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SUCCESS OF FUEL QUALITY IMPROVING POLICY IN REDUCING BENZENE AIR CONCENTRATIONS IN BANGKOK

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ABSTRACT: The Thai's policy in improving of fuel quality to the changing of emissions and concentrations of air pollutants in Bangkok is evaluated in this study. Benzene content in gasoline had been decreased from 3.5% (EURO II standard) to less than 1.0% (EURO IV standard) since the year 2012. The IVE (International Vehicle Emission) model was applied to develop emission factor of benzene taking into consideration actual fleets and characteristics of vehicles in Bangkok. These vehicles consisted of passenger car, motorcycle, van and pick up, taxi, bus and truck. Then, emission inventory of benzene emitted from mobile sources was calculated. It was found that about 83% of total emissions of benzene were contributed from motorcycle (43%) and passenger car (40%). Emission amounts were reduced from 1.32 x 10^3 ton/year to 0.57 x 10^3 ton/year as resulted from changing of fuel quality from EURO II to EURO IV standard. AERMOD dispersion model was used to simulate ambient ground level concentration of benzene prior and after implementing this policy. Results revealed significantly reduction of benzene concentrations in Bangkok's environment. Spatial distribution of benzene pollution map illustrated that areas having annual concentration higher than 1.7 μg/m^3 (the Thai's air quality standard for benzene) were still only found in traffic-congested zone of the central business district in the metropolitan area.

Keywords: Benzene, IVE, AERMOD, Emission rate, Bangkok

1. INTRODUCTION

Information from the Department of Land Transport, Ministry of Transport indicated that the cumulative number of vehicles in Thailand, registered in December 31, 2013 were 34,624,406. Among these, the numbers of cumulative registered vehicles in Bangkok were 8,216,859 or approximately 23.7% of the cumulative number of vehicles registered nationwide [1].

Benzene is carcinogenic to human (Group1) [2]. It generally found in petroleum products, such as gasoline and diesel fuel. The presence of benzene in gasoline (petrol), and as a widely used industrial solvent can result in significant and widespread emissions to the environment. This air toxic is emitted from gasoline service stations, motor vehicle exhaust and fuel evaporation, the burning of coal and oil, and various other sources. Mobile (i.e., cars, trucks, motorcycles and airplanes) are a major source of benzene. The increasing numbers of motor vehicles are the major cause of the high roadside benzene levels along the busy road [3]. People exposed to benzene at sufficient concentrations may experience various health effects, including cancer and damage to the immune system, as well as neurological, reproductive, developmental, respiratory, and other health problem. Plants and animals may also be harmed by exposures to benzene.

Status of benzene measured in Bangkok indicated that benzene concentrations were higher than its annual ambient air quality standard (1.7 μg/m^3) as shown in Fig.1. In addition, it is found that level of this carcinogen is generally higher than other area of the country. It is well known that the major emission source of air pollution in Bangkok areas is from mobile source since traffic emissions dominate as major source in the city [4]. Figure 1 shown annual concentration of benzene from 4 air quality monitoring stations measured during the period from 2008 to 2012 in Bangkok [5].

This study assessed amount of benzene emissions and concentrations from mobile sources in traffic-congested zone of the central business district in the Bangkok metropolitan area, Thailand. Fuel quality in Thailand has been improved from EURO II to EURO IV standard since the year 2012. Major improvement was reducing benzene content in gasoline from 3.5% (EURO II) to less than 1.0% (EURO IV). Therefore, the years 2011 and 2013 were selected as reference years for comparison in this study. Emission factors of benzene for each type of vehicle in these years were derived from the study by Thepanondh S. [6]. This study developed emission factors, based on travel distance information, for air toxic compounds from vehicles using the IVE (International Vehicle Emission) model. These emission factors were calculated using the actual fleet and fuel characteristics in the study area. Fleet characteristics of predicted years (2011 and 2013) were set taking into account the emission and fuel standards of Euro II and Euro IV, respectively [7]. Emission factors of each type of vehicle under the Euro II and Euro IV scenarios were as presented in Table 1. Total emission amount of benzene emitted from mobile sources were then calculated using these emission factors and the vehicle kilometer travel information.

