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Geospatial Modeling of Surface Temperature of Hatyai City, Thailand

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Abstract. The high temperature of urban heat island (UHI) which is higher than the surrounding rural areas not only affects the comfort of urban dwellers, but also increases energy consumption and the number of deaths for humans due to heat wave. The purpose of this study was to investigate the differences between deterministic and geostatistical approaches in predicting the temperature and humidity surface map of Hatyai City and to determine the UHI indicators from the remote sensing data. The deterministic and geostatistical models (IDW, Ordinary and De-trend Kriging) in creating temperature and humidity map of the city were compared. The results indicated that the temperature and humidity data were relatively normal in distribution and there was no transformation needed in the kriging model construction. The temperature and humidity data showed that the trend tended to exist in both north-south and east-west directions. However, there was no significant improvement of the predicting maps in term of prediction error and mean square error. The spatial characteristics of the normalized difference vegetation index (NDVI) and normalized difference built-up index (NDBI) were closely related to the UHI and could be used as indicator to identify optimum of urban green space allocation.

Keywords: Urban heat island, geospatial modeling, surface temperature, NDVI, NDBI

1. Introduction

Urban Heat Island Effects (UHI) is a phenomenon that the city temperature is higher than the natural environment temperature in suburban [1].The UHI are formed by the temperature rising in any human-made area in comparison to the lower temperature levels of the nearby natural landscape of the area [2], [3]. Higher temperatures not only affect the comfort of urban dwellers, but also increase energy use, ozone production, and the risk of death for humans in a heat wave. The urban green space can slow down UHI Effect. Numerous studies have shown that green space were effect of cooling about 2℃ compared to the town covered with concrete and asphalt surface [4].

Recently, it is still difficult to recognize spatial pattern of surface UHIs with in situ observation data due to their limited spatial coverage and poor spatial resolution [5].Different interpolation methods have been used to model the spatial distribution of air temperature. The most widely used are the inverse distance interpolation weighting, Voronoi tessellation, regression analysis or, more recently, geostatistical methods [6] -[8]. Several environment and spatial characteristics have been proposed as the effective UHI indexes, such as normalized vegetation index (NDVI) [9], [10] and the normalized difference built-up index(NDBI) [11], [12].Both indexes can be extracted by using remote sensing data [12]. Hence, the purpose of this study was to construct spatial database of UHI and to determine the relationship between spatial characteristics of NDVI, NDBI and UHI of Hatyai City.

2. Objectives

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The main aims of this paper were to compare different deterministic and geostatistical approaches in predicting the temperature and humidity surface map and to determine the UHI indicators from the remote sensing data.

3. Materials and Methods

3.1. Study area

Hatyai City and its vicinities are in southern Thailand near Malaysian border. It locates at 7°1′N 100°28′E, having a population of 203,035 in the city itself and about 800,000 in the greater Hatyai area. Hatyai is the largest city of Songkhla Province, the largest metropolitan area in the south, and recognized as the major economic center of the lower southern Thailand.

3.2. Temperature and Humidity data

The air temperature and humidity data as measured during 10.30 am -12.30 pm on 27^{th} - 29^{th}April 2012, with the total of 117 sampling locations covering Hatyai City. The mean temperatures in °C and humidity were used for the analysis.

3.3. The Exploratory Analysis and spatial models

The method comprised a set of techniques and estimators which used the spatial variability and correlation of a continuous spaced-distributed phenomenon to predict at unsampled locations. They generally consisted of two steps: a preliminary data exploratory and structural analysis of the information in order to describe the spatial variability of the variable, and the spatial prediction at unsampled points. The deterministic and geostatistic model were used for interpolating temperature and humidity values were made by forming weights from surrounding measured values. These values were used to create predictions at unmeasured locations. The ordinary kriging and de-trend kriging were next compared. The ordinary kriging equation was used to make the predictions.

$$Z(s) = \mu + \varepsilon(s) \tag{1}$$

With: S = an (X, Y) location space, Z = the amount of temperature/humidity at that location

The model assumed that there was no trend associated with the data, and a constant mean µ. It was also assumed that any random Ɛ(s) process was stationary. The de-trend kriging identified with the trend was then removed from the data and kriging on the detrended data.

3.4. NDVI and NDBI index

The normalized difference vegetation index (NDVI) and the normalized difference built-up index (NDBI) obtained from Landsat 5 TM were used to characterize the land use/cover types in the study area to study the relationship between land use/cover type and quantitative UHI. NDVI was generally used to express the density of vegetation [13].

NDVI = (ρ (band 4 – p (band 3)) / (ρ (band 4 + p (band3)) (2)

where, ρ represented the radiance in reflectance units, band 3, band 4 and band 5 represented the spectral bands of the Landsat images.

Another index, NDBI [11] was introduced in this study, which was sensitive to the built-up area.

NDBI = (*d*(band 5)−d(band 4)) / (*d*(band 5) + d(band 5)) (3)

where, *d* represented the digital numbers (DNs) of the relevant Landsat TM or ETM+ bands.

