USING REMOTE SENSING IMAGES TO IDENTIFY THE SPATIAL-TEMPORAL RELATIONSHIPS BETWEEN MOSQUITO DENSITY AND TEMPERATURE IN TROPICAL URBAN SETTINGS

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ABSTRACT: Climate warming has become an important issue as its negative impacts on human health should be concerned. Tropical vector-borne diseases, such as malaria and dengue, could increase the risk of being infected, especially in localized urban area due to the effect of urban heat island. The association between urban heat island and incidence of vector-borne diseases is still unclear. This study aims to identify spatial patterns of possible heat island effects and the spatial-temporal relationship between land surface temperature (LST) and mosquito density, with multidate high resolution (30mx30m) remote sensing images and high-densed sampling schemes for mosquitoes in dengue epidemic focus areas of Kaohsiung City, Taiwan. We apply spatial statistic to explore the spatial patterns and relationships between these variables. Our results indicate that there are nonlinear effects of temperature changes on mosquitoes. The study provides more insights into micro-scale spatial targeting of intervention and allocating resources for control programs against dengue outbreaks.
KEY WORDS: Remote sensing, Dengue, Mosquito Density, Urban Heat Island, Spatial-temperol Relationship

Introduction

Global warming has been a popular event for years, and there are more and more risks associated with it, such as the heat wave in Europe, and the coral bleaching in Caribbean Sea caused by the dust from Africa. One of the topics to be concerned about this event is epidemiology. Under the threat of global warming, tropical areas would be broaden, thus provides mosquitoes suitable environments to live, especially in rural areas. Aside from global warming, human-made environments play a role in increasing temperature. This phenomenon happens especially in urban areas, now is called Urban Heat Island. Some of the researchers used remote sensing (RS) to detect land surface temperature (LST) to do risk assessment. Tomlinson et al (2011) used the three elements (exposure, hazard and vulnerability) of risk to analyze where are in danger in Birmingham. Neteler et al.(2011) used RS detected LST to be a dependent variable in a logistic regression. Both of them are using a low resolution satellite, which is about 1km. Vazquez-Prokopec et al. (2010) tried to explain dengue spread using climate factors and Bayesian model to know the non-linear relationship between them. Another approach in climate factor on wiggler number is to concern the daily temperature range, with a thermodynamic model (Lambrechts et al., 2011). There are fewer studies using a high resolution satellite image, and most of the studies use administrative area as their study units, thus, the spatial pattern on the boundary might be ignored.

Suppose that mosquito number is a hazard to human, and the building area is the exposure, we can make the building area as our study area because we want to find out places with risk. In order to know the spatial pattern precisely, we use a high resolution satellite to detect LST, the raster grids as our study unit. We hope that our study might help the decision-making for government policy, hence to interfere with the wiggler number.

Materials and Methods

Study area

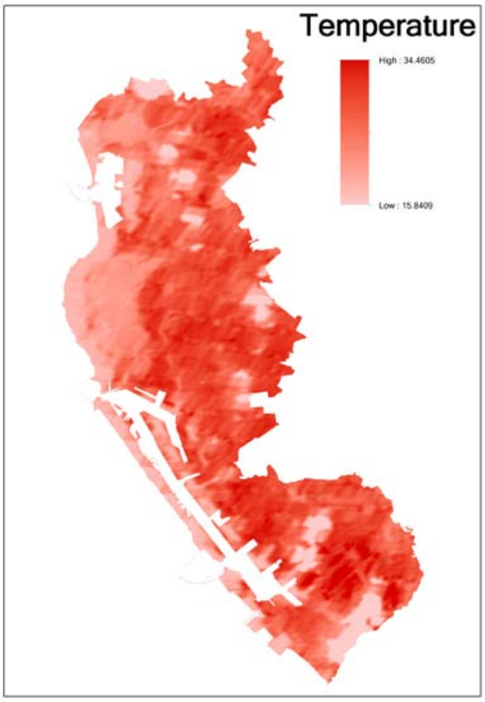
We choose former (that is, before it merged with Kaohsiung County) Kaohsiung city in Taiwan to be our study area. Kaohsiung City, whose area is about 153 km^2, is the south window of Taiwan because of the two international entrances (Kaohsiung international airport and port of Kaohsiung), with about 1.5 million people. Kaohsiung city is divided into 11 districts (shown in Figure. 3). The mean summer temperature here is about 28℃, and the mean winter temperature is about 19℃. It's a typically tropical climate.

