Temperature Distribution and Air Pollution in Phnom Penh, Cambodia - Influence of Land Use and the Mekong and Tonle Sap Rivers

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Abstract

The temperature distribution in Phnom Penh was measured using a car to evaluate the thermal characteristics and air pollution in the city. The measurements were made by using temp-hygro sensors with a data logger installed on the car roof and were conducted both during day and night to evaluate the influence of land use. The water temperature was also measured in the River Tonle Sap and the Mekong. By measuring the temperature as a function of distance from the banks of the Mekong and Tonle Sap, the cooling effect of the river was also investigated. Ambient particulates were simultaneously sampled at three different sites in the city along with NO_2 and PAHs and heavy metal concentrations were analyzed. The temperature distribution was compared with the concentration of chemical compositions and NO_2.

The maximum temperature difference, the so called heat island intensity, was observed during the daytime and was around 4-5°C, and was less than 2°C during the nighttime. The maximum and minimum temperatures respectively were observed in the southern part of the city and the river peninsula between the Tonle Sap river and the Mekong, and a strong cooling effect of river water was found. The water temperature was consistently lower than the ambient and temperature distributions perpendicular to the river and was found to increase with the distance from the riverbank, suggesting that inland areas were cooled to some extent. Comparison of the concentrations of anthropogenic PAHs and NO_2 were found to be closely related to temperature.

keywords: Urban air, temperature measurement, air pollutants, river temperature, GIS.

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INTRODUCTION

During past 10years after the election of 1993, the Cambodian economy has grown rapidly (JICA, 2001; National Institute of Statistics of Cambodia, 2006) and the urban area of Phnom Penh, the capital of Cambodia, has been also expanding, and a significant increase in energy consumption and the number of automobiles has occurred. This inevitably gives rise to an increase in air pollution as well as an increase in temperature, or, thermal pollution, which leads to health problems and an uncomfortable living environment (Oke, 1987). Since sources of emitted air pollutants and heat are frequently the same, air quality and heat pollution are closely linked with each other (Jonsson et al., 2004; Roberts, 2004). Although the available data are limited, a few investigations and measurements to the air pollution (Matsui, et al., 2002; Kashima et al., 2001) have been reported and these studies indicate a serious environmental situation. However, thermal pollution has not been evaluated in Phnom Penh.

In this study, the temperature distribution inside Phnom Penh was measured using a car to evaluate the thermal characteristics and air pollution in the city. Measurements using two sets of temp-hygro sensors with a data logger installed on the car roof were conducted both during the day and night to evaluate the influence of various heat sources. The water temperature in Tonle Sap and Mekong rivers was also measured. Temperature distributions were evaluated in relation to the distance from the riverside in order to investigate the cooling effect of the river. Ambient particulates were simultaneously sampled in three different sites in the city along with NO_2 and PAHs and heavy metal concentrations were also analyzed. Temperature distribution was compared with the concentrations of chemicals and NO_2.

STRUCTURE AND LAND USE OF PHNOM PENH AND METHODS OF TEMPERATURE MEASUREMENT

Structure and land use of Phnom Penh

Fig. 1 shows land use data evaluated from satellite data (ASTER, AST3A1, 20/02/2002) using commercial GIS software（ENVI ver.4.2） based on the supervised classification method (Tanaka et al., 2003; Johnson et al, 2003). Each type of land use is designated by 6 different gray levels (25(forest), 75(blank space 2), 100(water area), 130(blank space1), 200(paddy field) and 255(urban area)). The urban area on the left bank of the Tonle Sap and Mekong rivers, designated in white, is widely spread along radial streets from the central market and some main rings perpendicular to the radial streets: the busiest commercial area around the central market, intermingled commercial and residential areas spread to the west and south, governmental and commercial areas between Monivoung street and the riverbank, a residential area in north west, which are all spreading over a rather flat area of land. There are no skyscrapers but 6-8 stories

buildings dominate the central area particularly along the main roads and lower buildings cover a large area of the city. As can be seen from Fig.1, the area of vegetation occupies a very small portion but there are large rivers, Mekong, Tonle Sap and Bassac on the east side of the city, as well as rather large water ponds in north and south. There is heavy traffic on the main streets in the city each morning and evening.

Measurement of Ambient Air Temperature

The measuring probe consisted of a temperature-hygro sensor with a data logger (SATO KEIRYOKI SK-L200TH II) attached inside a PVC tube (55mm I.D., 300mm length and 2mm thickness) covered by an aluminum coated urethane foam sheet (6mm thickness) (See Fig. 2(a)). The probe has almost the same geometry as one used in a previously published paper (Wong and Yu, 2005). To avoid the influence of the direct impingement of airflow, the axis of the probe was directed perpendicular to direction the car was traveling. For the compensation, two sets of observation probes were installed on both sides of the roof of the car, as shown in Fig. 2(b).

