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Quantifying the relationship between impervious surface and urban heat environment in the southeast megalopolis of Vietnam

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Abstract

The impervious surface (IS) in urban area is known as the main component to impact on urban climate as it changes the land surface temperature (LST). It is also a kind of urbanization indicator when the land surface is changed by constructing materials. This paper presents the study on the relationship between LST and IS, carried out by investigating with urban factors extracted directly from the satellite image (IS, vegetation ND and open water WA) and the official census (population density PD) for Ho Chi Minh City (HCMC), a megalopolis of Vietnam rapidly developed from natural to artificial impervious landscape. IS was extracted by the integrated technique when using Maximum Likelihood Classification method with the thresholding NDVI. The final classification results achieved high accuracy (overall accuracy about 95% and Kappa coefficient about 0.9). LST was retrieved from the thermal infrared band using Planck law and corrected to the surface emissivity. The statistical analysis was carried out with multivariate regression between LST and IS, ND, WA, PD. The results show that LST is highly correlated to IS (r=0.873) and has the positive relationship with IS and PD, but negative relationship with ND and WA. In the linear multivariable regression by weighted least squares method with the IS as the weighted variable, it was found that IS variable plays a highest positive role (Beta=0.42) impacting on the change of LST in HCMC. This research can be used as reference to support the management of urban thermal environment and protect public healthy.

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Introduction

The urban climate change today has been known due to the concentration of population, expanding the living space and changing the materials constituting the Earth's surface (Yamashita and Sekine, 1991). These changes as well as land cover alteration in the urbanized area are the main impact of warming at local or regional level. Many studies have analyzed the impact of changing land surface to urban heat island (UHI) (Kim, 1992; Quattrochi and Ridd, 1994; Weng, 2003). These studies have shown that changing the land surface can cause local temperature increases in range from 1.7-2.2^{o}C for major metropolitan areas in the summer and 5.6^{o}C in winter when compared to surrounding suburbs. Overall, these studies indicate that the building materials of the urban environment have a great influence on the absorption of solar radiation and the emission back into the lower layer of the atmosphere, thus increasing the temperature of the surrounding air. When natural vegetation is removed and replaced with the IS lacking the evaporation ability, the exchange of latent heat is found higher in areas with more vegetation, while the exchange of sensible heat is predominant in areas with less vegetation but large number of IS.

The model of land surface temperatures is indicative of the existence of the surface energy balance and has been studied with remote sensing technology. The satellite thermal infrared sensors measure radiation outside the atmosphere, thereby brightness temperature of the land surface (also called blackbody temperature) can be derived with the use of Planck law. The difference between exo-atmospheric and land surface temperature ranges from 1 to 5K in 10-12µm spectrum depending on atmospheric conditions (Prata *et al.,* 1995). Study on land surface temperature shows that the division of the heat fluxes and surface energy response is a function of changes in the water content of the soil surface and vegetation cover (Owen *et al.*, 1998). For areas without vegetation cover, surface temperature measurement is typically represented as radiant temperature of the surfaces receiving radiation from the sun as bare soil and IS. When increasing the amount of vegetation cover, radiant temperature is recorded by the sensor closer to the temperature of the green leaves and canopy in plant spectrum maxima (Goward *et al.*, 2002).

Meanwhile, the movement of water from the active and sub-surface to the atmosphere is an important process, because most solar radiation energy, absorbed by the surface and transferred into latent heat, cannot be used to increase the temperature as sensible heat. Many studies (Shafir and Alpert, 1990; Oke *et al.*, 1999) analyzed the role of the hydrological cycle in the energy balance of the atmosphere in urban areas. These studies assume that the total energy including the latent heat is always dependent on the availability of surface water to make the evaporation process to cool the upper atmosphere layers.

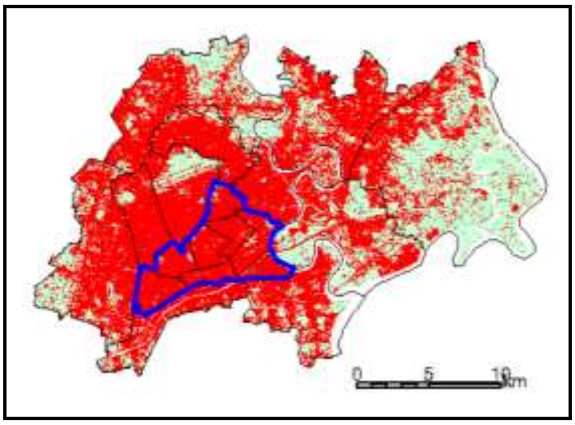
The main impact of the IS, water and vegetation mentioned above has the climatological meanings for urban atmosphere at different levels, and all these factors are associated with population growth and impact. Population growth requires the need for the housing sector. The activities associated with humans also being developed to cater to the survival. All these activities have contributed to the overall increase of the air and the surface temperature of the urban area. Oke (1973) had shown that, even urban areas with a population of 1,000 people will have the urban heat about 2.2^{o}C compared to surrounding rural areas. While research on UHI of Houston, Texas, Streuker (2003) found that the surface temperature of this city was increased 0.71K with a population density of 1,000 people over 1km^{2} in 2000.

