CARBON MONOXIDE 'HOT-SPOTS' IN URBAN AREA OF KOTA KINABALU CITY, SABAH

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ABSTRACT. *Air dispersion models have been widely used to address air quality problems at microscale in urban environments, as they are capable of providing valuable information for better and more efficient urban air quality planning. The aim of this paper was to measure the CO concentration near roadways and intersections at three major roads in Kota Kinabalu city centre during morning, afternoon and evening peak hours using CAL3QHC dispersion model and also to identify CO concentration "hot-spots". The maximum 1-hr averaging ground level concentrations of CO during peak hours were in the range of 5.2–10.8 ppm (morning); 5.4–11.2 ppm (afternoon); and 5.5–9.4 ppm (evening). CO concentration "hot-spots" were identified mainly at the major intersections. Comparisons between model outputs and measurements were made using quantitative data analysis technique and statistical methods and have indicated a good performance of the model. The present study has shown that the CO levels along the major roads were well below the Malaysian Ambient Air Quality Guideline of 30 ppm (1-hr, TWA). In the long term, however, receptors located close to the major intersections have the potential risk of being exposed to high CO concentrations and therefore deserve further attention in future urban transportation planning.*

KEYWORDS. *Carbon monoxide, CAL3QHC dispersion model, intersections, modelling, motor vehicles, receptors*

INTRODUCTION

Transportation activities have been identified as the single major source of air pollution in urban areas (Onursal & Gautam, 1997) with subsequent adverse human health effects (Chan *et al*., 2002; Colvile *et al*., 2001). Like other developing cities, commercial areas in Kota Kinabalu city attract and generate relatively large volumes of traffic, particularly during rush hours and weekends, that typically circulate at low speeds with frequent stops and starts. This traffic pattern produces relatively high CO emissions. Motor vehicles contribute over 90% of CO emissions in urban areas (Mukherjee & Viswanathan, 2001). In Kota Kinabalu city, motor vehicle-related pollution has been primarily related to emission of CO, particularly near roadsides and intersections (Sentian, 2003). Air quality near roadsides and intersections is also affected by a number of other factors, including traffic density with time, vehicle type, vehicle composition, terrain and local meteorological conditions. This particular pollutant has also been the target of investigation in most monitoring and modelling studies on vehicular pollution near roadways and major intersections in many cities (Bogo *et al*., 1999; Chan & Liu, 2001; Chan *et al*., 2002; Comrie & Diem, 1999; Sharma *et al*., 1999; Sivacoumar & Thanasekaran, 1999). CO is the result of incomplete fuel combustion that characterizes mobile as opposed to stationary pollution sources and therefore it can be used as a marker for the contribution of traffic to air pollution (Fenger, 1999).

Since commercial areas also attract large numbers of people, the potential for human exposure is great. Susceptible population groups within the city's commercial area such as in schools, residential flats and apartments and other public places are also a concern over the effect of traffic-related emissions on health and the local environment. These concerns have contributed to the demand for management of urban air quality to ensure a sustainable city.

Study of air quality problems at microscale in the urban environment requires application of an adequate methodology that permits understanding of source-receptor relations and the development of a proper strategy to reduce atmospheric pollution (Moussiopoulos *et al*., 2003). Air dispersion models have been widely used to address this issue as these models play an important role by providing information for better and more efficient air quality planning. For example, line source models are used to simulate the dispersion of pollutants near highways where vehicles are continually emitting pollutants. In the present work, CAL3QHC dispersion model was used to predict CO concentrations along the three major road links in Kota Kinabalu city centre. The objectives were to identify CO concentration hot-spots during typical peak hours (morning, 0730–1030; afternoon, 1130–1430; evening, 1630–1830) and to assess the potential exposure of selected receptors to pollutants within the studied area.

METHODOLOGY

Description of Experimental Sites

Kota Kinabalu (06º05'30"N; 116º07'30"E) with an estimated population of 400,000, is a developing city in the State of Sabah, Malaysia. The major commercial and business activities are concentrated in the city centre (Sentian & Lee, 2004). For the modelling study, three main road links were selected; these were labelled as Link A (KK Bypass Rd–Tunku Abdul Rahman Rd–Tuaran Rd), Link B (Tun Fuad Stephens Rd–Tun Razak Rd–Coastal Rd–Kemajuan Rd), and Link C (Tun Fuad Stephens Rd–Kemajuan Rd). Measurements of CO were carried out at eight monitoring sites within the city centre, mainly along the three main roads (Figure 1).