Table 1 Emission factor of benzene used in this study

Type of vehicle	Emission factor (g/km)	
	EURO II	EURO IV
passenger car	0.0151	0.0072
motorcycle	0.0401	0.0048
van and pick up	0.000445	0.000407
taxi	0.0182	0.0162
bus	0.0043	0.0044
truck	0.0096	0.0095

Remarks: These emission factors were calculated from IVE model [6]

These emission rates were used as input data to predict its ground level concentration using air quality dispersion model. AERMOD dispersion model version 8.8.9 was used to simulate ambient ground level concentration of benzene prior and after implementing the Thai's policy in improving of fuel quality in the year 2012 (changing of fuel quality from Euro II to Euro IV standard). Spatial distributions of benzene concentration in the study area were illustrated as pollution map. Sensitivity analysis of effectiveness of implementing fuel quality improvement policy was carried out by identifying differences of modeled results from simulation of with and without this policy.

2. METHODOLOGY

In this study, the study domain covered area of 4 km ×4 km in the traffic-congested zone of the central business district in the Bangkok metropolitan area, Thailand. Six major roads located within the modelling domain were included in this study. They were Phahonyothin road, Phayathai road, Dindaeng road, Rachawithi road, Rama-VI road and Makkasan road. Figure 2 illustrated a map of the study area. The characteristics of each road in study area were presented in Table 2.

Emissions and concentrations of benzene from vehicles in the study area were evaluated. These vehicles consisted of passenger car, motorcycle, van and pick up, taxi, bus and truck. The receptor used as locations to predict ground level concentration of benzene consisted of 6 discrete receptors which are representative of the sensitive areas within the study domain. They were Phramongkutklao hospital (PMK H.), Queen Sirikit National Institute of Child Health (Child H.), Suan Sunti Phap Park (SSP park), Phayathai 2 hospital (Phayathai 2 H.), Ratchathewi District Office (RCT off.) and Rajavithi hospital (Rajavithi H.). Spatial distribution of receptors in this study is illustrated in Fig.2.

Table 2 Characteristics of each major road in study area in 2013

Road	Length (km)	Width of the road (m)	Traffic density (vehicle per day)
Phahonyothin	1.65	21	60,400
Phayathai	1.82	21	72,033
Dindaeng	2.01	28	64,557
Rachawithi	1.61	21	20,357
Rama-VI	1.26	17.5	56,067
Makkasan	1.15	21	403

Composited emission factor of vehicles were derived from calculation of the IVE model using an actual fleet and fuel characteristic of each type of vehicles in Bangkok. The International Vehicle Emissions (IVE) model is a computer model designed to estimate emissions from motor vehicles. Its prime purpose is for use in developing countries. The model predicts local air pollutants, greenhouse gas emissions, and toxic pollutants. The IVE model has been developed as a joint effort of the University of California at Riverside, College of Engineering–Center for Environmental Research and Technology (CE-CERT), Global Sustainable System Research (GSSR), and the International Sustainable Systems Research Center (ISSRC). Funding for model development was provided by the U.S. Environmental Protection Agency [6].

Numbers of each type of vehicles driven on each road in the year 2013 were summarized in Fig.3. These data were obtained from direct counting of number of vehicle driven on these streets reported by the Department of Traffic and Transportation, Bangkok Metropolitan Administration in 2013 and the EIA (Environmental Impact Assessment) report; MRTA-Purple line Bang Sue-Samsen section project, in 2013 [8],[9]. Data revealed that motorcycle and passenger car were dominant types of vehicle within the study area.

