases ($\chi^2 = 65, p <
0.001). Figure 2g shows the results. In the mountainous township area, 2 age groups of males (30-39 and 65-69 year-olds) and one age group of females (45-59 year-olds) showed a higher incidence of scrub typhus than the other age groups. The male confirmed cases exceeded the female confirmed cases ($\chi^2 = 39.8, p < 0.001$). Figure 2h shows the results. In the Pescadore Islands, one age group of males (65-74 year-olds) and 2 age groups of females (0-9 and 50-64 year-olds) showed a higher incidence of scrub typhus than the other age groups. The number of confirmed case was not significantly different between males and females ($\chi^2 = 0.4, p = 0.509$). Figure 2i shows the results. In the Kinmen Islands, one age group of males (20-24 year-olds) and 2 age groups of females (55-64 and 70-79 year-olds) showed a higher incidence of scrub typhus than the other age groups. The male confirmed cases exceeded the female confirmed cases ($\chi^2 = 121.6, p < 0.001$). Figure 2j shows the results. In the Matou Islands, one age group of males (15-24 year-olds) and 2 age groups of females (60-64 and 70-79 year-olds) showed a higher incidence of scrub typhus than the other age groups. The male confirmed cases exceeded the female confirmed cases ($\chi^2 = 68.9, p < 0.001$). Figure 2k shows the results.

