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ESTIMATING VEHICULAR EMISSION IN KATHMANDU VALLEY, NEPAL

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Abstract

The study estimate, the vehicular emission load for CO, CO_2 , HCs, NO_X, SO_2, Dioxin/Furans, Particulate Matters ($PM_{1O,}$ $PM_{2.5}$, Black carbon and Organic Carbon) by using emission factors and Global Warming Potentials (GWPs) of the pollutants (CO_2, NO_X, BC and OC). For this purpose, data were collected through the video tape record (in 30 sites), questionnaire survey, field visit, and literatures review. The total estimated emission of Kathmandu Valley (KV) was 7231053.12 ton/year. Of the total emission, CO_2 emission was highest i.e., 91.01% followed by CO 5.03%, HC 0.96%, NO_X 0.60%, PM_{10} 0.18% and SO_2 0.10%. Annually 529353.36 µg Toxic Equivalent (TEQ) of Dioxin/Furan produced and directly disperse to the ambient environment. The total estimated $PM_{2.5}$, BC and OC emission were 9649.40 ton/year, 1640.4 ton/year and 2894.82 ton/year. The total carbon equivalence of the combined emissions (CO_2, NO_X and BC) for 100-years standard time horizon is 10579763.6 ton CO_2-eq i.e., 2885390.07 ton carbon.CO_2 alone will be responsible, for about 62% of the impacts for the next century from current emissions of CO_2, NO_X and BC. Of the total emission Heavy Duty Vehicles (HDV) emits 50%, Light Duty Vehicles (LDV) emits, 27%, 2-Wheelers emits 22% and 3-Wheeler (Tempo) emits 1% .The total emission of all pollutants combined per vehicle together was estimated to be 5.46 ton/year which was estimated as 23.63, 10.35, 1.83 and 5.58 ton/yearfor HDV, LDV, 2-Wheelers and 3-Wheeler respectively.

Key Words: Vehicular Emission, Global Warming Potentials, Carbon Equivalence, Toxic Equivalent, Kathmandu Valley

Introduction

Air pollution in the Kathmandu valley (KV) is a burning problem (Pokhrel, 2002; Giri *et al.*, 2008; Akira *et al.*, 2005) and the transportation sector is the major contributor (Shrestha and Malla, 1996; Shah and Nagpal, 1997). Air quality in KV has been deteriorating continuously with the development of road networks and rapid rise in the number of inferior quality vehicles on the traffic congested roads. Air pollution may become a serious problem for the KV in the future (Fleming, 1970).

Urban air quality in many developing countries is worsening and becoming a major threat to health and welfare of people and the environment (WHO and UNEP, 1992).It is estimated that air pollution in South Asian cities causes nearly 100000 premature deaths per year and over a billion work days of lost or reduced productivity (ADB, 2001).The pressure on transport systems are increasing in most developing countries, as part of the process of growth. Motor vehicles ownership and use are growing even faster than population, with vehicle ownership and use of 15 to 20% per year common in some developing countries (World Bank, 1995).

The annual average growth rate of the total registered vehicles in the valley from 1990-2011 is 14.3% and of motorcycle only is 17%. In past 10 years, the number of registered vehicles has increased 3.75 times. With the motorcycles dominating the vehicles composition by 73.2% and Car/Jeep/Van at 18.5% the transport dynamics is getting more and more private (almost 93% increase) (CANN/CEN, 2013). Dhakal (2006) projected that, Kathmandu valley's motorized travel demand will increase to 27 billion passenger-km by 2025.

Air Pollution from vehicles is the complex function of fuel characteristics, extents of combustion, reactions with other gases and atmospheric condition. Sharma and Roychowdhury (1996) and Faiz *et al.,* (1996) classify several factors accounts for the variability in emissions in different vehicles namely: Vehicle/Fuel Characteristics, Fleet Characteristics and Operating Characteristics.

