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# Monitoring of Volatile Organic Compounds at Gyeongju: A Historical and Tourist Place in South Korea

YOUNG KYO SEO, LAKSHMI NARAYANA SUVARAPU and SUNG OK BAEK*

Department of Environmental Engineering, Yeungnam University, Gyeongsan-si 712 749, Republic of Korea

*Corresponding author: Tel: +82 53 8102544; E-mail: sobaek@yu.ac.kr

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Volatile organic compounds monitoring in ambient air is an important task to the environmental researchers throughout the world due to their toxic effects to the human beings. Our literature survey revealed that not much attention has paid in the monitoring of volatile organic compounds at tourist and/or historical places in the world. The present study predicts the air quality in terms of the ambient concentrations volatile organic compounds at Gyeongju, a historical/tourist city in South Korea and recognized as world heritage site by the UNESCO. The extensive sampling and analysis of volatile organic compounds at this city reveals that only 34 volatile organic compounds are found at beyond the method detection limit among the 68 measured volatile organic compounds and only 8 volatile organic compounds including benzene, toluene, ethylbenzene and *m*-, *p*-xylenes (BTEX) are found in over 90 % detection frequency. We also compared the concentrations of BTEX obtained in present study with other tourist, historical and the UNESCO world heritage sites in the world. The concentrations of BTEX found in Gyeongju are much lower than the other cities in the world with which are compared. The questionnaire with the tourists regarding air quality at Gyeongju also tells us that over 97 % of the surveyed tourists are happy with the quality of air at sampling sites. It is suggested that the usage of electric car/bus for the public transport to further reduction in the concentration of volatile organic compounds in ambient air of Gyeongju. The major advantage of this study is it predicts the accurate exposure of volatile organic compounds by the tourists, because the sampling of volatile organic compounds is carried out with personal exposure samplers by moving around the tourist spots which is not fixed at a single spot.

**Keywords: Volatile organic compounds, Gyeongju, UNESCO world heritage site, Personal monitoring.**

## INTRODUCTION

Environmental monitoring includes the monitoring of pollutants exists in water, soil and air. The quality of air can be examined based on the concentrations of pollutants present in that particular area. The existence of volatile organic compounds in the atmosphere can cause damage to the kidney, liver and central nervous system in human beings. The extensive studies on the atmospheric volatile organic compounds by the IARC (International Agency for Research on Cancer) listed benzene, styrene and 1,3- butadiene in group 1 carcinogens, which can cause the acute non-lymphocytic leukemia in human beings[1]. According to The US EPA, volatile organic compounds are organic chemical compounds whose composition makes it possible for them to evaporate under normal atmospheric conditions of temperature and pressure. Volatile organic compounds can enter into the atmosphere in many ways and their sources can be divided into two types *i.e.*, natural and anthropogenic. The natural sources of volatile organic compounds including vegetation and forest fires[2,3] and anthropogenic sources not limited to gasoline and diesel vehicle emissions[4-6], biomass burning[7], paints[8] and industrial solvents[9,10].

In the modern world, tourism became one of the most popular leisure activities. According to the United Nations World Tourism Organization (UNWTO), there were 983 million tourist arrivals reported in 2011 throughout the world. Mostly the historical and cultural properties of the nations attract the tourists in all over the world. Our literature survey reveals that only few authors reported the ambient concentrations of volatile organic compounds at the popular tourist places in all over the world. Suthawaree *et al.*[11] reported the concentration of volatile organic compounds at Mountain Tai [listed in UNESCO (United Nations Educational, Scientific and Cultural Organization) world heritage sites] a popular tourist place in central east China during 2-28, June-2006. Muezzinoglu *et al.*[12] reported the ambient concentrations of volatile organic compounds at an Izmir-Cesme highway, a popular tourist/ recreational town near Izmir, Turkey.

In South Korea, ten places were recognized as world heritage sites by the UNESCO, among these ten sites, three are located in Gyeongju city. This makes Gyeongju as one of the most popular tourist destinations in South Korea. Gyeongju (35°51'N 129°13'E) is located at 370 km distance from southeast of South Korea capital city, Seoul. It is a coastal city of North Gyeongsang province in South Korea by covering 1,324 km$^2$ areas in this province with a population of 272,569 according to 2010 census. The mean of annual temperature of the city is 12.2 °C and the annual rain fall is 1091 mm. This city was the capital of the ancient kingdom of Silla (57BC-935 AD) and has a numerous archaeological sites and cultural properties. Due to the vast number of ancient properties the Gyeongju city also referred as "the museum without walls". This historical city major income is driven by tourism and its neighbor cities like Ulsan and Pohang has major industries. According to the Gyeongju city government official web page, this historical city attracts over 22.80 million tourists including over 624,000 foreigners during the year 2011. Around 62 % of tourist flow was observed in Gyeongju city in between the months of May-October compare to through out the year. In this study we collected and measured the concentration of volatile organic compounds at this heavy crowded period in the year 2011. This gives an accurate impact of the measured pollutants on the tourists.

The important aspect of the present study is determination of the concentrations of volatile organic compounds through personal monitoring samplers. The advantage about the personal monitoring sampling over the conventional fixed spot monitoring is the determination of exact exposure to volatile organic compounds by the tourists whereas, conventional fixed spot measurement gives only the ambient concentrations. Literature survey reveals that limited papers[13,14] described about personal monitoring than the conventional fixed spot measurements for volatile organic compounds in ambient air.