Seasonal differences in the occurrence of cases in 10 local climate regions

Table 2 presents a summary of the seasonal differences of scrub typhus infection from 2002 to 2011 in 10 local climate regions of Taiwan. In the Taiwan Area, this study shows 3697 cases of confirmed infection with the following seasonal prevalence: spring (468 cases, 12.7%), summer (1488 cases, 40.2%), autumn (1115 cases, 30.2%), and winter (626 cases, 16.9%). These results show significant seasonal variation ($\chi^2 = 704.7, p < 0.001$). The number of cases in the warm season (2540 cases, 68.7%) was significantly higher than that in the cold season (1157 cases, 31.3%) ($\chi^2 = 517.4, p < 0.001$). A monotonically increasing peak appeared in the months of June and July (472 cases and 638 cases, respectively) in the Taiwan Area (Fig. 3a). In Northern Taiwan, the total confirmed infection of 355 cases showed the following seasonal prevalence: spring (45 cases, 12.7%), summer (127 cases, 35.8%), autumn (73 cases, 20.6%), and winter (110 cases, 31%). These results show a significant seasonal variation ($\chi^2 = 45.9, p < 0.001$). The cases in the warm season (208 cases, 58.6%) were not unlike that of the cold season (147 cases, 41.4%) ($\chi^2 = 10.5, p = 0.0012$). Two high peaks appeared in January and July (53 cases and 59 cases, respectively) in Northern Taiwan (Fig. 3b). In Northwestern Taiwan, the total confirmed infection of 139 cases showed the following seasonal prevalence: spring (20 cases, 14.4%), summer (43 cases, 30.9%), autumn (24 cases, 17.3%), and winter (52 cases, 37.4%). These results show a significant seasonal variation ($\chi^2 = 20.1, p < 0.001$). The cases in the warm season (67 cases, 48.2%) were not unlike that of cold season (72 cases, 51.8%) ($\chi^2 =
0.18, \( p = 0.67 \). Two high peaks appeared in July and December (26 cases and 33 cases, respectively) in Northwestern Taiwan (Fig. 3c). In West-central Taiwan, the total confirmed infection of 294 cases showed the following seasonal prevalence: spring (28 cases, 9.5%), summer (137 cases, 46.6%), autumn (82 cases, 27.9%), and winter (47 cases, 16%). These results show a significant seasonal variation (\( \chi^2 = 93.6, p < 0.001 \)). The cases in the warm season (210 cases, 71.4%) were significantly higher than those in the cold season (84 cases, 28.6%) (\( \chi^2 = 54, p < 0.001 \)). A high peak appeared in July (66 cases) in West-central Taiwan (Fig. 3d). In Southwestern Taiwan, the total confirmed infection of 617 cases showed the following seasonal prevalence: spring (64 cases, 10.4%), summer (241 cases, 39.1%), autumn (233 cases, 37.8%), and winter (79 cases, 12.8%). These results show a significant seasonal variation (\( \chi^2 = 178.5, p < 0.001 \)). The cases in the warm season (457 cases, 74.1%) were significantly higher than those in the cold season (160 cases, 25.9%) (\( \chi^2 = 143, p < 0.001 \)). Three high peaks appeared in July, August, and September (96 cases, 91 cases, and 111 cases, respectively) in Southwestern Taiwan (Fig. 3e). In Northeastern Taiwan, the total confirmed infection of 50 cases showed the following seasonal prevalence: spring (7 cases, 14%), summer (10 cases, 20%), autumn (9 cases, 18%), and winter (24 cases, 48%). These results show an insignificant seasonal variation (Chi-square test, \( \chi^2 = 14.5, p = 0.002 \)). The cases in the warm season (20 cases, 40%) were not unlike those in the cold season (30 cases, 60%) (\( \chi^2 = 2, p = 0.16 \)). Two high peaks appeared in January and December (12 cases and 8 cases, respectively) in Northeastern Taiwan (Fig. 3f). In Southeastern Taiwan, the total confirmed infection of 844 cases showed the following seasonal prevalence: spring (160 cases, 19%), summer (220 cases, 26.1%), autumn (274 cases, 32.5%), and winter (190 cases, 22.5%). These results show a significant seasonal variation (\( \chi^2 = 33.6, p < 0.001 \)). The cases in the warm season (472 cases, 55.9%) were significantly higher than those in the cold season (372 cases, 44.1%) (\( \chi^2 = 11.8, p < 0.001 \)). A high peak appeared in November (104 cases) in Southeastern Taiwan (Fig. 3g). In the mountainous township area, the total confirmed infection of 423 cases showed a seasonal prevalence of spring (50 cases, 11.8%), summer (150 cases, 35.5%), autumn (117 cases, 27.7%), and winter (106 cases, 25.1%). These results show a significant seasonal variation (\( \chi^2 = 49.1, p < 0.001 \)). The incident cases of warm season (244 cases, 57.7%) was not unlike that of cold season (179 cases, 42.3%) (\( \chi^2 = 10, p = 0.0015 \)). A high peak appeared in July (59 cases) in the mountainous township area (Fig. 3h). In the Pescadore Islands, the total confirmed infection of 364 cases showed the following seasonal prevalence: spring (63 cases, 17.3%), summer (125 cases, 34.3%), autumn (164 cases, 45.1%), and winter (12 cases, 3.3%). These results show a significant seasonal variation (Chi-square test, \( \chi^2 = 148.5, p < 0.001 \)). The cases in the warm
season (274 cases, 75.3%) were significantly higher than those in the cold season (90 cases, 24.7%) \((\chi^2 = 93, p < 0.001)\). Two high peaks appeared in June and October (55 cases and 69 cases, respectively) in the Pescadore Islands (Fig. 3i). In the Kinmen Islands, the total confirmed infection of 516 cases showed the following seasonal prevalence: spring (31 cases, 6%), summer (365 cases, 70.7%), autumn (118 cases, 22.9%), and winter (2 cases, 0.4%). These results show a significant seasonal variation \((\chi^2 = 632.2, p < 0.001)\). The cases in the warm season (500 cases, 96.9%) were significantly higher than those in the cold season (16 cases, 3.1%) \((\chi^2 = 454, p < 0.001)\). Two high peaks appeared in June and July (150 cases and 173 cases, respectively) in the Kinmen Islands (Fig. 3j).

In the Matou Islands, the total confirmed infection of 95 cases showed the following seasonal prevalence: spring (0 cases, 0%), summer (70 cases, 73.7%), autumn (21 cases, 22.1%), and winter (4 cases, 4.2%). These results show a significant seasonal variation \((\chi^2 = 130.6, p < 0.001)\). The cases in the warm season (88 cases, 92.6%) were significantly higher than those in the cold season (7 cases, 7.4%) \((\chi^2 = 69.1, p < 0.001)\). Two high peaks appeared in July and August (35 cases and 21 cases, respectively) in the Matou Islands (Fig. 3k).