The problems of vehicular pollution within the KV has been in existence for some time now, yet not much research, inventories & monitoring has been conducted. This paper therefore contributes to get the true dimension of the enormity of pollutant emissions from specific vehicles. It estimate the vehicular emission load for CO, CO_2, HC, NO_X, SO_2, PM_{10}, PM2.5, Black Carbon/Organic Carbon and Dioxin/Furan from major fuels (Diesel, Gasoline and LPG) by using emission factors and estimates Global Warming Potentials.

Methodology

KV lies between the latitudes 27° 32′ 13″ and 27° 49′10″ north and longitudes 85° 11′ 31″ and 85° 31′38″ east and located at mean elevation of about 1300 masl (KVP, 2009). The total population of KV is around 2.7 million and is expected to exceed 4 million by 2020 with the population growth rate of 4.32% and population density was estimated to be 3186 persons per Km^2 (CBS, 2012). A 27Km long Ring Road circumscribes the main city area and connects all major radial roads which are linked to rural settlements or provide transportation corridors to high-ways or neighboring cities.

Data were collected during week days of April, 2014 through the video tape recording, questionnaire survey, field visit, and literatures review. Sample size for video trapping sites was determined on the basis of identified 410 major chowks of KV in 9 grids (size approximately 4km×4Km) on the Google earth map. For later manual counting of the numbers of vehicles, traffic volume was recorded in 30 different sites (Figure 1) including Highway/ Ring road, Arterial roads and Residential roads according to the proportion of identified chowks in each grid. GPS Coordinates of each site was also recorded.