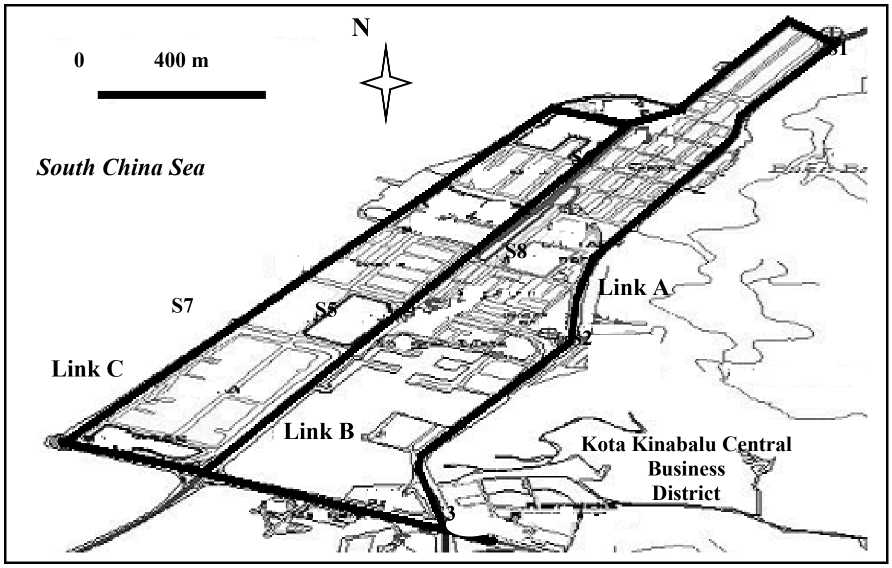


Figure 1. Kota Kinabalu city centre: The three major road links are labelled as Links A, B and C, and the field monitoring sites are labelled as S1–S8.

Field Measurements

The modelling output results were evaluated against the CO levels measured at eight monitoring sites in the field. The CO levels were measured using Carbon Monoxide Analyzer Model 416 NDIR, a portable continuous CO monitor with detection range of 0–100 ppm. The sample gas flow rate is 0.5 ± 0.25 L/min. The zero gas was passed through to warm up the instrument. The warm-up is completed when the zero point stabilizes (about 4 hours). A standard CO span gas and zero air were used to calibrate the instrument before and after each field measurement. The monitoring instruments were positioned about 1.5 m from the ground and at least 3 m from the road shoulder. The measurements were conducted continuously for 12 hours (0600–1800 hours) with 1-hr averaging time during the period June 2003–March 2004.

Traffic Data Collection

The three links are double carriageways with two lanes at each roadway; some intersections have 3–6 lanes. Motor vehicle count in the field was continuously monitored for different categories of vehicles (i.e. heavy duty, light duty petrol and diesel) for each direction. The average number of motor vehicles passing each of the monitoring sites was 3228–6795 veh/hr. The average vehicle speed was in the range of 20–50 km/hr. MOBILE 5A software programme was used to generate traffic source emission factors for input into the CAL3QHC model.

Meteorological Data

A portable meteorological weather station (ESM Model 900) was installed at the monitoring sites to continuously monitor the wind speed, wind direction, temperature and humidity. Meteorological data were also obtained from the nearest meteorological station managed by Malaysian Meteorological Service Department to determine the atmospheric stability class.

CO Emission Modelling

The modelling study utilized the CAL3QHC (Ver. 2) dispersion model to measure CO concentrations from both moving and idling vehicles. The model is a line source air quality model developed by the California Department of Transportation (Caltrans). The model is based upon Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion over the roadway. CAL3QHC is capable of processing a maximum of 120 roadway links and 60 receptor-points and 360 wind angles on each run. Input parameters that are required to run this model include roadway geometries, receptor locations, meteorological conditions, vehicular emission rates and additional traffic parameters such as saturation flow rate, signal type and arrival type. The model was run during all peak hours (morning, afternoon, and evening). The output of the dispersion model is one-hour average CO concentration at the receptors. The non-vehicle-originated (background) concentration of CO in trafficked sites was 0.2 ppm, which has been estimated using the equation simplified by Larson *et al*. (1996).