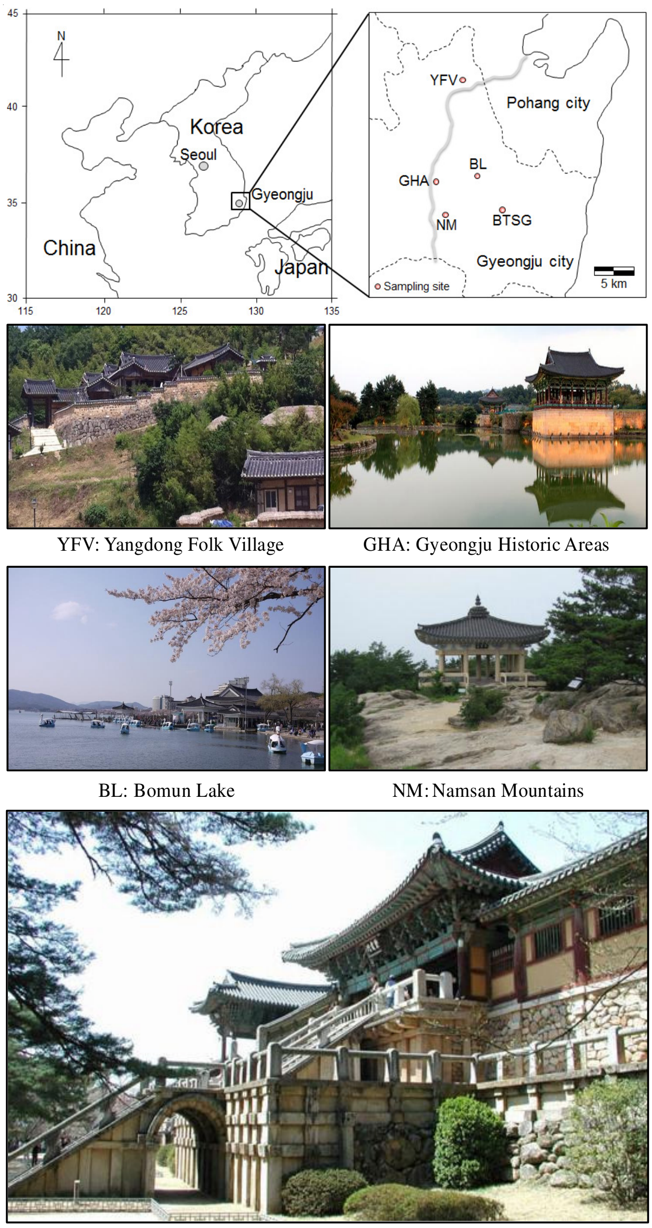
The present study reports the concentrations of volatile organic compounds at five different sites of Gyeongju including the World heritage sites listed by the UNESCO. The data produced during this study gives the clear picture about the air quality at Gyeongju tourist spots and human exposure to volatile organic compounds.

## EXPERIMENTAL

Ambient air samples were collected for the analysis of volatile organic compounds at five different sites in Gyeongju (Fig. 1) two days in a month (weekends) during May-October, 2011 with duration of 8h (9:00-13:00h, 14:00-18:00h) per day. All the sampling sites are crowded with tourists in weekend than weekdays. The characteristics of these five sites are described as follows.

**Yangdong folk village (YFV):** This is an ancient Korean traditional village exists since 15 th century. In this village 54 historic homes over 200 years old had been preserved and it was listed in the UNESCO world heritage sites in 2010. It is away from heavy traffic and industries but at weekends there was a moderate to huge vehicle traffic can be seen due to tourists.

**Gyeongju historic areas (GHA):** The historic areas within the core city of the Gyeongju were listed in world heritage sites by the UNESCO in 2000. This site is present within the core city with heavy traffic and residential areas along with historical monuments and buildings.




BTSG: Bulguksa Temple and Seokguram Grotto

Fig. 1. Location of the sampling sites in Gyeongju

**Bomun lake (BL):** It is a very good recreation center for the tourists and surrounded with so many resorts and hotels. Heavy traffic can be seen at the weekends due to the presence of amusement parks and recreation centers.

**Namsan mountains (NM):** This site is away from traffic and industries and has a huge number of Buddhist temples, stone statues, stone pagodas and stone lanterns. It is also listed in historic areas of Gyeongju and recognized as world heritage site by the UNESCO in 2000.

**Bulguksa temple and seokguram grotto (BTSG):** In the year 1995, Bulguksa temple and Seokguram grotto were listed in the UNESCO world heritage sites. It is one of the oldest Buddhist temples in the world and constructed in the year 742.

**Volatile organic compounds sampling by personal monitoring samplers:** In this study we used personal monitoring samplers for collecting volatile organic compounds by walking around the specified sampling sites. The personal monitoring samplers were carried out on shoulder (Fig. 2) and walk around the tourist spots as tourists to collect the ambient air. The inlet of the ambient air in personal monitoring samplers is very near to the nose which measures accurate exposure to the humans. The adsorbent tubes used in personal monitoring samplers were pre-conditioned at 250 °C for 2 h with helium as a carrier gas. The adsorbent tubes (1/4″ × 9 cm, Perkin Elmer, UK) packed with 120 mg Carbograph 2TD and 280 mg of Carbograph 1TD (40/60 mesh, Markes, UK) by a low flow rate pump equipped with a mass flow controller (Flec, Chematec Inc., Denmark) were used for sampling. During the sampling period the flow rate was maintained at 100 mL/min for 4 h for each tube.


