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Inhalation cancer risk from PM_{10} in the metropolitan subway stations in Korea

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ABSTRACT

Introduction: Although subways have many advantages as a transport system, passengers may be exposed to indoor air pollution. In such cases, the dominant risk factors are associated with particulate matter (PM) bound metals and polycyclic aromatic hydrocarbons (PAHs). In this study, inhalation cancer risks (ICR) were assessed at Seoul metro subway stations (SMS), South Korea, in 2014–2015.
Methods: The mass fractions of PAHs and metals in PM_{10} were calculated from the previous studies. The PM_{10} exposure and mass deposition in various sections of the human respiratory tract (HRT) was calculated using mass deposition technique. In addition, ICR via exposure of PM_{10} in HRT and incremental lifetime cancer risk (ILCR) were estimated for the teen and adult groups of commuters at SMS. Moreover, ICR levels have been compared with incremental lifetime cancer risk (ILCR) levels for SMS commuters.
Results: The PM_{10} pollution levels at SMS were found within the acceptable range for the subway platforms in Korean (150 $\mu g/m^3$). In addition, the maximum amounts of total deposition (TD) and head deposition (HD) in HRT were estimated for the adult group. Hence, tracheobronchial (TB) and alveoli (A) depositions were calculated height for the teen. For the adult and teen groups, ICR(TD) level found significant ($> 1 \times 10^{-6}$) for Cr and PAHs. But, among both age groups, significant values of total ICR(TBD + AD) were estimated for the teen (1.40×10^{-06}). In addition, the ICR(TD) and ILCR have estimated the same order of inhalation cancer risk for both groups.
Conclusion: In the SMS, cancer risk levels were estimated in the acceptable range (1×10^{-06} - 1×10^{-05}) of life carcinogenic risk for the commuters, provided by the World Health Organization (WHO). Furthermore, Cr and Ni were identified as significant contributors to inhalation cancer risks with 58% and 39% of total risk level, respectively for teen and adult.

1. Introduction

Underground rail commuting is a key mode of transportation in South Korea, with more than 8 million commuters using the Seoul Metropolitan Subway (SMS) daily (Kwon et al., 2015). However, subway passengers often suffer from the effects of indoor air

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pollution caused by particulate matter (PM). Compared with surrounding locations, higher PM concentrations have been reported in underground platforms worldwide, including those in London (Seaton et al., 2005), Stockholm (Johansson and Johansson, 2003), Budapest (Salma et al., 2009), Los Angeles (Kam et al., 2011), and South Korea (Kwon et al., 2015). PM is an important air pollutant occurring in the subway system in Seoul. It has a direct correlation with heart failure and mortality (Chuang et al., 2011; Shah et al., 2013). The leading risk factors are associated with PM-bound metals and polycyclic aromatic hydrocarbons (PAHs). Moreover, PM-bound metals and PAHs are associated with severe health effects, such as depressed immune function and lung cancer (WHO/IPCS, 1998; Behear, 2008; Kim et al., 2013). Furthermore, many countries such as the United States of America (USA), the European Union, China, Italy, and India have considered benzo[a]pyrene (B[a]P) and metals in air quality standards, owing to their high mutagenicity and carcinogenicity (WHO, 2002; Sin et al., 2003; Hien et al., 2007; Ravindra et al., 2008).

Subways provide an important and unique microenvironment for air pollution studies. Globally, many studies were performed to determine the pollution levels in subway metro. In Korea, SMS stations were the subject of an air quality and health risk study conducted between 2014 and 2015. Subsequently, very high PM levels were reported at some stations of the SMS (Kwon et al., 2015; Han et al., 2016). But still there is no significant detail cancer risk study has been reported for PM_{10}-bound metals and PAHs in subway metro station. In this study, particulate mass deposition (DM) and Inhalation Cancer Risk (ICR) with respect to PM_{10} were estimated in SMS station. Therefore, as per our concern, the unique aspects of this study could be: (1) determination of PM_{10} exposure and PM_{10} mass deposition for various sections of the human respiratory tract (HRT) considering different commuter age groups (teen and adult); (2) assessment of cancer risk level as an ICR for PM_{10} deposition on HRT at subway platform; and (3) comparison of ICR and ILCR levels for the subway commuters. The following assumptions were considered for the present study: 1) the potentially exposed target population was composed of commuters; 2) the passengers were exposed for 1 hr per day, throughout the year (252 days/year); 3) the subway commuters were subdivided as teen (14 years) and adult (70 years) age groups; (4) the Korean risk assessment parameters were considered for the cancer risk analysis, and (5) the concentration of Cr(VI) has been calculated as one-seventh of that of total Cr according to the United States Environmental Protection Agency (US EPA) model (Massey et al., 2013; Izhar et al., 2016).