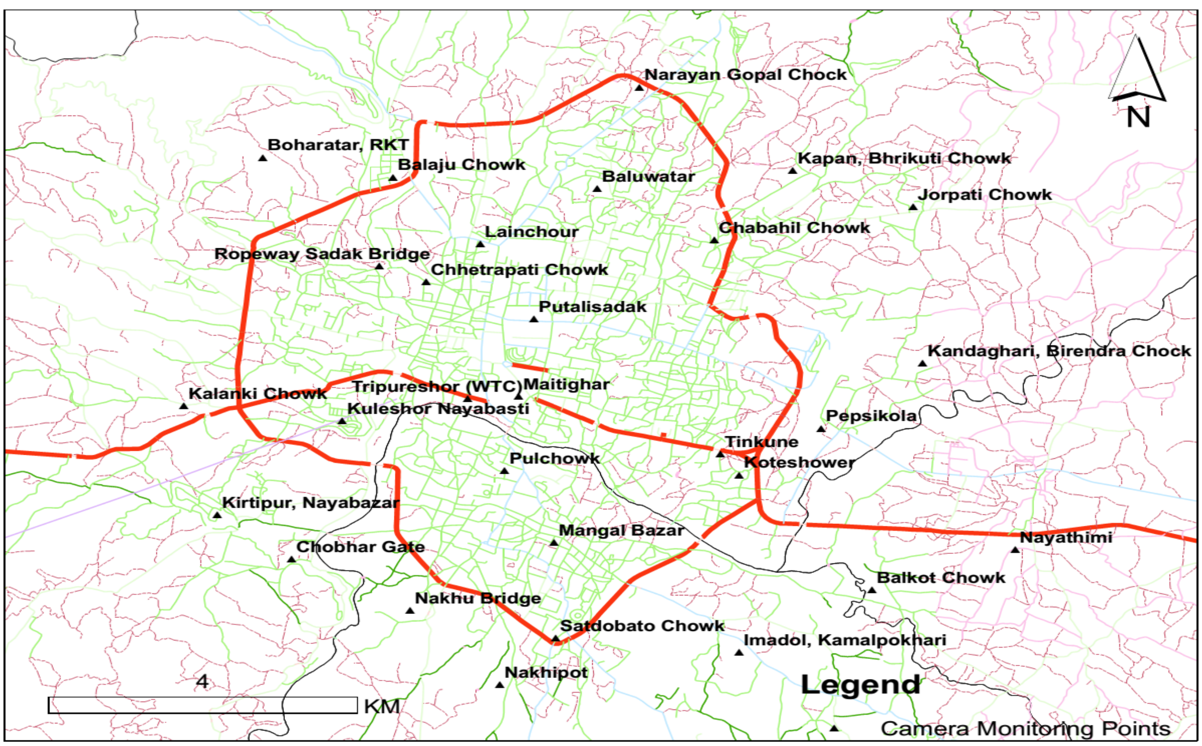

Figure 1: Map of Kathmandu Valley showing video recorded sites

Vehicles were counted for 15 minutes from any one peak hour [(8:00-10:00) a.m. and (4:00-6:00) p.m.] and 15/15 minutes from any 2 non-peak hours [(6:00-8:00) a.m., (10:00a.m-4:00 p.m.) and (6:00-7:00) p.m.]. Thus, in every 30 sites, altogether vehicles were counted for 45 minutes. The flow of particular vehicle type in 12-hours was calculated under the consideration that morning peak hours flow will be approximately equal to the evening peak hours flow and morning non-peak hours flow will be approximately equal to the afternoon as well as evening non-peak hours flow. The volumes of vehicles in both directions were counted. Light Duty Vehicles (Gasoline, LPG and Diesel vehicles) and Heavy Duty diesel vehicles was taken under study. Vehicle flow data during 12 hours period was calculated under the category of Bus/Minibus, Truck/Mini truck/tankers, Cran/Dozer/Roller/Excavator/Loader/Greder, Car/Jeep/Van, Diesel Microbus, Tempo, Tracter/ Power Tellor, Taxi and 2-Wheelers.

For the questionnaire survey, sample size was determined from the peak hour vehicle counted data of Highway/Ring roads and Arterial roads. The approved and pre tested questionnaires was conducted with 82 vehicle operators in the proportion of 5:2:1:1according to the vehicle category [2-Wheelers, Light Duty Vehicles (LDV), Heavy Duty Vehicles (HDV), and Others (Tempo)].

The data obtained was used to calculate the Emission Load by using emission factors and the prescribed mathematical equation (1) stated as:

The exhaust emission by vehicle type 'i' for pollutants type 'j' in year 't' is expressed as,

Pij(t) = Nj (t) * Fuel Consumption* EFij (t)……………………. (1) (Dhakal, 2003)

Where,

Nj (t) = Number of vehicles in operation of type 'j' in year 't', ton

EFij (t) = Emission Factors by pollutant type 'i' of vehicle type 'j' in year 't', g l^{-1} and,

Fuel consumption, l day^{-1}

To calculate emission load of CO, CO_2, HC, NO_X, SO_2 & PM_{1O}, specific emission factors given by Dhakal, (2003 and 2006) and for dioxin/furan, emission factors given by UNEP and IOMC, (2003) was used.

The concept of $PM_{2.5}/PM_{10}$ ratio of about 0.74 was attributed for the calculation of $PM_{2.5}$ (Naser *et al.*, 2008). Likewise the distribution percent (%) of Black Carbon (17%) and Organic Carbon (30%) in $PM_{2.5}$ were also considered.

The Carbon Dioxide Equivalent (CO_2-eq) of the pollutants (CO_2, NO_X, BC and OC) was calculated based on the products of emission rates of pollutants and their corresponding Global Warming Potentials (GWPs) for 100-years standard time horizon (Masters & Ela, 2009). GWPs for CO_2 and NO_X were taken from (Fuglestvedt *et al.*, 2009) and that for OC and BC were taken from (Bond *et al.*, 2011 and 2013). The total carbon equivalence of the combined emissions (CO_2, NO_X and BC) than was converted into tons of carbon by multiplying the C/CO_2 ratio.

Results and Discussion

Vehicle Fleet Characteristics in KV

According to the data of vehicle flow in 12 hours in KV, the composition of 2-Wheelers was high (77.47%) followed by Taxi (8.15%); Car/Jeep/Van (7.64%); Truck/ Mini Truck/ Tankers (1.96%); Bus/Minibus (1.71%) and Microbus (1.57%) respectively. But the shares of Tempo, Tractor/Power Tellor, LPG Microbus and Dozer /Roller/Excavator (0.9%,0.38%, 0.17% and 0.07% respectively) is relatively low (Figure 2).