This paper presents the study on the relationship between LST and IS, carried out by investigating with other urban factors extracted directly from the satellite image (IS, vegetation ND and open water WA) and the official census (population density PD). Our objective is to explain which of these factors has the strongest effect to the change of LST at city scale in Vietnam, to further support the management of urban thermal environment for public healthy.

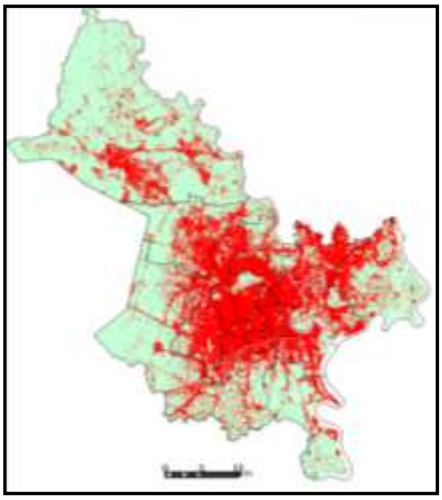
Materials and methods

Study area and data

Ho Chi Minh City (HCMC) is located in the South of Vietnam. Nowadays, HCMC is a young megalopolis in the stage of formation. The urban areas are mainly concentrated in the central of the city. The northern part is the agricultural land; the southern one is low-lying land with dense mangrove forest. The city is facing many challenges such as controlling spontaneous sprawl, realizing urban renewal, increasing the housing stock particularly for low-income families and protecting and developing green spaces and open water. The strong socio-economic growth with the population explosion has resulted the city extension, bringing considerable change to the city look. The study area has experienced great changes in the past two decades and undergone a quick urbanization process since 1989-1999. This period was marked by the Renovation policy, characterized by the economic opening-up and the market liberalization. The consequences of this opening were gradually felt. The residential control slackened, economic growth strengthened, and the disparities between urban and rural areas increased, have attracted an increasing number of immigrant towards the city. By statistic data in 2010, HCMC has population of more than 7 million in the total area of 2.095km^2, where in the city center the population reaches about 6 millions with population density by 12,267 per/km^2. (This does not include unregistered immigrants and visitors who are living and working in the city). The immigration increase in 2010 is two time higher than the natural increase (2.07% compared with 1.04%) (Fig. 1d).



(a)



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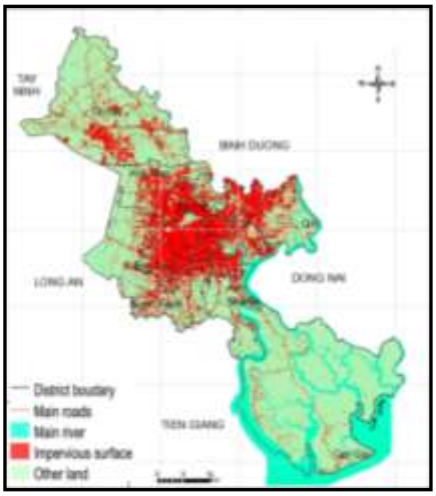

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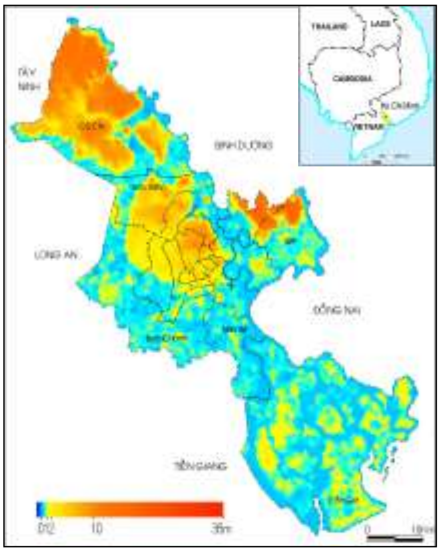


(d)

Fig. 1. IS distribution in comparison with different administrative scale of HCMC: (a) in 19 urban districts; (b) in northern part city without Can Gio district; (c) in whole city; (d) topographical map.