Fig. 2. View of the personal monitoring samplers

**Volatile organic compounds analysis and quality control:** An automatic thermal desorber (UNITY/ULTRA, Markes, UK) coupled with a capillary gas chromatograph fitted with a mass detector (HP 6890/5973, Hewlett-Packard, USA) was used for the quantitative analysis of volatile organic compounds collected through the adsorbent tubes. All the operating analytical conditions followed in this study are presented in Table-1. The analysis of volatile organic compounds and quality control for this study was followed from previous studies[9].

TABLE-1
ANALYTICAL CONDITIONS FOR VOLATILE ORGANIC COMPOUNDS WITH THERMO-DESORPTION GC/MSD

| Thermal Desorber UNITY/ULTRA (Markes, UK) | | GC/MSD (HP6890/5973, Hewlett Packard, USA) | |
|---|---|---|---|
| Oven temp. | 300 °C | GC column | Rtx-1 (0.32 mm, 105 m, 1.5 µm) |
| Desorb time | 10 min | Initial temp. | 50 °C (10 min) |
| Desorb flow | 50 mL/min | Oven ramp rate | 5 °C/min |
| Cold trap holding time | 5 min | Final temp. | 250 °C (5 min) |
| Cold trap high temp. | 320 °C | Post run | 250 °C (5 min) |
| Cold trap low temp. | -15 °C | Column flow | 1.4 mL/min |
| Cold trap packing | Tenax TA/ Carbopack B | Detector type | Quadropole |
| Min. pressure | 15 psi | Q-pole temp. | 150 °C |
| Inlet split | No | MS Source temp. | 230 °C |
| Outlet split | 10 mL/min | Mass range | 35-300 amu |
| Valve and line temp. | 180 °C | Electron energy | 70 eV |

## RESULTS AND DISCUSSION

In present study we measured almost 68 volatile organic compounds at all the sampling sites in Gyeongju during May-October, 2011. The detection frequencies and mean concentrations of measured volatile organic compounds at Gyeongju are shown in Table-2. The detection frequency for each volatile organic compounds is calculated by dividing the number of samples detected with the total number of samples analyzed. From Table-2, it is clear that among 68 measured volatile organic compounds only 16 compounds are found in Gyeongju with over 50 % detection frequency and only 8 including BTEX are found with over 90 % detection frequency. Among the 68 measured volatile organic compounds almost half of them are not detected at all the sites of Gyeongju. In overall, only 23 % in measured 68 volatile organic compounds are found in excess of 50 % detection frequency and only 12 % volatile organic compounds are found in excess of 90 % detection frequency.

The mean (n = 96) concentrations of 68 measured volatile organic compounds at Gyeongju are presented in Table-2. At Gyeongju almost 34 volatile organic compounds are found in below the detection limit and 16 volatile organic compounds including number of human toxics are found in level of ≤ 0.01 ppb and only 10 volatile organic compounds are found in over 0.1 ppb concentration levels. The most abundant volatile organic compounds found in Gyeongju is toluene with the concentration of 0.63 ppb followed by acetone (0.47 ppb), benzene (0.26 ppb) and *m*-, *p*-xylenes (0.19 ppb). The most toxic volatile organic compounds such as 1,3-butadiene (listed as group 1 carcinogen by the IARC), acrylonitrile and chloroform are found in the level of ≤ 0.01 or below the detection limit. Among the measured 68 volatile organic compounds, only 21 (30 %) volatile organic compounds are found in concentration levels between 0.01-0.63 ppb.

**Spatial distribution of volatile organic compounds:** The concentrations of volatile organic compounds measured at 5 different sites at Gyeongju namely Yangdong Folk Village (YFV), Gyeongju Historic Areas (GHA), Bomun Lake (BL), Namsan Mountains (NM) and Bulguksa Temple and Seokguram Grotto (BTSG) are presented in Table-3. The concentrations of BTEX at YFV site are found as 0.24, 0.61, 0.14 and 0.22 ppb, respectively while at GHA site are 0.25, 0.43, 0.11 and 0.13 ppb, respectively. The BTEX concentrations at BL are 0.31, 0.64, 0.12 and 0.23 ppb, respectively where as at NM site are 0.18, 0.21, 0.07 and 0.10 ppb, respectively and at BTSG site are 0.25, 0.32, 0.07 and 0.11 ppb, respectively. From this it is observed that among the 5 different sites of Gyeongju, the concentrations of BTEX are found higher in BL site. This site represents the road side and also surrounded with number of big hotels and resorts. Due to the presence of hotels, resorts and recreation centers heavy traffic inflow is observed in weekends. The vehicular emissions may be the major source and reason for the higher BTEX concentrations at this site. Similarly another volatile organic compounds mostly emitted from vehicle exhaust *i.e.*, methyl *tert*-butyl ether (MTBE) also found higher in BL site than the other sites.