**Confirmed cases of scrub typhus and their correlation with meteorological factors in 10 local climate regions**

Table 3 presents a summary of the Pearson product moment correlation between scrub typhus incidences and meteorological factors from 2002-2011. These results show that all tests were insignificant in the 4 local climate regions of the main Taiwan island (i.e., Northern Taiwan, Northeastern Taiwan, Southeastern Taiwan, and the mountainous township area). In Northwestern Taiwan, the results were negatively correlated with relative humidity \((r = -0.243)\). West-central Taiwan showed a positive correlation with surface temperature \((r = 0.475)\), precipitation \((r = 0.249)\), and sunshine duration \((r = 0.400)\), and a negative correlation with atmospheric pressure \((r = -0.450)\). Southwestern Taiwan showed a positive correlation with surface temperature \((r = 0.422)\), precipitation \((r = 0.279)\), relative humidity \((r = 0.276)\), and wet days \((r = 0.381)\), and a negative correlation with atmospheric pressure \((r = -0.411)\). The Pescadore Islands showed a positive correlation with surface temperature \((r = 0.370)\), and a negative correlation with atmospheric pressure \((r = -0.316)\). The Kinmen Islands showed a positive correlation with surface temperature \((r = 0.623)\), precipitation \((r = 0.354)\), relative humidity \((r = 0.567)\), and sunshine duration \((r = 0.473)\), and a negative correlation with atmospheric pressure \((r = -0.630)\). The Matou Islands showed a positive correlation with surface temperature \((r = 0.583)\), and sunshine duration \((r = 0.592)\), and showed a negative correlation with atmospheric pressure \((r = -0.535)\).
The fitted results of the geographically weighted regression models

Figure 4 shows a map of the geographical distributions of SIR-district scrub typhus, the percentage of farmer workers, and the land share ratio (percentage) of forest land uses in Taiwan’s main island in 2005. The survey of forest land uses included timber management area, recreational forest area, national protective area, natural reserve area, plantation area, clearcut area, and other purpose area. Figures 5 to 12 present maps of parameter estimates, the significant determination of the false discovery rate, and local $R^2$, in which scrub typhus figures fit the GWR models with the explanatory variables of the farm worker, timber management area, recreational forest area, national protective area, natural reserve area, plantation area, clearcut area, and other purpose area.

In the GWR models, the farm worker explanatory variable showed significant and positive signs of parameter estimates in clusters of Southeastern Taiwan (low-land townships in Hualien County and Taitung County and local $R^2$ ranging from 0 to 0.4), the central mountainous township area (local $R^2$ ranging from 0 to 0.4) and southern portions (local $R^2$ ranging from 0.2 to 0.6), and Heping Township in Taichung County (local $R^2$ ranging from 0.2 to 0.4). The explanatory variables for timber management area showed significant and positive signs of parameter estimates in Laiyi Township, Jiadong Township, Chunrih Township, and Fangliao Township (all in Pingtung County, local $R^2$ ranging from 0.2 to 0.4), and showed negative signs of parameter estimates in the central mountainous township region (local $R^2$ ranging from 0 to 0.4). The explanatory variables of recreational forest area showed significant and positive signs of parameter estimates in the central mountainous township region and Taitung County (local $R^2$ ranging from 0 to 0.2). The explanatory variables of natural reserve area showed significant and positive signs of parameter estimates in the southern mountainous township region (local $R^2$ ranging from 0 to 0.8) and 5 townships (i.e., Taitung County of Jinfong Township, Daren Township and Dawu Township, and Hualien County of Jhuosi Township and Ful Township, with local $R^2$ ranging from 0 to 0.2), and showed negative signs of parameter estimates in 8 townships (i.e., Taoyuan Township in Kaohsiung County and Taitung County of Haiduan Township, Chenggong Township, Chihshang Township, Guanshan Township, Donghe Township, Luye Township, and Yanping Township) with local $R^2$ ranging from 0 to 0.2. The explanatory variables of other purpose area showed significant and positive signs of parameter estimates in the central mountainous township region and Taitung County (local $R^2$ ranging from 0 to 0.8), and showed negative signs of parameter estimates in 5 townships (i.e., Hualien County of Wanrong Township, Fonglin Township, Fongbin Township, Guangfu Township, and Rueisuei Township) with local $R^2$ ranging from 0
to 0.2. However, the explanatory variables of national protective area (local $R^2$ ranging from 0 to 0.2), plantation area (2 ranges of local $R^2$ from 0 to 0.2 and from 0.4 to 0.6, respectively), and clearcut area (local $R^2$ ranging from 0 to 0.2) showed significant but negative signs of parameter estimates.
Discussion