According to the 2010 statistical yearbook of Kaohsiung city, the number of cases of notifiable diseases in Kaohsiung is 2978. While the number of dengue fever is 2012, accounting for 67.5% of all the cases. If we can find the relationship between LST and wiggler number, we might control the case number.

Data source

The data of the mosquitoes are from a survey which is population-stratified. That is, the sample sites are randomly selected per 400 people, using three different tools (wood sticks, sticky plastics, and both). The sample points are collected indoors and outdoors every week, from June 2009 to June 2010. The data contains the number of mosquito eggs, wiggler *Aedes aegypti* and *Aedes albopictus*. The LST data are from the LandSAT satellite in five different time periods (August 19th and October 29th in 2009, February 11th, March 6th and May 25th in 2010, through hot season to cold season) with a high (30m×30m) resolution (Figure. 1). From Figure.1, the high temperature values are almost concentrated in central or south part of Kaohsiung City. We assume that the LST is the same in a week.

(a)


Temperature
High : 34.4605
Low : 15.8409

(b)


Temperature
High : 41.8895
Low : 12.4823

(c)


Temperature
High : 39.6305
Low : 12.7472

(d)


Temperature
High : 40.6423
Low : 20.5457

(e)

Figure. 1 The spatial pattern of temperatures on (a) August 19th in 2009, ranging from 15.8409℃ to 34.4605; (b) October 29th in 2009, from 12.4823℃ to 41.8895; (c) February 11th in 2010, from 12.7472℃ to 39.6305; (d) March 6th in 2010, from 20.545℃ to 40.6423℃; (e) May 25th in 2010, from 11.6183℃ to 37.1071℃.

Data processing and analysis

We take the sum of the number of *Aedes aegypti* and *Aedes albopictus* as the response variable (y), and take the transferred mean daily temperature from LandSAT image (for that there are errors between real and measured LST) as explanatory variable in our study, the LST are transferred by the following formula:

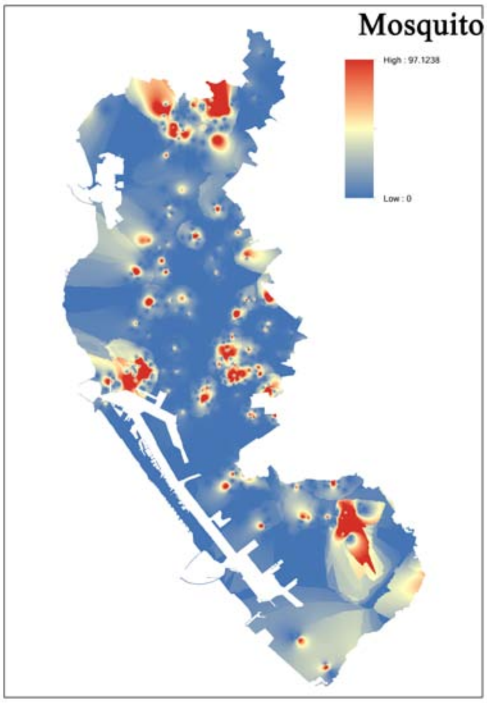
LST = -4.272576 + 1.1762276 * (original satellite temperature)

In order to do statistical analysis, we transferred the independent variable (mosquito sample points) into five continuous 30m×30m rasters using inverse distance weighting (IDW) method, and then convert both mosquitoes and LST rasters to polygon (Figure. 2). Then, we run ordinary least square (OLS) regression to see how well a stationary approach can explain the relationship between them. The model is set as follows:

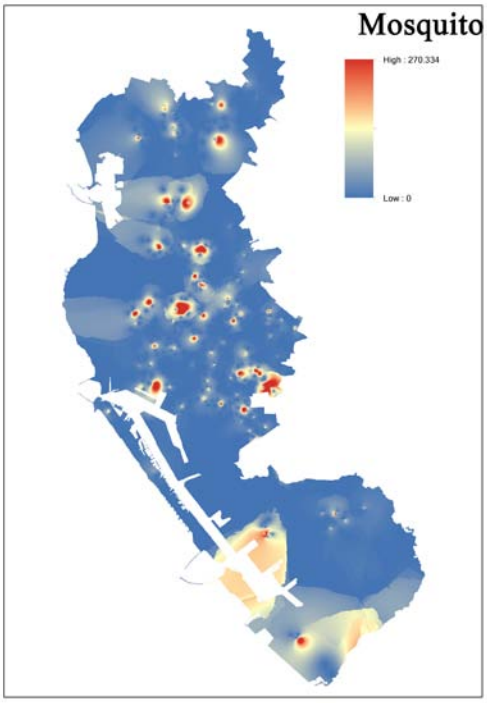
Mosquito number = $\beta_0+\beta_1$(LST)

