Environmental Engineering and Management Journal July 2019, Vol. 18, No. 7, 1591-1598
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

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URBAN HEAT ISLAND EFFECT OF CHENGGONG DISTRICT IN KUNMING, CHINA

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Abstract

This paper measures the temperatures along a test route through Chenggong District, Kunming, by mobile measurement, and revises the measured data to 4 different time points of the test period, aiming to enhance the data utilization efficiency. The modified data were plotted into isotherm slices at the four time points, and the urban heat island (UHI) features, as well as its influencing factors were analysed on geographic information system (GIS) software. The results of the measurements showed that, high temperatures were measured in university district, residential area and government administrative area are the highest, reaching 19.94°C, 20.01°C, and 20.05°C, respectively, while the lowest temperature was observed at Guanshan Reservoir, which was only 17.64°C. The maximum UHI intensity stood at 2.41°C, which occurred at 19:30. In addition, cooling effect of local water bodies depends on the size of the water body and the distance from the living area.

Key words: geographic information system (GIS), isotherm, mobile measurement, urban heat island (UHI)

Received: January, 2019; Revised final: April, 2019; Accepted: May, 2019; Published in final edited form: July, 2019

1. Introduction

Recent years has seen a growing occurrence of extreme weather conditions across the globe. In its *Annual Report on Climate System 2016*, Japan Meteorological Agency (JMA) summarized the trends of climate change since 2007. According to the report, the global average surface temperature (GAST) in 2016 was higher than the 1981~2010 average of 0.45 ± 0.13°C, making 2016 the hottest year on record. In addition, the GAST had been rising at a rate of 0.72°C/decade since 1891. High-temperature regions were widely distributed in Eurasia, North America, the tropical Pacific, and the Indian Ocean. The GAST had been increasing continuously, despite some slight variations. This trend is expected to continue in the coming years.

Under the urban heat island (UHI) effect, overheated urban areas spend at least twice as much as other areas to mitigate the risk of climate change. The existing assessment of climate change risk are focused by a few countries and on limited types of disasters, such as the rising sea level and the depletion of water resources. Facing the serious outcomes of climate change, more and more large cities are integrating climate change into their long-term strategy for urban development (Lee et al., 2017; Wai et al., 2017). A team of researchers built a model to quantify the regional and global climate based on the data collected from 1,692 cities around the world, which shows that local mitigation measures for climate risk are easier to execute and more effective than national policies. The adaptation of plans to address urban climate change can slow down the UHI effect, and boost the international emission reduction efforts (Estrada et al., 2017; Kadhim-Abid et al., 2019).

The urban overheating phenomenon was mentioned first by Luke Howard in The Climate of

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London: the temperature of central London was higher than its suburbs, creating the UHI effect. Since then, many research has been done on the thermal environment, especially the effects of temperature on climate. Measurement and numerical simulation are the main ways to survey the thermal environment. Measurement usually takes place in observation sites to conduct fixed-point research, mobile measurement areas to acquire small-scale meteorological data, or remote sensing equipment to cover a large area of land. Numerical stimulation relies on the cutting-edge environmental prediction techniques, such as computer software simulations and wind tunnel experiments.

Numerical simulation relies on computer software to gather various influencing factors of the environment and analyse them without any direct impact on the environment. Through numerical simulation, researchers can determine the thermal properties of their models in different environments and climate conditions, and develop corresponding improvement measures. For instance, Kakoniti (2016) studied the effects of different surface coverings on the UHI by computational fluid dynamics (CFD), revealing that optimizing the material of the underlying surface may effectively improve the urban thermal environment. With the aid of ArcGIS and CFD, Hsieh (2016) investigated the direction of the wind corridor in Taiwan, China, and put forward suggestions about the urban surface in four zones on the basis of the ground data. Roth (2017) gathered the meteorological data from a compact low-rise residential area in Singapore, evaluated a 3D urban microclimate model using ENVI-met 3.1, and managed to capture the daily spatial variation of the study area as well as predicting the temperature reduction effects of five strategies.

Despite its convenience and flexibility, numerical simulation needs to rely on the accuracy of the atmospheric data gained from field measurement. Therefore, actual measurement is still an important area of research. Besides the provision of abundant climate data, actual measurement offers a way to check whether the numerical model is accurate and valid. It is impossible to achieve precise simulation without sound measured data.