Scrub typhus was discovered in China and has since been classified into summer type and autumn-winter type. Before 1986, scrub typhus was endemic to Southern China. Because human infections typically occur between June and August, the most common form of scrub typhus is called summer-type scrub typhus. The geographical distribution of summer-type scrub typhus includes Southern China (south of the Yangtse River), including Guangdong, Hainan, Guangxi, Fujian, Zhejiang, Yunnan, and Hunan provinces. *Rattus losea, Rattus flavivestis,* and *Apodemus agrarius* are main hosts of summer-type scrub typhus. The key vector chigger mite for this disease is *Leptotrombidium deliense,* and serotypes against *Orientia tsutsugamushi* include the Karp type, Gilliam type, and Kato type. During the autumn-winter period of 1986, a new type of scrub typhus was identified in Shandong and northern Jiangsu province of northern China. This newly recognized scrub typhus subsequently appeared in many areas of northern China (north of the Yangtse River), including Shandong, northern Jiangsu, Tianjing, Shanxi, Hebei, and Hennan provinces. This new variety of the disease was called autumn-winter type scrub typhus [22-23]. *Apodemus agrarius, Cricetulus triton,* and *Rattus norvegicus* are main hosts of the autumn-winter type, and vector chigger mite is *Leptotrombidium scutellare.* A prevalent serotype is Gilliam type [22-23]. In Eastern Taiwan, the main reservoir hosts include *Apodemus agrarius, Bandicota indica,* and *Rattus losea,* and the key vector chigger mite is *Leptotrombidium imphalum.* Serotypes against *Orientia tsutsugamushi* include the Karp type, Gilliam type, and Kato type [24-25]. However, the abundance of vector chigger mites (e.g., *Leptotrombidium deliense*) is positively correlated with temperature in the Pescadore Islands [26]. However, different chigger mites transmit scrub typhus; *Leptotrombidium deliense* in Southern China and the Pescadore Islands (Taiwan) and *Leptotrombidium imphalum* in Eastern Taiwan (Hualien County and Taitung County).

The relationship between the incidence of scrub typhus and climate largely reflects the responses of chiggers to the environment [2]. The occurrence of scrub typhus is frequently related to temperature, and occasionally to rainfall [2, 6-8]. The habitats and altitudinal distribution of chiggers vary by species, but chiggers are likely to be located in areas with moist soil and abundant rodents [8]. Taiwan’s main island and small associated islands (Pescadore, Kinmen, and Matou islands) are located off the coast of Southern China. The eastern two-thirds of Taiwan are characterized by rugged mountains covered with tropical and subtropical vegetation, whereas Western Taiwan is characterized by flat to gently rolling plains. In the Taiwan Area, a higher risk of scrub typhus infection is not only endemic to Southeastern Taiwan and
mountainous township area, but also in the Pescadore Islands, Kinmen Islands, and Matou Islands. A higher incidence commonly occurs from May to January, and shows variation within 10 local climate regions. In the high-risk area, the Kinmen and Matou islands show the typical summer-type infection. Cases of human infection are highly and positively correlated to air temperature and sunshine duration. In the Pescadore Islands, the incidence of scrub typhus is positively correlated to air temperature, but seasonal prevalence does not show the typical summer-type variety. In Southeastern Taiwan and the mountainous township area, the incidence of scrub typhus is independent of the studied meteorological factors. The prevalent type of scrub typhus is different from that in Southern China. The results of this study indicate that the scrub typhus endemic to Taiwan’s main island and small associated islands is the island-type scrub typhus rather than the summer type.