The focal points for the observations were as follows: 1) influence of land use on temperature distribution, 2) difference between the day and night temperature distribution and influencing factors, and 3) cooling effect of the rivers. The routes and conditions for the observation are

Table 1 Observing conditions

Ambient air temperature

Route	Measuring period	Measuring interval	Travel distance (km)	Average speed (km/h)	Weather
Route-1	25/09/2005 11:14 - 25/09/2005 12:45	1 min.	37.3	24.9	cloudy/fine/rainy
Route-2	25/09/2005 19:09 - 25/09/2005 21:45	10 sec.	48.9	22.6	fine
Route-3	25/09/2005 11:11 - 25/09/2005 12:45	11 sec.	44.3	29.8	fine

River water temperature

Sites	Measuring date	River	Latitude	Longitude	Map Datum
P-M	01/08/2005 16:18	Mekong	11 34 18.2	104 57 01.0	Indian Thailand
P-T	01/08/2005 16:18	Tonle Sap	11 33 52.3	104 56 16.6	Indian Thailand

Ambinet air pollutants

Sites	Sampling date and duration	Sampling duration (min)	weather
Central downtown	30/05/2005 7:20 - 31/05/2005 6:54	1363	fine/cloudy・rainy/fine
Residential area	30/05/2005 9:06 - 31/05/2005 7:54	1368	fine/cloudy・rainy/fine
River Peninsula	30/05/2005 10:43 - 30/05/2005 16:05	231	fine/cloudy・rainy
Central downtown	29/05/2005 8:20～30/05/2005 7:10	1351	fine/rainy/fine
Central downtown	31/05/2005 7:05 ～01/06/2005 6:56	1431	fine

shown respectively in Figs. 3(a)-(c) and Table 1: Route-1 to examine the overall situation regarding temperature distribution as the first observation, Route-2, being almost same as Route-

1, for night time observation along with the influence of distance from the river on temperature and Route-3 the influence of the distance from the river on temperature.

After leaving the starting point, or, the Diamond Hotel located in the central downtown area, the observing car passed though checkpoints A, B, C…, which were determined in advance, following the traffic lights. The average speed and total travel distance for each route are also shown in Table 1. Temperature and humidity were recorded at preset time intervals (10 sec. – 1 min.) while the time was recorded at each checkpoint. The temperature was also measured at the top of the Diamond Hotel, or an 8 story building, to monitor changes in temperature and humidity during the observations.
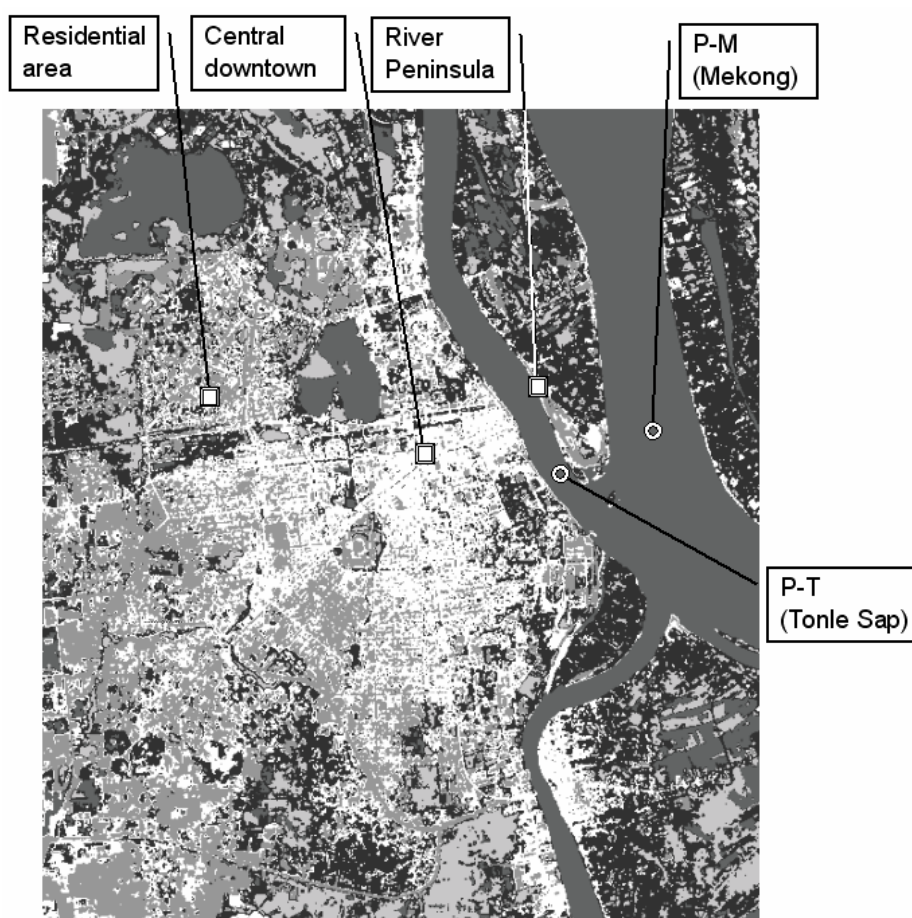