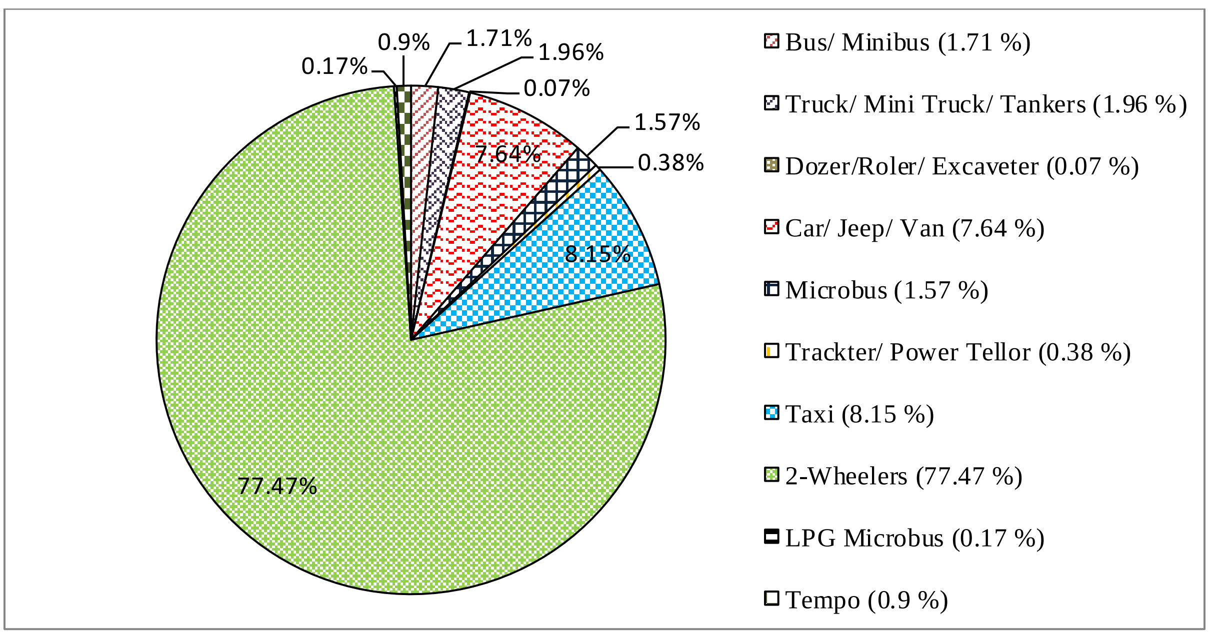

Figure 2: Vehicle flow composition in 12-hoursin KV

(Source: Video Tape Records, 2014)

As the age of the vehicles is a key factor for the emission, 62.2% respondent reported that the major cause of the vehicular emission in KV is old vehicles. The vehicles age over the 15 years are represented by 12.2% (Figure 3) and these vehicles are major emitter because they consume more fuel and give less mileage. Most of the respondents (out of 82), Claimed that their vehicles are not efficient mainly due to the poor fuel quality (47.6% claimed it) and traffic jam (42.7% claimed it).