To quantitatively measure LST and urban land cover such as IS, vegetation and water in the study area, Landsat 5 TM image acquired on February 11, 2010 was selected. Image thermal band 6 with 120m-spatial resolution in the atmosphere window of 10.4-12.5µm was used for deriving the LST. Band 1-5 and 7 have a spatial resolution of 30m were used for extracting urban land cover. Additionally, the digital topographic map with a scale of 1:25000 was used for geometric correction and image statistic calculation. Census population data in 2010 was collected from the HCMC Bureau of Statistics.

Methods

Impervious surface extracted from satellite image

The satellite sensors record the earth surface images from the radiation value which depends on the land cover spectral characteristics. Urban areas are heterogeneous and complex with different kinds of the impervious construction materials, which exhibit different reflective and absorptive capacity. So the IS will be one land cover category for indicating the urban area in this study. In digital interpretation, the confusion of the bare land, moisture land and urban IS in the satellite images usually happens. Therefore, detecting and interpreting IS from satellite images require the integrated techniques plus the expert knowledge for the high accuracy. In this study, the IS type will be retained as the main category distinguished with other non-IS types in the whole process of digital image. At first, the supervised classification - Maximum Likelihood Classifications - was used for extracting 4 main types of land cover, including IS, bare land, vegetation and water. Supervised classification method shown that IS was excellently separated from water and moisture land, but some bare land was mixed into that one. The Normalized Difference Vegetation Index (NDVI) image then was used for making threshold, where the NDVI value less than "0" usually represents for urban IS and water types. Classified IS and threshold NDVI images were multiplied to remove the mix pixels. The final IS result was accepted for setting up the map of urban spatial distribution. In addition, the land cover type as vegetation and water will be extracted from classified image and be used in statistical analysis.

The NDVI image is computed from the red (0.63-0.69µm) and near-infrared (0.76-0.90µm) bands of Landsat data as follow:

$$NDVI = \frac{NIR - Red}{NIR + Red} \qquad (1)$$

Retrieving of land surface temperature

By (Gupta, 1991) the radiant temperature (T_R) is defined as the equivalent temperature of blackbody which would give the same amount of radiation, as obtained from a real body. The radiant temperature depends on actual surface temperature (T_S) and emissivity (ε). It corresponds to the temperature actually obtained in a remote sensing measurement. In the case of non-blackbody, the total amount of radiation (B) emitted, is given by the Stefan-Boltzman's Law as:

$$B = \varepsilon\sigma T_R^4 = \sigma T_S^4 \qquad (2)$$

This gives

$$T_S = \frac{1}{\varepsilon^{1/4}} T_R \qquad (3)$$

Where σ is the Stefan Boltzmann constant ($5.67 \times 10^{-8} Wm^{-2}K^{-4}$). The radiant temperature for a natural body will thus be less than that for the blackbody at the same temperature. This also implies that temperature measured by remote sensing methods are less than the surface temperature by a factor of $\varepsilon^{1/4}$. Emissivity (ε) for a blackbody is unity and for most natural materials is less than 1.

Satellite thermal infrared sensors measure radiances at the top of the atmosphere, from which brightness temperatures T_B (also known as blackbody temperatures) can be derived by using Plank's law (Markham and Barkewr, 1986):

$$T_B = \left(\frac{hc}{k\lambda}\right)\left(\frac{1}{\ln\left(\left(2hc^2\lambda^{-5}\right)/B_\lambda + 1\right)}\right) \qquad (4)$$

Where h is Planck's constant (6.62×10^{-34} J-sec), c - velocity of light (2.998×10^8 m/sec), λ is wavelength of emitted radiance (m), B_λ is blackbody radiance ($Wm^{-2}\mu m^{-1}$). Here $T_B = T_R$, so the formula (3) can be rewrite as following:

$$T_S = \frac{1}{\varepsilon^{1/4}} T_B \quad (5)$$

Emissivity is a property of materials controlling the radiant energy flux. It is very critical for determining the surface temperature, therefore, corrected LST for emissivity should be performed. Emissivity for natural surfaces may vary significantly due to differences in soil and vegetation cover characteristics (Van De Griend and Owe, 1993). According to the study of (Valor and Caselles, 1996), the surface emissivity was calculated from NDVI values by using the formula:

$$\varepsilon = \varepsilon_v P_v + \varepsilon_s (1 - P_v) \quad (6)$$

Where ε_v, ε_s are the emissivity of the full vegetation and bare soil, P_v is the vegetation cover fraction. They can be calculated by NDVI according to the following equation (Carlson and Ripley, 1997):

$$P_v = \left(\frac{NDVI - NDVI_s}{NDVI_v - NDVI_s} \right)^2 \quad (7)$$

Where $NDVI_v$ and $NDVI_s$ are the NDVI values of full vegetation cover area and of bare soil.