2. Material and methods

2.1. Study area

Six subway stations of the SMS, South Korea were considered for this study. Air quality assessments of PM_{10} were performed simultaneously at all subway platforms. Monitoring stations were selected according to maximum passenger movement and long passenger wait time. The daily ridership varied from 8984 to 105,655 people. The depth of the platforms is 9.8–23.1 m and the air drafts were blocked from the train operator by the platform screen door system. Proper ventilation for 14–19 h and cooling to 28 °C in summer were the operational conditions inside the subway platforms. Detailed descriptions of the monitoring stations have been conferred in a previous study (Kwon et al., 2015).

2.2. Sampling protocols and sample collection

Air quality monitoring of PM_{10} was performed at six subway stations in SMS. The samples were collected at each platform as the mean value of 1 min and were then combined to show the seasonal variation and annual average levels. The sampling points were located 1.5 m above the floor to avoid outlet and inlet air flow and so as not to disturb the passengers. The sampling was performed in summer, autumn, and winter from August 2014 to January 2015. An optical particle sizer (OPS, TSI model 3330) with light-scattering technology was used to analyze the PM concentration levels and size distribution. The OPS synchronized all signals collected through the data logger each second and provided 1-min-averaged data. The OPS was calibrated in a laboratory with PM_{10} data obtained by the gravimetric method and a particulate matter sampler (MiniVol TAS, Airmetrics, Eugene, Oregon, USA). The density of PM at the SMS has been reported as 1.9 g/m^3 (Cha and Olofsson, 2018).

2.3. Determination of PAHs and metal fractions

The mass fractions of PAHs and metals in PM_{10} were calculated from studies conducted by Jung et al. (2012), Park et al. (2012), and Park et al. (2014) at subway platforms in Seoul. The ratios of PM_{10}-bound carcinogenic PAHs and metals were calculated on the nano-gram and microgram scale, respectively. The concentration levels of PM_{10}-bound organic and inorganic components depend on the major pollution sources in the study area. Literature on the source apportionment of PM_{10} in the study area (SMS) indicates that the internal sources including rails, brakes, wheels, and electric cables in addition to soil and red dust contributed to the highest pollution levels in 2014 and 2012, at 73.1% and 74.8%, respectively. Other combined factors such as the source of secondary nitrate and Cl^{-1} mixed with secondary sulfates were responsible for 27% and 25% in 2014 and 2012, respectively (Park et al., 2012, 2014). Thus, the equal mass ratios of PAHs and metals were assumed for both periods.

2.4. HRT mass deposition

The deposition of PM_{10} in three areas (H, TB, and A) of the HRT was calculated to estimate the internal doses of PAHs and metals. PM deposition in the HRT includes impaction, diffusion, and sedimentation mechanisms. The electrostatic and interception deposition are secondary mechanisms. In this study, several parameters such as air flow, breathing frequency, lung capacity, particle size distribution and concentration, structure and morphology of HRT physiology, and age-specific lung geometries for teen (14 years) and adults (70 years) were considered for the HRT deposition calculation. Morphological parameters of the pulmonary system such as breathing frequency (BF) and tidal volume (TV) were used for mass deposition calculation.

The parameters used in the age dependent calculation of PM mass deposition were developed by the Chemical Industry Institute of Technology (CIIT, USA) and the National Institute of Public Health and Environment (Van-Bree and Cassee, 2000; Anjilvel and Asgharian, 1995; Cassee et al., 1999) are given in Equations (1) and (2):

$$DMR_i = DF_i \times N(t) \times TV \times BF \times 10^{-6} \tag{1}$$

$$DM_i = \int_0^T DMR_i \times (t)\, dt, \tag{2}$$

where *DF* is the deposition fraction, *N* is the aerosol concentration, *t* is time, *i* is the lung region, *DMR* is the deposited mass rate, *T* is exposure time, and *DM* is the deposited mass. The PM mass deposition throughout the pulmonary system was calculated by using the above equations and parameters. The deposition fractions of PM_{10} in various sections of the pulmonary tract for Teen and adult were taken from the RIVM report 650010031/2002 (Winter-Sorkina and Cassee, 2002) and Vu et al. (2017), respectively (Supplementary Table ST1-ST2).