The field research on the thermal environment and UHI mainly falls into three categories, namely, meteorological station monitoring, mobile measurement and remote sensing. The advantages of meteorological data are obvious, as these data include the overall climate change features of an area in a certain period of time. Demetris (2015) collected climate data from 6,190 meteorological stations in the northern hemisphere during the period of 1800~2013, which can be used to examine the absolute change in the global climate, and design measures to improve the location of climate sites to the make data more effective. Other representative studies were carried out by Arima (2016) in Japan, Zhong (2017) in China and Woolway (2017) in Europe.

Mobile measurement can obtain a large amount of temperature data along the test route, making it easier to represent the regional heat features in an analysis. Charabi (2011) probed into the thermal environment of Muscat, the capital of Oman, through mobile measurement and meteorological station monitoring, and analysed the effects of temperature data obtained at different locations over the UHI effect, suggesting that the evaluation error in regional UHI effect is inevitable regardless of the benchmark. Through mobile measurement, Yokobori (2009) analysed the diurnal and seasonal variations of the UHI in Tokyo, Japan from 2006 to 2008, and obtained the relationship between the UHI intensity and the adjacent land cover. Borbora (2014) combined mobile measurement and meteorological station monitoring, to study the UHI in Guwahati, India, confirmed that the highest UHI existed at night (2.12°C) based on the mobile measurement data, and discussed the influence of the monsoon on the UHIs in other cities. To disclose the overall temperature change in Xi'an, China, Liu (2007) investigated the relationship between the industrial commercial activity, the water body and the heat island of the downtown using mobile measurement.

Remote sensing, newer than the other two field research methods, was developed after the computer and satellite technologies have matured. Muthamilselvan (2015) used Landsat Enhanced Thematic Mapper (ETM) to estimate the surface temperature of tropical land, such as areas covered by plants and water, to evaluate the thermal environment in the process of urbanization, concluding that vegetation coverage, wetland, and water body are typically at a low temperature, while land and sandy areas are typically at a high temperature. Haashemi (2016) adopted the remote sensing technology to observe the seasonal variation of surface biophysical variables in downtown Tehran, Iran, and estimated the relationship between the seasonal variability of the surface temperature, land use and covering, elevation, impervious surface and reflectance. Krehbiel (2017) analysed the effect of the seasonal development of surface vegetation on the surface UHIs using Landsat data, the normalized difference vegetation indices (NDVIs) in 2003~2012 were taken as a quadratic function of the heating period, and found that the UHI effect is related to the distance of the perennial vegetation to the urban core, regardless of the population or latitude. Liao (2017) extracted the surface temperatures of 2008~2012 in 32 major Chinese cities through Moderate Resolution Imaging Spectroradiometer (MODIS), and quantified the surface temperature at night-time and daytime, revealing that the positive correlation between nighttime surface UHI and energy consumption.

The above studies show that meteorological station monitoring is too regional to reflect the climate trend of a large area, not to mention that of the entire region, and consumes too much time, manpower and material resources to obtain data. By contrast, remote sensing is not subjected to regional constraints, and can obtain complete data on surface temperature using infrared radiation. However, this method fails to provide researchers with real-time dataset of high spatial resolution (Ren et al., 2015) and requires huge technical and financial supports. Mobile measurement, more flexible than the above two methods, manages to acquire lots of meteorological data in a short time and directly measure the temperature 1.5m above ground, reducing the error of temperature inversion in remote sensing. The measured data are close to the human body temperature, because 1.5m is the perceptual location of the thermal comfort zone of pedestrians under the effect of ground thermal buoyancy (Priyadarsini et al., 2008). In addition, mobile measurement is easy to carry out, especially in small towns or new urban districts with few or no meteorological stations (Buckus et al., 2017).

Of course, the meteorological data obtained by mobile measurement should be revised before being used for regional climate analysis, as they are collected at different times and from various places. The traditional revision takes the middle time of the observation period as the revision moment. Wang (2013) suggests revising mobile measurement data to any moment in the observation period, but does not provide any example to explain the revision method.

