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Corroborating the Land Use Change as Primary Determinant of Air Quality Degradation in a Concentric City

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ABSTRACT

Bandung City is characterized by concentric land use pattern as found in many naturally grown cities. It radiates from mixed commercial areas in the center to low density residential areas in the periphery. This pattern generates significant traffic volume towards city center. The generated traffic releases emissions and degrades urban air quality since fossil fuel is predominantly used by vehicles in Bandung. In the absence of air polluting industries as well as construction and demolition activities, traffic load generated by land use changes is the only major contributor to air quality degradation in the city. The land use change can therefore be seen as primary determinant of air pollution in Bandung. This study analyses land use changes and its impacts on traffic pattern and air quality. Multivariate correlation between traffic load and land use changes is employed as tool to substantiate the proposition. Relationships between the degree of changes in land use, as reflected in traffic loads, and the quantity of two principal air pollutants, namely SO2 and HC are also established to validate the argument. The result of analysis substantiates the correlation between land use changes and air quality degradation.

1. Introduction

Land use change is one of the most important indicators of urban growth. This change is usually manifested by alterations of urban landscape and mobility pattern of the citizens. Transportation system on the other hand, that emerges to facilitate mobility of citizen, is one of the most important consequences of urban growth (Taylor, 2002). Development of transportation networks will significantly alter the urban landscape, and it will continue to grow along with the expansion of urban area. This fact clearly shows that alteration of land use, as an urban growth precursor, is closely correlated to transportation. (Beimborn, 1996) and Cao *et al.* (1998) verified such association. Some studies have been undertaken to comprehend the relationships between land use and transport as revealed by Kitamura *et al*. (1997), Sun *et al*. (1998), Barter (1999) and Snellen (2002). However, the relationship between land use changes and the state of urban air quality has not been sufficiently investigated. This shows that understanding on the degradation of urban air quality in relation with land use changes is inadequate to keep up with the pace of urban dynamics. It is true that the degradation of urban air quality cannot be singularly attributed to only land use changes, since other contributing variables do exist. However, with the absence of air polluting industries and other sources of air pollution in the city, land use can be the primary indirect contributor to air pollution. This is because of essential role of land use in harboring every single urban activity which possibly directly or indirectly affects urban air quality. One of the obvious facts is traffic generated land use, as we can observe in many cities those have loose urban development control as exhibited in the study area.

Land use changes as part of the urban sprawling process lead to two different consequences: motorized transport-dependent citizens and extensive commuters. This two-side of the same coin phenomenon was seemingly affirmed by some studies as demonstrated by Newman (1996), Newman and Kenworthy (1999) and Snellen (2002). These two consequences are essential gestures of the corroboration of land use as the primary indirect determinant of urban air quality degradation issue in the study area. With this premise, the objective of this study is to substantiate the correlation between present land use changes and the degradation of urban air quality, by way of traffic load generated as intermediary.

This study investigates the land use changes, through the extent of land conversion, from natural areas to be built-up areas. At the same time period, traffic loads at immediate collector roads, where the land use changes took place, are measured. The logical proposition behind this linear correlation is that land conversion from previously natural and inhabited areas to be residential or commercial areas, for example, would need facilitation for undertaking both motorized and non-motorized travel by the inhabitants for various trip purposes. This motorized travel would be reflected in the increase of traffic loads in the immediate collector roads. By this proposition, it is valid to say that land use changes influence traffic loads. Simultaneously, to validate the correlation between traffic load and concentration of air pollutants, road side air quality was observed and measured providing that traffic as a single main source of air pollution in the city.