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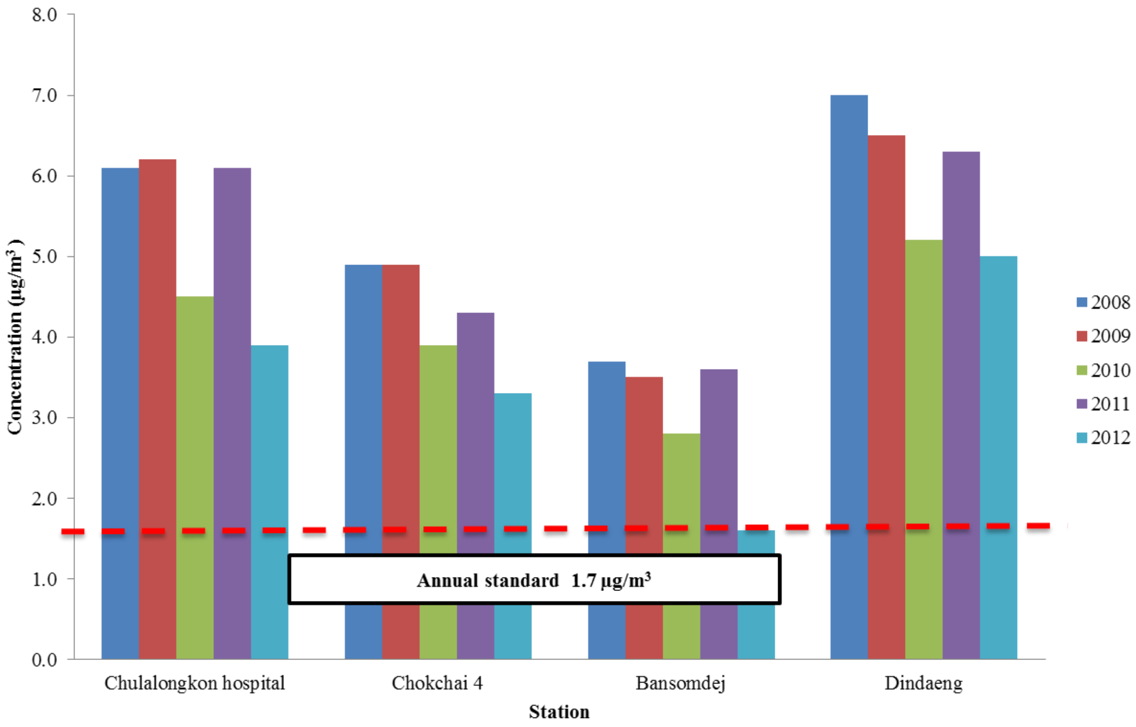

Fig.1 Annual ambient concentration of benzene from 2008–2012 in Bangkok [5]