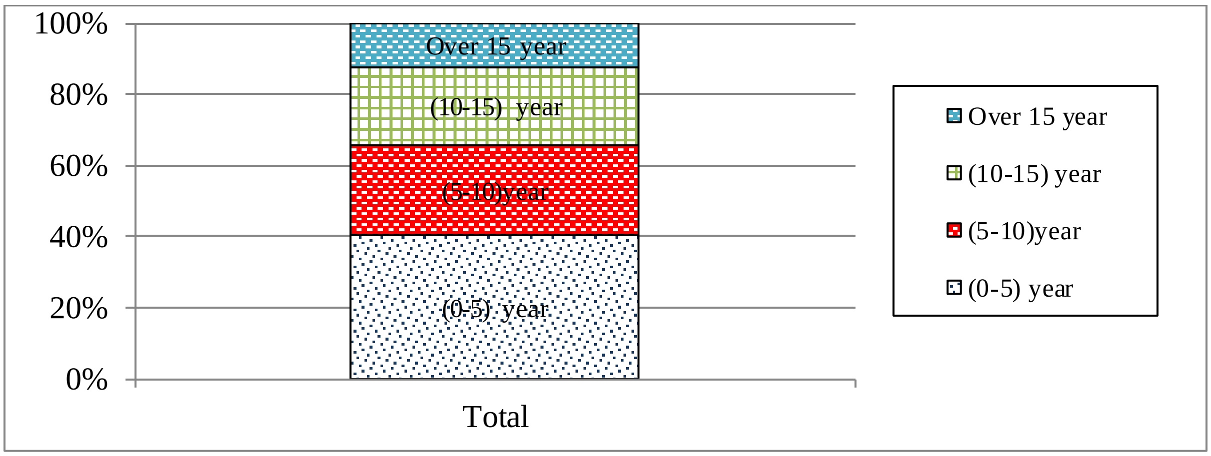

Figure 3: Age of Vehicles plying in Kathmandu Valley

(Source: Questionnaire Survey, 2014)

The observed number of vehicles counted was high in Tripureshwor (11192) followed by Lainchour (10711), Koteshor (10249), Chabahil Chowk (7962), Putalisadak (7663), Narayan Gopal Chowk (7177), Kalanki (6915) etc. As a result, the vehicular emission is significantly high in these sites. The observed numbers of vehicles was found to be high in Arterial roads than Highway/Ring road and Residential roads.

Estimated Emissions Load of KV

According to our study, the total estimated emission (CO, CO_2, HC, NO_X, SO_2 and PM_{10}) of KV was 7231053.12 ton/year (Table 1).Whereas the emission estimated for KV was 36678 ton/year (that includes: TSPs, CO, HCs, NO_X, SO_2) (Shrestha & Malla, 1993) and 57337 ton/year (that includes: PM, CO, HC, NO_X, SO_X, Pb) (Dhakal, 1996).The annual average growth rate of the total registered vehicles in the valley from1990-2011 was 14.3% and the number of registered vehicles has increased by 3.75 times (CANN/CEN, 2013).

Of the total estimated emission of KV, the CO_2 emission was highest (91.01%) followed by CO (5.03%), HC (0.96%), NO_X (0.60%), PM_{10} (0.18%) and SO_2 (0.10%). Of total emission, share of Bus/ Minibusemission is maximum (22.07%); followed by 2-Wheelers (21.85%), Diesel Microbus (18.69%), Car/ Jeep/Van (18.06%) and Taxi (12.04%), Truck/Mini trucks/Tankers (4.51%), Tempo (1.39%), LPG Microbus (1.02%), Dozer/Roller/ Excavator (0.20%) and tractor/ Power Tellor (0.17%) (Table1).The emission from Bus/Minibus (1595691.92 ton/year) is very high due to their increasing number in the present time than study conducted by Dhakal (1996) in which of the total emission 736 ton was by Bus and 794 ton by Minibus. According to 48.8% respondents, introduction of cleaner vehicle is an essential ingredient to reduce the emission in the valley. But it is not possible with the support of government interventions as a soft loan or subsidy.

The total emission of all pollutants combined per vehicle together was estimated as 5.46 ton/year which was estimated as 0.76 ton/year by Shrestha & Malla (1993). Also, the emission of all pollutants combined per HDV, LDV, 2-Wheelers and 3-Wheeler were estimated as 23.63, 10.35, 1.83 and 5.58 ton/year respectively.Of the total estimated emission, the LDV accounts the highest share 50%, followed by HDV 27%, 2-Wheelers 22% and 3-wheeler (Tempo) 1%.

Table 1: Estimated Emission of Kathmandu Valley, (ton/year)