The GWR method is a local version of spatial regression that generates parameters disaggregated by the spatial units of analysis. This makes it possible to assess spatial heterogeneity in the estimated relationships between response and explanatory variables. Global models typically test whether the parameter (referred to as the coefficient) estimates differ significantly from zero. This can be accomplished with a t-test, in which the output provides the t statistics and their associated p values. The model excludes variables with non-significant parameter estimates. In the GWR, one set of parameters is associated with each regression point and one set of standard errors. Therefore, potentially hundreds or thousands of tests would be required to determine if parameters are locally significant. Parameter estimates for variables close to zero, indicating that in these parts of the study area, changes in this variable do not influence changes in the response variable. The Benjamini-Hochberg (1995) false discovery rate (FDR) procedure represents a solution for GWR because it modifies the significance level for each test in a consistent manner [27-28]. The focus on geographical medicine study is to determine spatial heterogeneity (hot spots). Clusters are calculated by the regression models, which parameter estimates are significant and positive sign. Therefore, this study shows that higher SIR-district scrub typhus is positively associated with the explanatory variables (e.g., farm worker, timber management area, recreational forest area, natural reserve area, and other purpose area) on the main island of Taiwan.
Conclusion
The results of this study indicate that scrub typhus endemic regions in Taiwan’s main island and several small associated islands belong to the island type of scrub typhus. Higher SIR-district scrub typhus, which occurs in the central and southern portions of the mountainous townships area and Southeastern Taiwan, is associated with farm worker density and forest land use (e.g., farm worker, timber management area, recreational forest area, natural reserve area, and other purpose area variables) in Taiwan. These results are useful for assessing spatial risk factors, which, in turn, can improve planning for the most advantageous types of health care policies and implementing effective health care services.
Competing interests
The authors declare that they have no competing interests.

Author’s contributions
PJ was responsible for the study design, epidemiological investigation, data collection, statistic calculation, and manuscript drafting. HC assisted with the study design and participated in data collection for the meteorological factors.

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References

17. Ahmad OB, Boschi-Pinto C, Lopez AD, Murray CJL, Lozano R, Inoue M: Age


Figure legends

Figure 1. Ten climate regions and 24 local meteorological stations in Taiwan.

Figure 2. Age-specific incidence rate of scrub typhus (per year per 100,000 people) from 2000 to 2010 in 10 local climate regions of Taiwan: (a) the Taiwan Area, (b) Northern Taiwan, (c) Northwestern Taiwan, (d) West-Central Taiwan, (e) Southwestern Taiwan, (f) Northeastern Taiwan, (g) Southeastern Taiwan, (h) mountainous township area, (i) Pescadore Islands, (j) Kinmen Islands, (k) Matou Islands.

Figure 3. Seasonal incidence of scrub typhus in Taiwan Area and 10 local climate regions (1998-2011): (a) the Taiwan Area, (b) Northern Taiwan, (c) Northwestern Taiwan, (d) West-Central Taiwan, (e) Southwestern Taiwan, (f) Northeastern Taiwan, (g) Southeastern Taiwan, (h) mountainous township area, (i) Pescadore Islands, (j) Kinmen Islands, (k) Matou Islands.

Figure 4. Spatial maps of 349 townships in Taiwan in 2005
Figure (a) shows the standardized incidence ratio (SIR) of scrub typhus. Figure (b) shows the percentage of farm workers. Figure (c) shows the land share ratio of timber management area. Figure (d) shows the land share ratio of recreational forest area. Figure (e) shows the land share ratio of national protective area. Figure (f) shows the land share ratio of natural reserve area. Figure (g) shows the land share ratio of plantation area. Figure (h) shows the land share ratio of clearcut area. Figure (i) shows the land share ratio of other purpose area.