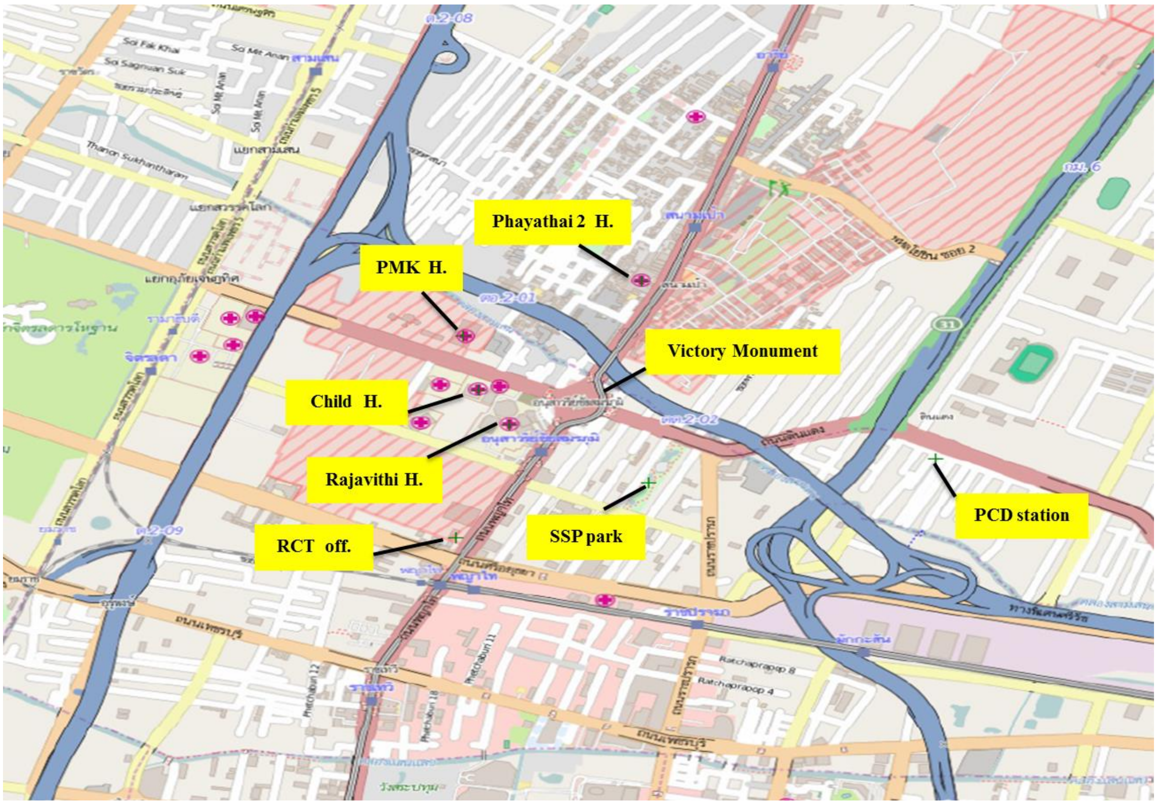

Fig.2 Map of the study area

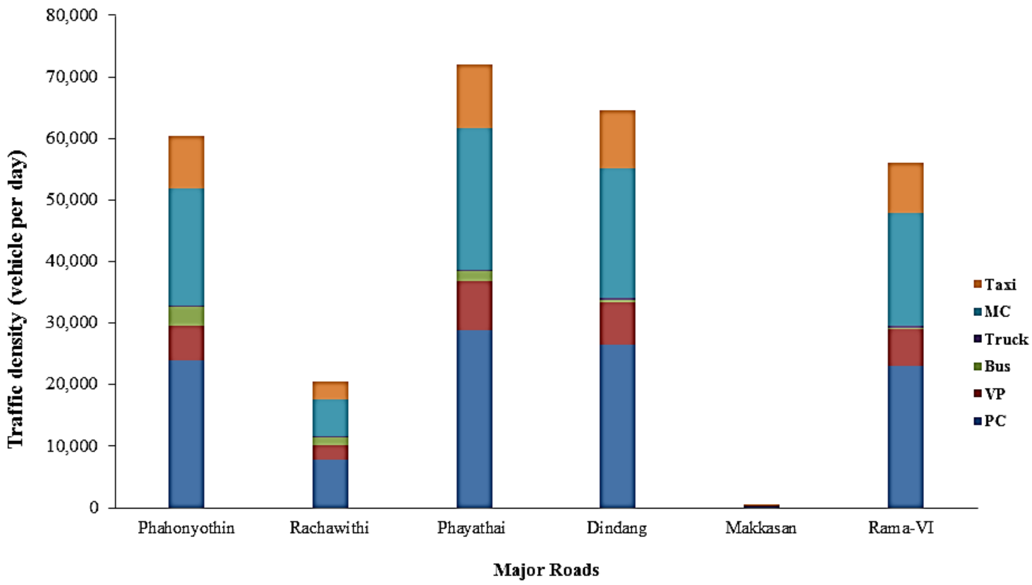

Fig.3 Proportion of each type of vehicle in study streets (vehicle per day)

These data were then used to predict ambient air concentrations of benzene by using the AERMOD dispersion model version 8.8.9. AERMOD is a steady-state plume model which assumes that a plume disperses in the vertical and horizontal directions resulting in Gaussian concentration distributions [10]. It is a regulatory dispersion model of U.S. Environmental Protection Agency, and in place of its predecessor Industrial Sources Complex Short Term (ISCST) model. It has been widely used for environmental impact assessment purpose [11]. The model assumes the concentration distribution to be Gaussian in both the vertical and horizontal. In the convective boundary layer (CBL), the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function (pdf). Using a relatively simple approach, AERMOD incorporates current concepts about flow and dispersion in complex terrain. Where appropriate the plume is modeled as either impacting and/or following the terrain. One of the major improvements that AERMOD brings to applied dispersion modeling is its ability to characterize the planetory boundary layer (PBL) through both surface and mixed layer scaling. AERMOD constructs vertical profiles of required meteorological variables based on measurements and extrapolations of those measurements using similarity (scaling) relationships [10]. AERMOD system consists of three main processors: AERMAP as the terrain processor, AERMET as the meteorological processor, and AERMOD as the main dispersion model processor [12]. The AERMOD system is considered accurate for dispersion modelling at distances not exceeding 50 km. from the emission source [13]. In this study, the model was simulated taking into consideration diurnal variation of number of vehicles on the road. The weekday-weekend profiles were also considered in this simulation.