The study tries to know whether the buildings in the city play a role in mosquito number, so the analysis unit is set as the 30m×30m grids in the building area in 2010 (Figure 3.), excluding industry area because they might affect the temperature (and that is not we want to discuss in this study). Also, we run geographically weighted regression (GWR) model to test the non-stationary relationship. GWR is a model including the effects of neighbors by multiplying a spatial weight matrix. Thus, theβ_1 in different unit with different neighbors might not be the same. We use an adaptive search method and Bandwidth parameter equals to 30 (thus for every grid, 30 neighbors are chosen). All of the data analysis and processing are completed by ESRI®ArcGIS™10.

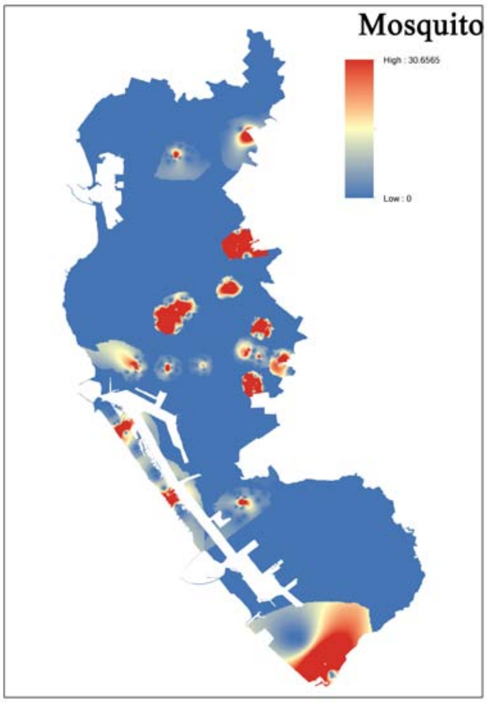
(a)



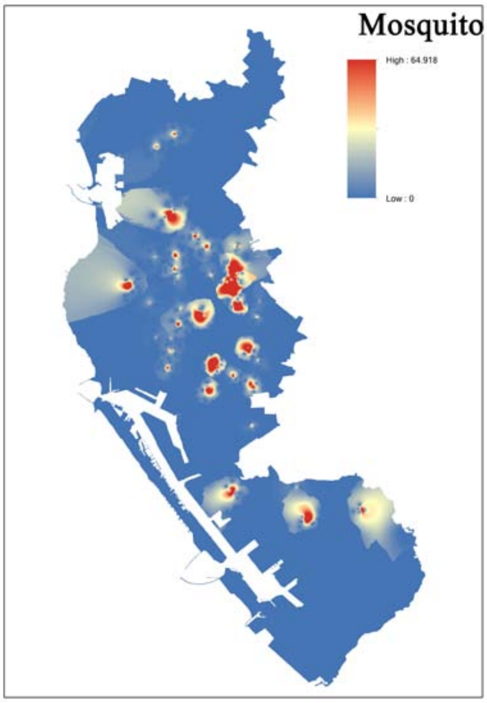
(b)



(c)



(d)



(e)