Defining Receptors

Receptors are defined as locations close to the roadway where pollutant concentrations caused by mobile sources are to be measured. Receptors can exist as part of a grid or as discrete receptors. A receptor should be located outside the "mixing zone" of a roadway, which is the total width of the travel lanes of a roadway plus 3 meters (10 feet) on either side. A total of 47 discrete receptors were assessed in terms of potential exposure of CO by comparing with the Malaysian Ambient Air Quality Guideline of 30 ppm (1hr-TWA). Potential exposures that exceed the ambient standard may be of greater concern to public health because they increase the total body burden for CO (USEPA, 1999).

RESULTS AND DISCUSSION

CO modelling

A microscale CO dispersion modelling using CAL3QHC was carried out at three major roads (Link A, Link B and Link C) within Kota Kinabalu city centre during peak hours: morning (0730–1030), afternoon (1130–1430) and evening (1630–1830). Link A, with average of 5,222 veh/hr has maximum CO concentration (1 hr-TWA) during peak hours of 10.3 ppm (morning), 10.9 ppm (afternoon) and 9.2 (evening). CO "hot-spots" along the link were mainly found at major intersections. One of the hot-spot was at S3, which is the largest traffic intersection in the city (Figure 2). Link B, which is one of the busiest roads in the city with an average of 5,983 veh/hr, has the highest concentration of CO (8.0–13.9 ppm, 1-hr TWA) during peak hours. The maximum CO concentrations during peak hours were 13.3 ppm (morning), 13.9 ppm (afternoon) and 13.2 ppm (evening). Meanwhile, Link C, which has comparably lower traffic density (2,220 veh/hr) with the exception of intersection S3, has maximum CO concentrations of 10.6 ppm (morning), 11.0 ppm (afternoon) and 9.2 ppm (evening). Similar to Link A, CO "hot-spots" in Link B and Link C were clearly identified at major intersections, particularly S6 (Figure 3 and Figure 4).