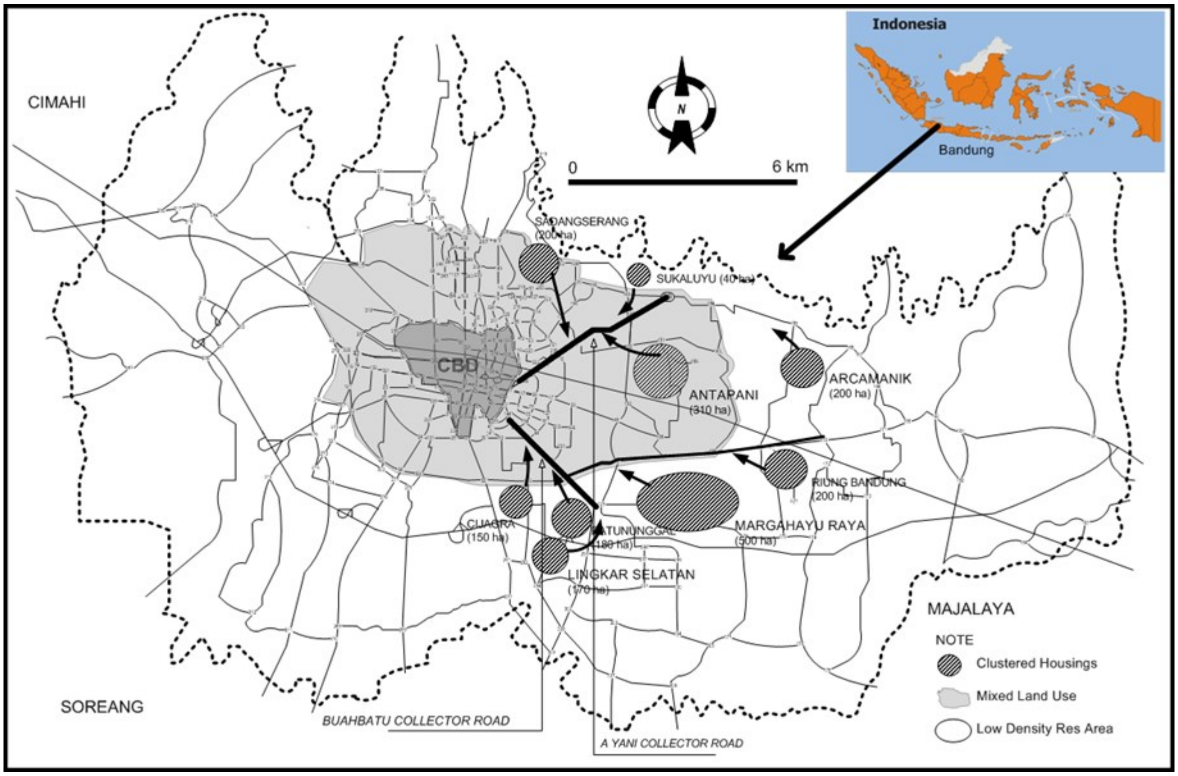

Figure 1: *Bandung City and two Arterial Roads included in the Model*

At the time of urban air quality was observed, traffic loads were also simultaneously measured and analyzed. This was undertaken to directly establish the correlation between those two variables. A mobile air quality monitoring system was employed to gauge the air quality, and the gauging process was undertaken at some predetermined points where mobile air quality monitoring system was parked at the road-side. The gauging of air quality was undertaken on the basis of eight-hour monitoring system with one-hour interval, and corresponding traffic volumes were measured and analyzed by applying passenger car unit equivalent, since vehicles that passed through the observation points were of different kinds.

The impacts of land use changes on the generation of traffic loads were analyzed by comparing two conditions those are with and without land use changes. Traffic loads with land use changes were obtained by analyzing the traffic volumes at immediate collector roads with a condition that land use changes were undergoing in the catchment area of the collector road. Concurrently, traffic volumes without land use changes were predicted by developing multivariate correlation between traffic volumes, land use changes and some other contributing variables. Then, correlation between traffic loads and the concentration of air pollutants were established by employing linear regression models. These three analytical processes are expected to substantiate the proposition.

2 Present Condition of the Land Use, Traffic and Air Quality in the Study Area

Comprehension on existing land use and corresponding traffic conditions that affect air urban air quality are essential towards overall understanding on the correlation among these three constituents. The study was undertaken in a developing city where city planning was loosely implemented, particularly with respect to land use and transport integration.

2.1 Brief Explanation of the Study Area

Bandung City, the study area, is approximately located on 107^{O} East and 6^{O}55' South. The present area of the City is 16,767 hectares and is geographically located in the center of West Java Province (refer to Figure 1). Urban expansion of Bandung City has been undergoing with inconceivable pace during the period of 1970-1980. In many Indonesian big cities including Bandung, the annual population growth of this period accounted for 2.4 to 3.0 per cent (Simmons, 2000). With this growth, Bandung suffered from the pressures on demand of land, infrastructure and services. During this period, residential area in the city has been expanded by about nine per cent. This expansion was predominantly in the Southern periphery, since this area was relatively flat ready for development compared to the others, although numerous spots in this area are flood vulnerable. Due to the threats of annual flooding, the expansion was therefore frequently impeded and thus shifted to eastern side of the city amid rolling and undulated lands exist. Urban expansion to west and north directions was not possible because of two issues: different administrative entity exists in the west side and hilly land in the north side of the city. The urban expansion in 1970-1980 periods was accounted for forty-five per cent with respect to total city area.

Further development of eastern part of the city was signified by leap-frog and in-fill types of development. This situation was mostly because of unclear policy on urban development particularly for housing development by private sector and individuals as well as loose urban development control. The eventual result of this development process is extensive urban sprawl that leads to more noticeable characters of Bandung as a concentric city with CBD as single major destination of job place for most commuters those reside in the peripheries. With the absence of adequate public transport, private vehicle becomes the best transport mode choice for the commuters to travel for working

Table 1: Land Use Development in Bandung City

Land Use Category	Area in 10-year Interval (hectares)									
	1970		1980		1990		2000		2010	
	Area	%	Area	%	Area	%	Area	%	Area	%
Low Residential Area	2,557	40.0	2,796	30.0	3,579	35.0	8,792	52.4	9,980	59.5
Industry	64	1.0	280	3.0	307	3.0	610	3.6	610	3.6
Mixed Use, Commercial Area	469	7.3	656	7.0	902	8.8	988	5.9	1,250	7.5
Military Area	300	4.7	300	3.2	348	3.4	348	2.1	348	2.1
Institutional Area	250	3.9	373	4.0	409	4.0	557	3.3	750	4.5
Roads and Rivers	400	6.3	450	4.8	580	5.7	933	5.6	1,294	7.7
Conserved and Reserved Area	952	14.9	3,266	35.0	3,101	30.3	3,802	22.7	2,105	12.6
Greenery	1,400	21.9	1,200	12.9	1,000	9.8	737	4.4	430	2.6
TOTAL	**6,392**	**100.0**	**9,320**	**100.0**	**10,226**	**100**	**16,767**	**100**	**16,767**	**100**

Source: CDPA (2006, 2010)

purpose. It is then not surprising if the city becomes heavily congested city particularly at the arterial roads *en route* for the CBD during peak hours in any working days.