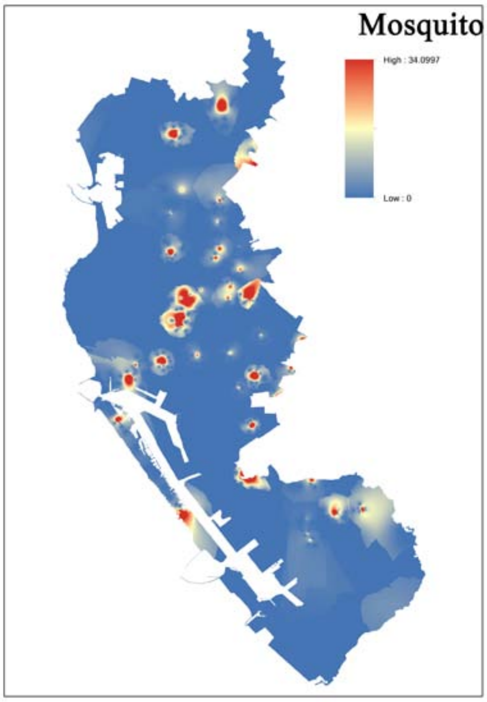


Figure. 2 Spatially interpolated mosquito data. The blue part is the area whose mosquito number is close to zero, and the red part is where the mosquitoes concentrate in. (a) On August 19th in 2009, most of the mosquitoes are in the north, central and south part; on October 29th, the north and south part in (a) disappeared; (c) February 11th in 2010, the central and south part appeared again; (d) March 6th, the central part scattered and the south part disappeared; (e) May 25th, like(d), but the spatial distribution changed.

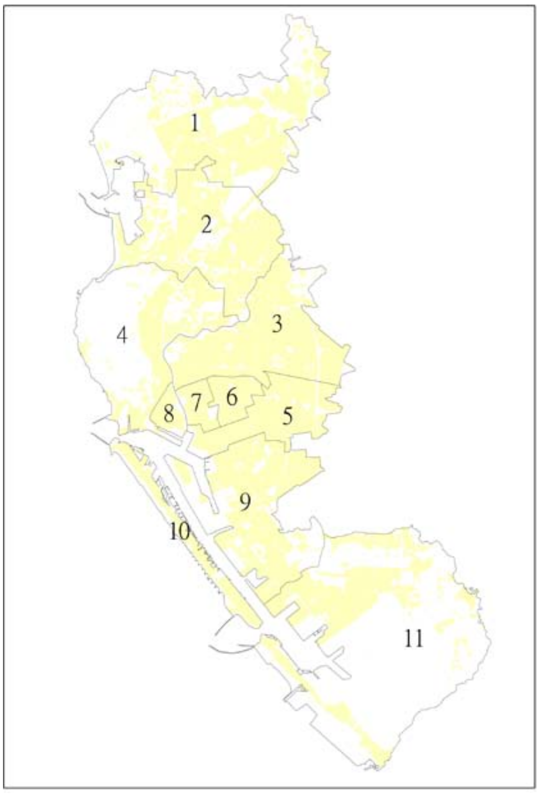


Figure 3. Kaohsiung City. The yellow part symbolizes the building area.