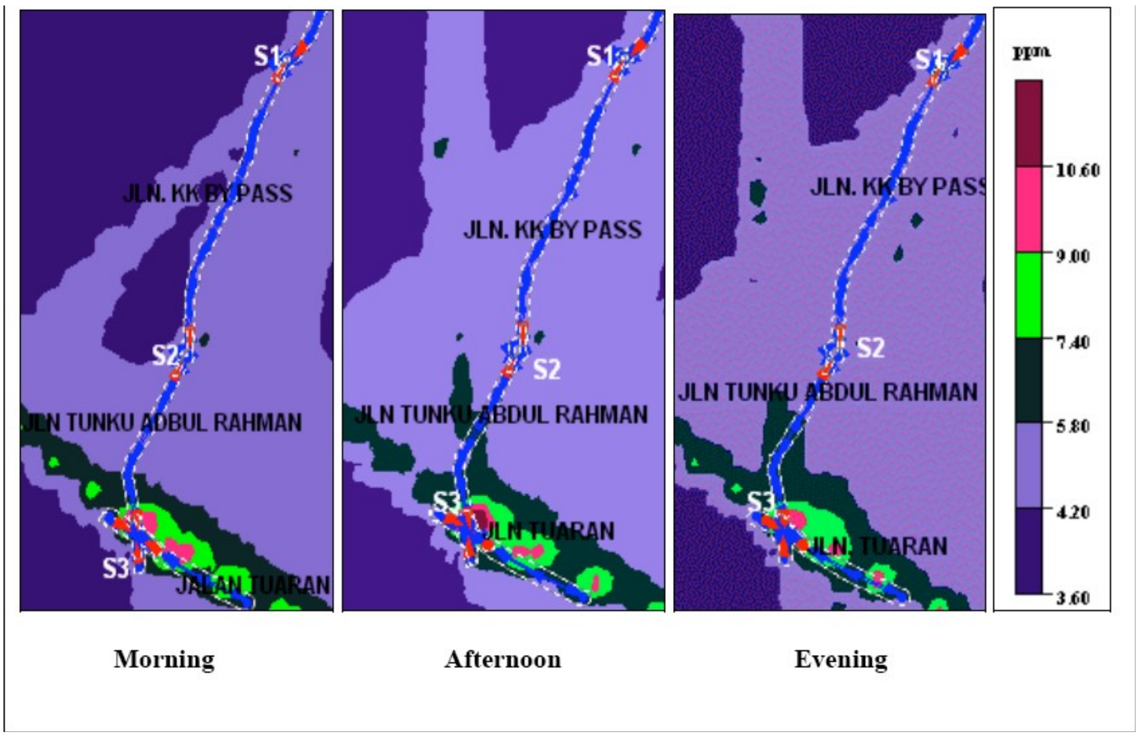


Figure 2. Carbon monoxide concentrations (1hr, TWA) during peak hours at Link A

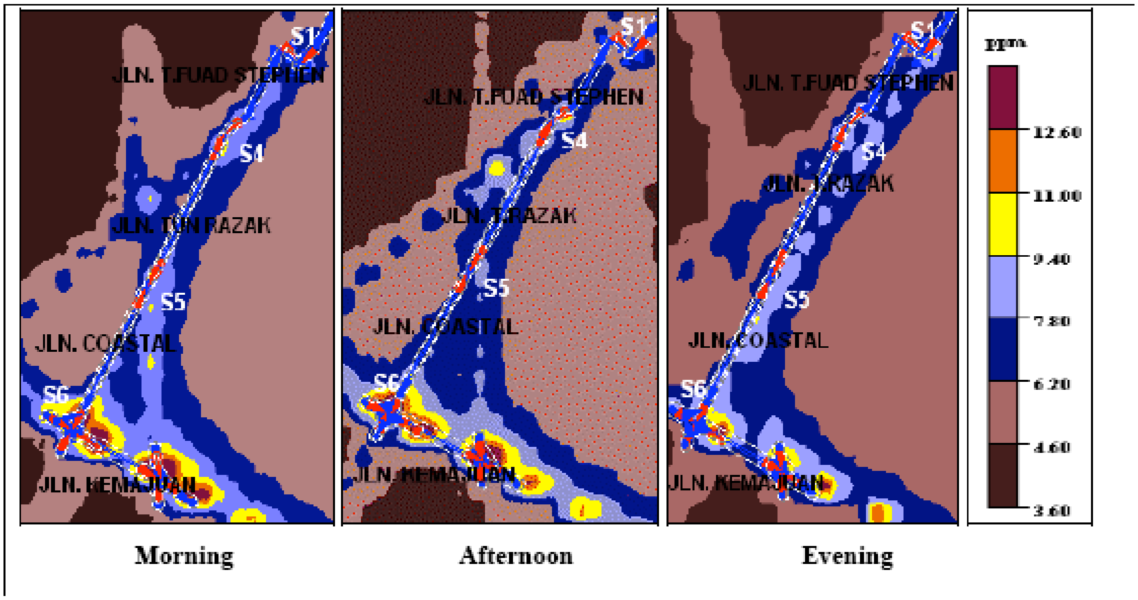


Figure 3: Carbon monoxide concentrations (1hr, TWA) during peak hours at Link B

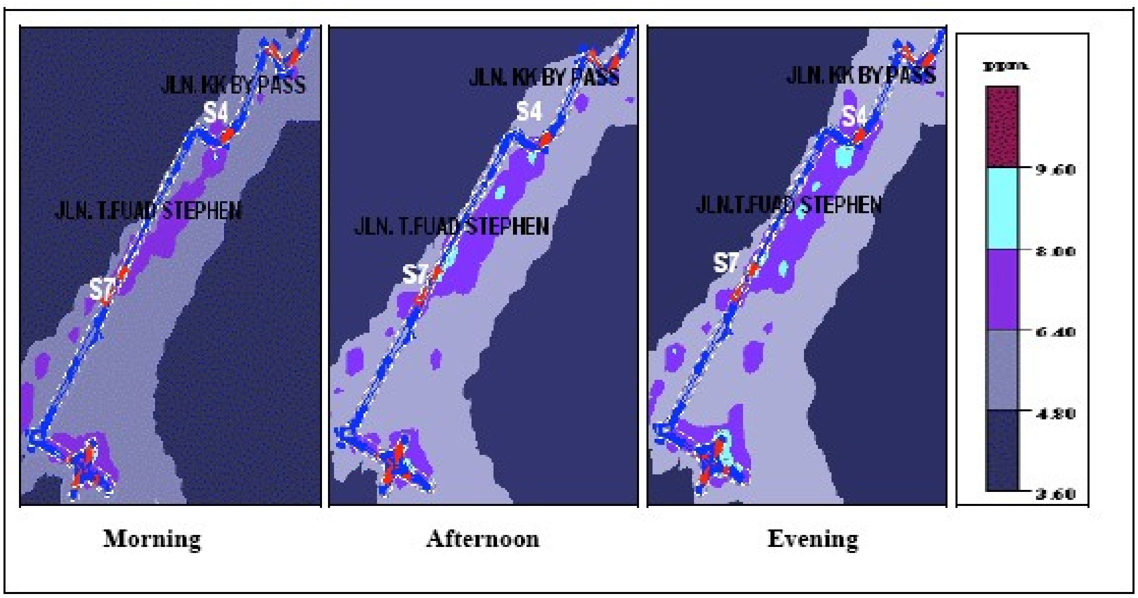


Figure 4. Carbon monoxide concentrations (1hr, TWA) during peak hours at Link C

High concentrations of CO, mostly at the intersections, mainly originated from motor vehicle emissions. Strong positive relationships between the CO concentrations and the number of vehicles at all monitoring sites (R^2 between 0.76–0.98) were found in this study, indicating that motor vehicles contributed most of the CO emissions (Figure 5). Similar conclusions were also observed elsewhere concerning CO emission from motor vehicles (Bogo *et al*., 1999; Borrego *et al*., 2003; Chan & Liu, 2001; Chan *et al*., 2002; Gramotnev *et al*., 2003; Potoglou & Kanaroglou, 2005).

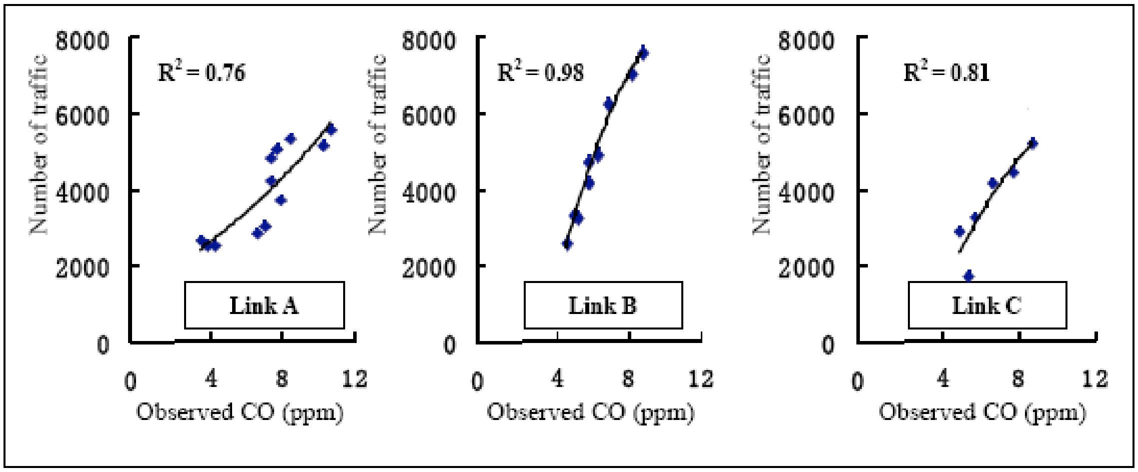


Figure 5. Relationships between the CO concentrations (ppm) and the number of traffic at Link A, Link B and Link C.

Traffic flow conditions also caused the high CO concentration particularly at the intersections. Intersections S6 and S3, for example, apart from recording higher number of motor vehicles, these intersections were also observed to be over-saturated with traffic, particularly during the afternoon and evening peak hours. This condition could have contributed significantly to the CO concentrations (Zhou and Sperling, 2001). It was also observed that the average signal cycles at S3 (140 sec) and S6 (120 sec) were