A significant expansion of the urban area, which was marked by considerable residential development, occurred during the period of 1990-2000. Total urban area had expanded by about sixty-three per cent during this period. In the same period, the residential area had also expanded by about 145 per cent. At the end of 2010, the length of urban roads was only about 1,200 km (CDPA, 2011) and the number of motorized vehicles (car and motorcycle) was 863,964 units (Bandung Statistical Office, 2011). With 719 vehicles per km of road plus inbound vehicles from outside of the city, we can roughly imagine the traffic situation in the city.

2.2 *Traffic-generated Urban Air Quality*

Studies in some developing countries showed that air pollution was a significant threat on economics, environment and human health. Alberini and Krupnik (2000) found that in Taiwan the ratio between cost of respiratory illness and payment made by the sufferers was 1.61 to 2.61. This might indicate that the level of respiratory illness was significant. With certain level of welfare, citizens of Bangkok were willing to share for a relatively higher contribution to protect their health from air pollution related symptoms (Chestnut *et al*., 1997). Larson *et al.* (1999) reported that air pollution related mortality risks in Volgograd, Russia were about 960 to 2,667 per million of population per year. These studies reflect non-negligible effects of air pollution on human health.

Understanding on traffic-generated urban air quality would not be comprehensive without clear perception on land use as one of the air quality determinants. Previous studies have used various types of urban forms to capture the effect of land use changes on travel behavior. It has been quite typical to consider only a single variable to measure the urban form. Bhat and Singh (2000) as well as Dunphy and Fisher (1996), for example, have demonstrated the use of urban density variable to describe travel behavior of the citizens. Wee (2011) asserts that the theory of utilitarian travel demand is the theoretical foundation of the relation between travel behavior and spatial structure. He further argues that the demand for travel does not derive its utility from the trip itself, but originates rather from the need to reach the locations where activities take place, such as the dwelling, workplace, and services and facilities. These well versed views confirm that transport and urban spatial structure are complementing one another. Still within the land use – transportation – air quality nexus, Olowoporoku *et al*. (2012) highlighted the importance of integrating air quality management into the local transport plan process and thus local policy. This thought clearly indicates that transport plan cannot simply ignore air quality issues. In other words, transport and air quality is strongly connected. The discussion concludes that land use, transport and air quality is linearly interconnected.

2.3 *Land Use, Its Changes and Traffic Connectivity*

The term “land use changes” in this study refers to alteration of category of the use of land from previously non built-up to be built-up areas. The changes are particularly manifested by the development of residential or commercial areas on previously fallow or urban forest as illustrated in Table 1.

Based on year-long observation (CTSB, 2005; Permana, 2005), it was preliminarily concluded that the development has brought into the substantial increase of traffic volumes in some collector roads. It also shows that there is a correlation between land use and mobility variables. This result is supported by some studies in developed countries. Kitamura *et al.* (1997) and Sun *et al.* (1998), for instance, found that based on a travel survey in Portland, spatial factors do explain some variation in travel behavior and travel patterns. In contrary, Snellen (2002), who undertook a study in Southern California, concluded that there was no evidence if land use variables influence travel behavior, although in general, land use and transportation were interconnected to some degree. Similarly, Hanson (1995) found that socio-demographic variables outweigh spatial variables within the interconnection of transport-demographic-spatial variables. These studies conclude a comparable proposition on the association between the land use pattern and mobility variables.

A study conducted in nine Asian cities as well as their counterparts in developed countries undertaken by Barter (1999) implied that there was strong association between urban form and mobility pattern, while Kodialam and Orlin (1992) affirmed that mobility pattern was formed by origin and destination through a shortest path movement. With this basis, the association could then be described by employing the origin-destination and shortest path movement. It was therefore true that urban form would certainly govern physical mobility pattern.

Very long distance from urban center may influence the frequency of journeys, particularly for more discretionary journeys such as for social or entertainment purposes (Williams *et al*., 2000). The proximity of origin and destination is a generic idea to reduce motorized travel needs. However this issue could be valid with the support of standardized complement of public facilities as identified by Friedman (1996) and size of settlement as studied by Williams *et al*. (2000). They argue that mixed land uses might affect the physical separation of activities and therefore influence travel demand, though some evidences suggest that this influence is not as strong as that imposed by density. Nevertheless, the different level of mixed use may contribute to different travel demand, particularly through the decentralization of heterogeneous employments. The proximity of origin and destination could then be one of generic solutions to modify travel behavior of citizens towards the reduction of motorized travel needs.