In this paper, the mobile measurement method is used to study the UHIs in Chenggong District, an area witnessing rapid urbanization in southwestern China's Kunming municipality. The mobile measurement data were revised to multiple moments in the observation period to improve the data utilization efficiency and obtained the spatial distribution features and time variation law of the study area. Considering the lack of meteorological stations and the insufficiency of the mobile measurement method in thermal environment analysis, the temperature images were described by Surfer and Geographic Information System (GIS), before analysing the thermal environment and spatial climate change trend of the pedestrian height in this area.

2. Methodology

2.1. Study area

Kunming, the seat of southwestern China's Yunnan Province, is located between 102°10' and 103°40' E, 24°23' and 26°22'N. The geographical location, coupled with the high altitude (1,892m), blesses the city a year-round spring-like climate. Our study area, Chenggong District, lies in a flat area amidst rolling hills to the east, north and south and Dianchi Lake to the west. In addition to the lake, the study area is crisscrossed by several large rivers and dotted by some small lakes. The wind situation in the study area is influenced by the monsoon in the long-term and the land-lake breeze during the day and night. According to the wind rose of Kunming, the prevailing wind direction in the study area is the southwest.

As shown in Fig. 1, the test route passes through a fluctuating terrain. The temperature changes slightly with the altitudes. For simplicity, this slight effect was neglected and the altitude of the test route was assumed to be constant.

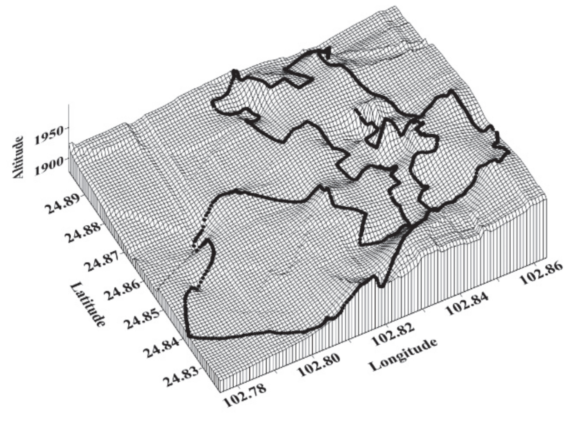

Fig. 1. Test route elevation

2.2. Test plan and devices

To design a proper test plan, the author investigated the impacts of different urban landscapes on the surrounding climate, and designed a test route that passes through all types of landscapes, including empty fields, buildings, dense residential areas, construction sites, and the spacious road adjacent to Dianchi Lake. Firstly, the locations of various urban landscapes were imported to the map and the best routes were selected. Then, a field survey of these lines was performed to avoid areas closed for construction and other inaccessible places. Finally, a concise and feasible route (Fig. 2) was determined for our research. The route was from the starting point (SP), there were four residential areas (Residential District, RD) (Muchunyuan District, RD1; Yuhuayuxiu District, RD2; Shuxiangdadi District, RD3; Hui Lan Park, RD4), four villages (Village, V) (Wujiaying Village, V1; Xiazhuang Village, V2; Sanchakou Village, V3; Yuejiao Village, V4), two construction areas (CA), Kunming Municipal Government (MG), two parks (Park, P) (Luolong Park, P1; Dayu Park, P2), three rivers and lakes (Lake, L) (Laoyu River, L1; Luolong Lake, L2; Fanchun Lake, L3), one waterbody Dianchi Lake (water area, WA), two field lands (FL) and one Reservoir (Guanshan Reservoir, R).

As to the size of the waterbody, Dianchi Lake is the largest, which has a surface area of 330 square kilometers. The size of L2 and L3 are 13.32 hectare and 10.27 hectare respectively. The surface area of Guanshan Reservoir is 25.17 hectare.

The mobile measurement, capable of recording the data of multiple locations with a few devices, was carried out with a steerable vehicle. The temperature and humidity recorder, GPS, and other instruments were all connected to the triangular suction plate and installed on top of the vehicle, so that the temperature and humidity could be measured at about 1.5m above the ground. The travel speed was controlled at 40km/h and one datum was recorded every 11m. In this way, the effect of wind speed on the test data was minimized and the data recording positions were relatively uniform.