Figure 5. The results of the GWR model for the standardized incidence ratio (SIR) of scrub typhus and the percentage of farm workers in 2005 on the main island of Taiwan.
Figure (a) shows the parameter estimate. Figure (b) shows the significant determination by the false discovery rate (FDR). Figure (c) shows the local $R^2$ value.

Figure 6. The results of the GWR model for the standardized incidence ratio (SIR) of scrub typhus and the land share ratio of timber management area in 2005 on the main island of Taiwan.
Figure (a) shows the parameter estimate. Figure (b) shows the significant determination by the false discovery rate (FDR). Figure (c) shows the local $R^2$ value.

Figure 7. The results of the GWR model for the standardized incidence ratio (SIR) of
scrub typhus and the land share ratio of recreational forest area in 2005 on the main island of Taiwan.

Figure (a) shows the parameter estimate. Figure (b) shows the significant determination by the false discovery rate (FDR). Figure (c) shows the local $R^2$ value.

Figure 8. The results of the GWR model for the standardized incidence ratio (SIR) of scrub typhus and the land share ratio of national protective area in 2005 on the main island of Taiwan.

Figure (a) shows the parameter estimate. Figure (b) shows the significant determination by the false discovery rate (FDR). Figure (c) shows the local $R^2$ value.

Figure 9. The results of the GWR model for the standardized incidence ratio (SIR) of scrub typhus and the land share ratio of natural reserve area in 2005 on the main island of Taiwan.

Figure (a) shows the parameter estimate. Figure (b) shows the significant determination by the false discovery rate (FDR). Figure (c) shows the local $R^2$ value.

Figure 10. The results of the GWR model for the standardized incidence ratio (SIR) of scrub typhus and the land share ratio of plantation area in 2005 on the main island of Taiwan.

Figure (a) shows the parameter estimate. Figure (b) shows the significant determination by the false discovery rate (FDR). Figure (c) shows the local $R^2$ value.

Figure 11. The results of the GWR model for the standardized incidence ratio (SIR) of scrub typhus and the land share ratio of clearcut area in 2005 on the main island of Taiwan.

Figure (a) shows the parameter estimate. Figure (b) shows the significant determination by the false discovery rate (FDR). Figure (c) shows the local $R^2$ value.

Figure 12. The results of the GWR model for the standardized incidence ratio (SIR) of scrub typhus and the land share ratio of other purpose area in 2005 on the main island of Taiwan.

Figure (a) shows the parameter estimate. Figure (b) shows the significant determination by the false discovery rate (FDR). Figure (c) shows the local $R^2$ value.
Table 1. Age-adjusted standard incidence rates of scrub typhus infection from 2000 to 2010 in 10 local climate regions of Taiwan

<table>
<thead>
<tr>
<th>Local climate regions</th>
<th>male*</th>
<th>female*</th>
<th>male : female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taiwan Area (total)</td>
<td>1.83</td>
<td>1.03</td>
<td>1.78</td>
</tr>
<tr>
<td>Northern Taiwan</td>
<td>0.61</td>
<td>0.33</td>
<td>1.86</td>
</tr>
<tr>
<td>Northwestern Taiwan</td>
<td>0.45</td>
<td>0.27</td>
<td>1.66</td>
</tr>
<tr>
<td>West-central Taiwan</td>
<td>0.79</td>
<td>0.49</td>
<td>1.63</td>
</tr>
<tr>
<td>Southwestern Taiwan</td>
<td>0.82</td>
<td>0.56</td>
<td>1.47</td>
</tr>
<tr>
<td>Northeastern Taiwan</td>
<td>1.55</td>
<td>1.04</td>
<td>1.50</td>
</tr>
<tr>
<td>Southeastern Taiwan</td>
<td>15.57</td>
<td>9.31</td>
<td>1.67</td>
</tr>
<tr>
<td>Mountainous townships</td>
<td>24.22</td>
<td>16.32</td>
<td>1.48</td>
</tr>
<tr>
<td>Pescadore Islands</td>
<td>36.48</td>
<td>40.44</td>
<td>0.90</td>
</tr>
<tr>
<td>Kinmen Islands</td>
<td>95.79</td>
<td>32.15</td>
<td>2.98</td>
</tr>
<tr>
<td>Matou Islands</td>
<td>185.54</td>
<td>27.72</td>
<td>6.69</td>
</tr>
</tbody>
</table>