Results

Table 1. Multidate OLS results

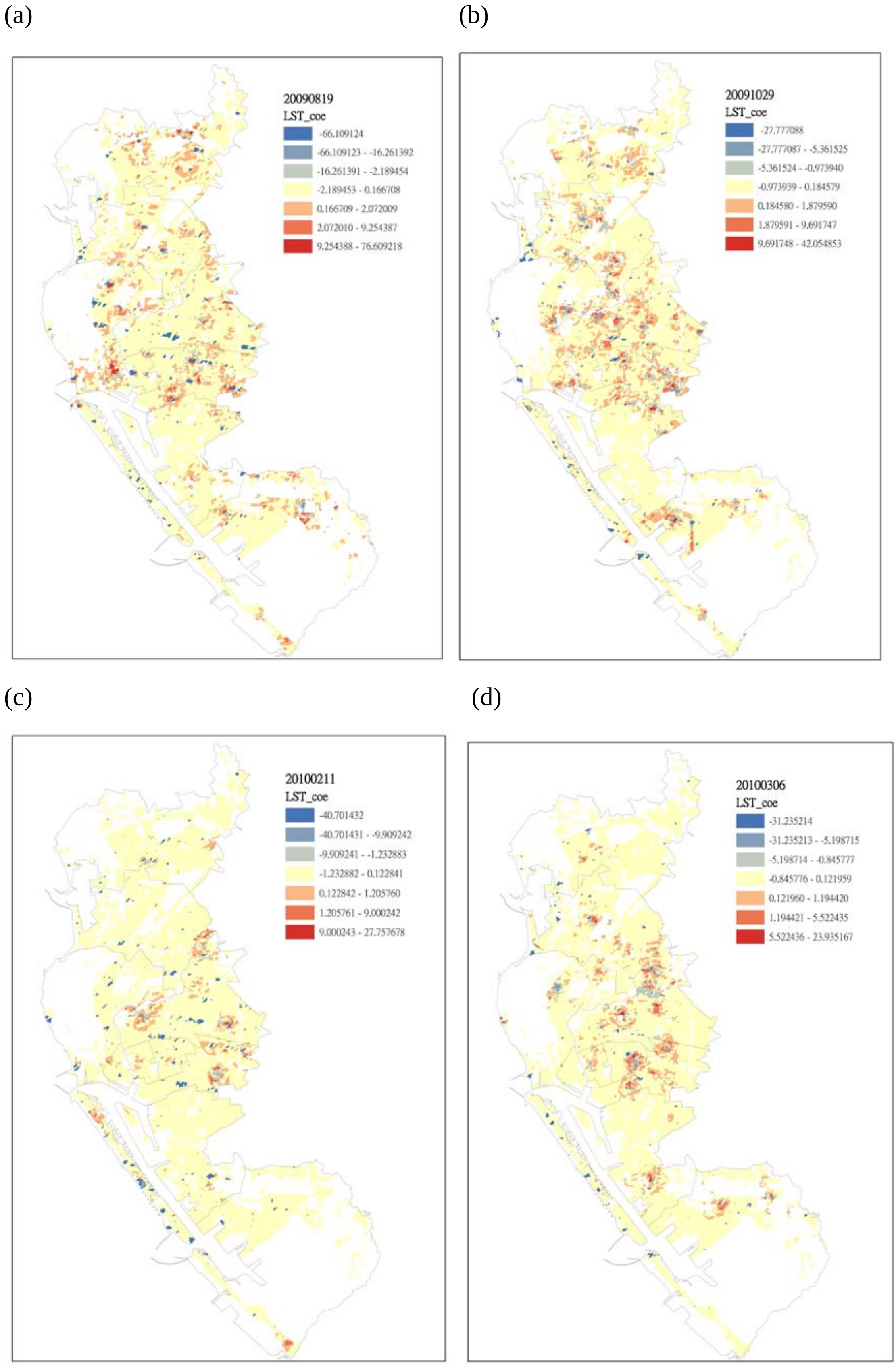
	Date				
Parameter	**2009/8/19**	**2009/10/29**	**2010/2/11**	**2010/3/6**	**2010/5/25**
Intercept	0.442379	0.28843	0.067702	-0.300001	0.590589
P-value	0	0.000495	0.016965	0	0
LST	0.012701	0.027556	0.003489	0.019076	-0.01148
P-value	0	0	0.000621	0	0
Adjusted R^2	0.000284	0.000912	0.000109	0.00287	0.001387
AIC	405707.1731	438151.982	227371.5155	274234.0747	270174.7
Jarque-Bera p-value	0	0	0	0	0

The OLS results are listed on Table 1. Except for 2010/05/25, the effect of LST shows a positive relationship toward wiggler number. All of the LST are significantly not to be 0, thus they do affect the independent variable. Each Adjusted R^2indicates that the model is not suitable under the assumption of OLS regression (R^2<0.001). The less the Akaike Information Criterion (AIC), the more the model explains. The Jarque –Bera p-value is used to test the normality of the residual, and all of the residuals are not normally distributed (p-value=0).

Table 2. GWR results

			Date		
Parameter	**2009/8/19**	**2009/10/29**	**2010/2/11**	**2010/3/6**	**2010/5/25**
minLST	-66.109124	-27.777088	-40.701432	-31.235214	-21.643338
maxLST	76.609218	2.882816	0.535834	1.731106	26.015094
Adjusted R^2	0.986276	0.992939	0.996911	0.999644	0.966861
AIC	-184.297666	-297.259674	-3053.677896	-1829.97094	-433.569911

The spatial pattern of coefficient of LST is shown in Figure4. The results are shown in Table 2. We can see that the coefficient of LST on August 19th in 2009 ranges from -66 to 76 in summer, more than other dates. While in winter (February 11th, 2010), the maxLST is the smallest of all. All of the adjusted $R^2$are above 0.9, saying that more than 90% variance in the wiggler number can be explained in GWR model.