2.5. Inhalation cancer risk assessment

Inhalation cancer risk (ICR) was calculated considering Cr (VI), Ni, Pb, and PAHs. Toxic equivalency factors (TEF) were used for the conversion of carcinogenic aromatic hydrocarbons (cPAHs). The overall carcinogenicity for all cPAHs was calculated according to the B[a]P equivalent (Nisbet and LaGoy, 1992). The toxic equivalent concentration (TEQ) was estimated by using the median concentration of PAHs, as per Equation (3) (Sarigiannis et al., 2015):

$$TEQ = \sum_{i=1}^{10} C_i \times TEF_i, \tag{3}$$

where C_i is the concentration of the *i*th PAH (μg/m^3), and TEF_i is the TEF for the *i*th PAH. The TEQ is presented as B[a]Pequ.

The ICR by metals and PAHs can be calculated using the Equation (4).

$$ICR = \sum_i \frac{\mathrm{E_i} \times \mathrm{CSF_i}}{\mathrm{BW} \times \mathrm{AT} \times \mathrm{cf}} \tag{4}$$

where E_i is the exposure concentration level of the *i*th element (μg/m^3) in air. Deposited mass of each PM_{10}-bound element was considered as exposure concentration at different section of HRT. The CSF_i is the cancer slope factor of the *i*th element (kg × day/mg). The CSF values for Ni, Pb, Cr(VI), and B[a]P are given in Table 3 (Widziewicz et al., 2018). ICR is expressed as unit cancer risk of 10^{-6}.

2.6. Incremental lifetime cancer risk

The ILCR was calculated using the Equation (5) (Widziewicz et al., 2018; Sarkar and Khillare, 2011; U.S. EPA, 2011).

$$ILCR = \sum_i E_i \times EF \times ED \times IR \times CSF_i \times cf \div (BW \times AT) \tag{5}$$

where E_i is the concentration of the *i*th element (μg/d) in PM_{10}; EF is exposure frequency; ED is exposure duration; CSF_i is cancer slope factor for ith element; IR is inhalation rate, cf is conversion factor (10^{-3}) (μg/mg); AT is average time; and BW is body weight. The EF, ED, AT, IR, and BW values are given in Supplementary Table ST1 (as per Korean). The CSF_i values for Cr(VI), Ni, and Pb are given in Table 3, according to the Risk Assessment Information System (RAIS) (https://rais.ornl.gov/tox/profiles/chromium.html), Widziewicz et al. (2018), and California Environmental Protection Agency and U.S. EPA (CEPA, 2004; U.S. EPA, 2000).

3. Results and discussion

3.1. PM_{10}, PM_{10}-bound metals and PAHs levels in the subway

The average and seasonal distributions of PM_{10} and PM_{10}-bound metals (Cr, Ni, and Pb) and PAHs in the platform area of the subway are reported in Table 1. The highest PM_{10} concentration was estimated winter, followed by autumn and summer with the levels of 138.2 ± 49.1 μg/m^3, 107.8 ± 66.2 μg/m^3, and 79.3 ± 44.3 μg/m^3,respectively, on the platform. It is believed that excessive use of outdoor fuel combustion units to run the heating system in winter may have caused higher particulate pollution levels on the platform during that season. The seasonal and annual average PM_{10} concentration levels dose not exceeded the Korean standard for subway platform as150 μg/m^3 (Park et al., 2012). The previous studies were reported the same PM_{10} trend and level at subway platforms and tunnels in Seoul, South Korea as given in Table 4. More specifically, at platform, the height PM_{10} concentration

Table 1
Seasonal variation in polycyclic aromatic hydrocarbons and carcinogenic metals concentration levels at the subway platform.