Fig. 2. Test route

The mobile measurement devices include a HOBO U23-001 ProV2 automatic temperature and humidity recorder and two HOLUX M-241 wireless GPS recorders. During the measurement, the GPS recorders captured the latitude, longitude and altitude along the test route. Then, the captured data were combined with Google Earth maps into track records and images of each location. To save time, the "record mode" was set to "time record" with a 5-second interval. To ensure the integrity and validity of the records, the devices were turned into the record mode 5~10 minutes before the measurement.

The automatic temperature and humidity recorder were placed in both outdoor and indoor environments to automatically monitor the temperature and humidity. During outdoor measurement, the recorder was placed in the middle of a radiation shield to avoid ultraviolet irradiation and prevent inducing a change in the air temperature and humidity, and arranged in a well-ventilated place. Before monitoring, the time record interval was set to 5 seconds to facilitate data processing. To ensure the accuracy of the measurement, the data are observed under clear and cloudless days.

2.3. Data processing

Air temperature data obtained from mobile measurement at a certain recording time is only one value at certain spatial location, while the air temperature data of all the positions at any recording time are required to show the time and spatial distribution of the result. Thus, synchronous modifying is needed, which is the basis of dealing with data obtained from mobile measurements.

The reason why air temperature data obtained from fixed points measurement in urban areas can be used to modify the data obtained from mobile measurement is the temporal air temperature changes at all the locations on observation route have been occurred in parallel, which means that moving observations were conducted for calculating the air temperature differences between all the data recording locations on the observation route and the representative fixed points. This air temperature differences were generally assumed to be stable and independent of time. All the data modifications in mobile measurement are complying with this precondition. Simulation equation can be regressed using the measurement data at fixed points in study areas, and then, simulation equation can be used for calculating the simulating value of all the recording time during mobile measurement.

The temperature distribution of the original data decreased progressively along the mobile measurement line, failing to reflect the differences between functional areas in temperature features (Fig. 3). As mentioned above, with synchronous modifying, it would be necessary to modify all the air temperature data obtained from mobile measurement with a chosen reference time, which can be any time within the period of observation, initial time and ending time are also included. Usually, the data obtained from mobile measurement are modified to the middle time of the measurements, which are easier to understand and calculate (Fig. 4).

However, by doing this may generate some problems, for example, air temperature distribution at initial time or ending time or any other recording time during the mobile measurement would be neglected. Therefore, the original data are processed to different time in this paper, aiming to disclose the time law and improve time resolution of the spatial distribution of air temperature data.

3. Analysis of results

3.1. Temperature distribution in Chenggong District

The mobile measurement was carried out twice a day on March 19th and 20th, 2016. The duration time of diurnal observations were from 14:30 to 16:20, and the night-time observation were from 19:20 to 21:25. The weather was clear and cloudless on the test day, the temperature ranged from 11.0°C and 23.0°C, with a southwest wind below level 3. During the diurnal observations, high temperature centers covered the eastern part of Chenggong District, where human and economy activities is intensive, and the belt of S102 road to V3, where are arterial traffic connecting the new town and old town of Chenggong District, released great anthropogenic heat. The high temperature reached to as high as 23.6°C. The areas of East Lake Road near Dianchi Lake(WA) were low temperature areas, which was 0.6~1.4°C lower than high temperature areas. Areas of other rivers and lakes, such as L1, L2 and L3, as well as Guanshan Reservoir (R), air temperatures were 0.3~0.5°C lower the their surrounding environments.

Heat island during daytime hours is usually non-standard for heat island studies. More common is to measure UHI after sunset when urban-rural and intra-urban temperature differences are more pronounced. Hence, the night-time measurement data were processed and analysed in detail. The data obtained from mobile measurement carried out during the night on March 19th, 2016 were taken as an example. The test data were processed and modified into 4 time points: 19:30, 20:00, 20:30 and 21:00. The isotherm time series diagram was drawn on Sufer software (Fig. 5).

It can be seen from Fig. 5 that the temperature of the study area peaked at 19:30, and the temperature appeared in Guanshan Reservoir (R). At 20:00 and 20:30, the isotherm distribution remained stable and the temperature changed slowly. This is attributable to the similar heat radiation rates of the various landscapes during this period. Dianchi Lake (WA) had a lower temperature than the other areas and witnessed the fastest temperature drop, owing to the impact of water on the thermal environment. These trends indicate that water can improve the comfort of the thermal environment..