Types of Vehicles	CO	CO_2	HC	NO_X	SO_2	PM_{10}	Total
Bus/ Minibus	11823.85	1551387.91	5468.53	17538.71	3029.86	5764.13	1595691.92
Truck/ Mini Truck/ Tankers	2416.04	317004.06	1117.42	3583.79	619.11	1177.82	326046.73
Dozer/Roller/ Excavator	108.69	14261.57	50.27	161.23	27.85	52.99	14665.95
Car/ Jeep/ Van	51950.46	1206812.95	17718.13	7012.99	975.17	1399.85	1305588.55
Diesel Microbus	9571.37	1327641.61	4013.80	4322.55	2373.55	2778.78	1351709.39
tractor/ Power Tellor	90.10	11821.42	41.67	133.64	23.09	43.92	12161.04
Taxi	50837.35	773527.51	17062.25	5745.65	145.58	440.63	870649.59
2-Wheelers	233364.06	1210035.85	22459.24	3630.75	240.98	1381.61	1579837.49
LPG Microbus	1600.24	71121.89	699.37	419.62			73841.12
Tempo	2185.81	97147.08	955.28	573.17			100861.33
Total	363947.97	6580761.85	69585.95	43122.10	7435.19	13039.73	7231053.12

Pollutants wise Estimated Emissions Load

The emission of all the pollutants was high in Arterial Roads compared to Highway/ Ring road and Residential roads due to the higher numbers of vehicles plying in the Arterial roads. The emission load of pollutants and their share (%) from different vehicle categories were presented in figure 4.

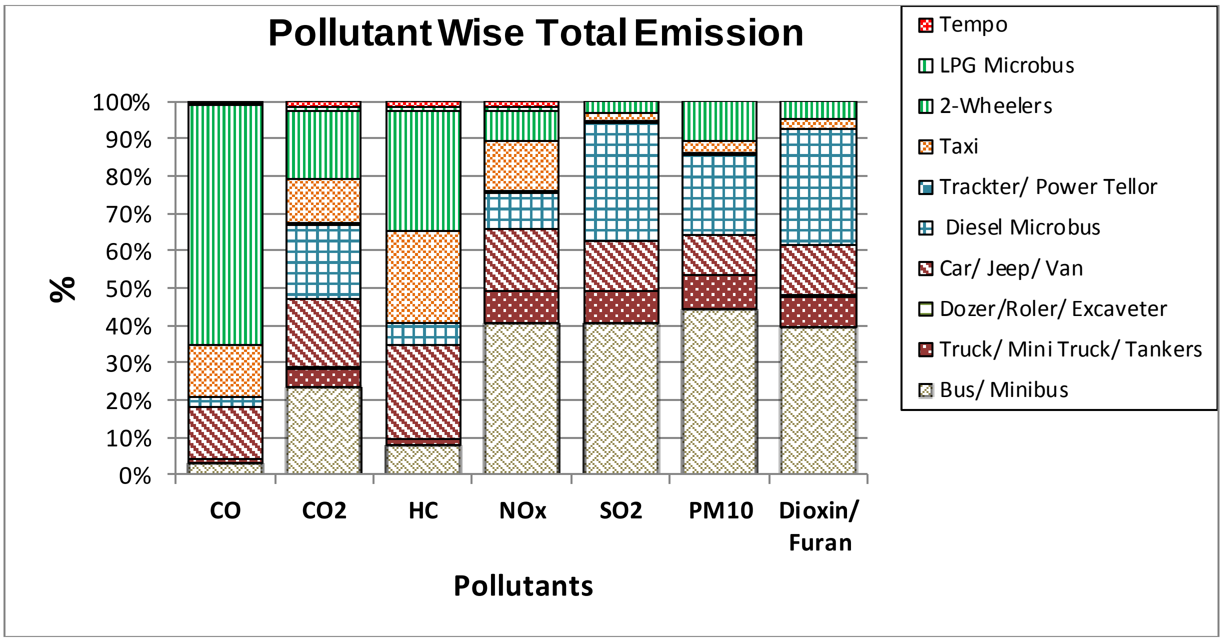

Figure 4: Pollutant wise total emission of Kathmandu Valley

As per our study, diesel vehicles, gasoline vehicles and LPG vehicles divide their shares of total CO_2 emission as 52.5%, 45.4% and 2.2% respectively. Whereas, Dhakal (2003) for the base year 2000 reported that, the diesel vehicles, gasoline vehicles and LPG vehicles divide their share of CO_2 emission (423648 ton/year) as 70.1%, 27.5% and 2.4% respectively. The estimated emission load of CO_2 was highest from Bus/Minibus (23.57%) due to the more fuel consumption (26.33 l day^{-1}) than the 2-Wheelers (1.02 l day^{-1}) even though the emission factor (E.F. of Bus/Minibus=3149 g l^{-1} & 2-Wheelers=3766 g l^{-1}) and number of 2-Wheelers (863028) was more than that of Bus/Minibus (51263).