4. Results and Discussion

4.1. Exploratory Analysis

Exploratory analysis was made to examine the distribution of the concerned data. The possible trends in the data were help to understand the spatial autocorrelation and identify any directional influences of the data for fine-tuning of the prediction model. The location and distribution of temperature and humidity data collected at Hatyai City as shown in Fig. 1

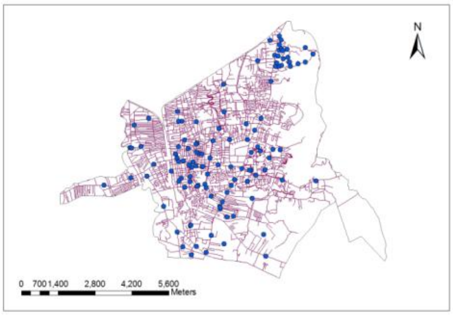
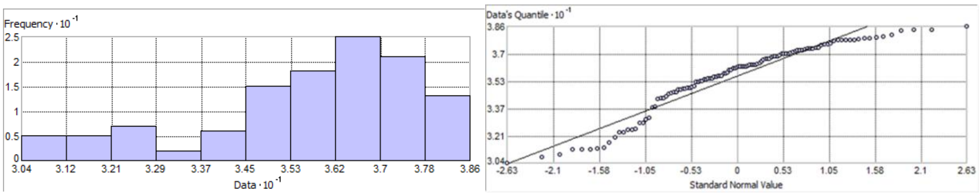


Fig. 1: The sampling locations used for measuring temperature and humidity

4.2. A histogram

The histogram of the data set showed that there was a skew to the left. Also, the mean was smaller than the median (mean value of 35.619 and median value of 36.16) of the set. The mass of the data distribution concentrated on the right (Figure 2a). The data were also plotted on a Normal Q-QPlot in order to compare the data to a normal distribution (Figure 2b). The data were relatively close to the normal distribution with the only significant distance from the line occurring at values with a small amount of mean temperature.



(a) Historgram (b)Q-QPlot

Fig. 2: Histogram and Q-Q plot of temperature

However, the degree of skewness considered in the analysis was not seriously violated as the values of 2 standard errors of skewness felt within the range (0.447 was less than the skewness of 0.9035) and the transformation of the data was not necessary.

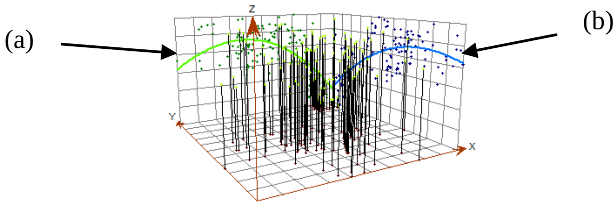


Fig. 3: Trend Analysis Diagram of Mean Temperature data

The green line (a) of the trend analysis diagram was the east-west trend line, while the blue line (b) was the north-south trend line. The diagram showed that there were relatively higher temperature values at the center part of the dataset of both directions of east-west and north-south, which corresponded to the center of the built-up commercial zone in comparison with the surrounding zone of higher green space. The second order polynomial was found to be the best fit of these trends (Fig. 3).

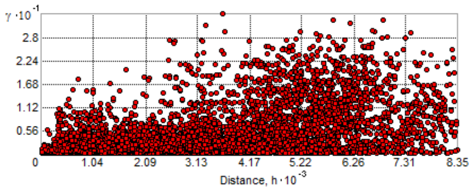


Fig. 4: Semivariogram of the average temperature of the Hatyai City on 27th -29th April 2012.

The spatial autocorrelation between all measured sample points was shown in the semivariogram plots (Figure 4) by comparing the mean temperature among all pairs of the points against the distance between each pair. This study found that there was a clear spatial autocorrelation in the dataset, which was indicated by the smaller semivariogram values between the close locations, while points with greater distances between them tended to have higher semivariogram values. A large number of points that sticked out above the cloud of values in the semivariogram was due to the clustering of low temperature data at the city park location at the NE part of the dataset. A second-order polynomial was used to remove the global trends in the kriging model. By removing the trend in the data, the spatial autocorrelation between points can be modeled without having to consideration of the trend in the data. The trend was then added back before the final surface model was created.