Fig. 1. Structure and land use in Phnom Penh as evaluated from Satellite (ASTER) data, where air pollutant sampling sites (residential, central downtown and river peninsula) and the locations of water temperature measurements (P-T(Tonle Sap) and P-M(Mekong)) are also shown.
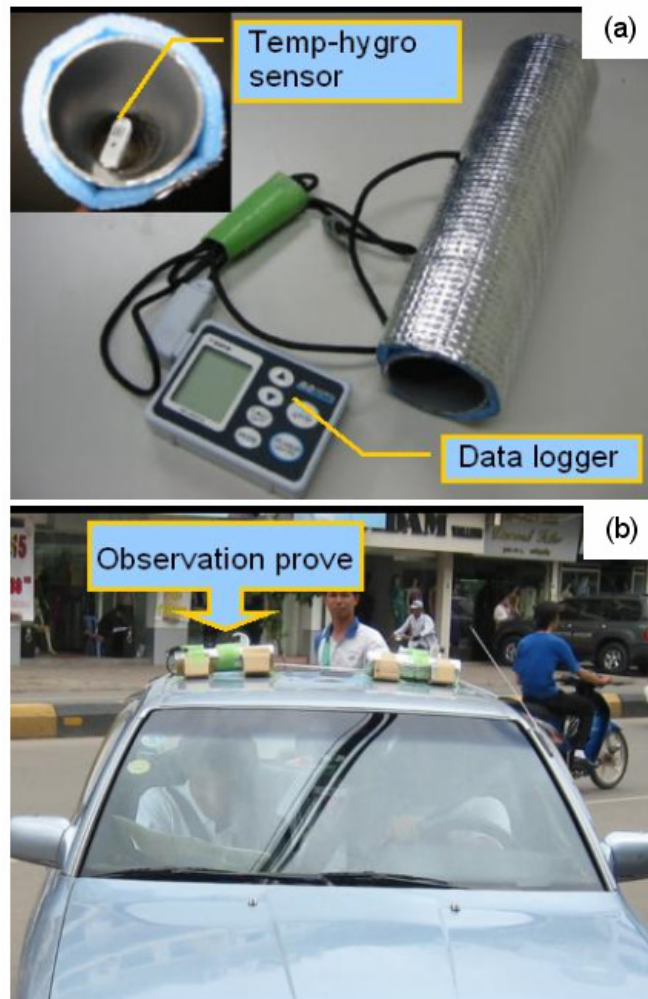
Fig. 2. (a) Observation probe (a temp-hygro sensor with data logger), (b) observation probes installed on the roof top of a car.

Measurement of River Water Temperature

The water temperatures in both Tonle Sap and Mekong rivers were measured at the sites shown in Fig. 1. After boating to each site, the water temperature distribution from the bottom to the surface of the river was measured using three different types of thermometers: "multi-parameter water quality profiler (Alec Electronics Co. Ltd., type AQ1183 with 10 m cable)", which measures the vertical profile of dissolved oxygen (DO), pH, chlorophyll concentrations, temperature, turbidly and electrical conductivity of waters at intervals of 5cm. The others were "Compact CT Meter (Alec Electronics, Japan)" and "Hobo Water Temp Pro (Onset Computer, USA)". Data sampled every 10 or 20 minutes were stored in loggers connected to each thermometer.
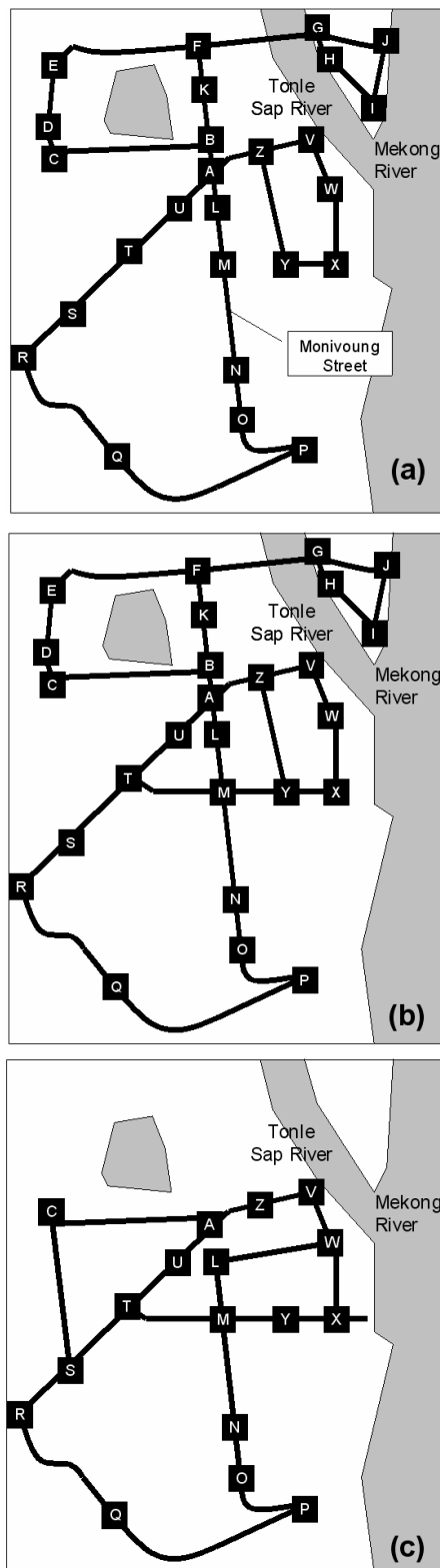
Fig. 3. Observation route maps: (a) Route-1 (daytime), (b)Route-2 (nighttime) and (c)Route-3 (daytime).

The temperatures were measured from Jan. 2005 to Dec. 2005 and the 1st of August was the closest day to the air temperature measurement. Tanaka *et al* (2003) reported that the water level in August and September in Phnom Penh during past several years was almost constant. According to the Mekong Secretariat (1994), the flow rate of the River Mekong in August is ca. 10% less than that in September and the average air temperatures are the almost same so that the difference in water temperature during these months would be expected to be small. Therefore, the river water temperature in August is used in the following discussion.