Statistical Analysis

The analysis of the effect of IS on urban thermal environment was carried out by investigating its relationship with other urban factors. Urbanization is a process of transformation of the territory into urban. Original territory could be agro-forestry land, vacant land, bare hills or rural residential area (Vo Kim Cuong, 2004). Population becoming crowded, has led to demand for housing and infrastructure increased rapidly, meaning that increasing the area of impervious surfaces. Besides, green area and a small open water on agricultural lands also disappeared for building land. That is also the processes of land surface change happening in HCMC. From this argument, when considering component affecting the change of the urban thermal environment, three satellite images-based factors of urban land cover, which were related to the surface transition, were investigated and quantified to analyze the correlation such as impervious surface area IS, vegetation cover area ND and water surface area WA. They all was calculated in unit of % area. In addition, PD factor as population density (unit of person/ha) was also taken into consideration. This variable is not related to the land surface processes; however, in practice, it is also a criteria considered in the process of urbanization and has significant impact on the change of urban temperature as mentioned above.

The input data set is statistics about the area and is extracted directly from the satellite image including IS variables, ND, and WA. LST is restored from the thermal infrared channel with Celsius unit. These values have the advantage of being objective and highly reliable, regardless of the statistical survey data with many errors due to the subjectivity of surveyor. Area measurement of the IS, vegetation cover and water surfaces are averaged for the 24 district, which are then converted into a percentage. Population density data PD is taken according to the HCMC Department of Statistics.

Results and discussion

Impervious surface patterns in HCMC

The results of IS classification from Landsat image processing were assessed by ground truth survey. 200 ground truth samples of urban IS were taken on the whole city. The result of image-derived IS was obtained at a fairly high accuracy with the overall accuracy about 95% and Kappa coefficient about 0.9. With this precision, the result of urban IS extracted from the integrated technique of this study is sufficiently reliable for establishing distribution map of urban space.

During the development process, HCMC undergone several administrative boundary changes. From the beginning, the city covered the area of Saigon-Cholon and Gia Dinh, now expanded to an area of 2095 km^2. Historically, the northern part of Ho Chi Minh City was urbanized rapidly after the time of separating the five new district (7, 9, 2, 12 and Thu Duc) in 1997. Fig. 1 and Table 1 present the IS distribution in different administrative scale of HCMC in 2010. The IS was concentrated and expanded from the central part of the city with a growing tendency to the North, West and East and along the main roads.

The IS area by 2010 accounted for 24.78% nearly 1/4 of the total area of the city. The entire suburban district Can Gio is the mangroves land, so IS changes were not much. If HCMC does not take Can Gio, the proportion of the IS, compared with the whole region, was increased fairly high and accounted for 37.71% more than 1/3 of the entire city (fig. 1b). Especially in the urban core (located in the thick border on the fig. 1a), including 8 districts, the IS area takes up most of the land surface of about 93.09%, except for the green parks and rivers. If scaling of space including 19 urban district, the IS area covers more than half the area of the city, accounting for 61.25%. Meanwhile, the IS area in the suburban district is very small, only about 13.52%. The distribution of IS area quite fit the topography of the city. Urban development focuses on high ground in the central core, north and east of the city. The southern part is low and weak ground, so built-up land development will be difficult. However, vacant land in the central part is no longer, but the population is growing, making the need to develop housing for city resident increasing. In these lowlands suburbs, the ground has been enhanced up to create IS for housing construction and the place of entertainment. This is a vast land area but low investment cost; moreover, this is also considered for expanding the city's development in the future, so many buildings have been invested more and more. By calculation the rate of urbanization in suburbs districts rises such as Cu Chi by 16.99%, Binh Chanh by 23.56% and Nha Be by 28.80%. With the development trend of the population, particularly migration from other provinces, and forecast to the year of 2020, the HCMC population will increase to 10 million people (Le Van Thanh, 2006), so the need to expanding the IS area is sure to happen and can fully cover all the city's rural land.

LST differences on IS distribution and land cover types

The satellite image retrieved LST maps show the picture of LST distribution in an area. To check the accuracy of the satellite LST retrieval results, we collected the temperature from meteorological stations. Measurements were carried out in the day of acquired image at 10a.m. when the satellite passed over the area. Therefore, the Landsat image LST value was used to compare with this ground one. It showed that the bias of estimated values and ground measurements were less than 2^{o}C. The map in Fig. 2 was produced to show the spatial distribution of emissivity-corrected LST in 2010. The highest LST (greater than 45^{o}C) were found in the industrial zones, where high temperatures were caused by production activities as well as solar radiance. The urban areas have experienced temperatures ranging between 36 and 40^{o}C. However, in suburban areas where agricultural land still remains with full vegetation cover, the LST is usually lower. Some hot spots were found in the entire study area. In the LST map, an extensive hot spot was concentrated in the 19 urban districts located in central part of the city. A second SUHI was developed in the north of the city in Cu Chi district. The last one was located in the south-west belonging Binh Chanh suburban district. This is another look on hot spot due to the existing bare land after harvested crop in dry season.