Land use of the study area is obviously concentric pattern as in other secondary cities of Indonesia. This was because of the influence of European cities at that time particularly Dutch cities and planners. Most of the secondary cities in Indonesia, including Bandung City, were planned by Dutch planners during the colonial era (1617 to 1945). Thereby the influence of medieval Dutch cities of this pattern on most cities in Indonesia was inescapable. Comparison with similar concentric pattern of land use in some primary cities shows an almost identical physical mobility. In Jakarta for example, the concentric pattern was manifested by the presence of central business district in *Sudirman-Thamrin* area, while low density residential areas largely exist at the peripheries. The conurbation has also physically and politically developed as materialized by the formation of *Jakarta-Bogor-Depok-Tangerang-Bekasi (Jabodetabek)* region. The impact of this state to the traffic situation is that trips are strongly focused on the central area of Jakarta, with consequent problems of congestion on access roads (Lo and Yeung, 1996). Jakarta is now struggling with this persistent problem. The situation has been worsening with the absence of adequate mass rapid transit system. Similarly, the concentric pattern of land use in Bangkok has created this metropolitan as a car-dependent metro (Perera, 2006), despite the improvement of urban air quality in Bangkok due to integrated efforts towards this commendable achievement.

Previous discussion acknowledges the influence and interconnection of transport and land use pattern. Road network, transit system and other transportation components shape the land use through land development, while the distribution of land use categories and type of land uses affect travel pattern of the citizens as well as the development of transportation facilities. Land use change, therefore, alters travel behavior of the road users. The behavior of road users is affected by numerous conditions and purposes. To be named, for instance, housing and job locations, technological advance of transportation systems (Cera, 2001), automobile ownerships (Kenworthy and Hu, 2002), land use, socio-economic and demographic factors (Cao *et al*., 1998), spatial and socioeconomic variables such as home-to-work trips, grocery shopping trips, non-grocery shopping trips and recurring leisure trips e.g. regular trips to sports and club activities (Snellen, 2002).

The variety of travel behaviors and purposes is a fundamental factor to predict traffic generation caused by land use changes with the premise that travel purposes are governed by land use form, for instance, because of origin and destination separation (US-EPA, 1999), and accordingly, the traffic generated air pollution. The interconnection of these three key determinants of land use, traffic and air quality is discussed in the subsequent sections.

3 Substantiating the Correlations among the Three Determinants

This section elaborates the establishment of interconnection of the three determinants and substantiates that such connection is instituted. As an additional explanation of earlier discussion, the relation between land use changes and traffic generation in the study area is established through the development of multivariate models of two collector roads: *Jalan A Yani* and *Jalan Buah Batu* (refer to Figure 1). These two collector roads are the receivers of catchment areas where most land use changes took place. The development of a single multivariate model for the whole study area is not possible since land use change has undergone in a different manner for different regions of the city. Traffic generation is analyzed by employing origin-destination of the shortest distance as suggested by Kodialam and Orlin (1992). It has been confirmed by a travel survey in the same study area from residential areas in the region of the city (origin) and central business district (destination). In the same fashion, the relation between traffic volumes and concentration of air pollutants are established by employing regression analysis.

3.1 *Multivariate Model of Traffic Generation and Land Use Changes*

To establish a multivariate model of land use changes, two collector roads i.e. *Jalan A Yani* and *Jalan Buah Batu*, were selected. The selection was based on the fact that these two collector roads are the most affected links by urban expansion in Bandung City. *Jalan A Yani* collector road was mostly affected by the changes of land use from previously abandoned and rice field lands to residential areas in the eastern sector of the city. These changes were manifested by the development of *Antapani* housing estate (550 ha), *Arcamanik* (300 ha), *Sukaluyu* (50 ha), and others (700 ha), hence total land use change up to the end of 2010 is 1,600 ha. There are four variables that suspected to have direct relationships with

Table 2: *Data for Multivariate Models on Jalan A Yani and Jalan Buah Batu*

Year	Traffic Load [PCU] (y)		Land Use Change [ha] (x1)		Per 1000 persons Car Own-ership [unit/1000 person]	Length of Road [km] (x3)	Per Capita Income [USD] (x4)
	AY	BBT	AY	BBT	AY/BBT	AY/	AY/
1994	1,460	2,203	430	300	170	725	310
1995	1,565	2,326	450	500	184	902	368
1996	1,670	2,448	565	670	198	904	427
1997	1,695	2,497	600	870	213	904	479
1998	1,721	2,522	600	870	222	940	614
1999	1,808	2,547	750	870	223	940	646
2000	1,895	2,573	750	990	232	940	682
2001	1,991	2,598	800	1,200	248	1,050	810
2002	2,087	2,650	850	1,200	264	1,050	966
2003	2,188	2,703	850	1,250	284	1,050	1,151
2004	2,290	2,820	850	1,300	312	1,080	1,180
2005	2,406	2,915	900	1,300	328	1,080	1,300
2006	2,522	3,010	1,100	1,300	335	1,100	1,400
2007	2,638	3,105	1,300	1,400	352	1,100	1,500
2008	2,754	3,205	1,500	1,400	386	1,200	2,000
2009	2,870	3,295	1,600	1,500	388	1,200	2,500
2010	2,986	3,390	1,600	1,500	405	1,200	3,000

Source: CDPA (2006), CTSB (2010) and Author's Analysis
Note: AY: Jalan A Yani Region, and BBT: Jalan Buah Batu Region

traffic, namely land use change as identified by Newman (1996), Beimborn (1996), Boarnet and Sarmiento (1998), Barter (1999), Bhat and Singh (2000). In this model, land use change is an independent variable (x_1). Car ownership (expressed in unit per thousand persons) is also suspected to affect traffic as asserted by Hanson (1995), Newman (1996), Kitamura *et al*. (1997), Newman and Kenworthy (1999). The car ownership is assigned as independent variable of x_2. Length of road is an independent variable of x_3. In the case of Bandung City, based on household survey, good road condition with less traffic congestion along with other variables would stimulate people to own private cars (Permana, 2005). Per capita income is definitely affect lifestyle, and it is assigned as independent variable of x_4. With these variables, multivariate models of traffic load generation of two collector roads are established.