Measurement of Air Pollutants

Total suspended particulates (TSP) and NO_2 were simultaneously sampled at three different sites in Phnom Penh respectively using high volume air samplers (SHIBATA HV-500F) and passive samplers (ADVANTEC Personal Passive Sampler: Filter badge NO_2). The sampling sites are shown in Fig. 1:1) Central downtown (the Diamond Hotel), 2) Residential area, 3) River peninsula between the River Macon and Tonle Sap. Quartz fibrous filters (ADVANTEC QR-100) were weighed after storing them in a constant humidity and temperature for 72 hours using a descicator. The sampling conditions are summarized in Table 2. Since the observations of temperature and air pollutants were done in different months but in the same rainy season, pollutant data can be discussed with temperature data.

The filters were weighed after a 72 hour conditioning period then analyzed to determine the concentrations of heavy metals and polycyclic aromatic hydro-carbons (PAHs). Heavy metals were analyzed by ICP-AES after decomposing the samples with nitric, hydrofluoric and perchloric acids. 15 different PAH compositions, that is, Naphthalene (Nap), Acenaphthene (Ace), Phenanthrene (Phe), Anthracene (Ant), Fluorene (Fle), Fluoranthene (Flu), Pyrene(Pyr), Benz[a]anthracene (BaA), Chrysene (Chr), Benzo[a]pyrene (BaP), Benzo[b] fluoranthene (BbF), Benzo[k]fluoranthene (BkF), Dibenz[a,h]anthracene(DbA), Indeno[1,2,3-cd]pyrene (IDP) and Benzo[ghi]perylene (BghiPe) were analyzed using HPLC with a fluorescence detector + acetonitril/ultra pure water mobile phase after ultrasonically dissolving the samples on the filter in an ethanol/benzene (1:3) solution and evaporation with a rotary vacuum evaporator. NO_2 was analyzed by means of a spectrometer following a previously reported procedure (Yanagisawa and Nishimura, 1980).

RESULTS AND DISCUSSION

Difference and temperature distribution along main streets for day versus night

Figs. 4(a)-(c) show the temperature distributions respectively along Route-1, 2 and 3. Since the temperature variation during the observation was less than $0.3^{o}C$, the temperature data were

Table 2 Concentration of air pollutants near check points

Site	Central downtown			Residential area			River peninsula		
Nearest check point	A			C			I		
TSP ($\mu g/m^3$)	107.4			151.1			162.6		
NO$_2$ (ppb)	25.2			16.4			9.66		
Heavy metals	($\mu g/m^3$)	($\mu g/\mu g$)	(%)	($\mu g/m^3$)	($\mu g/\mu g$)	(%)	($\mu g/m^3$)	($\mu g/\mu g$)	(%)
Al	1.99	0.019	24.9	6.13	0.041	28.8	3.30	0.020	23.8
Ca	2.52	0.024	31.5	6.99	0.046	32.8	1.93	0.012	13.9
Co	0.60	0.006	7.5	1.57	0.010	7.4	1.10	0.007	7.9
Fe	2.18	0.020	27.2	5.56	0.037	26.1	3.76	0.023	27.1
Ga	0.01	0.000	0.1	0.01	0.000	0.1	0.09	0.001	0.6
Mg	0.18	0.002	2.3	0.37	0.002	1.7	0.31	0.002	2.2
Zn	0.06	0.001	0.8	0.04	0.000	0.2	0.04	0.000	0.3
P	0.07	0.001	0.9	0.05	0.000	0.2	2.76	0.017	19.9
V	0.40	0.004	5.0	0.58	0.004	2.7	0.60	0.004	4.3
PAH	(ng/m^3)	(ng/μg)	(%)	(ng/m^3)	(ng/μg)	(%)	(ng/m^3)	(ng/μg)	(%)
Flu	0.22	0.0020	1.0	0.30	0.0020	1.5	0.15	0.0009	4.3
Pyr	0.53	0.0050	2.3	0.18	0.0012	0.9	0.19	0.0012	5.7
BaA	0.88	0.0082	3.9	0.69	0.0046	3.6	0.17	0.0011	5.2
Chr	1.81	0.0168	7.9	0.56	0.0037	2.9	0.21	0.0013	6.3
BbF	3.31	0.0308	14.5	2.06	0.0136	10.5	0.34	0.0021	10.0
BkF	1.79	0.0167	7.8	1.16	0.0077	5.9	0.16	0.0010	4.8
BaP	4.88	0.0455	21.3	5.79	0.0383	29.7	0.38	0.0023	11.2
DBA	0.50	0.0046	2.2	1.52	0.0101	7.8	0.40	0.0024	11.8
BghiPe	4.81	0.0448	21.0	4.19	0.0277	21.5	0.34	0.0021	10.2
IDP	4.16	0.0387	18.2	3.07	0.0203	15.7	1.03	0.0063	30.5
Total PAHs	22.89	0.2131	100	19.54	0.1293	100	3.37	0.0207	100

not modified. In Figs. 4(b) and (c), the average temperature of the Tonle Sap and Mekong rivers is also shown. Regarding Route-1, the temperature increased along the main road with two lanes (A→B→C) and decreased around the residential area (D) with more vegetation. The temperature then reached a peak in the traffic circle (F). The temperature drastically decreased down to the minimum over the Route-1 at the cape of the peninsula (I). Along the main road (Monivoung Street) running north to south, the temperature gradually increased through the central downtown (A) to the south (A→M→N→L→O→P) and reached a peak (P→Q). After these points, the temperature increase was not so clear in central downtown while it decreased near the river bank (V→W→X). A rapid decrease just before arriving at the starting point corresponded to the initiation of precipitation. The maximum temperature difference, so called "heat island intensity" was 4.6°C. This is almost on level with the heat island intensity and population for cities in Japan (Ishida and Katsumoto, 1999).