TABLE-2
DETECTION FREQUENCY AND MEAN CONCENTRATIONS OF VOLATILE ORGANIC COMPOUNDS MEASURED IN THIS STUDY

| No. | Target compounds (n = 96) | Frequency (%) | No. | Target compounds (n = 96) | Mean (ppb) |
|---|---|---|---|---|---|
| 1 | Benzene | 100.0 | 1 | Toluene | 0.63 |
| 2 | Toluene | 99.0 | 2 | Acetone | 0.47 |
| 3 | Acetone | 99.0 | 3 | Benzene | 0.26 |
| 4 | *m,p*-Xylenes | 97.9 | 4 | *m,p*-Xylenes | 0.19 |
| 5 | Carbon tetrachloride | 97.9 | 5 | Methyl *tert*-butyl ether | 0.18 |
| 6 | Ethylbenzene | 96.9 | 6 | Methyl ethyl ketone | 0.17 |
| 7 | Methyl *tert*-butyl ether | 91.7 | 7 | Vinyl acetate | 0.17 |
| 8 | Methyl ethyl ketone | 91.7 | 8 | Hexane | 0.15 |
| 9 | Hexane | 86.5 | 9 | Ethyl acetate | 0.14 |
| 10 | *o*-Xylene | 85.4 | 10 | Ethylbenzene | 0.13 |
| 11 | Naphthalene | 81.3 | 11 | Carbon tetrachloride | 0.07 |
| 12 | 1,2,4-Trimethylbenzene | 76.0 | 12 | *o*-Xylene | 0.06 |
| 13 | Ethyl acetate | 68.8 | 13 | Methyl isobutyl ketone | 0.05 |
| 14 | Vinyl acetate | 59.4 | 14 | 1,2,4-Trimethylbenzene | 0.04 |
| 15 | Heptane | 58.3 | 15 | Cyclohexane | 0.04 |
| 16 | Methyl isobutyl ketone | 58.3 | 16 | Naphthalene | 0.03 |
| 17 | 4-Ethyltoluene | 45.8 | 17 | Heptane | 0.03 |
| 18 | 1,3,5-Trimethylbenzene | 42.7 | 18 | Styrene | 0.02 |
| 19 | Freon113 | 40.6 | 19 | Freon-113 | 0.01 |
| 20 | Styrene | 38.5 | 20 | Tetrachloroethylene | 0.01 |
| 21 | Cyclohexane | 27.1 | 21 | Isopropyl alcohol | 0.01 |
| 22 | Phenol | 27.1 | 22 | 1,3,5-Trimethylbenzene | < 0.01 |
| 23 | Freon-11 | 9.4 | 23 | Carbon disulfide | < 0.01 |
| 24 | Carbon disulfide | 9.4 | 24 | Phenol | < 0.01 |
| 25 | Isopropyl alcohol | 8.3 | 25 | 4-Ethyltoluene | < 0.01 |
| 26 | 1,2-Dichloroethane | 5.2 | 26 | 2-Ethoxyethanol | < 0.01 |
| 27 | Trichloroethylene | 5.2 | 27 | 1,3-Butadiene | < 0.01 |
| 28 | 1,3-Butadiene | 4.2 | 28 | Trichloroethylene | < 0.01 |
| 29 | Tetrachloroethylene | 3.1 | 29 | N,N-Dimethylformamide | < 0.01 |
| 30 | 2-Ethoxyethanol | 3.1 | 30 | 1,2-Dichloroethane | < 0.01 |
| 31 | 1,2-Dichloropropane | 2.1 | 31 | Freon-11 | < 0.01 |
| 32 | N,N-Dimethylformamide | 2.1 | 32 | 1,2-Dichloropropane | < 0.01 |
| 33 | 2-Ethoxyethylacetate | 2.1 | 33 | 2-Ethoxyethylacetate | < 0.01 |
| 34 | Chloroform | 1.0 | 34 | Chloroform | < 0.01 |
| 35 | Freon-12 | N.D. | 35 | Freon-12 | N.D. |
| 36 | Freon-114 | N.D. | 36 | Freon-114 | N.D. |
| 37 | Vinyl chloride | N.D. | 37 | Vinyl chloride | N.D. |
| 38 | Bromomethane | N.D. | 38 | Bromomethane | N.D. |
| 39 | Ethyl chloride | N.D. | 39 | Ethyl chloride | N.D. |
| 40 | Acrylonitrile | N.D. | 40 | Acrylonitrile | N.D. |
| 41 | 1,1-Dichloroethene | N.D. | 41 | 1,1-Dichloroethene | N.D. |
| 42 | Methylene chloride | N.D. | 42 | Methylene chloride | N.D. |
| 43 | *trans*-1,2-Dichloroethylene | N.D. | 43 | *trans*-1,2-Dichloroethylene | N.D. |
| 44 | 1,1-Dichloroethane | N.D. | 44 | 1,1-Dichloroethane | N.D. |
| 45 | *cis*-1,2-Dichloroethylene | N.D. | 45 | cis-1,2-Dichloroethylene | N.D. |
| 46 | Tetrahydrofuran | N.D. | 46 | Tetrahydrofuran | N.D. |
| 47 | 1,1,1-Trichloroethane | N.D. | 47 | 1,1,1-Trichloroethane | N.D. |
| 48 | 1,4-Dioxane | N.D. | 48 | 1,4-Dioxane | N.D. |
| 49 | Bromodichloromethane | N.D. | 49 | Bromodichloromethane | N.D. |
| 50 | *cis*-1,3-Dichloropropene | N.D. | 50 | *cis*-1,3-Dichloropropene | N.D. |
| 51 | *trans*-1,3-Dichloropropene | N.D. | 51 | *trans*-1,3-Dichloropropene | N.D. |
| 52 | 1,1,2-Trichloroethane | N.D. | 52 | 1,1,2-Trichloroethane | N.D. |
| 53 | Methyl butyl ketone | N.D. | 53 | Methyl butyl ketone | N.D. |
| 54 | Dibromochloromethane | N.D. | 54 | Dibromochloromethane | N.D. |
| 55 | 1,2-Dibromoethane | N.D. | 55 | 1,2-Dibromoethane | N.D. |
| 56 | Chlorobenzene | N.D. | 56 | Chlorobenzene | N.D. |
| 57 | Bromoform | N.D. | 57 | Bromoform | N.D. |
| 58 | 1,1,2,2-Tetrachloroethane | N.D. | 58 | 1,1,2,2-Tetrachloroethane | N.D. |
| 59 | Benzyl chloride | N.D. | 59 | Benzyl chloride | N.D. |
| 60 | 1,3-Dichlorobenzene | N.D. | 60 | 1,3-Dichlorobenzene | N.D. |
| 61 | 1,4-Dichlorobenzene | N.D. | 61 | 1,4-Dichlorobenzene | N.D. |
| 62 | 1,2-Dichlorobenzene | N.D. | 62 | 1,2-Dichlorobenzene | N.D. |
| 63 | 1,2,4-Trichlorobenzene | N.D. | 63 | 1,2,4-Trichlorobenzene | N.D. |
| 64 | Hexachloro-1,3-butadiene | N.D. | 64 | Hexachloro-1,3-butadiene | N.D. |
| 65 | 2-Methoxyethanol | N.D. | 65 | 2-Methoxyethanol | N.D. |
| 66 | Epichlorohydrin | N.D. | 66 | Epichlorohydrin | N.D. |
| 67 | Aniline | N.D. | 67 | Aniline | N.D. |
| 68 | Nitrobenzene | N.D. | 68 | Nitrobenzene | N.D. |