It is assumed that the model can be described through designation of some independent variables those originated from the data at different level. For instance, while traffic load was measured at collector roads level, per capita income was at city level. Seventeen years of data (1994-2010) were gathered. All of these variables are shown in Table 2.

Multivariate analysis was done by using data from Table 2 for the catchment areas served by two collector roads. The analysis found that the correlation between traffic volume and land use, car ownership, length of road, and per capita income variables for the catchment area served by *Jalan A Yani* is expressed by the following equation:

$$y = 426.389 + 0.174x_1 + 4.942x_2 + 0.150x_3 + 0.028x_4$$

This equation possesses the characteristics of multiple regression coefficient, r=0.997, with coefficient of determination r^2=0.994, and 95 per cent level of confidence, and with standard error of 39.25. The statistical properties of this equation are shown in Table 3.

Table 3 shows that coefficient of variable of the car ownership is the most significant compared with other variables to predict traffic volume. It is because the value of t-statistics i.e., 7.952 is larger than the value of t-critical i.e. 1.812. The other three variables are less significant. This implies that car ownership is the main contributor of traffic load, while land use change is second greatest contributor. In 2003, at the same collector road, by employing the same model, land use change was the largest contributor. From 2004 onward, it seems that car ownership was leading contributor, while land use change is getting more and more insignificant role. This is because the space for land use change to take place in Bandung City is saturated and exhaustive. No more potential convertible natural land can be easily altered for built environment purpose. The model, however, is useful to predict the traffic volume generated by land use changes in *Jalan A Yani* region of the city. The intercept is not assigned to be zero because of the unbounded control volume, where Bandung city opens from incoming traffic from outside of the city. Although all variables (x_1, x_2, x_3 and x_4) are equal to zero, traffic volume (y) will not be equal to zero. The prediction of traffic volumes without land use changes in *Jalan A Yani* region is computed by assigning x_1=0 (no land use changes). The historically recorded traffic volume data at the same collector road is assigned as traffic volumes with land use changes. The comparison of traffic volumes with and without land use changes at *Jalan A Yani* (east collector road) is shown in Figure 2.

Figure 2 shows that the contribution of land use changes on traffic volume at *Jalan A Yani* region tends to be constant over time. In average, during the period of 1994 to 2010, the contribution was 7.69 per cent. Similar process is also applied to the development of model for another city sector i.e. *Jalan Buah Batu Collector Road* that receives traffic load from its catchment area. By using the same data, the model for *Jalan Buah Batu* sector is developed (refer to Table 2). The land use changes in this sector were due to the development of *Batununggal* estate (180 ha), *Cijagra* (200 ha), *Lingkar Selatan* (300 ha), *Margahayu Raya* (620 ha), and *Riung Bandung* (200 ha), hence the total area of land use change up to the end of 2010 was 1500 ha. The multivariate model for *Jalan Buah Batu* Sector is expressed as the following equation:

Table 3: *Statistical Properties of the Regression Equation of Jalan A Yani*

Variables	Statistical Properties				Verbal Evaluation
	Coefficient	Standard Error	t-statistics	t-critical	
Intercept	426.389	146.443	2.911		Statistically significant
Variable x1	0.174	0.113	1.533		Statistically insignificant
Variable x2	4.942	0.621	7.952	1.812	Statistically significant
Variable x3	0.150	0.235	0.637		Statistically insignificant
Variable x4	0.028	0.049	0.575		Statistically insignificant

$$y = 1582.961 + 0.009x_1 + 3.358x_2 + 0.107x_3 + 0.099x_4$$

Above equation has the properties of regression coefficient, r=0.992, and coefficient of determination r^2=0.984, with 95 per cent level of confidence, and with standard error of 49.290. The statistical properties of this equation are shown in Table 4.

The situation at *Jalan Buah Batu* collector road exhibits same pattern with its counterpart, in which car ownership contributes greatly to traffic load compared to other variables. On the other hand, contribution of land use change is getting insignificant. Based on 1994-2010 data, the contribution accounted for only 1.65 per cent. Study in 2003 by first author showed land use changes was the greatest contributor to the increase of traffic load.

3.2 Relation of Traffic Loads and Concentration of Air Pollutants

There are few studies that attempted to correlate traffic volumes with air pollutants concentration by road-side measurements, for instance, research was done by Keuken (2002), and Ohnishi and Namikawa (2001). This study attempted to correlate traffic loads and two principal air pollutants. The relation was developed by employing longitudinal data on traffic loads and air quality. There are only 4 years of data at nine monitoring points all over Bandung City as shown in Table 5.