Over Route-2, the temperature difference was not as large as in the daytime but gradually increased toward the south through Monivoung Street and the highest value was recorded in the

south (N) while the lowest was at the bank of the river peninsula (G), almost the same as the average river temperature. The maximum temperature difference was 1.3°C. The temperature in
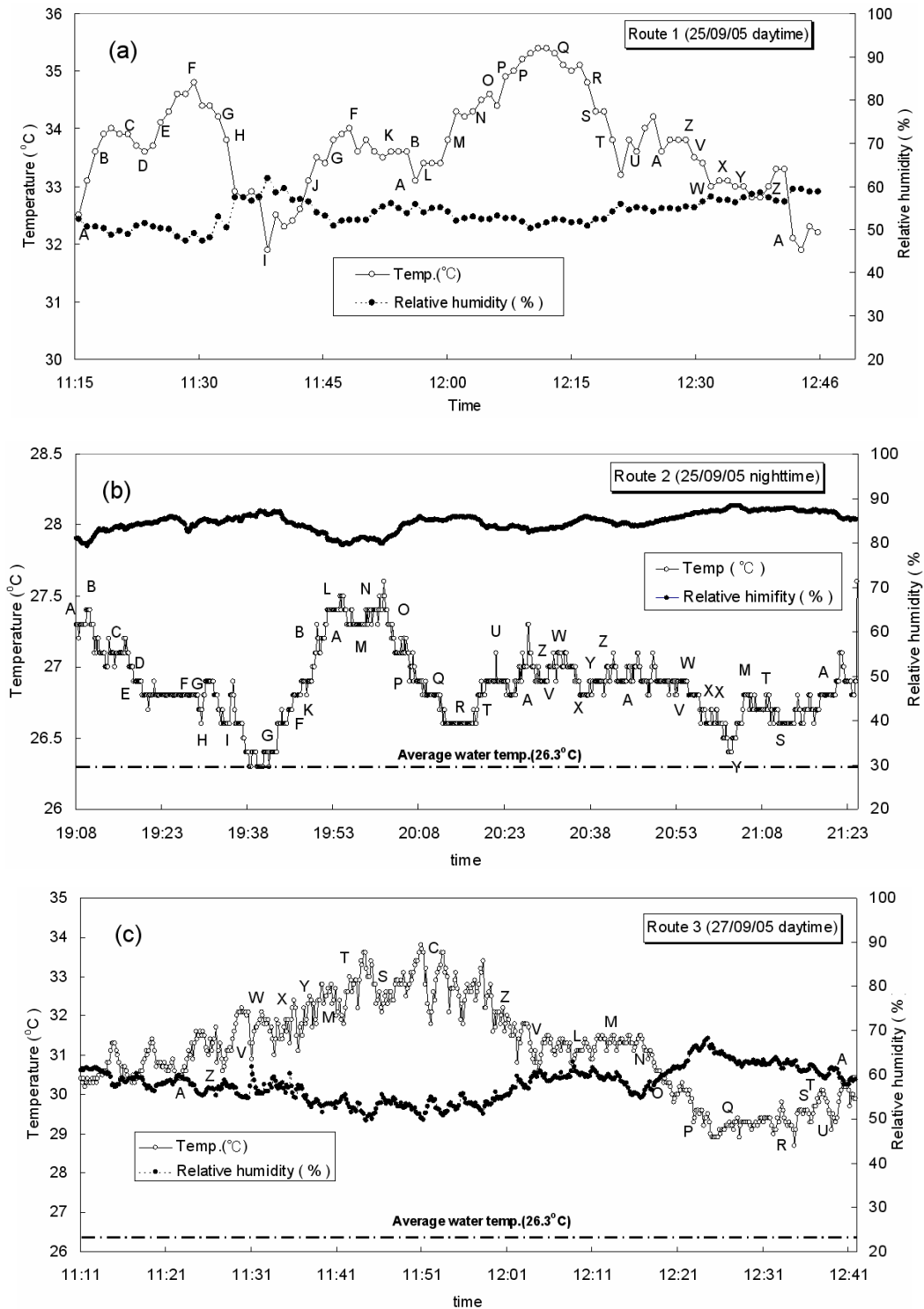

Fig. 4. Temperature distributions along (a) Route-1 (day time), (b) Route 2 (night time) and (c) Route-3 (day time)

the central urban area was around 27.0^{o}C, about the average temperature over the route. Along Route-3, although there was a difference due to the difference in weather conditions, a similar tendency to Route-1 was observed.

Temperature variations through the straight part of Monivoung Street (F→O in Route-1 and 2), which is one of the main axes of the city, running almost parallel to the river, is shown in Fig. 5, where the difference between the temperature and the average temperature T_{av} over each route is plotted against the distance from point F. During the nighttime, the temperature increased toward the central downtown area then reached a peak around L-N, followed by a decrease to the urban periphery. During the daytime, point A, which is located in the busiest area, was classified as being in a cooler area and a similar increase was found from the central to the southern downtown area (A→M). The urban area of Phnom Penh has a rather uniform land use but the north of the busiest area has a less wall developed urban area (See Fig.1) so that the center of the "heat island" should be located in the south. There might also be an influence of river cooling around point A, which will be described below. The higher temperature around point F during the daytime was possibly due to the heavy traffic through a traffic circle.