* indicates incidence rates per 100,000 people

Table 2. Seasonal differences of scrub typhus infection from 2002 to 2011 in 10 local climate regions of Taiwan

<table>
<thead>
<tr>
<th>Local climate regions</th>
<th>Total</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
<th>Warm</th>
<th>Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taiwan Area</td>
<td>3697</td>
<td>468 (12.7)</td>
<td>1488 (40.2)</td>
<td>1115 (30.2)</td>
<td>626 (16.9)</td>
<td>2540 (68.7)</td>
<td>1157 (31.3)</td>
</tr>
<tr>
<td>Northern Taiwan</td>
<td>355</td>
<td>45 (12.7)</td>
<td>127 (35.8)</td>
<td>73 (20.6)</td>
<td>110 (31)</td>
<td>208 (58.6)</td>
<td>147 (41.4)</td>
</tr>
<tr>
<td>Northwestern Taiwan</td>
<td>139</td>
<td>20 (14.4)</td>
<td>43 (30.9)</td>
<td>24 (17.3)</td>
<td>52 (37.4)</td>
<td>67 (48.2)</td>
<td>72 (51.8)</td>
</tr>
<tr>
<td>West-central Taiwan</td>
<td>294</td>
<td>28 (9.5)</td>
<td>137 (46.6)</td>
<td>82 (27.9)</td>
<td>47 (16)</td>
<td>210 (71.4)</td>
<td>84 (28.6)</td>
</tr>
<tr>
<td>Southwestern Taiwan</td>
<td>617</td>
<td>64 (10.4)</td>
<td>241 (39.1)</td>
<td>233 (37.8)</td>
<td>79 (12.8)</td>
<td>457 (74.1)</td>
<td>160 (25.9)</td>
</tr>
<tr>
<td>Northeastern Taiwan</td>
<td>50</td>
<td>7 (14)</td>
<td>10 (20)</td>
<td>9 (18)</td>
<td>24 (48)</td>
<td>20 (40)</td>
<td>30 (60)</td>
</tr>
<tr>
<td>Southeastern Taiwan</td>
<td>844</td>
<td>160 (19)</td>
<td>220 (26.1)</td>
<td>274 (32.5)</td>
<td>190 (22.5)</td>
<td>472 (55.9)</td>
<td>372 (44.1)</td>
</tr>
<tr>
<td>Mountainous townships</td>
<td>423</td>
<td>50 (11.8)</td>
<td>150 (35.5)</td>
<td>117 (27.7)</td>
<td>106 (25.1)</td>
<td>244 (57.7)</td>
<td>179 (42.3)</td>
</tr>
<tr>
<td>Pescadore Islands</td>
<td>364</td>
<td>63 (17.3)</td>
<td>125 (34.3)</td>
<td>164 (45.1)</td>
<td>12 (3.3)</td>
<td>274 (75.3)</td>
<td>90 (24.7)</td>
</tr>
<tr>
<td>Kinmen Islands</td>
<td>516</td>
<td>31 (6)</td>
<td>365 (70.7)</td>
<td>118 (22.9)</td>
<td>2 (0.4)</td>
<td>500 (96.9)</td>
<td>16 (3.1)</td>
</tr>
<tr>
<td>Matou Islands</td>
<td>95</td>
<td>0 (0)</td>
<td>70 (73.7)</td>
<td>21 (22.1)</td>
<td>4 (4.2)</td>
<td>88 (92.6)</td>
<td>7 (7.4)</td>
</tr>
</tbody>
</table>

Four seasons were defined: spring (from March to May), summer (from June to August), autumn (from September to November), and winter (from December to February).