3.2. Multi-time UHI feature analysis

The temperature distribution of each position on the test route was analysed using GIS software. During the test period, the maximum and minimum temperatures were 20.05°C and 17.44°C, respectively. Taking these extreme values as a reference, the test route temperature distributions at four time points were plotted (Fig. 6).

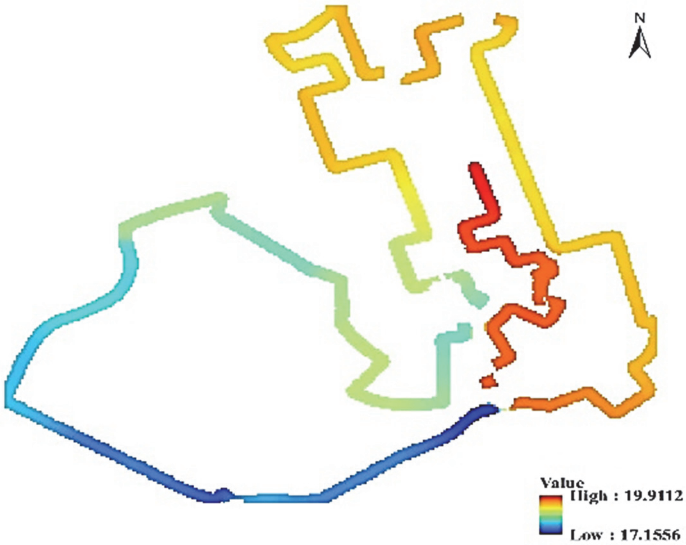

Fig. 3. Air temperature distribution of the original data

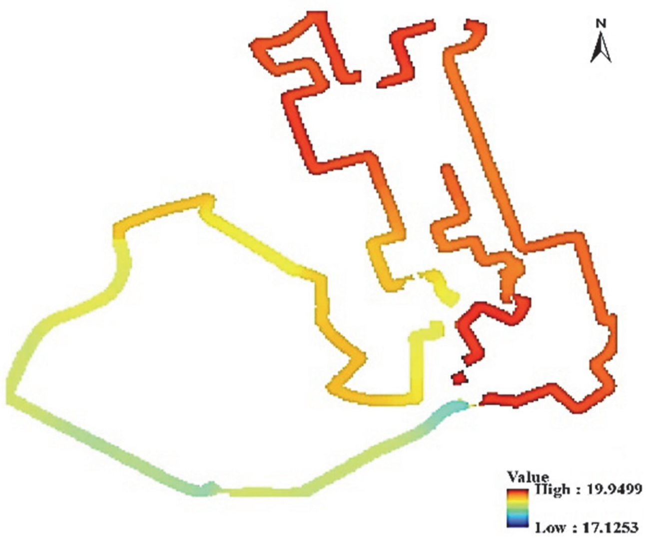

Fig. 4. Air temperature distribution after synchronous modifying to the middle time