Table 1. Distribution of IS area in different administrative scale of HCMC.

Urban scale	Percent of IS area (%)
in whole city	24.78
in northern part of city without Can Gio district	37.71
in urban districts (19 units)	61.25
In urban core	93.09
in suburban district (5 units)	13.52

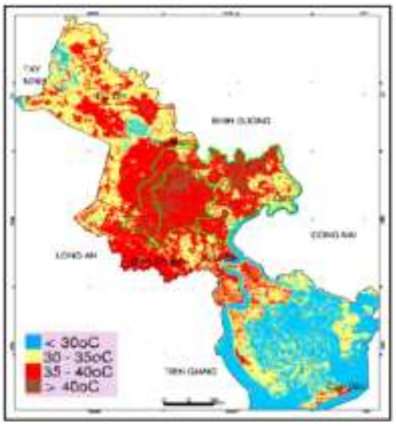


Fig. 2. LST image retrieved from Landsat TM on February 11, 2010.

A diagram on fig. 3 illustrates mean LST value by district compared with the percentage of IS area accounted in that one. This shows that the distribution of impervious surfaces is strongly positively related to LST value. The LST map shows the extension of the high LST areas with the expansion of developed urban areas. High mean LST (>38ºC) mostly concentrated in the urban core and urbanized districts (Go Vap and Tan Phu) with the high percentage of the IS area (>80%). The suburban districts own low mean LST (<35ºC), particularly the mean LST value in Can Gio suburban district is the lowest about 30°C with the percentage of the IS area only about 2%, due to a large of wetlands and evergreen mangroves.

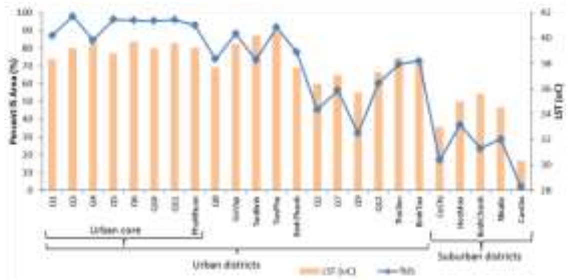


Fig. 3. Correlation between the IS area percent and mean LST value in each district.

Chart on fig. 4 presents the mean LST on different types of land cover. Highest mean LST was found on the ISs. Lowest mean LST was shown on the water and vegetation. Mean LST on bare land was higher than on vegetation and water but lower than on the ISs. The difference of mean LST between bare land and IS is about 1.37ºC, while the difference of that one between the IS and vegetation is about 4.3ºC and between the IS and the water is 5.3ºC. This can be explained as follows, solar radiation reaching the ground will impact directly to the different types of land cover, in turn, each type of land cover with different material composition will response different thermal situation. Due to the heat retention and incapability to evaporate from the IS when illuminated by solar radiation, the surface temperature on the IS will elevate. Conversely, when solar radiation reaches the vegetation and water surfaces, evaporation process will occur and make their surface temperature lower.

Meanwhile, under the influence of solar radiation, the surface temperature on the bare land can change depending on the amount of water contained in the soil: on moisture bare land, evaporation process will take place, making the surface temperature lower than that of the dry bare land. Thus, the temperature difference of the land cover types will have impact on the thermal environment. This is something to keep in mind in the process of urban development. Vegetation and water have the potential to reduce urban heat, so it needs to strengthen the open water and the greenery. Bare land also increases the heat, so instead of barren land, we should plant trees to help reduce the heat environment.

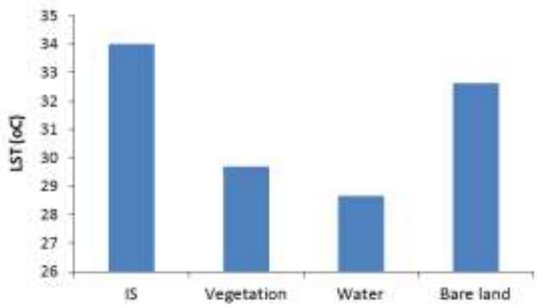


Fig. 4. Mean LST on different urban land cover.

Relationship between LST, IS and other urban factors

In this study, statistical analysis will be performed in 2 parts:

- analyze the correlation and univariate regression in pairs
- correlation analysis and multivariate regression for all participating variables

Where, the independent variables are the IS, ND, WA and PD, the dependent variable will be the LST.