Table 4: *Statistical Properties of the Regression Equation of Jalan Buah Batu*

Variables	Statistical Properties				Verbal Evaluation
	Coefficient	Standard Error	t-statistics	t-critical	
Intercept	1,582.961	228.492	5.603		Statistically significant
Variable x1	0.009	0.133	0.069		Statistically insignificant
Variable x2	3.358	0.789	4.255	1.812	Statistically significant
Variable x3	0.107	0.413	0.260		Statistically insignificant
Variable x4	0.099	0.054	1.830		Statistically significant

Table 5: *Air Quality at Selected Monitoring Points in Bandung [Figures are in ppm]*

Monitoring Point	Year	Traffic Load (PCU)	SO_2	CO	NOx	O_3	HC	PM
Leuwipanjang	2002	1,974	0.040	2.067	0.047	0.033	1.409	112.00
	2003	3,835	0.048	3.000	0.091	0.030	1.940	139.60
	2005	5,696	0.057	3.933	0.119	0.025	2.471	167.20
	2007	7,557	0.065	4.866	0.149	0.035	3.002	194.80
Cicaheum	2002	2,730	0.043	2.670	0.075	0.031	1.600	120.00
	2003	3,471	0.054	3.601	0.080	0.030	1.970	121.60
	2005	4,212	0.065	4.532	0.085	0.029	2.340	123.20
	2007	4,953	0.077	5.063	0.090	0.027	2.710	124.80
Elang Raya, Cibeureum	2002	1,266	0.034	1.960	0.047	0.040	1.240	98.67
	2003	3,430	0.046	2.400	0.059	0.038	1.302	128.80
	2005	5,594	0.058	2.840	0.071	0.030	1.364	158.93
	2007	7,758	0.070	4.280	0.083	0.020	1.426	189.06
Margahayu Raya	2002	458	0.027	1.059	0.013	0.054	0.980	60.53
	2003	610	0.023	1.400	0.043	0.042	1.130	91.00
	2005	962	0.019	1.741	0.059	0.030	1.280	121.47
	2007	1,314	0.015	2.082	0.070	0.024	1.430	151.94
Sarijadi	2002	650	0.024	1.670	0.043	0.048	0.820	96.50
	2003	1,460	0.036	2.060	0.075	0.039	1.350	99.60
	2005	2,270	0.048	2.450	0.090	0.030	1.880	102.70
	2007	3,080	0.061	2.840	0.104	0.020	2.410	105.80
Buah Batu	2002	2,542	0.022	2.450	0.067	0.038	1.850	120.00
	2003	3,891	0.043	3.680	0.075	0.037	2.060	129.40
	2005	5,240	0.065	4.910	0.083	0.036	2.270	138.80
Cibiru	2002	1,431	0.039	1.618	0.059	0.036	1.000	106.70
	2003	2,310	0.042	2.400	0.063	0.031	1.480	112.00
	2005	3,189	0.045	3.182	0.067	0.026	1.960	117.30
	2007	4,068	0.048	3.964	0.071	0.021	2.440	122.60
Ujunr Berung, Rumah Sakit	2002	1,575	0.032	1.230	0.043	0.039	0.670	76.90
	2003	1,733	0.033	2.054	0.052	0.033	1.353	88.60
	2005	1,891	0.034	2.878	0.061	0.026	2.036	100.30
	2007	2,049	0.036	3.702	0.070	0.019	2.719	112.00
Ahmad Yani, Persib	2003	4,950	0.052	3.450	0.072	0.020	1.880	116.50

Source: Office of Environmental Impacts Management Agency of Bandung (EIMA, 2010)