comparably longer than at other intersections. This condition allowed vehicles from various directions to idle for a longer time and thus emit more CO. Motor vehicles with the engine running in an idle position have been shown to emit more CO than in free flow conditions (Luria *et al*., 1990; Mukherjee & Viswanathan, 2001). Highest CO levels at busiest intersections could have been due to the impact of elevated exhaust plumes from slow-moving vehicles as observed in another study (Moseholm *et al*., 1996). The traffic occupancy effect that has been related to the effect of vehicle induced air turbulence in the “mixing zone” could also be responsible for the CO variations at the monitoring sites. Among other factors that could play important roles in the variation of CO concentration but have not been investigated in this study are type of fuel used (Bradley *et al*., 1999; Schifter *et al*., 2003), age of the motor vehicles (Schifter *et al*., 2003), local meteorological conditions (Comrie and Diem, 1999; Sjodin *et al.*, 1994), and urban high-rise buildings (Zhou and Sperling, 2001)

Verification of Modelling Results with Field Monitoring Data

Evaluation of the performance of an air quality model generally focuses on assessing the accuracy of model prediction relative to observed concentrations. In this study, evaluation was performed statistically on each link for each peak period and the analysis indicated that the predicted CO level from the microscale dispersion model compares well with the measurements of CO in the field (regression coefficient, R^2 between 0.76–0.96) as shown in Figure 6.