Parameter	Concentration in μg/m^3			Average
	Summer	Autumn	Winter	
PM_{10}	79.3	107.8	138.2	108.4
Cr	0.178	0.241	0.31	0.243
Ni	0.772	1.05	1.346	1.056
Pb	1.17	1.591	2.04	1.6
Concentration in ng/m^3				
BaA	3.04	4.14	5.3	4.16
BbF	2.83	3.85	4.94	3.873
BkF	13.35	18.14	23.26	18.25
Ant	4.02	5.47	7.01	5.5
Chr	9.28	12.62	16.17	12.69
Flu	3.76	5.12	6.56	5.146
Fl	1.01	1.38	1.77	1.386
Phe	4.15	5.64	7.23	5.673
Pyr	2.25	3.06	3.93	3.08
Ace	3.79	5.15	6.61	5.183

Table 2
Mass deposition of PM_{10} and PM_{10}-bound metals and PAHs (BaPequ) in HRT (teen and adult).

Teen						Adult				
Elements	TD	HD	TBD	AD	TBD + AD	TD	HD	TBD	AD	TBD + AD
PM_{10}	6.60E+04	2.41E+04	3.49E+04	7.76E+03	4.27E+04	4.64E+05	4.36E+05	1.87E+04	9.37E+03	2.81E+04
Cr(VI)	1.48E+02	5.39E+01	7.82E+01	1.74E+01	9.56E+01	1.04E+03	9.77E+02	4.20E+01	2.10E+01	6.30E+01
Ni	6.42E+02	2.34E+02	3.40E+02	7.56E+01	4.16E+02	4.52E+03	4.24E+03	1.83E+02	9.12E+01	2.74E+02
Pb	9.73E+02	3.55E+02	5.15E+02	1.15E+02	6.30E+02	6.85E+03	6.43E+03	2.77E+02	1.38E+02	4.15E+02
BaPequ	1.72 E+00	6.28E-01	9.11E-01	2.03E-01	1.11E+00	1.21E+01	1.14E+01	4.89E-01	2.45E-01	7.34E-01

was reported by Kim et al. (2008), followed by Jung et al. (2012), Kim et al. (2010), and Park and Ha (2008), with the levels of 359 μg/m^3, 137 μg/m^3, 130 μg/m^3, and 129 μg/m^3, respectively as given in Table 4.

The concentrations of 10 PAHs and 3 metals were estimated for PM_{10} in summer, autumn, and winter, along with average data. The PAHs and metals levels were highest in winter, followed by autumn and summer. The maximum average concentration among all PAHs was estimated for benzo[k]fluoranthene (BkF) (18.25 ng/m^3), followed by chrysene (Chr) (12.69 ng/m^3). The concentrations of the other eight PAHs were in the range of 1.39 ng/m^3–5.67 ng/m^3. For metal, Pb had the highest concentration with the value of 1.6 μg/m^3, followed by Ni and Cr at 1.06 μg/m^3 and 0.24 μg/m^3, respectively. The preceding studies conducted in the SMS system were considered to identify possible sources for this study (Park et al., 2012, 2014). Cr and Ni are the marker elements of oil combustion sources (Song et al., 2001; Morawska and Zhang, 2002; Lee et al., 2002). Moreover, Ni and Pb are commonly identified as markers for vehicle exhaust pollution sources (Lim et al., 2010). These elements can be generated by diesel vehicles being repaired in the subway at night. Park et al. (2014) showed oil combustion sources contributed 17% to the total PM_{10} levels in the subway tunnel. Also reported in the subway tunnel, Ni and Pb levels produced by outdoor-related sources such as vehicles, and oil combustion were contributed as 4.0% and 6.0% of total PM_{10}, respectively (Park et al., 2012). Moreover, Park et al. (2014) concluded that internal sources such as wear of brakes, rails, and wheels; combustion of oil; secondary aerosols; cable wear; and road and soil dust were the major contributors in the subway tunnel, at 60%, 17.0%, 10.0%, 8%, and 5%, respectively. Park et al. (2012) reported that the SMS contains 53% inorganic, 10% anions, and 37% other materials including organic and inorganic carbons, cataions, and other unmeasured components of the total mass of PM_{10}. A different study by Byeon et al. (2015) summarized the probable sources in the order as iron-containing > soil/road dust > carbonaceous > others > aluminum > secondary nitrates/sulfates.

3.2. PM mass deposition in the HRT

The PM deposition in the HRT was estimated for teen and adults at the platform. HRT physiology and lung geometries were considered when calculating the deposited mass. The deposition fractions (DF) for the teen and adult are presented in Supplementary Table ST2.