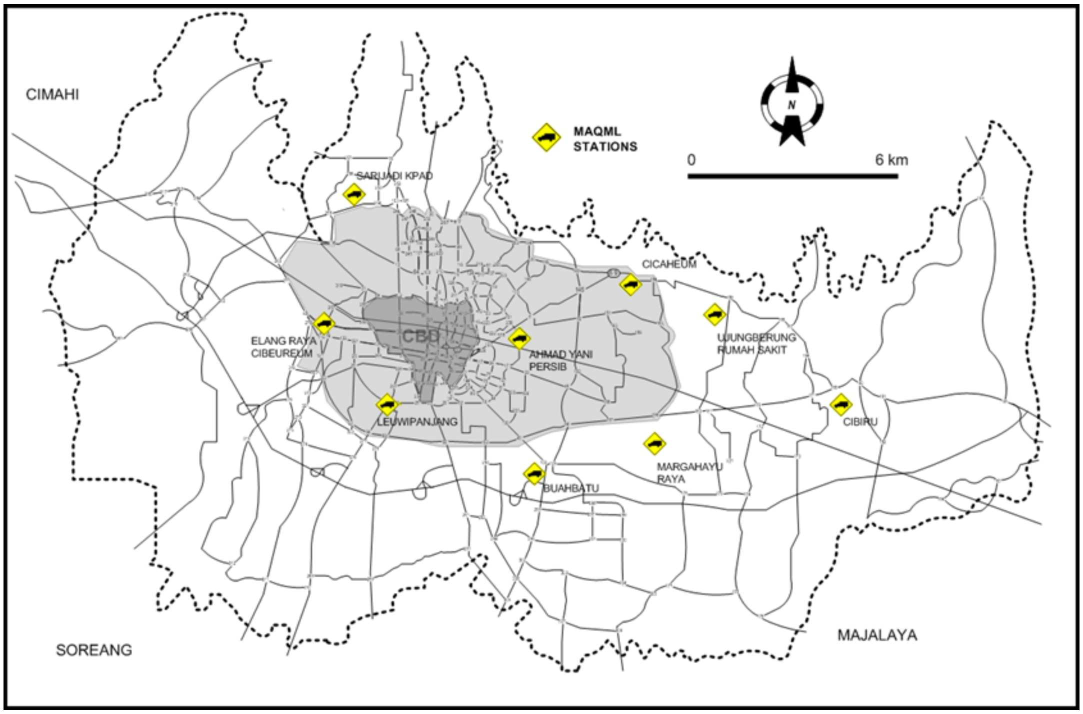

Figure 3: *Location of the Measurement of Air Quality*

Air quality data were measured by employing a mobile air quality monitoring laboratory (MAQML) at nine observation points as shown in Figure 3. Because of its mobile nature, the MAQML could be operated anywhere. The measurement was undertaken by parking the MAQML at the road-side, and then MAQML observed the air quality. At the same time traffic volumes were simultaneously counted and analyzed. This straightforward procedure was undertaken to establish the correlation between traffic volume and air quality.

The ambient air quality was observed in hourly basis during 8:00 to 16:00 hours for seven consecutive days. There were eight-hour interval data samples, with minimum, maximum, and average parameters. Eight air pollutants viz. SO, CO, O_3, HC, Non CH_4, CH_4, SPM and SO_x were monitored. However, analysis was only undertaken on two principal air pollutants, namely SO_2, and HC. Fifteen points of the air quality monitoring stations across the city were actually available. However, by considering the incompleteness of data records, only nine points were considered and included in the analysis.

Various studies on traffics and emissions relationships were conducted. All studies confirmed that traffic loads and emissions are linearly correlated. One of the studies was conducted by Zhongan. Zhongan *et al.* (2002) has attempted to rationally correlate traffic and emission intensity. This study resulted in a rational correlation as expressed by the following formula:

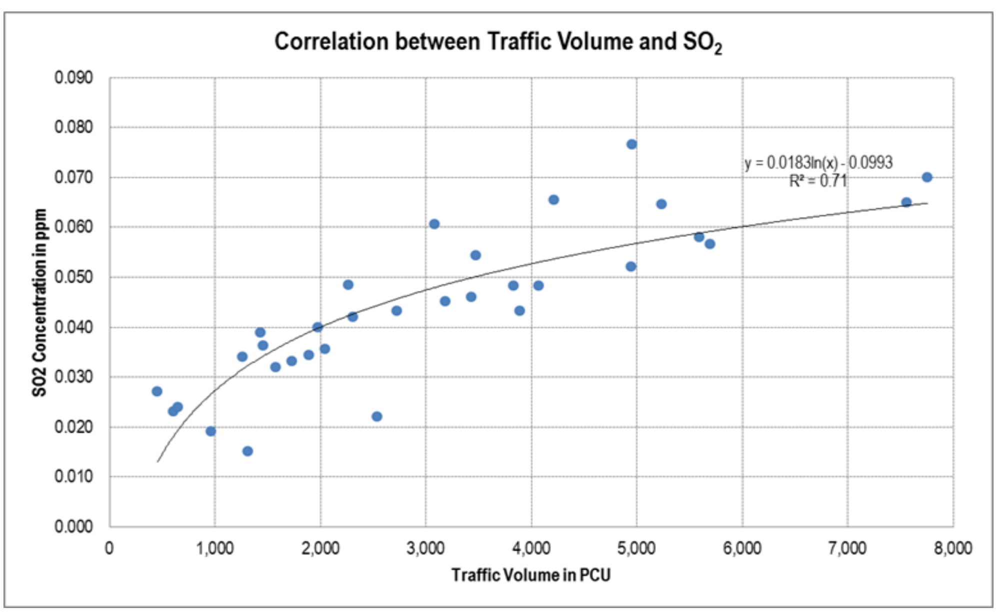

Figure 4: *Traffic Load and SO_2 Concentration*

$$E_p = \sum_{i=1}^{n} L \times N_i \times F_{pi}$$

Where E_p is emission intensity of a line segment (gram/hour/km), L is length of road researched (km), N_i is traffic flow, vehicles of type i passing through the road segment (vehicles/km/hour), i is vehicle type (1 to n) and F_{pi} is emission factor of vehicle type i (g/km). The dissimilarity between Zonghan's and this study is that Zonghan considers the source of emission as a line domain while this study observes a point domain to assess the quantity of emission. This study relies mainly on empirical correlation instead of rational explanation.

In this study, data sets as shown in Table 5 were analysed by employing regression analysis. Regression analysis was carried out on two principal air pollutants to confirm the correlation between traffic loads and the quantity of air pollutants. Linear regression shows moderate to low determination factors, which are 0.71 and 0.45 for SO_2 and HC respectively. The correlation can be directly established since traffic is the only dominating source of air pollution in the study area.

Relation between SO_2 and Traffic Load: A longer data record is certainly required for a reliable establishment of the correlation. It is acknowledged that the quantity of SO_2 is positively associated with traffic volume. The correlation is shown in Figure 4.