3. RESULTS AND DISCUSSION

As for estimation of emission amount of benzene by using the IVE model, results indicated that its total emissions were decreased from 1.32×10^3 ton/year (using emission factor of the year 2011) to 0.57×10^3 ton/year (using emission factor of the year 2013). This amount was about 43% reduced from its EURO II fuel quality standard scenario. About 83% of total emissions of benzene were contributed from motorcycle (43%) and passenger car (40%).

AERMOD was used to simulate ambient ground level concentration of benzene prior and after implementing of measures to change the fuel quality from Euro II to Euro IV standard. Model was simulated covering the whole period of the year 2013. Annual concentrations of benzene at each receptor sites were computed. Figure 4-5 illustrated the spatial distribution of areas having benzene annual concentration higher than 1.7 $\mu g/m^3$ (the Thai's air quality standard for benzene). Comparison of predicted annual concentrations of benzene between the year 2011 and 2013 is as presented in Fig.6. Results clearly indicated significant reduction of benzene ground level concentration within study area from implementation of fuel quality improvement policy.

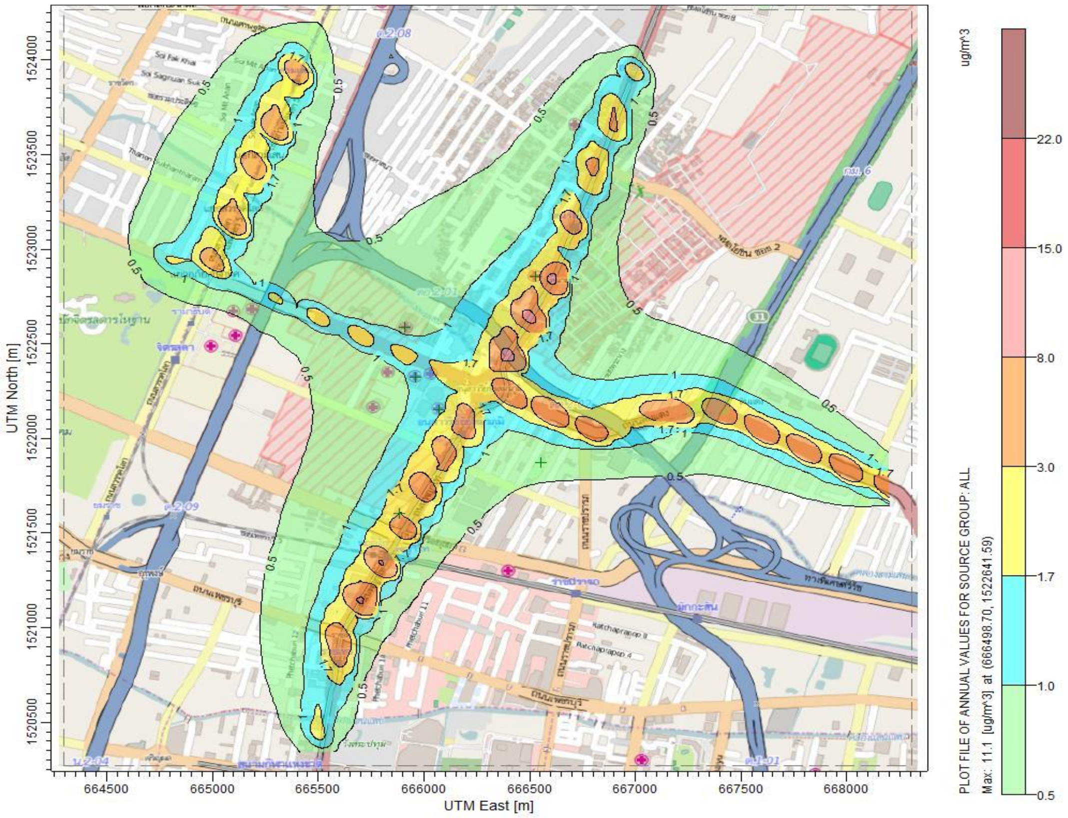

Fig.4 Spatial distribution of benzene pollution map (EURO II scenario)