Univariate linear regression to explain the relationship between LST and each urban component

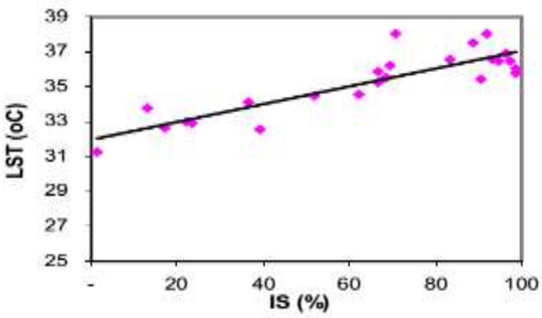
Pearson correlation coefficient (r) is used to measure the relationship between LST and urban factors. This is a statistical indicator to quantify tight degree of linear relationship between two quantitative variables.

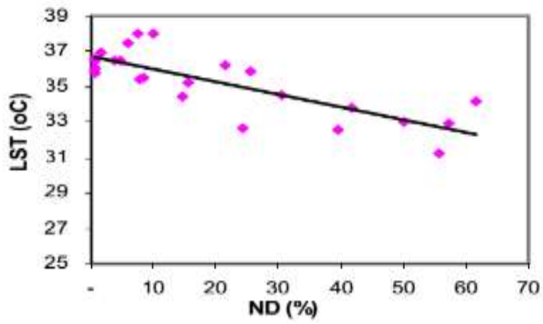
Its values range from -1 to +1. The correlation coefficient equals 0 (or nearly 0) means that the two variables are not related to each other; whereas, if the coefficient of -1 or +1, which means the two variables have an absolute relationship, in opposite or positive directions. Table 2 is the result of linear correlations between pairs of variables, where, the best correlation was found between LST and IS with absolute value of Pearson coefficient |r|=0.873, next, was between LST and ND with |r|=0.800. The correlation between LST and PD only is passable with |r|=0.708. Lowest correlation occurred between LST and WA variables with |r| =0.689.

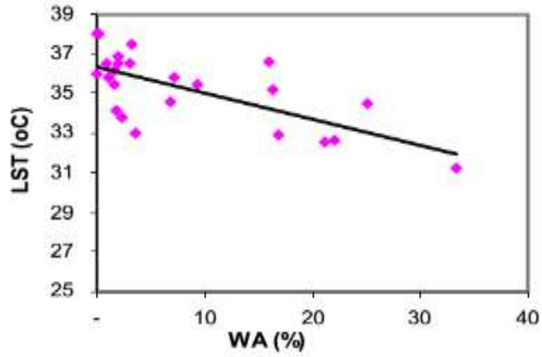
Table 2. Statistics of univariate regression in pairs.

Variable pair	r	Sig. F
LST-IS	0,873	0,000
LST-ND	0,800	0,000
LST-WA	0,673	0,001
LST-PD	0,708	0,000

Scatter graphs are used to represent the relationship between surface temperature and the variables describing urban land cover. Fig. 5 shows that the relationship between LST and variables IS, PD is a positive, i.e. LST tends to rise when these variables increase; the relationship between LST and variables ND, WA is negative, i.e. LST tends to decrease when they rise.







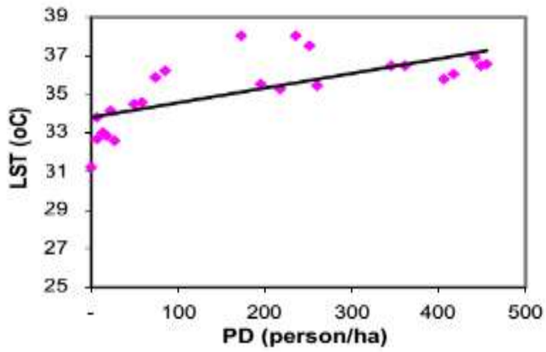


Fig. 5. Scatterplot and linear correlation shape between LST and IS, ND, WA, PD.

Multivariate linear regression to explain the relationship between LST and urban components

Entities existing always have a mutual relationship with each other, so, practically impossible to separate consideration of each factor without calculating other impacts. On a total natural area, while increasing the IS area, we certainly will have to reduce the area of vegetation cover (farmland, forest...) or to level, or encroach on part of the water area (ponds, lakes, rivers). In the case of having to increase the population density, it is required to increase the IS area for housing demand and living facility for humans. As many influence factors, it will be certainly a multifactorial relationship, not just the relationship of each individual factor as in the univariate regression. The correlation relationships between phenomena are usually expressed in the linear equation form. In many cases, the fact is that the relationship is non-linear, but it is said that "if there is no big error, you can use linear equations to describe roughly and approximately the phenomena, then the calculation process will be simpler. Sometimes the form of the relationship was still unclear, it is also assumed to be a linear relationship" (Nguyen Tran Que *et al*, 2008).