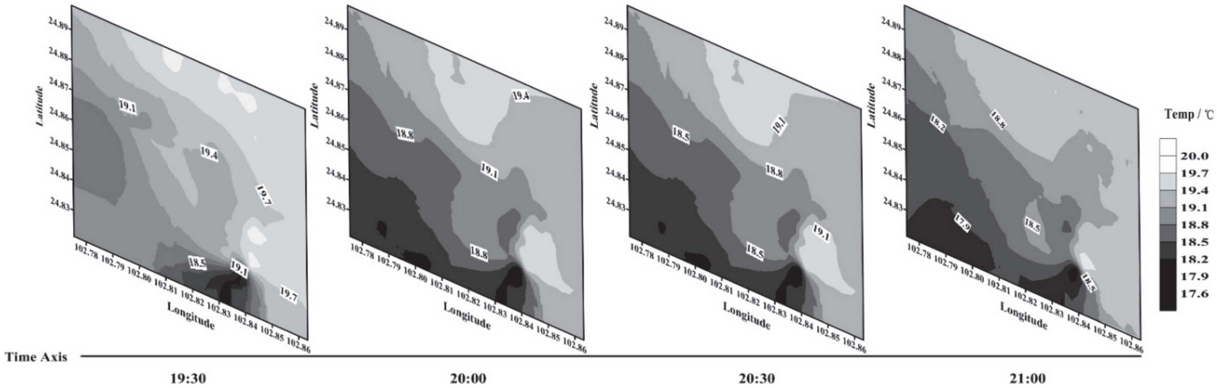

Fig. 5. Isotherm time series diagram

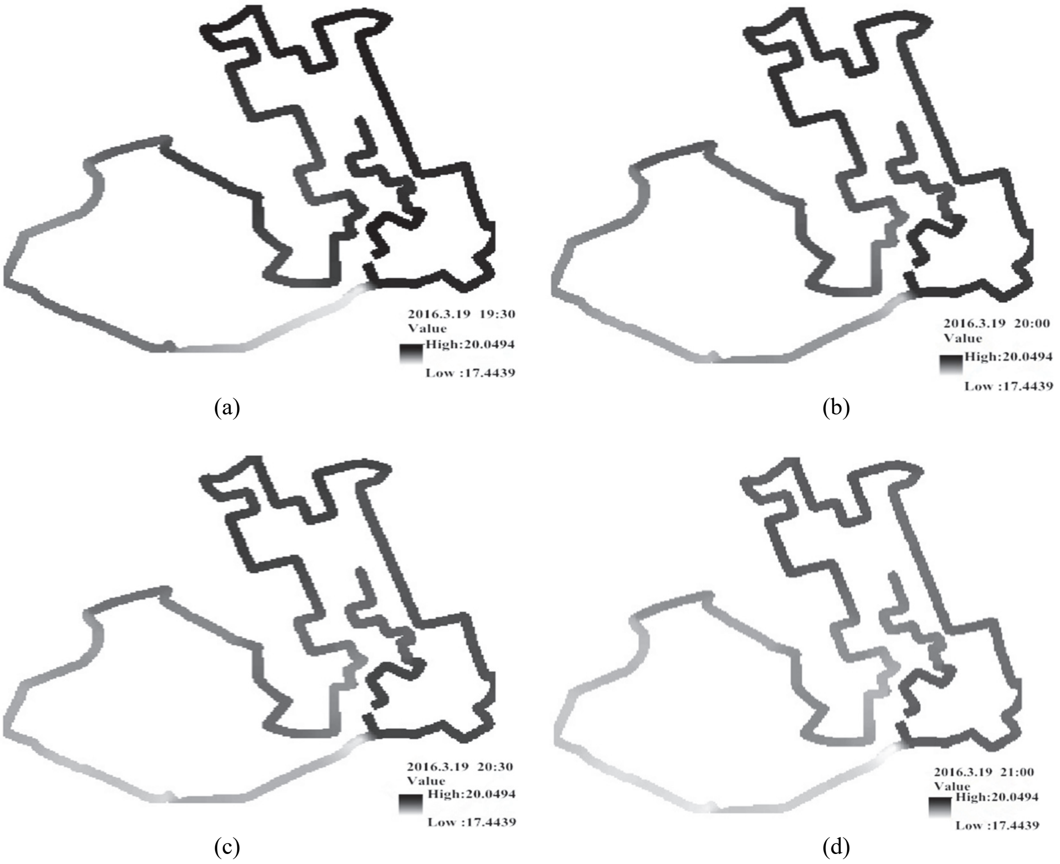

Fig. 6. Test route temperature distributions at four time points: (a) 19:30; (b) 20:00; (c) 20:30; (d) 21:00

Fig. 6(a) shows the temperature distributions at 19:30. The high temperatures appeared in the university district, residential area, and government administrative district, which were 19.94°C, 20.01°C, and 20.05°C, respectively. The high temperatures are the result of the artificial underlying surfaces, high-density buildings, and the large amount of artificial heat. The lowest temperature (17.64°C) was measured at Guanshan Reservoir (R). The UHI intensity was determined by comparing the highest and lowest temperatures at the same time point. The results show that the maximum UHI intensity emerged at 19:30, reaching 2.41°C. The previous studies have placed water as the leading influencing factor of the thermal environment in the study area. However, there is still a disagreement on the exact impact of water on the thermal environment. Some researchers held that the water body can reduce the UHI effect through daytime absorption of the environmental heat, due to its high specific heat capacity (Hathway et al., 2012; Syafii et al., 2017).