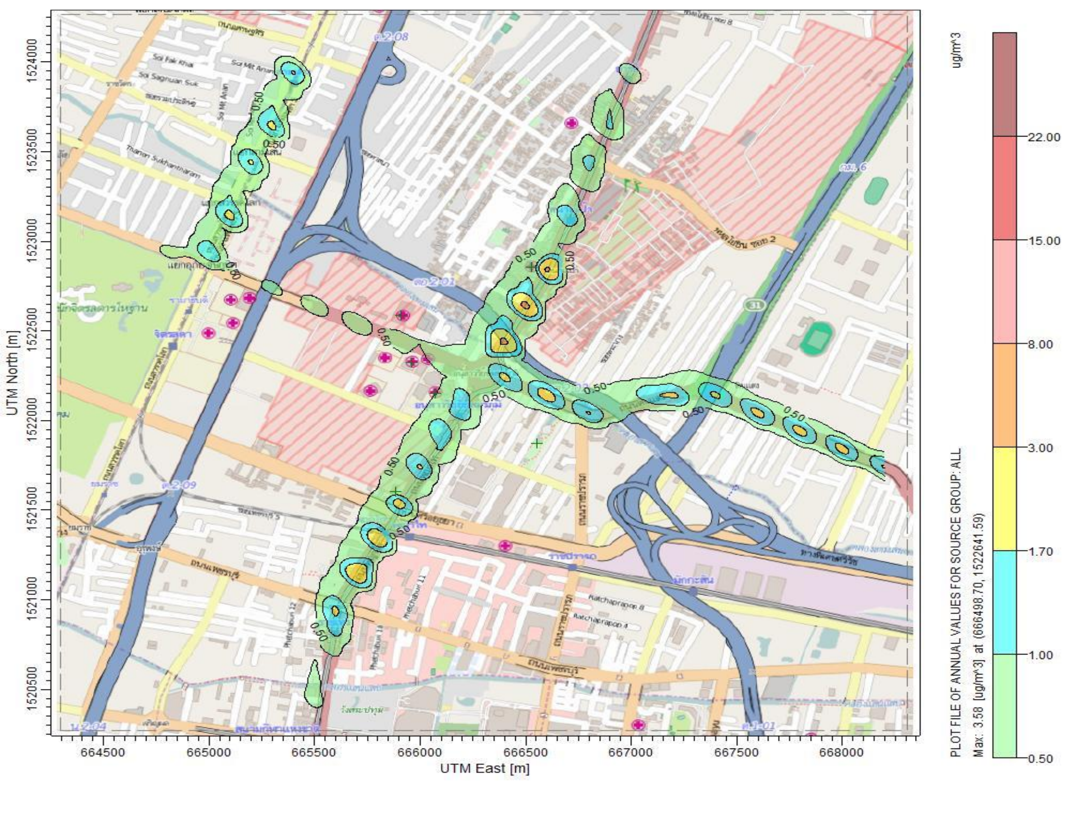

Fig.5 Spatial distribution of benzene pollution map (EURO IV scenario)