Therefore, the authors have limited research in linear regression model to describe the relationship between the independent and dependent variables. Understanding the basics of linear regression model is the foundation for understanding the more complex ones. In this study, statistical analysis will be performed by correlation analysis and multivariate regression for all participating variables, where, the independent variables are the IS, ND, WA and PD, the dependent variable will be the LST. By that argument, multivariate linear regression equation performing dependence of surface temperature variable with 4 variables representing urban factor will be expressed as:

$$LST = a + b*IS + c*ND + d*WA + e*PD \quad (8)$$

Where, the coefficients a, b, c, d and e must be estimated from input data set. According to the test results on the correlation of variables pairs as above, in the multivariate model, we expect that the coefficients b and e will be positive and the coefficients c and d will become negative.

Table 3 is a linear regression results by Ordinary Least Squares method (OLS). In this table, when testing on each independent variable and the value of T-student and significance level Sig. T of each variable, only the WA variable meets the conditions that T-student is greater than 2 and Sig. T is less than 0.05 (95% significance level). Three remaining variables (IS, ND and PD) are not satisfied. Concluding that the regression coefficients are not statistically significant. In addition, when considering the sign of the regression coefficients, the b, c and d have signs as expected, but e has opposite sign. This indicates that the OLS estimating regression coefficients in this case cannot be used.

Table 3. Multiple linear regression with 4 variables (IS, ND, WA and PD) by OLS method.

Variable	Unstandardized Coefficient LST		Standardized Coefficient LST	T	Sig. T	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
Constant	35.171	1.414		24.873	0.000		
IS	0.0259	0.017	0.448	1.565	0.136	0.110	9.094
ND	-0.0374	0.020	-0.425	-1.897	0.075	0.180	5.564
WA	-0.0617	0.024	-0.330	-2.579	0.020	0.552	1.812
PD	0.0165	0.002	-0.152	-0.741	0.469	0.214	4.676

In this case, the linear regression model with Weighted Least Squares method (WLS) is replaced where the selected weight is one of the independent variables. Under this method, the minimum of the sum of squares of weighted residuals is (Nguyen Tran Que *et al*, 2008):

$$\sum_{i-1}^{n} W_i e_i^2 = \sum_{i-1}^{n} W_i (Ts_i - a_w - b_w * IS_i - c_w * ND_i - d_w * WA_i - e_w * PD_i)^2 \quad (9)$$

Where, a_w, b_w, c_w, d_w and e_w are the weighted estimated regression coefficients; W_i is the weight, expressed as follows:

$$LST_w = a_w + b_w*IS + c_w*ND + d_w*WA + e_w*PD \quad (11)$$

$$W_i = \frac{1}{X_i^n} \quad (10)$$

where n is the exponent of the power so that its value maximizing the function in log of the dependent variable. WLS regression equation determining surface temperature (LST_w) will have the same formula of the OLS regression equation with the corresponding regression coefficient will be:

Table 4 is the result of the correlation coefficient calculated from the multivariate regression by WLS method with weighted variable as different independent variables. The results showed that when choosing IS as weighted variable, the multiple correlation coefficient R and R^2 have the very high value at nearly 1, the adjusted R^2 is very close to R^2, while the standard error is smallest in 4 cases.

Therefore, variable IS is chosen as weighted variable to find the best regression equation.

Table 4. Multiple linear regression by WLS method with different weighted variables (R_w is correlation coefficient).

Weighted variable	R_w	R_w^2	Adjusted R_w^2	Sig. F
IS	0.985	0.971	0.954	0.000
ND	0.939	0.882	0.854	0.000
WA	0.961	0.924	0.907	0.000
PD	0.968	0.937	0.922	0.000

When carrying the regression on four variables, the results in Table 5 showed that the sign of regression coefficient e_w, related to population density PD variable, was true as initial expectations with a positive sign.

In contrast, the test values of PD variable were not satisfied such as T = 0424 <2 and Sig. T = 0.6768 >0.05. Therefore, the regression coefficient of PD variable has no statistical meanings, or it can say, PD variable is not necessary in this case and will be excluded. Continued to implement the regression on the remaining three variables, the results shown in Table 6. Considering the T-Student test for 3 variables IS, ND, and WA, obviously they are satisfied when T >2 with significance level Sig. T <0.05 (i.e. probability to accept false hypothesis is 5%). The regression coefficients related 3 variables as IS, ND, and WA are statistically significant, and the final multiple linear regression equation look like this:

$$LST_w = 34{,}17 + 0{,}03*IS - 0{,}02*ND - 0{,}06*WA \quad (R^2= 0.9687) \qquad (12)$$

Table 5. 4-variable linear regression by WLS method with IS weighted variable.