Total Deposition Mass (TDM) is a key parameter used in health impact studies. The DM values were calculated for both age groups at different areas of the HRT for PM_{10} on platform using DMR values. The PM_{10} mass deposition for the commuters at platform is given in Table 2. The PM_{10}, TD level was estimated $4.64 \times 10^{+5}$ and $6.60 \times 10^{+4}$ for adult and teen, respectively. The PM_{10} TBD for teen ($3.49 \times 10^{+4}$) was found grater then the TBD value for adult ($1.87 \times 10^{+4}$). The HD and AD values were calculated higher for

Table 3
Inhalation cancer risks for deposition of PM_{10}-bound metals and PAHs (BaPequ) in different section of HRT for teen and adults in SMS station.

		Teen						Adult					
Elements	CSF_i $(mg/kg*day)^{-1}$	ILCR	ICR(TD)	ICR(HD)	ICR(TBD)	ICR(AD)	ICR(TBD + AD)	ILCR	ICR(TD)	ICR(HD)	ICR(TBD)	ICR(AD)	ICR(TBD + AD)
Cr(VI)	4.10E+01	**1.18E-06**	**1.25E-06**	4.55E-07	6.61E-07	1.47E-07	8.07E-07	**5.00E-06**	**3.40E-06**	**3.20E-06**	1.38E-07	6.88E-08	2.06E-07
Ni	9.10E-01	7.97E-07	8.43E-07	3.07E-07	4.46E-07	9.91E-08	5.45E-07	**3.38E-06**	**2.30E-06**	**2.16E-06**	9.29E-08	4.64E-08	1.39E-07
Pb	4.20E-02	5.58E-08	5.89E-08	2.15E-08	3.12E-08	6.93E-09	3.81E-08	2.36E-07	1.61E-07	1.51E-07	6.50E-09	3.25E-09	9.74E-09
BaPequ	3.85E+00	9.04E-09	9.56E-09	3.48E-09	5.06E-09	1.12E-09	6.18E-09	9.87E-08	2.61E-08	2.45E-08	1.05E-09	5.27E-10	1.58E-09

Table 4
Summary of the particulate matter levels in the subway system in South Korea.

Country	City	References	Assessment Year	Particulate Matter	Average Concentration
Republic of Korea	Seoul (line no 1–4)	Kim et al. (2008)	2004–2005	PM_{10}, $PM_{2.5}$	359, 129 (μg/m^3) (at platform)
	Seoul (line no 4)	Park et al. (2014)	2012	PM_{10}	200.75 (μg/m^3) (at subway tunnel)
	Seoul (line no 1, 2, 4, and 5)	Park and Ha (2008)	–	PM_{10}, $PM_{2.5}$	129.3, 105.4 (μg/m^3) (at platform)
	Seoul (line no 2, 3, and 4)	Kwon et al. (2008)	2007	PM_{10}	142 (μg/m^3) (at subway tunnel)
	Seoul (Jegi, Chungmuro, yangjae, and Seouldae)	Jung et al. (2012)	2009	PM_{10}	137 (μg/m^3) (at platform)
	Seoul (line no 1–4)	Y. S. Kim et al. (2010)	2008	PM_{10}, $PM_{2.5}$	130, 75 (μg/m^3) (at platform)
	Seoul (This Study)	Kwon et al. (2015)	2014–2015	PM_{10}	108.4 (μg/m^3) (at platform)

adult than teen. Moreover, TBD + AD values were found higher for teen ($4.27 \times 10^{+4}$) than adult ($2.81 \times 10^{+4}$). Morphological parameters of the pulmonary system such as BF and TV and DF of PM_{10} could be responsible for the height TBD + AD for teen (Winter-Sorkina and Cassee, 2002). The deposition of carcinogenic elements at TB and A sections of HRT are directly associated with the cancer risks (Boström et al., 2002; Sarigiannis et al., 2015).