The CO emission from Gasoline vehicles, Diesel vehicles and LPG vehicles are 91.8%, 7.4% and 0.9% respectively. Similarly, 81.3% of the total HCs emission comes from gasoline vehicles, 16.8% from diesel vehicles and remaining 2% comes from LPG vehicles. According to Dhakal (2003) for the base year 2000, the emission of CO and HCs was 3.6% from diesel vehicles, 1.1% LPG vehicles and 95.3% gasoline vehicles were responsible.

The emission share of Diesel vehicles, LPG vehicles and gasoline vehicles for NO_X was 59.9%, 2% and 38.1% respectively. But, Dhakal (2003) estimates 2578 ton of NOx for the base year 2000 from diesel vehicles (38.4%), LPG vehicles (2.3%) and gasoline vehicles (59.3%).

Annually, 91% diesel vehicles and 9% gasoline vehicles are responsible for 7435.19 ton SO_2. In contrary, Dhakal (2003) for the base year 2000 estimated 273 tons of SO_2 in the valley from 79.8% diesel vehicles and 20.2% gasoline vehicles.

(a) Particulate Matters Emission

Out of total emission load, 0.18 % (13039.73 ton/year) of emission is PM_{10} emission. The 79.2% diesel vehicles and 20.8% gasoline vehicles shares the total emission of PM_{10} which supports the study conducted by Dhakal (2006), that PM_{10} was mainly emitted from the diesel fuelled vehicles. The estimated PM_{10} emission is comparable with the two comprehensive emission inventories conducted by World Bank URBAIR Project (1997) and ESPS (2001) were 570 and 2176 tons/year respectively (KEVA, 2003). The PM_{10} was drastically increased by 471 % between these years. Comparing our estimated emission with the emission of 2001, $PM_{10}$was found to be increased by 500 %.

The total estimated emission of $PM_{2.5}$, BC and OC were 9649.40 ton/year, 1640.4 ton/year and 2894.82 ton/year respectively. The emission of BC and OC was mainly related to the diesel fuelled vehicles. These carbonaceous aerosols (BC & OC) have the potential to influence many heterogeneous reactions involving atmospheric particles and trace gases (Grgic *et al.,* 1998; Lary *et al.,* 1999).The calculated value of OC/BC ratio was 1.76 but as per Shakya *et al.,* (2010), which was ranged between 3.01 and 6.59 in KV during winter. Similarly, the percentage of OC and BC to PM_{10} mass in KV is calculated as 22.2% and 12.6% respectively. But it was accounted for 8.5% and 4.3% respectively during summer at Tianjin, China (Gu *et al.,* 2010).

(b) Dioxin and Furans (Unintentional POPs) Emission

Annually 529353.36 µg Toxic Equivalent (TEQ) of Dioxin/Furan produced and directly disperse to the ambient environment. The total estimated emission load of Dioxin/Furan was from Bus/Minibus (39.55%) followed by Diesel Microbus (30.99%), Car/Jeep/Van (13.50 %), Truck/Mini Truck/Tanker (8.08%), 2-Wheelers (4.49%), Taxi (2.71%), Dozer/Roler/Excavator (0.36%) and Tractor/Power Tellor (0.30%) in Kathmandu

Valley (Figure 4).The emission of Dioxins and furans are the part of the group of persistent organic pollutants (POPs) and spreads extensively in the environment as manner as polychlorinated biphenyls and some chlorinated pesticides (Viainio *et al.*,1989).As stated by Viainio *et al.*,(1989) if the annual emission rate of dioxin/Furans grows as well, in the future it can cause serious problems.

Estimation of GWPs of Pollutants

The total carbon equivalence of the combined emissions of CO_2, NO_X and BC for 100-years standard time horizon is 10579763.6 ton CO_2-eq (Table 2), which is equivalence to 2885390.07 ton of carbon.