The temperatures at the check points along the river, particularly in the river peninsula (H-J) were consistently lower than the others. This may be due to the cooling effect of the rivers. In order to determine the area encompassed by the cooling effect, the temperature difference between air and river water, $T - T_r$, is plotted against the longitudinal distance D from the riverbank in Figs. 6(a)-(b), where T and T_r are, respectively, air and river water temperatures and $T - T_r$ is normalized by the difference between average temperature T_{av} over each observing route and T_r; the distance D is also normalized by the average distance between the straight section of Monivoung street (F-O) and the riverbank D_M (~1.47km). During the daytime (Fig. 6(a)), the air temperature can be expressed in almost the same relation regardless of the observation day, where T abruptly increases near the riverbank from T_r then gradually increases with distance. The cooled area may extend to $D/D_M \sim 1$, which covers most of the area between Monivoung Street and the riverbank. At locations that are influenced more by traffic, denoted by open circles, the air temperature became slightly higher. Some locations influenced by traffic had lower temperatures, probably due to cooling by the river (Traffic&River). During the nighttime (Fig. 6(b)), T increased gradually from the riverbank and a clear peak in the temperature was noted around Monivoung Street ($D/D_M \sim 1$). Thus, there might also be some river cooling effects in the nighttime. However, the temperature variation may be influenced to a greater extent by land use, since the temperature decreased in $D/D_M > 1$ and the difference between T_{av} and T_r was small.
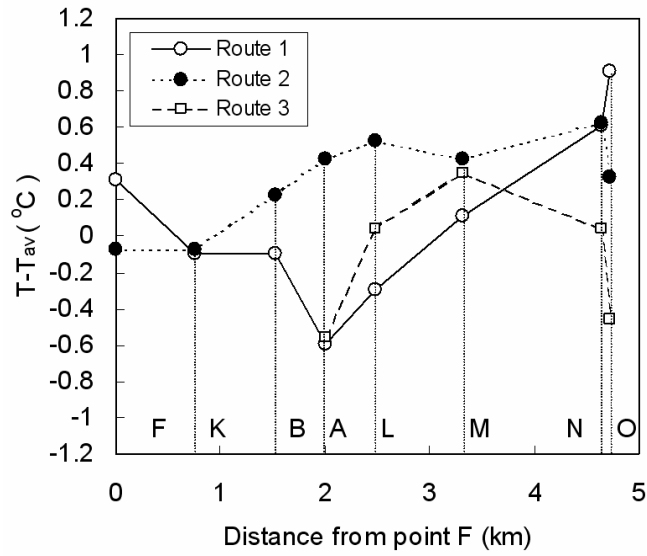
Fig. 5. Variation in air temperature T along the main road (Monivoung Street) running from north to south through the Phnom Penh urban area, where T_{av} is the average temperature for each route.
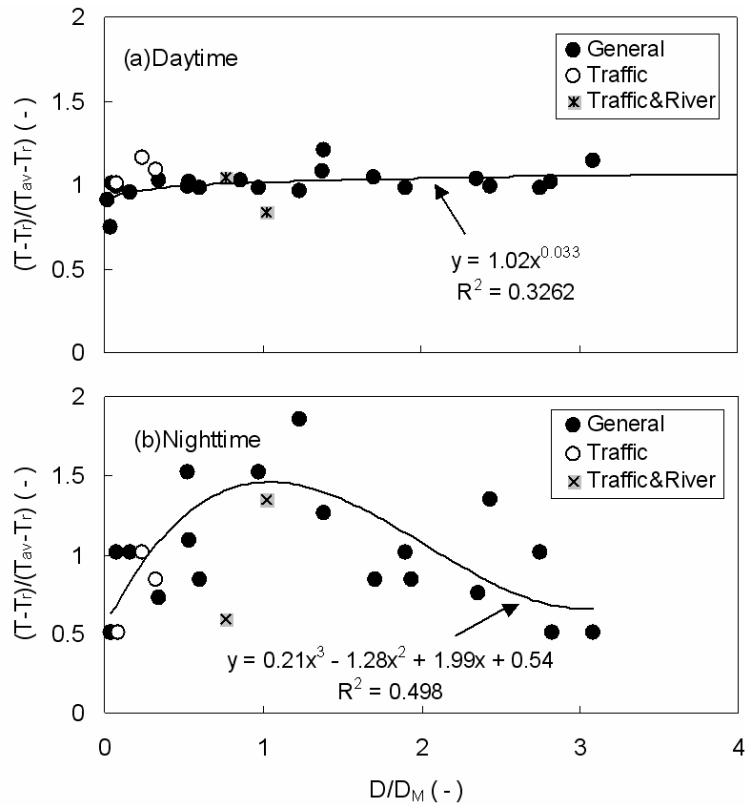