3.3. Inhalation cancer risk at the platform

The inhalation cancer risks at SMS station were calculated as ICR and ILCR for teen and adult is given in Table 3. All values were calculated on a risk level scale of 10^{-6}. The CR of 10^{-6} generally represents a lower-bound zero risk value (Sarkar and Khillare, 2012; Roy et al., 2017). For the adult, ICR(TD) and ICR(HD) level found significant (1×10^{-6}) for Cr and Ni. The ICR(TD) of Cr shown the considerable levels for teen. The total ICR(TD) for metals and PAHs were estimated as 5.89×10^{-06} and 2.16×10^{-06} for adult and teen, respectively. For teen, the sum of ICR were found as considerable for TD, TBD, and TBD + AD, with the value of 2.16×10^{-6}, 1.14×10^{-6}, and 1.40×10^{-6}, respectively. Hence, ICR for TD and HD were found significant for adult with the value of 5.89×10^{-6} and 5.53×10^{-6}, respectively. The significant levels of total ICR(TBD + AD) were found for teen among the both age groups. The teen age group of commuters are directly associated with the cancer risks than adult group (Boström et al., 2002; Sarigiannis et al., 2015). Moreover, the ILCR levels were found in considerable range for Cr and Ni for adult with the value of 5.00×10^{-6} and 3.38×10^{-6}, respectively. For teen, only Cr showed the considerable range of cancer risk with the value of 1.18×10^{-6}. The total ILCR levels were estimated as 2.04×10^{-6} and 8.71×10^{-6}, for teen and adult, respectively. The cancer risk for PM_{10}-bound PAHs found insignificant ($< 10^{-6}$) for both age groups at subway platform. The similar result was reported by Jung et al. (2012) in Korea. Globally, Lovett et al. (2018) reported cancer risk in the level of 4.2×10^{-5} at subway transit route in Los Angele which was not only higher than the cancer risk level obtained in SMS station but also exceeded acceptable range (1×10^{-06} - 1×10^{-05}) of life carcinogenic risk for the commuters, provided by the World Health Organization (WHO).

The total ICR values were compared with ILCR levels for the ten and adult as shown in Fig. 1. For Teen, the ILCR, ICR(TD), and ICR(TBD) were fallen in same range for PM_{10}-bound Cr, Ni, Pb, and BaPequ. Hence, ILCR and ICR(TD) values were found in the same range for adult age group. Furthermore, all cancer risk levels were estimated in the acceptable range (1×10^{-06} - 1×10^{-05}) of life carcinogenic risk for the commuters (teen and adult), provided by the World Health Organization (Xu and Hao, 2017). The percentage contributions of Cr, Ni, Pb, and BaPequ were computed as 58%, 39%, 3%, and 0%, respectively for all category cancer risks and age groups considered for this study as shown in Fig. 2. In a different study, higher concentrations of Cr in the subway were indirectly recommended the indoor sources of Cr in the subway (Chillrud et al., 2004). Cr also identified as a most significant element for cancer risk level at subway in Los Angele, California (Lovett et al., 2018). Jung et al. (2012) identified PM_{10}-bound organic extracts (OE) as a genotoxic component at subway tunnel in Seoul, Korea. In the present study, Ni, Cr, and Pb were identified as significant contributors in cancer risk levels in the SMS. These elements could be markers for both internal pollution sources such as oil combustion and wear of brakes, rails, and wheels, and external pollution sources such as road and soil dust. These elements can enter an underground subway station through vents and as dust generated in the cabins or transported on the clothing and shoes of passengers (Fromme et al., 1998).