Table 2: Global Warming Potentials (GWPs) for 100-years' time horizon

Pollutants	Total Estimated Emission, (ton/year)	GWP_{100}	Emission in CO_2-eq, (ton)
CO_2	6580761.85	1	6580761.85
NO_X	43122.10	58.5	2522642.98
BC	1640.40	900	1476358.77
OC	2894.82	-42	-121582.49

Of the total Carbon, 62.02% is an actual Carbon Dioxide and rest is other pollutants. This shows that almost 62 % of the impacts for the next century from current emissions of CO_2, NO_X and BC will be caused by CO_2 only. But the OC shows the cooling effects towards the global warming phenomena (Figure 5).

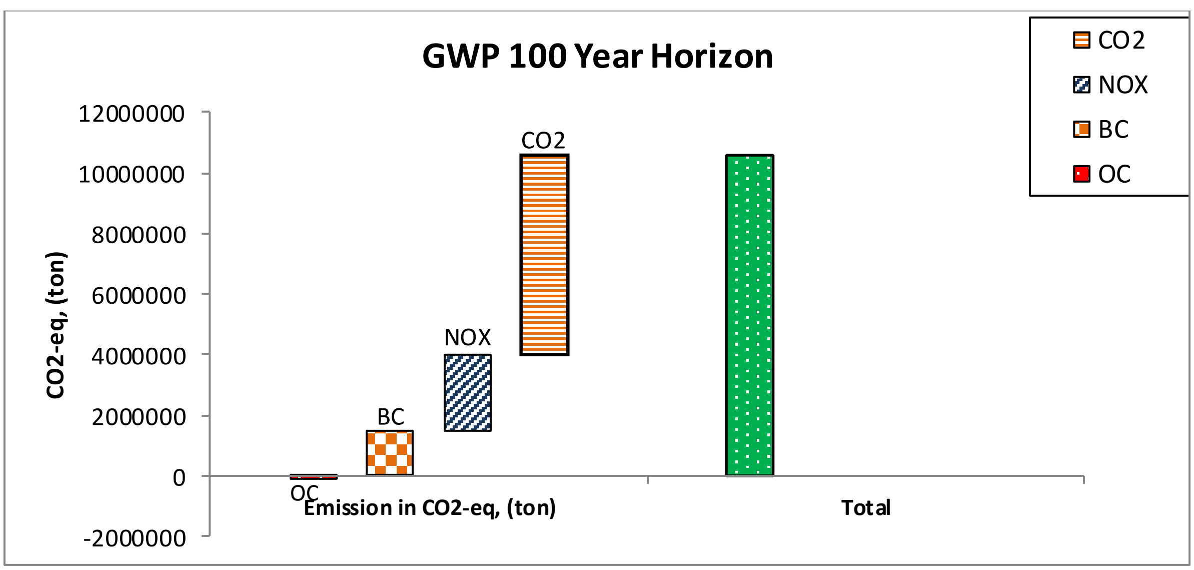

Figure 5: Total Carbon Equivalence of Pollutants

Conclusion

The total estimated emission (CO, CO_2, HC, NO_X, SO_2 and PM_{10}) of KV is 7231053.12 ton/year. Similarly for $PM_{2.5}$, BC and OC were 9649.40 ton/year, 1640.4 ton/year and 2894.82 ton/year respectively. Annually, 529353.36 µg Toxic Equivalent (TEQ) of Dioxin/Furan produced from road transportation in KV. Of the total emission of KV the CO_2 emission was highest (91.01%) followed by CO (5.03%), HCs (0.96%), NO_X (0.60%), PM_{10} (0.18%) and SO_2 (0.10%). The result shows that, from the current emissions of CO_2, NO_X and BC, almost 62 % of the impacts for the next century will be caused by CO_2 alone. The GHG (CO_2) emission from Bus/Minibus is high among the vehicle studied. So, GHGs emission should be reduced by promoting cleaner vehicles. The transportation activity is projected to grow dramatically in the coming years. Emissions of pollutants are expected to increase as well in the absence of stringent emission control measures.

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