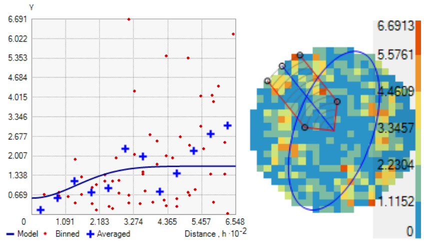
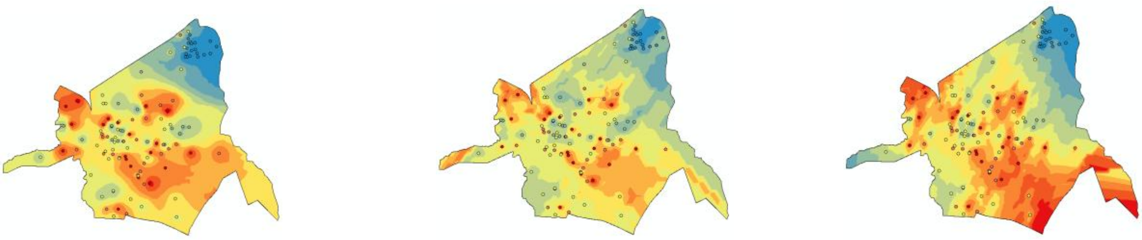


Fig. 5 Semivariogram map and the trend surface of semivariogram map

4.3. Model Evaluation

The interpolated temperature surface maps from 3 models (IDW, Ordinary and De-trend Kriging) were compared. The quick deterministic interpolator of IDW served as a good way to look at an interpolated surface (Fig. 6). The cross-validation charts showed comparison of actual and predicted values using different models. This result demonstrated that the prediction from all models made relatively accurate predictions. This finding was further shown by the best fit line which was close to the 1:1 line (Fig. 7).

The prediction accuracy of the predicted temperature map was found to be acceptable in term of standard prediction error and mean absolute error as indicated by the mean prediction error of close to 0, and the root mean square error close to 1 (Table 1).



IDW | Ordinary Kriging | De-Trend Kriging

Fig. 6: The prediction map of temperature map of study area

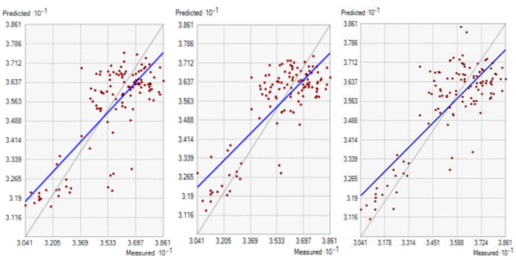


Fig. 7: Cross validation chart of the IDW, Ordinary Kriging and De-Trend model

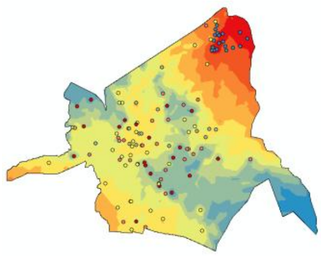


Fig. 8: The average humidity map from De-Trend Kriging model.

Table 1: Error statistics based on cross validation for different interpolators.

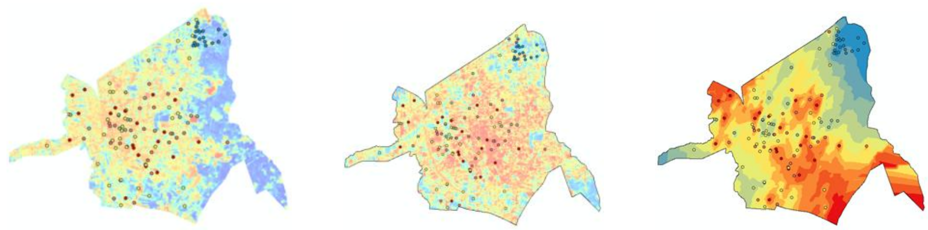
Error Statistics	IDW	Ordinary Kriging	De-Trend
Mean prediction Error	-0.213	-0.023	-0.039
Root Mean Square Error	1.256	1.187	1.2132

The predicted humidity map of the study area showed almost exactly opposite of the temperature map. The high temperature area in the city trended to possess lower humidity values, with average of 54% humidity compared to the high values of 65% at the city park at the NE part of the city.

4.4. NDVI and NDBI index

The values of NDVI were closely related to the percent vegetation covering of the study area and it was negatively related to the temperature level when NDVI was limited in range. The spatial distribution of heat islands was also related to the concentrated urbanized area. The high value of NDVI distributed in the east, north and northeast of the city. These areas were mostly vegetation covering with rubber plantation and city park areas. The area with lower value of NDVI was mainly located in urban and dense residential areas with less vegetation (Fig. 9a).

On the other hand, the value of NDBI was found positively correlated with temperature. The high value of NDBI was located with a scattered pattern related to the bare land, semi-bare land and city centers where temperature was warmer than vegetation land use type in the east and northeast outskirts of the city. (Fig. 9b).



(a)NDVI (b)NDBI (c)De-trend

Fig. 9: The NDVI (a), NDBI (b) as compared to the temperature level from De-trend model map.

5. Summary

The exploratory analysis has shown that the mean temperature data was relatively normal distribution apart from a small skew to the left due to a clustering of low temperature values in the northeast corner of the dataset at the city park location area. There was no transformation needed in the kriging model construction. The trend analysis was shown that it existed in both north-south and east-west directions. The second-order polynomial was best fit to the trend for the accurate prediction of the temperature surface map. NDBI and NDVI indices could be used to provide methods of predicting spatial characteristics of the UHI for the establishment of environmentally and friendly urban planning.

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