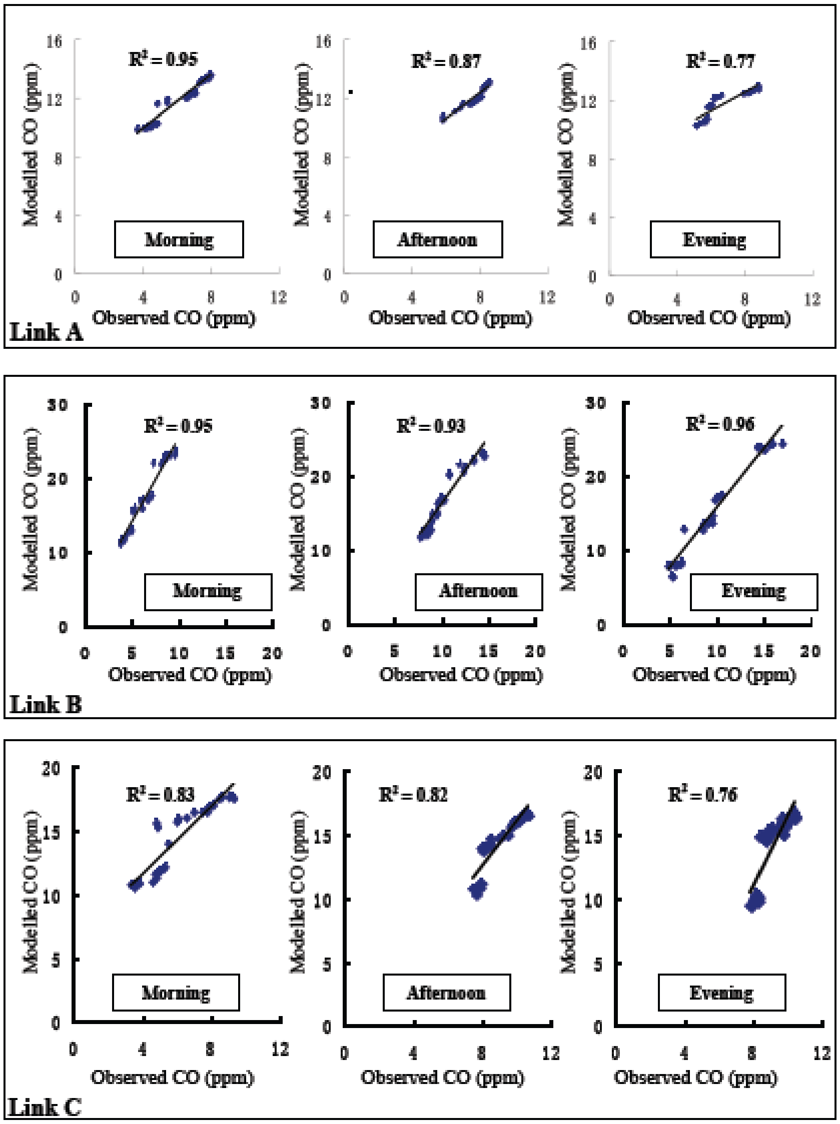
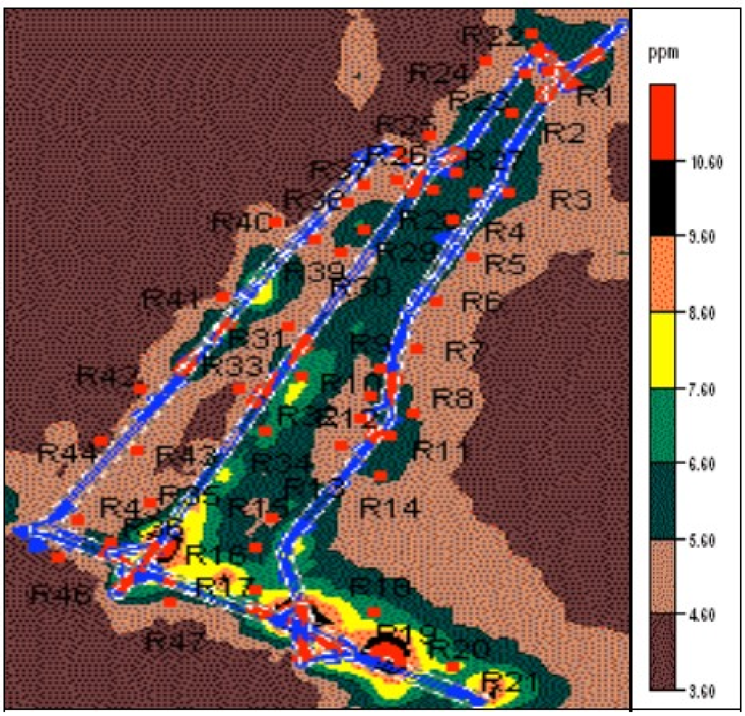