TABLE-3
CONCENTRATIONS (ppb) OF VOLATILE ORGANIC COMPOUNDS MEASURED AT DIFFERENT SITES OF GYEONGJU

| Volatile organic compounds | Yangdong folk village (n = 12) | | | Gyeongju historic areas (n = 42) | | | Bomun lake (n = 12) | | | Namsan mountains (n = 12 | | | Bulguksa, Seokguram (n = 18) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean ± SD | Median | Range | Mean ± SD | Median | Range | Mean ± SD | Median | Range | Mean ± SD | Median | Range | Mean ± SD | Median | Range |
| Acetone | 0.33±0.13 | 0.36 | N.D.-0.51 | 0.48±0.27 | 0.45 | 0.04-1.44 | 0.48±0.15 | 0.45 | 0.27-0.82 | 0.51±0.26 | 0.40 | 0.23-0.96 | 0.51±0.17 | 0.56 | 0.23-0.80 |
| Methyl *tert*-butyl ether | 0.14±0.14 | 0.09 | 0.04-0.43 | 0.18 ±0.20 | 0.11 | N.D.-1.08 | 0.30±0.23 | 0.20 | N.D.-0.76 | 0.09±0.13 | 0.04 | N.D.-0.39 | 0.20±0.18 | 0.12 | N.D.-0.67 |
| Vinyl acetate | 0.17±0.14 | 0.16 | N.D.-0.49 | 0.15±0.18 | 0.11 | N.D.-0.87 | 0.19±0.19 | 0.16 | N.D.-0.50 | 0.13±0.20 | 0.10 | N.D.-0.69 | 0.21±0.26 | 0.07 | N.D.-0.87 |
| Methyl ethyl ketone | 0.18±0.29 | 0.08 | N.D.-0.90 | 0.14±0.12 | 0.10 | 0.03-0.60 | 0.26±0.38 | 0.11 | N.D.-1.14 | 0.17±0.22 | 0.07 | N.D.-0.64 | 0.20±0.14 | 0.19 | N.D.-0.55 |
| Ethyl acetate | 0.06±0.08 | 0.04 | N.D.-0.25 | 0.13±0.23 | 0.04 | N.D.-1.05 | 0.09±0.12 | 0.04 | N.D.-0.35 | 0.19±0.40 | N.D. | N.D.-1.12 | 0.22±0.46 | 0.07 | N.D.-1.91 |
| Hexane | 0.15±0.11 | 0.11 | 0.02-0.36 | 0.11±0.09 | 0.09 | N.D.-0.37 | 0.27±0.28 | 0.17 | N.D.-0.72 | 0.13±0.15 | 0.05 | N.D.-0.42 | 0.19±0.15 | 0.16 | N.D.-0.61 |
| Benzene | 0.24± 0.16 | 0.20 | 0.07-0.50 | 0.26±0.14 | 0.25 | 0.04-0.55 | 0.34±0.21 | 0.31 | 0.12-0.74 | 0.21±0.13 | 0.18 | 0.05-0.48 | 0.26±0.12 | 0.25 | 0.07-0.48 |
| Carbon tetrachloride | 0.06±0.02 | 0.06 | 0.03-0.10 | 0.07±0.02 | 0.07 | N.D.-0.11 | 0.07±0.02 | 0.07 | 0.03-0.09 | 0.07±0.03 | 0.08 | N.D.-0.10 | 0.07±0.03 | 0.07 | 0.03-0.13 |
| Cyclohexane | 0.02±0.04 | N.D. | N.D.-0.13 | 0.01±0.03 | N.D. | N.D.-0.10 | 0.11±0.16 | 0.01 | N.D.-0.47 | 0.02±0.04 | N.D. | N.D.-0.11 | 0.06±0.14 | N.D. | N.D.-0.57 |
| Trichloro-ethylene | N.D. | N.D. | N.D. | 0.00±0.01 | N.D. | N.D.-0.06 | N.D. | N.D. | N.D. | 0.01±0.02 | N.D. | N.D.-0.06 | N.D. | N.D. | N.D. |
| Heptane | 0.03±0.04 | 0.03 | N.D.-0.10 | 0.03±0.03 | 0.02 | N.D.-0.09 | 0.07±0.05 | 0.09 | N.D.-0.14 | 0.02±0.03 | N.D. | N.D.-0.08 | 0.03±0.04 | 0.03 | N.D.-0.13 |
| Methyl isobutyl ketone | 0.05±0.06 | 0.04 | N.D.-0.17 | 0.04±0.10 | 0.03 | N.D.-0.63 | 0.05±0.06 | 0.03 | N.D.-0.14 | 0.03±0.04 | 0.01 | N.D.-0.12 | 0.05±0.08 | N.D. | N.D.-0.28 |
| Toluene | 0.61±0.44 | 0.62 | 0.08-1.16 | 0.54±0.41 | 0.43 | 0.15-1.88 | 1.25±1.42 | 0.64 | 0.21-4.86 | 0.34±0.35 | 0.21 | N.D.-1.11 | 0.64±1.06 | 0.32 | 0.14 -4.48 |
| Tetrachloro-ethylene | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | 0.08±0.22 | N.D. | N.D.-0.72 | 0.01±0.03 | N.D. | N.D.-0.10 | N.D. | N.D. | N.D. |
| Ethylbenzene | 0.14±0.15 | 0.08 | 0.03-0.50 | 0.13±0.10 | 0.11 | 0.03-0.49 | 0.20±0.21 | 0.12 | N.D.-0.62 | 0.09±0.09 | 0.07 | N.D.-0.27 | 0.10±0.10 | 0.07 | 0.03-0.39 |
| *m,p*-Xylenes | 0.22±0.23 | 0.14 | 0.04-0.74 | 0.17±0.14 | 0.13 | N.D.-0.56 | 0.34±0.32 | 0.23 | 0.05-0.95 | 0.12±0.10 | 0.10 | N.D.-0.31 | 0.17±0.17 | 0.11 | 0.05-0.63 |
| Styrene | 0.03±0.05 | N.D. | N.D.-0.14 | 0.01±0.02 | N.D. | N.D.-0.11 | 0.05±0.07 | 0.02 | N.D.-0.21 | 0.02±0.03 | N.D. | N.D.-0.09 | 0.01±0.02 | N.D. | N.D.-0.07 |
| *o*-Xylene | 0.06±0.08 | 0.03 | N.D.-0.28 | 0.06±0.04 | 0.04 | N.D.-0.18 | 0.12±0.13 | 0.07 | N.D.-0.39 | 0.04±0.04 | 0.03 | N.D.-0.12 | 0.06±0.05 | 0.04 | 0.02-0.17 |
| 1,2,4-Trimethyl benzene | 0.05±0.06 | 0.03 | 0.02-0.18 | 0.03±0.03 | 0.02 | N.D.-0.08 | 0.08±0.08 | 0.04 | N.D.-0.25 | 0.03±0.03 | 0.02 | N.D.-0.10 | 0.03±0.02 | 0.03 | N.D.-0.07 |
| Naphthalene | 0.03±0.04 | 0.02 | N.D.-0.13 | 0.05±0.05 | 0.04 | N.D.-0.18 | 0.04±0.04 | 0.04 | N.D.-0.15 | 0.02±0.03 | 0.01 | N.D.-0.11 | 0.02±0.03 | 0.01 | N.D.-0.09 |

*N.D.: not detected

**Seasonal/monthly variation of volatile organic compounds:** The concentrations of volatile organic compounds measured during this study represents three seasons *i.e.*, spring (May), summer (June, July and August) and fall (September and October). Our results show that there is no seasonal relation to the variations in concentration of volatile organic compounds at Gyeongju city. But it is clearly observed that the concentrations of volatile organic compounds particularly benzene, ethylbenzene and methyl tert-butyl ether are lower and higher in July and October, respectively (Fig. 3). The precipitation data during the sampling period and before one week of sampling obtained from the National automatic weather station of Gyeongju is shown in Fig. 3. Highest and lowest precipitation during sampling period was observed in the months of July and October. From this it is concluded that the precipitation may be the reason for variations in the concentrations of volatile organic compounds during the sampling period. The higher precipitation may decrease the concentration of volatile organic compounds in the atmosphere.