Fig. 6. Difference between air and river water temperatures plotted against the distance from the riverbank of River Mekong, where the temperature difference is normalized by the difference between the averaged temperature T_{av} along each route and the river water temperature T_r. and the distance from the riverbank D is normalized by the average distance D_M between Monivoung street along check points F to O.
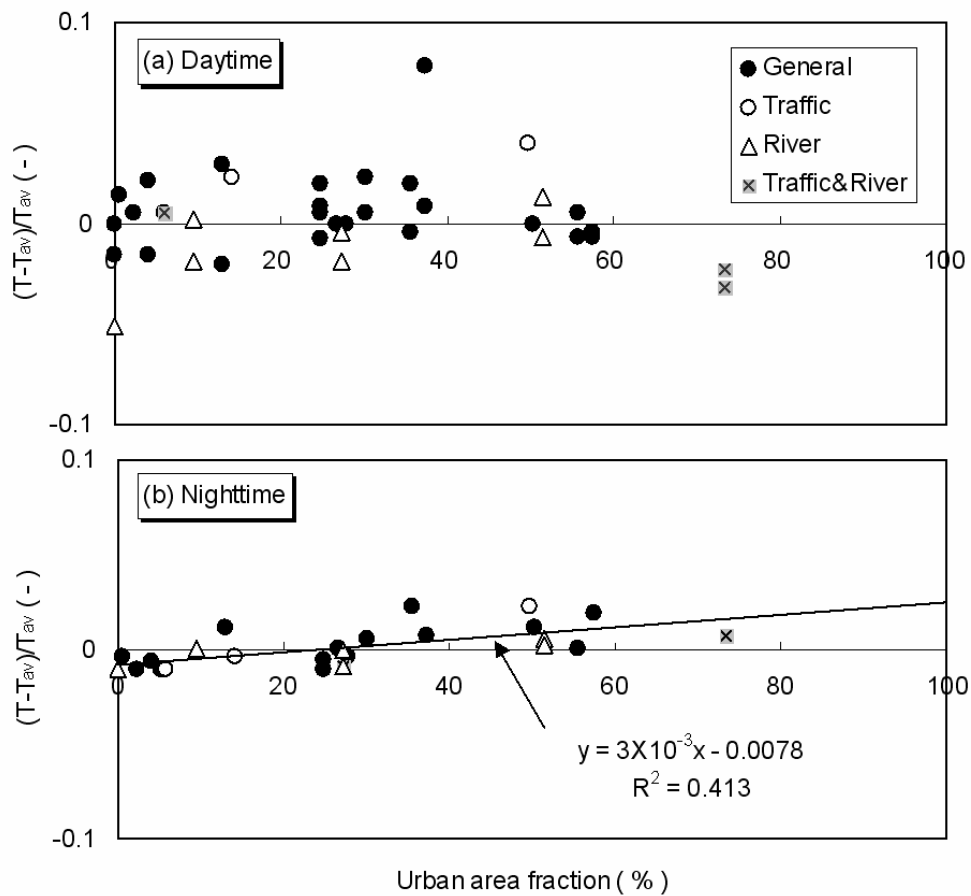
Fig. 7. Variation in normalized air temperature from the average temperature over each observation route plotted against the urban area fraction evaluated from ASTER data: (a) daytime and (b) nighttime

Relation between land use and air temperature

Fig. 7(a) shows the relation between the urban area fraction and air temperature variation from the average temperature over each observation route during the daytime, where the temperature variation is normalized by the average temperature T_{av} and the area fraction was evaluated for a 200m X 200m mesh including each checkpoint from the land use data shown in Fig. 1. A data category denoted by closed circles, which is classified as a group without any river and traffic related influence, appears to be almost independent of land use. However, a group classified as being affected by river cooling always shows lower temperatures and a group influenced more by traffic is in a higher temperature area. Fig. 7(b) shows a similar relation for nighttime. The influence of river cooling and traffic are not so clear because of less traffic and air temperature variation while a clear dependence of air temperature on the urban area fraction was found. The temperature during the nighttime appears to be more sensitive to land use than during the daytime.

Relation between air temperature and the concentration of ambient pollutants

In Table 2, the concentrations of total suspended particulates (TSP), total PAHs with four or more aromatic rings (Flu, Pyr, BaA, Chr, BbF, BkF, BaP, DBA, BghiPe, IDP), heavy metals and NO_2 are listed for three observation, where the nearest checkpoints for the air temperature measurement are also shown. These PAH compositions are carcinogenic and their concentration is a measure of anthropogenic emission sources (Seinfeld and Pandis, 1998, Spurny, 1999) and NO_2 is an index of traffic emissions. Larger TSP concentrations were observed in residential areas (D) and the river peninsula (I) probably because of the re-suspension of soil dust from un-paved roads and the riverbank: this can be seen for a large concentration of soil bound elements (Al, Ca, Fe). A larger concentration of phosphate in the river peninsula might be from fertilizer for vegetation in a memorial park, where the sampler was installed. The PAH concentration was the lowest in the peninsula while the highest was at the Diamond hotel (A). PAH concentration and the mass ratio between PAH composition are similar in the downtown and residential areas, suggesting similar influences from the same emission sources. The NO_2 concentration in the residential area, which is about 20% less than the central downtown, may be due to less influence by traffic. In the river peninsula, the mass fraction of PAH in particles was ca. 1/10 that of the central downtown area and 1/5 that of residential areas and NO_2 concentration was less than 40 % that of the central downtown area, indicating much less contribution from fuel burning and traffic. Moreover, in the peninsula, the PAH ratio is slightly different, e.g., smaller BaP and larger IDP as well as a larger fraction of PAH with four rings. The much lower PAH concentrations and different PAH fractions in the peninsula may be related to the air flow along the Tonle Sap and Mekong rivers, which also has a cooling effect as described above. The southwest Monsoon wind, which was always observed in the central downtown area during the sampling, could transport air pollutants from the downtown area to the river peninsula because it is located just 0.5km downstream from the downtown area. However, this is not, actually the case. The wind along the rivers might dilute the pollutants and prevent their transportation from downtown to the peninsula while cooling areas near the riverbank. This may be reinforced by the fact that over the entire period of sampling, the north wind along the Tonle Sap river was confirmed from flagpoles along the riverbank although, for the detailed discussion, meteorological data should be obtained.