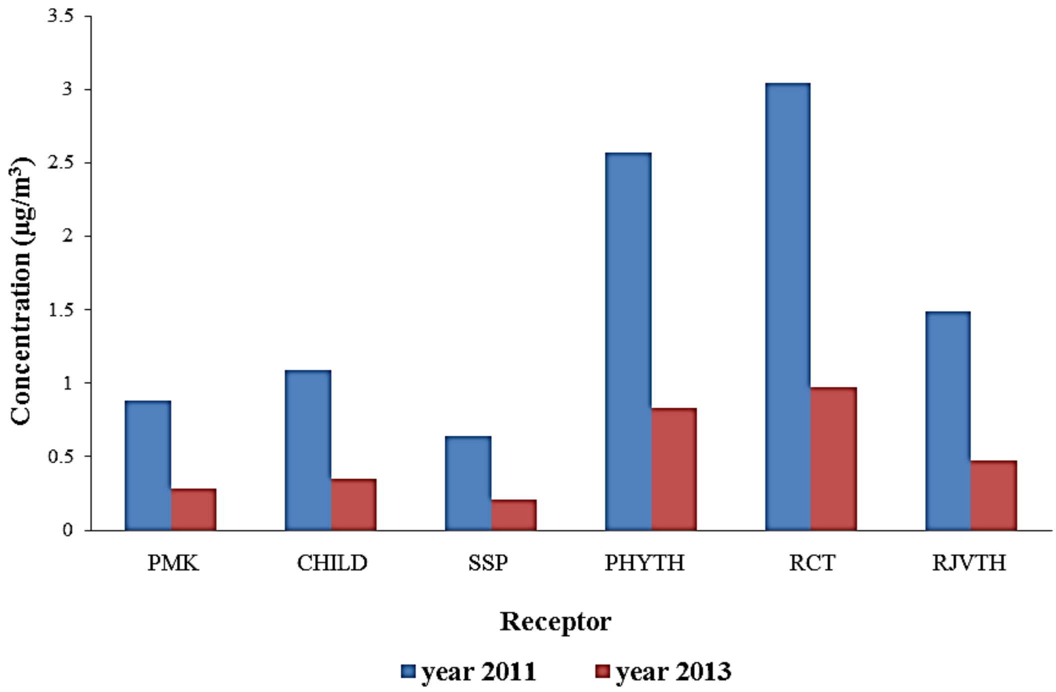

Fig.6 Comparison of predicted annual concentrations of benzene (µg/m^3)

Predicted results of annual concentration of benzene at receptor positions also revealed the decreasing trend when EURO IV standard had been implemented. Annual benzene concentrations at every receptor were predicted to be within the level of benzene air quality standard as shown in Fig. 6. Results from this study were coincided with significantly reduction of benzene concentrations obtained from direct measurement in Bangkok's environment. The maximum benzene annual concentration measured as 11.1 µg/m^3 in 2011 was dramatically decreased to 3.58 µg/m^3 in 2013 at the same location [14]. These findings strongly supported that the implementation of measures to improve the fuel quality from Euro II to Euro IV standard was one of a success policy in reducing both emission and concentrations of airborne benzene in Bangkok metropolitan area.

In addition, ozone and photochemical oxidants are one of the major air pollutants which Bangkok is faced at present. These pollutants together with variation of meteorological conditions can affect to temporal distribution and dissipation of benzene. Evaluation of natural dissipation of benzene is also interested to identify natural contribution of this compound. Therefore future study to evaluate influences of these factors and relationship between air toxics and photochemical oxidants are very much interested. These further studies can assist in elucidating atmospheric chemistry of air pollutants for better management of policy to tackle this problem.

4. CONCLUSION

The Thai's policy in improving of fuel quality was evaluated to elaborate for its success in reducing emissions and concentrations of benzene in Bangkok's air. Benzene content in gasoline had been decreased from 3.5% (EURO II standard) to less than 1.0% (EURO IV standard) since the year 2012. The IVE model was applied to develop emission factor of benzene using actual fleet and fuel characteristics of vehicles in Bangkok. These vehicles consisted of passenger car, motorcycle, van and pick up, taxi, bus and truck. Then, emission inventory of benzene emitted from mobile sources was calculated. It was found that about 83% of total emissions of benzene were contributed from motorcycle (43%) and passenger car (40%). Emission amounts were reduced from 1.32 x 10^3 ton/year in the EURO II scenario to about 0.57 x 10^3 ton/year in the EURO IV scenario. Annual ground level concentrations of benzene emitted from mobile sources were predicted using AERMOD dispersion model. A traffic-congested zone of the central business district in the Bangkok metropolitan area was selected for this evaluation. AERMOD model was simulated to predict ambient ground level concentration of benzene prior and after implementing the EURO IV policy. Results revealed significantly reduction of benzene concentrations in Bangkok's environment. This study indicated the success and effectiveness of implementing fuel quality improvement policy in managing benzene pollution in Bangkok metropolitan area.

5. ACKNOWLEDGEMENTS

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