**Comparison of BTEX concentrations of the present study with other tourist/historical/residential sites in the world:** A large number of volatile organic compounds are found and measured by the various researchers in all over the world but due to public health point of view and the capability of formation of ozone in the atmosphere most of them are concentrated in the measurement of benzene, toluene, ethylbenzene and *m*-, *p*-xylenes[15]. Due to this reason we compared the present BTEX results with the other studies. In this present study we measured the concentrations of BTEX as 0.26, 0.63, 0.13 and 0.19 ppb, respectively. We compared these results with other tourist/historical /residential sites in the world which were reported in recent years. We compared the present Gyeongju site results with other cities in the world such as, Shanghai and Mount Tai of China, Rome of Italia, Tarragona of Spain and Agra of India which are of tourist and historical importance and recognized as world heritage sites by the UNESCO. From the Table-4 it is clear that the BTEX concentrations reported at the present study sites were much lower than any other sites (except Mount Tai of China) with which were compared. The reported benzene concentration at the present sites was twice to thrice lower than other cities of South Korea such as, Daegu and Seoul. The remaining volatile organic compounds such as, toluene, ethylbenzene and *m*-, *p*-xylenes at the present study sites were almost ten to hundred times lower than other South Korean cities.

Mallorqul *et al.*[16] reported the BTEX concentrations at one of the historical centre of the city Tarragona of Spain. The concentrations of benzene and toluene reported at this site were comparable to the present results while the concentrations of ethyl benzene and *m*-, *p*- xylenes were much higher than the present site. Fuselli *et al.*[17] reported the BTEX concentrations at a University campus in Rome of Italia during 2007. The BTEX concentrations found at this site were three to four times higher than the Gyeongju site of South Korea. Singla *et al.*[18] reported BTEX concentrations at a city which has Taj Mahal one of the wonders of the world and world heritage site (recognized by the UNESCO). The concentration of benzene, toluene and *m*-, *p*- xylenes reported at this site were 56, 13 and 13 times higher than at the Gyeongju site. The concentration of benzene reported in Agra (14.70 ppb) is much higher than the Indian National Ambient Air Quality Standards which is 1.51 ppb. Suthawaree *et al.*[11] reported the lower concentrations of toluene, ethylbenzene and *m*-, *p*- xylenes than the present study results measured at Mount Tai of China. The