Another important pollutant in the study area is Hydrocarbons (HC), particularly benzene (C_5H_5), and the correlation between HC and traffic volume is discussed below.

Relation between Hydrocarbons (HC) and Traffic Load: In the study area, hydrocarbon is the only pollutant, in which the concentration exceeds national standard since a long time ago. With similar data sets used, relationship between concentration of hydrocarbon and volume of traffic is exhibited in Figure 5.

The tendency of the concentration of these two air pollutants is increasing over time as traffic loads increase. This exhibits the need of suitable coping strategies to deal with the degradation of air quality in the study area. The strategies, derived from the analysis, can be strongly considered along with other presently available appropriate strategies.

4 The Necessity of Coping Strategies

Studies on urban air quality related coping strategies have recommended various policy instruments, for instance, land use and transport. Some of the studies proposed integrated, comprehensive and simultaneous approaches to cope with urban air quality issues (GTZ, 2002; Ahearn, 1997). Urban planning, land use and spatial related policy instruments were also proposed, for example, by GTZ (2002), US-EPA (1999), Wheaton (1998), Friedman (1996). Traffic management and traffic reduction were proposed by Keuken (2002), Rutter *et al.*, (1997). World Bank (2001) emphasized the strategy on public transport. Economic instruments were the most favorable tools to cope with urban air quality degradation for economists, for instance, Alberini and Krupnick (2000), Anas and Xu (1999). The provision of air quality standards is also acknowledged as suggested by Haq and Han (2002). The need of cleaner production and encouraging integrated environment management with more flexible and outcome-oriented approaches is also offered by Ahearn (1997). The strategies can also contribute to climate change mitigation.

The need of integrated and wide-range coping strategies has been a common demand to improve urban air quality in Bandung City. Since these strategies have long been available for many years in the cities in developed and developing world. Looking at the land use as the primary cause of the degradation of urban air quality, as previously discussed, the strategies to cope with urban air quality issues in the study area are more desirable to be extended on how land use would be able to reduce travel needs without hampering urban dynamics. This strategy aims at creating the proximity of origin and destination without creating any conflicts among land use categories. A city-based synergistic and comprehensive approach is required while improving urban environment as a whole. Fractional, discontinuous and scattered

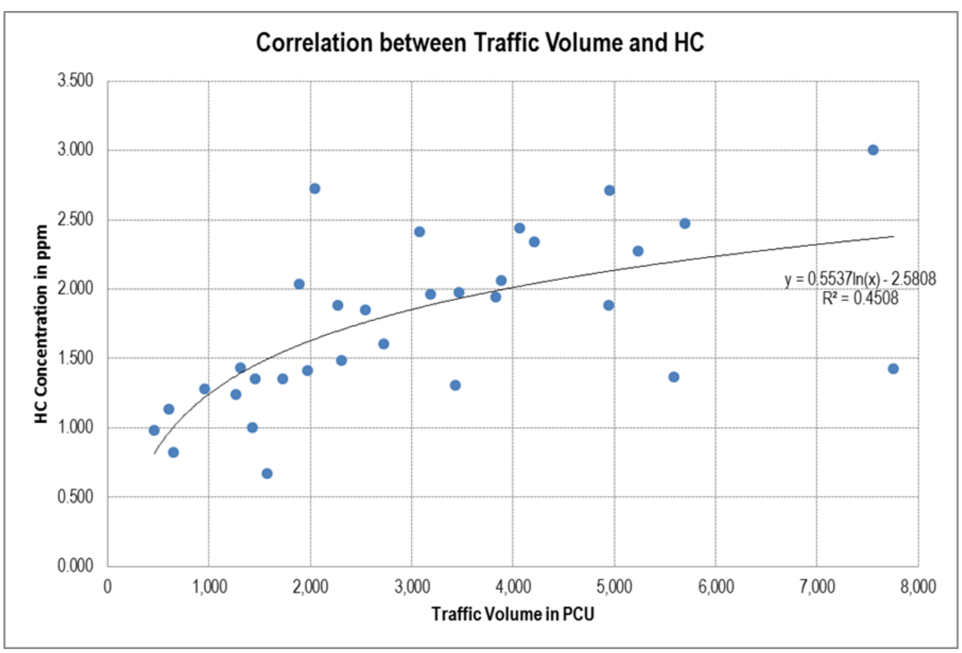

Figure 5: *Traffic Load and HC Concentration*

interventions would only lead to the ineffective programs.

5 Conclusions

This study shows that land use change is no longer primary determinant of the degradation of air quality in Bandung City. The model exhibits the contribution of land use change is 1.65 only per cent at the catchment area of *Jalan Buah Batu* and 7.69 per cent at *Jalan A. Yani*. It is worth explaining that by using the same model, a larger contribution by land use change on traffic generation was occurred prior to 2003. At that time, the land use change contribution was around 30 per cent compared to 20 per cent by car ownership. This fact shows that while the natural-to-built land conversion is being saturated as limited land does exists, the private car is being important mode of transport amid inadequate public transport in the city. This tendency would keep exist unless a revolutionary action to improve urban public transport system takes place. At the same time, vertical living should become customary for most citizens. A strong and effective development control is necessary.

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