(a)
20090819
LST_coe
-66.109124
-66.109123 - -16.261392
-16.261391 - -2.189454
-2.189453 - 0.166708
0.166709 - 2.072009
2.072010 - 9.254387
9.254388 - 76.609218
(b)
20091029
LST_coe
-27.777088
-27.777087 - -5.361525
-5.361524 - -0.973940
-0.973939 - 0.184579
0.184580 - 1.879590
1.879591 - 9.691747
9.691748 - 42.054853
(c)
20100211
LST_coe
-40.701432
-40.701431 - -9.909242
-9.909241 - -1.232883
-1.232882 - 0.122841
0.122842 - 1.205760
1.205761 - 9.000242
9.000243 - 27.757678
(d)
20100306
LST_coe
-31.235214
-31.235213 - -5.198715
-5.198714 - -0.845777
-0.845776 - 0.121959
0.121960 - 1.194420
1.194421 - 5.522435
5.522436 - 23.935167

(e)

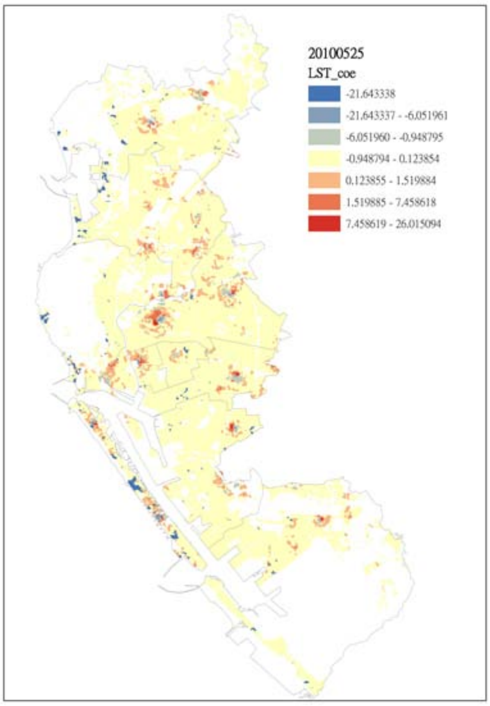


Figure 4. The spatial pattern of GWR modelβ_1. In (a), most part of positiveβ_1 values concentrate in number 1, 5, 6, 7, and 8. In (b), the positive β_1 values are almost in the densest building part of Kaohsiung City (district 2, 3, 5, 6, 7,and 8). In (c), the ratio of high and low β_1 values decreases, while in (d) the places with high value increase. In (e), there are more high and low values in district 10.

Discussion

Table. 3 Comparing OLS and GWR model

	Date				
Parameter	**2009/8/19**	**2009/10/29**	**2010/2/11**	**2010/3/6**	**2010/5/25**
AIC(OLS)	405707.1731	438151.982	227371.5155	274234.0747	270174.6782
AIC(GWR)	-184.297666	-297.259674	-3053.677896	-1829.97094	-433.569911

The result shows a great interpretation for GWR model and Temperature to mosquito numbers. According to the OLS and GWR results, we could know that under OLS assumption (that is, the dependent and independent variables are all normally distributed, and all dependent variables are independent on one another), the wiggler number is not well interpreted by LST (the R^2 cannot even explain 1% variance). The Jarque-Bera test tells us that there are other variables to be accounted in this model, or there is a non-stationary relationship between them. We then run GWR model to further explore the model, and the AICs show better results than OLS regression (Table.3).

In Figure. 4,we can see an obvious non-stationary of all the LST. On August 19th in 2009 (Figure. 4 (a)), with the largest range of all (range is some 142), the β_1 values are more evenly distributed than other dates. On October 29th in 2009, the higherβ_1 values (in red) are concentrated in the densest building area. On February 11th in 2010, when Kaohsiung was in winter, high values are centralized in some smaller areas; while on March 6th, those clusters are on other places. On May 25th, the cluster in district 3 and 5 on March 6th are still there. According, we can roughly see the temporal variation of β_1 increases on October 29th, then decreases on February 11th, almost the same on March 6th, and decreases again on May 25th.

Interestingly, the north part of district 9 has almost no effect on wiggler number. It might be caused most by the interpolated wiggler numbers (lots of the wiggler numbers are 0, even after IDW, lots of them are close to zero). Or, it is a place where its temperature does less impact to mosquito numbers.

Another one is that the high values are often accompanied with low values. It might suggest that some buildings with higher contribution to wiggler numbers are surrounded by lower ones. Maybe we can examine the finer level on building area, such as land use to find out the reason to do further research, in order to pre-control the mosquito number.

The results do show a spatial non-stationary, however, we suppose that the building area remains the same in our study. In doing so, we would not know in this time period how the effect of change in the building area.

Conclusions

The study provides an insight into how the LST in the building area works with mosquito number, and indicates where have more influences than others. We can try to interfere with mosquito number through different LST before they reproduce, or try to find the reason behind the low LST areas.

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