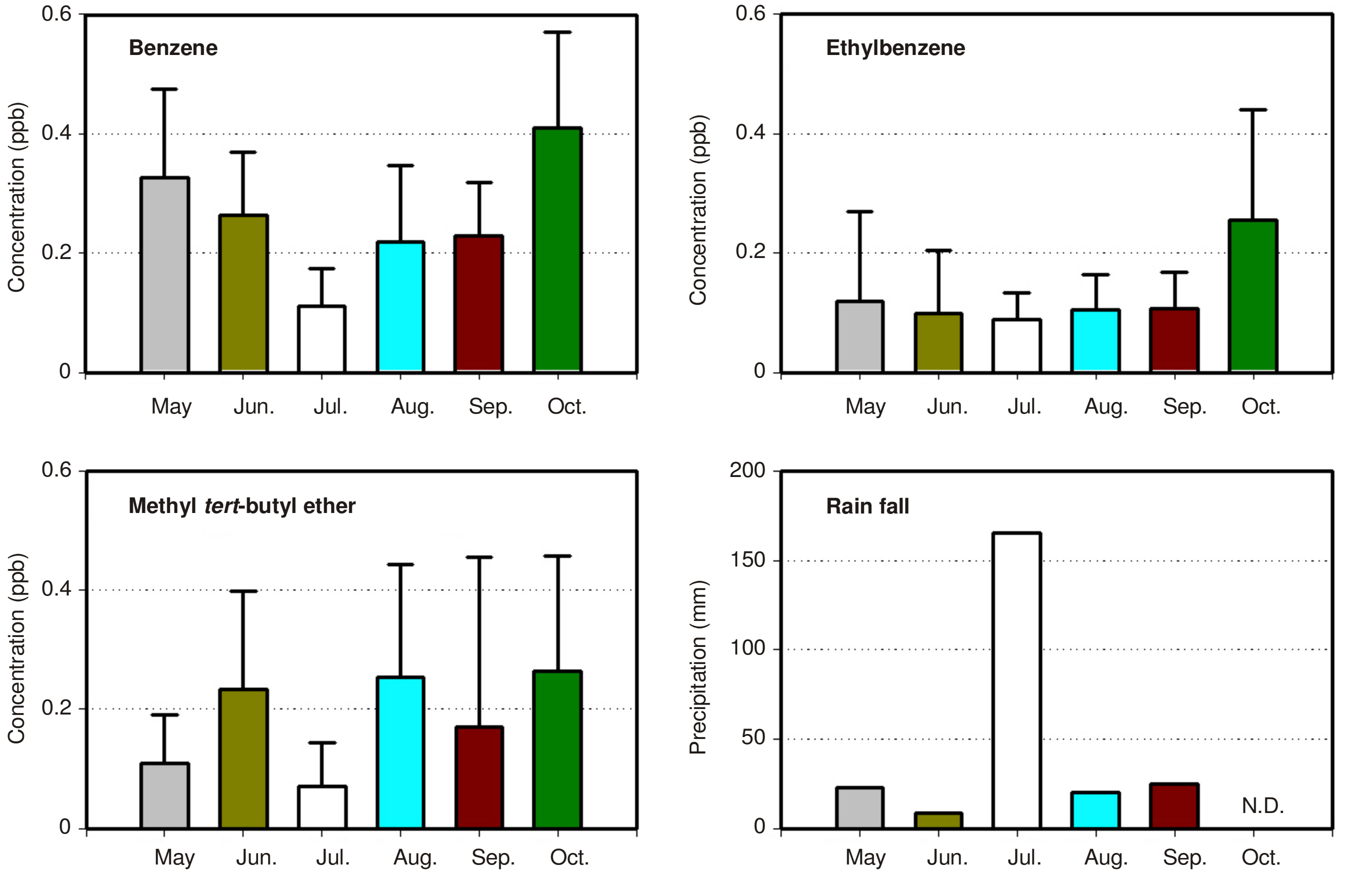



Fig. 3. Monthly variation of volatile organic compounds concentrations in Gyeongju city

TABLE-4
COMPARISON OF THE BTEX CONCENTRATIONS OF THE PRESENT STUDY WITH OTHER TOURIST / HISTORICAL/RESIDENTIAL SITES IN THE WORLD

| S. No | City/Country | Sampling Period | Analytical Method | Sampling Site | No. of data | B (ppb) | T (ppb) | E (ppb) | X (ppb) | B:T:E:X | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Daegu/Korea | May-Oct, 2010 | Adsorption tubes/GC-MS | Roadside | 126 | 0.43 | 6.35 | 0.58 | 1.04 | 1:14.8:1.3:2.4 | 9 |
| 2 | Seoul/Korea | Feb-Jul, 2009 | Adsorption tubes/GC-MS | Urban residential | 18 | 0.58 | 5.39 | 0.72 | 0.82 | 1:9.3:1.2:1.4 | 19 |
| 3 | Yangsan/Korea | Feb-Dec, 2006 | TAT* + GC/MS | Non-Industrial site | 35-44 | 0.19 | 0.84 | 0.67 | 0.51 | 1:4.4:3.5:2.7 | 20 |
| 4 | Daegu/Korea | Jan, 2006-Feb, 2009 | Online TD unit-GC/FID | Residential | - | 0.78 | 2.50 | 0.46 | 0.66 | 1:3.2:0.6:0.8 | 21 |
| 5 | Shanghai/China | Jan, 2007-Mar, 2010 | 6L Silonite canister/GC-MS | Commercial | 284 | 1.81 | 4.70 | 1.23 | 1.40 | 1:2.6:0.7:0.8 | 10 |
| 6 | Rome/Italy | 2007 | Radiello Passive sampler/GC-MS | University Campus | 24 | 0.81 | 2.76 | 0.31 | 0.55 | 1 :3.4 :0.4 :0.7 | 17 |
| 7 | Tarragona/Spain | Dec-2005 and Jan-2006 | Multisorbent beds/GC-MS | Historical centre of city | - | 0.00-1.32 | 1.63-3.27 | 0.29-1.00 | 0.71-2.53 | -- | 16 |
| 8 | Mountain Tai/ China | June-2006 | Canisters/GC-FID, MS | UNESCO World heritage site | - | 0.64 | 0.21 | 0.06 | 0.04 | 1:0.3:0.1:0.1 | 11 |
| 9 | Agra/India | Apr, 2010-Mar, 2011 | Activated charcoal tubes / GC-FID | Road side | 74 | 14.70 | 8.10 | - | 5.10 | 1:0.6:-:0.3 | 18 |
| 10 | Gyeongju/Korea | May-Oct, 2011 | Adsorption tubes/GC-MS | UNESCO World heritage sites | 96 | 0.26 | 0.63 | 0.13 | 0.19 | 1:2.4:0.5:0.7 | Present Study |

reason for the lower concentrations may be attributed to the location of the site *i.e.*, mountain site. From this discussion it is clear that the Gyeongju site is very much clear with respect to the concentrations of volatile organic compounds particularly BTEX.