However, others argued that the water body has little and even negative effect on the thermal environment, as the heat absorbed in daytime is released at night (Liu et al., 2013). To assess the impact of the water body on night-time UHI, the data collected along the road near Dianchi Lake (WA) were analysed in details. The temperature difference between the related points on the test route between 19:30 and 21:00 was plotted in Fig. 7.

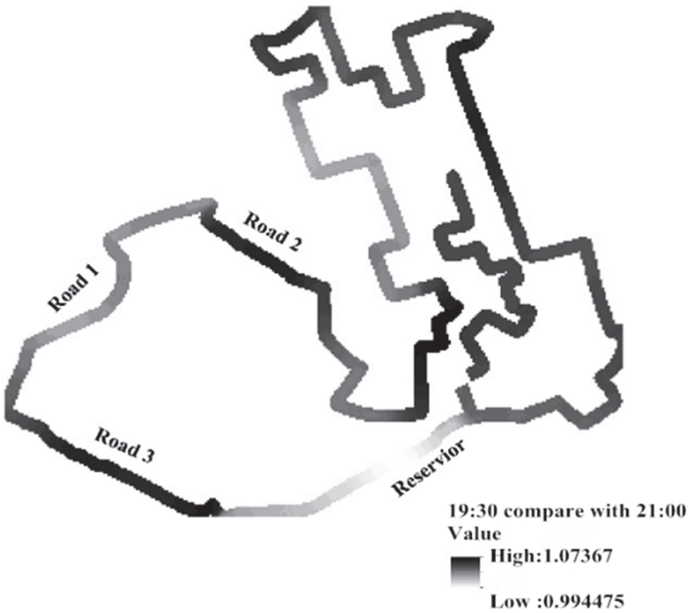

Fig. 7. Test route temperature difference in 19:30~21:00

Comparing Fig. 6(a) and Fig.7, it clearly shows that East Lake Road (Road 1), which is the closest to Dianchi Lake, had a lower temperature than Road S102 (Roads 2) and the Chengdong South Road (Road 3), but its temperature drops (1.07°C) less than those of the latter.The three roads, all open and unobstructed, share similar surrounding environment and the same material in their underlying surfaces. Hence, the distance to the water body is the main reason for the difference in the temperature distribution of these roads. The temperature of Road 1 remained within a certain range throughout the day. For Roads 2 and 3, the cooling effect of the lake was not obvious in daytime but gradually increased at night.

In comparison, the cooling effect of the Guanshan Reservoir (R) was more obvious than Dianchi Lake (WA). The reservoir's regulation of its ambient temperature is displayed in Fig. 6 and Fig.7. The ambient temperature increased insignificantly during the day and a small amount of heat was released at night, making the temperature relatively stable. Thus, it can be concluded that a large water body (i.e. the lake) helps to preserve the heat at night, which hinders the heat dissipation in nearby places; the cooling effect of water increases with the distance to the water body; small and medium-sized water body (i.e. the reservoir) do not emit lots of heat at night and cool down the surrounding environment, thus improving the thermal environment.

4. Conclusions

This paper carries out a mobile measurement in Chenggong District, Kunming, and investigates the UHI features in this area in spring. The following conclusions can be drawn from our research:

(1) In the spring, the night-time UHI centre of Chenggong District lies in the university district and government administrative area. The data were divided into 4 time points to disclose their spatiotemporal law. The maximum UHI intensity was found at 19:30, reaching 2.41°C.

(2) The cooling effect of the local water bodies depends on the size of the water body and the distance from the living area. Large water bodies like Dianchi Lake emits lots of heat at night, creating a prominent heat preservation phenomenon, while small and medium-sized water bodies release small amount of heat and display a cooling effect at night.

(3) The high temperatures appeared in the university district, residential area, and government administrative district, which were 19.94°C, 20.01°C, and 20.05°C, respectively. The high temperatures are the result of the artificial underlying surfaces, high-density buildings, and the large amount of artificial heat. The lowest temperature (17.64°C) was measured at Guanshan Reservoir.

(4) Abundant temperature data were acquired by the mobile measurement method in a short time and were revised to multiple time points, by doing this, time resolution of the air temperature spatial distribution can be improved.

(5) The research results provide a valuable reference for the development plans of the study area. For example, the thermal environment can be improved by configurating water bodies around areas with dense buildings and population.

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