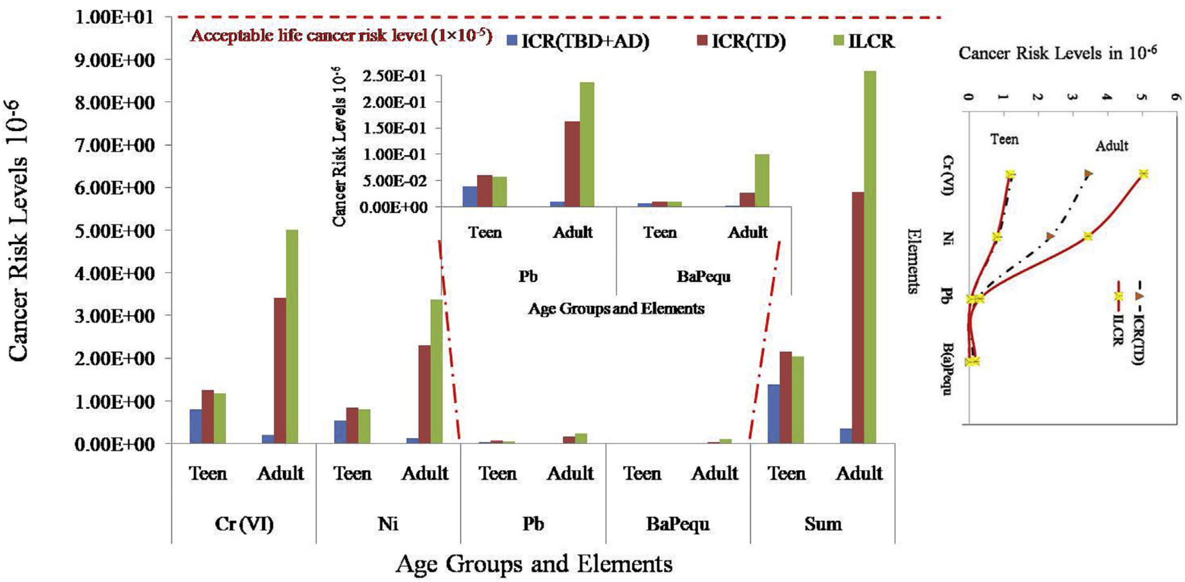

Fig. 1. Results of inhalation cancer risk due to tracheobronchial and alveoli deposition (ICR(TBD + AD)) and total deposition (ICR(TD)) in HRT and incremental lifetime cancer risks (ILCR) for teen and adult groups in SMS Station. (Note: Cr as Cr(VI)).

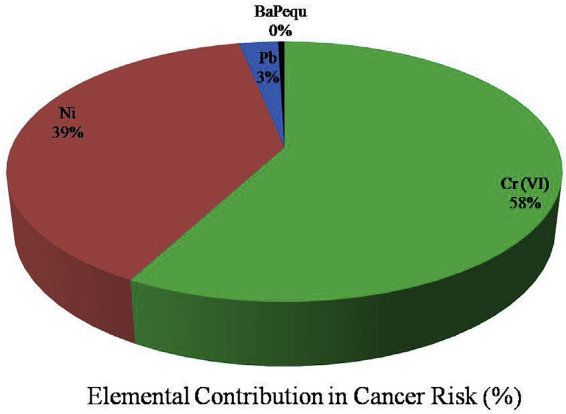

Fig. 2. Results of percentage contributions of PM_{10}-bound elements in cancer risks (ICR(TD, ICR(TBD + AD), and ILCR) for teen and adult.

3.4. The uncertainty of this study

The uncertainties are most important for the health risk assessment. Authors were very careful about the interpretation of data. Still some uncertainty can be exists in the cancer risk assessment. The concentration levels of metals and PAHs were calculated from previous research (Park et al., 2012, 2014). Authors have hypothesized that the data quality obtained from the different laboratory was same. The actual exposure levels, time of stay in subway, and frequency of traveling depend on several factors such as travel time; train frequency; commuter type such as school or university students, visitors, office workers, subway workers, and others; and travel purpose. All probable factors are associated with the time of day, such as early morning, peak office hours, noon, evening, and night; week day or weekend; festival coincidence; and platform area, such as commercial area, office area, or remote location not in close proximity to the platform. Moreover, in this study, cancer risk as an ICR was calculated considering exposure levels of PM on the platform with the maximum duration of stay in the subway system.

4. Conclusions

The genotoxicity assessment for PM_{10}-bound metals and PAHs is very unique approach in subway system. Very limited studies are available on cancer risk assessment at inside the subway. In this study, PM_{10} pollution levels at Seoul, metro subway stations were found within the acceptable range for the subway platforms in Korean (150 $\mu g/m^3$). Moreover, cancer risk levels were also estimated in the acceptable range (1×10^{-06} - 1×10^{-05}) of life carcinogenic risk for the commuters, provided by the World Health Organization. Hence, inhalation cancer risk and incremental lifetime cancer risk levels showed the same range of risk levels for the teen and adult. Furthermore, the significant inhalation cancer risks were identified for Cr and Ni, with the percentage contribution of 58% and 39%, respectively for teen and adult. It is assumed that the elements can enter an underground subway station through vents and as dust generated in the cabins or transported through the clothing and shoes of passengers. Various factors such as brake systems, subway ventilation systems, air conditioning, wheel type, and system age have been determined to be responsible for the metal and PAH concentrations in subway tunnels. Such elements can also enter the passenger cabins through air is exchanged when passengers enter and exit the subway. Presently, steel wheels, concrete railway ties, and a significantly improved ventilation system are used in the SMS station to comply with the policy of Ministry of Environment in Korea. However, non-cancer and cancer risk assessment for particulate bound metals and PAHs could be the future scope of research for more detail investigation of human health risks inside the subway.

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Appendix A. Supplementary data

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