**Survey with tourists regarding the air quality at Gyeongju:** During the sampling period we made a survey among 350 tourists about the air quality of Gyeongju. Among the 350 tourists 97 % were satisfied with the air quality at the historical and tourist city of Gyeongju. This indicates that not only the scientific data and public opinion also states that the Gyeongju city is clean with respect to air pollutants particularly in terms of volatile organic compounds. We also given a question during the survey about the alternate public transport for reducing the air pollutants in tourist city of Gyeongju for this question around 80 % of the people answered that electric car/bus for public transport may be useful to reduce the air pollutants.

**Conclusion**

This study predicts the accurate exposure of volatile organic compounds by the tourists, because the sampling of volatile organic compounds is carried out with personal exposure samplers by moving around the tourist spots which is not fixed at a single spot. From the results of this study concludes that the Gyeongju city is cleaner with respect to ambient volatile organic compounds concentrations than many other tourist/historical importance and world heritage sites recognized by the UNESCO in the world. The mean concentration of benzene, a group 1 carcinogen at Gyeongju city is found as 0.26 ppb which is almost six times lower than the Korean ambient air quality standards (1.51 ppb). The survey made during the sampling period at all the sampling sites is also useful for the implementation of eco-friendly alternative transport system in tourist cities such as Gyeongju. Even the Gyeongju is clean city with respect to volatile organic compounds concentrations in ambient air it is suggested that the usage of electric bus/car for public transport may reflect in further decrease in volatile organic compounds concentrations.

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