Figure 6. Relationships of the observed and modelled CO concentrations during peak hours at Link A, Link B and Link C.

Receptor Exposure

A number of selected discrete receptors within the studied area were assessed in terms of potential exposure to pollutants compared with the Malaysian Ambient Air Quality Guideline of 30 ppm (1 hr-TWA). A total of 47 receptors (mostly public places such as shopping complexes, offices, residential flats and apartments, schools, hotels, petrol kiosks and restaurants) were selected. Based on the modelling results, the CO concentrations at selected receptors were in the range of 4.3 to 11.7 ppm with the highest CO concentration at R19 (ESSO Petrol Kiosk) (Figure 7). All the selected receptors were exposed to CO concentrations well below the ambient standard of 30 ppm (1hr, TWA). In considering the average annual increase of registered motor vehicles in Kota Kinabalu of about 7.58%, long-term exposure to CO of some receptors such as R17 (Kota Kinabalu Police Station Headquarters and residential flats) deserve further attention in future urban transportation planning.



R1	WismaPerkasa
R2	Tong Hing Supermarket
R3	Dewan Bandaraya KK
R4	Jesselton Hotel
R5	Gaya Street
R6	WismaIntiutama
R7	Padang Merdeka
R8	Bus Station
R9	ESSO Kiosk(1)
R10	Wisma Dang Bandang
R11	Bandaraya Berjaya
R12	GSC
R13	Wisma Kebudayaan
R14	Shangrila Hotel
R15	Chung Hwa School
R16	All Saints Church
R17	Karamunsing Police Station (HQ)
R18	Karamunsing Complex
R19	ESSO Kisok (2)
R20	SHELL Kiosk
R21	Wisma RTM
R22	TAR Jetty
R23	Port View Restaurant
R24	Customs Department
R25	Wisma Sabah
R26	Wisma Merdeka
R27	ESSO Kiosk (3)
R28	Capitol Hotel
R29	Segama Complex
R30	Post Office
R31	Sinsuran Complex
R32	ESSO Kiosk(4)
R33	Centre Point
R34	Asia City
R35	Api-Api Centre
R36	Tang Dynasty Hotel
R37	Hyatt Hotel
R38	Sunrise Restaurant
R39	KK Plaza
R40	KK Market
R41	Philippines Market
R42	Waterfront
R43	Promenade Hotel
R44	Anjung Senja
R45	Wawasan Plaza
R46	Bus Station
R47	Banks

Figure 7. Carbon monoxide concentrations (1hr, TWA) at selected receptors in Kota Kinabalu city centre

CONCLUSION

The maximum 1-hr (TWA) concentrations of CO during peak hours at three major links in Kota Kinabalu city centre were in the range of 5.2–10.8 ppm (morning), 5.4–11.2 ppm (afternoon), and 5.5–9.4 ppm (evening), which are well below the Malaysian Ambient Air Quality Guideline of 30 ppm. Motor vehicles and the traffic flow conditions were among the main factors that have been identified as contributing to the higher levels of CO at the major intersections and busiest links in the city. CO concentration "hot-spots" were also identified, mainly at major intersections such as S3 and S6. Even though the present study has shown no alarming situation on CO levels, receptors located close to the major intersections have the potential risk of being exposed to high CO concentration in the long term and therefore deserve further attention in future urban transportation planning.

ACKNOWLEDGMENT

The authors wish to thank Universiti Malaysia Sabah for providing the financial support (B-0803-01-ER/U45).

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