Warm-cold seasons were defined: warm season (from May to October), and cold season (from November to April).
Table 3. Correlations between the monthly incidences and meteorological factors for scrub typhus in 10 local climate regions of Taiwan (2002-2011).

<table>
<thead>
<tr>
<th>Local climate regions</th>
<th>surface temperature(^{b})</th>
<th>precipitation(^{b})</th>
<th>relative humidity(^{b})</th>
<th>atmospheric pressure(^{b})</th>
<th>wet days(^{d})</th>
<th>sunshine duration(^{c})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(°C)</td>
<td>(mm)</td>
<td>(%)</td>
<td>(hBa)</td>
<td>(&gt;0.1 mm/day)</td>
<td>(hour)</td>
</tr>
<tr>
<td>Northern Taiwan</td>
<td>0.182</td>
<td>-0.02</td>
<td>-0.09</td>
<td>-0.14</td>
<td>-0.12</td>
<td>0.213</td>
</tr>
<tr>
<td>Northwestern Taiwan</td>
<td>0.016</td>
<td>-0.09</td>
<td>-0.243*</td>
<td>0.00</td>
<td>-0.14</td>
<td>0.16</td>
</tr>
<tr>
<td>West-central Taiwan</td>
<td>0.475*</td>
<td>0.249*</td>
<td>0.00</td>
<td>-0.450*</td>
<td>0.12</td>
<td>0.400*</td>
</tr>
<tr>
<td>Southwestern Taiwan</td>
<td>0.422*</td>
<td>0.279*</td>
<td>0.276*</td>
<td>-0.411*</td>
<td>0.381*</td>
<td>0.16</td>
</tr>
<tr>
<td>Northeastern Taiwan</td>
<td>-0.176</td>
<td>-0.07</td>
<td>-0.10</td>
<td>0.14</td>
<td>0.00</td>
<td>-0.08</td>
</tr>
<tr>
<td>Southeastern Taiwan</td>
<td>0.202</td>
<td>0.16</td>
<td>-0.08</td>
<td>-0.09</td>
<td>0.01</td>
<td>0.18</td>
</tr>
<tr>
<td>Mountainous townships</td>
<td>0.187</td>
<td>0.14</td>
<td>0.07</td>
<td>-0.16</td>
<td>0.12</td>
<td>0.04</td>
</tr>
<tr>
<td>Pescadore Islands</td>
<td>0.370*</td>
<td>0.15</td>
<td>0.08</td>
<td>-0.316*</td>
<td>0.15</td>
<td>0.188</td>
</tr>
<tr>
<td>Kinmen Islands(^{a})</td>
<td>0.623*</td>
<td>0.354*</td>
<td>0.567*</td>
<td>-0.630*</td>
<td>0.11</td>
<td>0.473*</td>
</tr>
<tr>
<td>Matou Islands(^{a})</td>
<td>0.583*</td>
<td>0.00</td>
<td>0.18</td>
<td>-0.535*</td>
<td>-0.227</td>
<td>0.592*</td>
</tr>
</tbody>
</table>

\(p < 0.01\)

\(^{a}\) indicates that available data from 2004 to 2011 was used for this variable.

\(^{b}\) The averaged value was calculated for each month.

\(^{c}\) The value was accumulated for every day in a month.

\(^{d}\) The measured value all day long was larger than 0.1 mm (defined as one wet day), and dry otherwise.
Figure 2
Figure 4
Figure 6

(a) Parameter Estimates
-747.2 to -600
-599.9 to -450
-499.9 to -300
-299.9 to -150
-149.9 to 0
0 - 150

(b) Significant Determination by FDR
non-significance
significance

(c) Local R Square
0 - 0.20
0.20 - 0.40
0.40 - 0.60
0.60 - 0.80
0.80 - 1
Figure 8