Variable	B	St. Error	Beta	T	Sig.T
IS	0.027326	0.009579	0.360252	2.853	0.0110
ND	-0.018493	0.008722	-0.165757	-2.120	0.0490
WA	-0.059107	0.007869	-0.522735	-7.512	0.0000
PD	0.000933	0.002200	0.037356	0.424	0.6768
Constant	34.180215	0.528986		64.615	0.0000

Testing the fitness of the regression equation: Initial hypothesis was set out that there is capability of linear relationship between LST and urban factors. R^2 or adjusted R^2 value is considered as the fitness of the model for an input data set. Results in Table 4 show that R^2 = 0.97 or adjusted R^2 = 0.96 is quite large. It means that the results of the multiple linear regression equation (12) is appropriate for the input data set reached 96%, or we can say, 96% difference of mean LST values, observed over 24 districts, can be explained by differences in changes of surface processes, including: impervious surface, vegetation cover and open water. Additionally, the value of the square of the standard error is very small (St. Error =0.029), which showed that the fitness of the equation for the input data set is fairly good. So acceptable multiple regression equation is linear with regression coefficients of the urban land cover variables and significant to analyze and assess the impact on urban surface temperature. Impervious surface variable IS positively impacts on the change of the surface temperature LST, while the variables of vegetation cover ND, and water WA tend to negatively affect it.

Standardized Beta coefficient means describing the relative importance of the independent variables in a multiple regression model (Nguyen Tran Que *et al*, 2008), so it is used to consider the importance of each variable effecting on surface temperature change in this study. Table 7 shows that the IS variable among the independent ones with Beta = 0.42, means the greatest positive effect on the surface temperature changes, i.e. when increasing the area percentage of IS, it will lead to increased surface temperature. The greatest negative impact was found in the area percentage of water variable with Beta = -0.48, next, of vegetation cover with Beta = -0.18. This reflects that the need to reduce the IS area, to increase open water and vegetation cover is necessary to fall down the temperature trend in urban areas.

Table 6. 3-variable linear regression by WLS method with IS weighted variable.

Variable	B	St. Error	Beta	T	Sig.T
IS	0.030302	0.006711	.417460	4.515	0.0003
ND	-0.019577	0.009103	-.177155	-2.151	0.0453
WA	-0.057047	0.007434	-.477803	-7.674	0.0000
Constant	34.166266	0.557930		61.238	0.0000

From multivariate equation above, when separately considering each effective variable, we could to assume the remaining variables not to influence. The natural area of HCMC is 209,500ha, if increasing the IS area to 1% of the total natural area, equivalent about 2,095ha, it will increase the mean surface temperature of the city about 0.03°C. Meanwhile, if we increase the area of vegetation cover or water, it is capable of improving the surface temperature rising due to the inverse relationship of them and LST variable. Specifically, when increasing the area of vegetation cover or water to 1% of the total natural area, equivalent about 2,095ha, it will reduce respectively, about 0.02°C or 0.06°C of mean surface temperature of the entire city.

In fact, if the demand for housing and areas for living, recreation, infrastructure for people to rise, then it will lead to increase the construction, turning natural surfaces into concrete, asphalt, tile roof..., occluding permeable surface. Finally, the evident truth happens that it increases the absorption of solar energy, making urban surfaces hotter. In addition, an inevitable consequence is that this will also increase the surface runoff, the pollution and flooding during heavy rain and high tides. Conversely, if we strengthen area of vegetation cover and open water such as ponds and lakes, the warming urban surface temperatures will be significantly reduced.

Conclusion

The impervious surface is known not only as typical feature representing urban area in urbanization process, but also the main component to impact on urban climate as it changes the urban temperature. Temperature as meteorological factor is very sensitive and is most affected by other natural and meteorological processes, while the urbanization process is influenced by humans. If we know better regulate the urbanization process, it will help mitigate the extent of the current warming. In this study, impervious surface was found and analyzed for HCMC as a megalopolis in South of Vietnam. Its relationship with LST was carried out by investigating with urban factors extracted directly from the satellite image. The three independent variables are all retained during the multivariate regression procedure, which suggests that impervious surface, vegetation and water are all important factors in modulating urban temperature. Impervious surface contributes most positively to LST rise, while vegetation and water act inversely.

In this study, we are limited in a linear regression model, which describes a linear relationship between the three independent variables indicating urbanization related land surface processes and the dependent variable as the surface temperature. Obviously, it is not entirely realistic and very convincing for all kinds of diversified relations in the real world. But understanding the basics of linear regression model above is the foundation for understanding the more complex model when considering additional socio-economic factors, infrastructure... So the this result hints as orientation to help planners and managers more interested in the long-term strategy of building and urban management for HCMC.

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