Based on these results, it can be said that the wind over the Tonle Sap and Mekong Rivers cooled the atmosphere and influenced the transportation of pollutants from the downtown area to the river peninsula. This indicates that the temperature and pollutant distribution in Phnom Penh are strongly dependent on the wind over the rivers. There might be some correlation between air temperature and pollutant concentration during the daytime because of the influence of traffic and river cooling on the air temperature corresponding, respectively, to the emission and dilution of pollutants. Fig. 8 shows relations between the day-averaged air temperature and the concentration of pollutants (TSP and PAH) measured at the central downtown (the Diamond Hotel, May 2005),

indicating an increase in the pollutant concentration with the air temperature. These results may be an evidence for the temperature dependency of air pollutants concentration although it will need to be verified based on further observations.
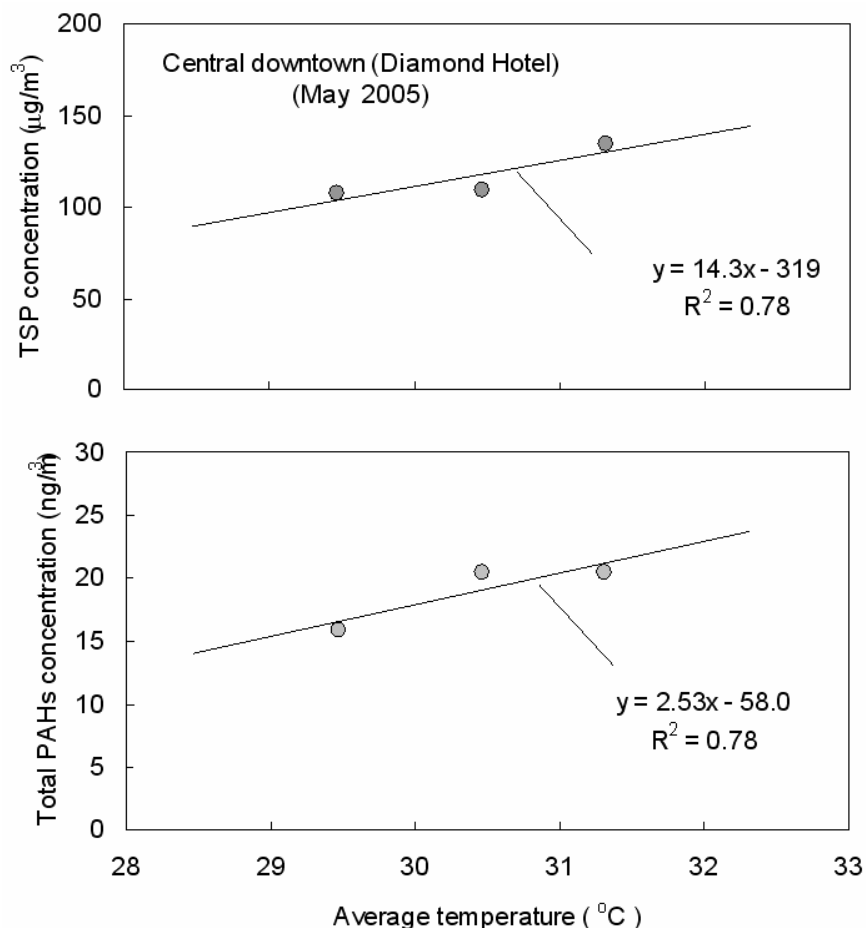

Fig. 8. Concentrations of total suspended particulates (TSP) and total PAH compositions with four or more aromatic rings plotted against the day-averaged air temperature obtained at the site in the central downtown (Diamond Hotel, May 2005).

CONCLUSIONS

The temperature distribution and air pollutant concentrations inside Phnom Penh were measured along with the water temperature of Mekong and Tonle Sap rivers, to evaluate the thermal characteristics of the area and its relation to air pollution. The influence of land use and the cooling effect of the Mekong and Tonle Sap rivers are discussed. Temperature distribution was compared with the concentration of ambient pollutants. As a result, the following conclusions are drawn:

(1)The maximum temperature was observed, not in the busiest area, but in the southern part of the city both during the day and night. The maximum temperature difference, the so called the

heat island intensity, was 4.6 ^{o}C, which is almost on a correlation with the intensity and population for cities in Japan.

(2)A clear influence of the Mekong and Tonle Sap rivers was found regarding the cooling of ambient temperature in the downtown area during the daytime, extending to around 2 km from the riverbank.

(3)The air temperature seemed to be more sensitive to land use during the nighttime while it may be more influenced by traffic and river cooling effects during the daytime.

(4)The wind over the rivers may dilute air pollutants and prevent their transportation from downtown to the river peninsula.

(5)The Mekong and Tonle Sap rivers have important roles in the thermal and environmental characteristics of the ambient atmosphere in Phnom Penh.

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