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Do land use changes influence air quality?

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A B S T R A C T

Bandung, the study area, is characterized by a concentric land use pattern that radiates from mixed commercial area in the center to low density residential area in the periphery. This pattern generates significant traffic volume toward the city center. This traffic creates more emissions and degrades urban air quality since fossil fuel is dominantly used by vehicles in Bandung. This study analyses the correlation between land-use changes, traffic volume, and urban air quality. Longitudinal data of land-use changes and corresponding traffic volume caused by the changes have been investigated. In line with this, the correlation between traffic volume and the quantity of air pollutants i.e. SO2, and CO were established. It was found that three urban variables of land-use changes, traffic volume, and air quality are correlated.

Keywords: land use changes, traffic volume, air quality, urban environment.

ARTICLE HIGHLIGHTS

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1 Introduction

Cities, whether well-planed or just naturally grown, are dynamics and always changing not in a decade but every day! No cities without changes. The changes are driven by particularly demographic pressures or economic development. Some cities in developing countries experienced from economic-driven growth rather than a planned growth (Permana et al., 2015). One of the most significant changes due to demographic and economic pressures is land use change. Marques et al. (2019) asserted that the most observable urban land use changes in a naturally city is the changing from natural environment e.g. forests and farmland becomes built-environment that includes normally residential and commercial areas. This form of land transformation would not only alter the urban landscape but also the consequences beyond. Land use change is one of the most central marks of urban growth. The changes would affect the physical mobility of the citizens. In a sense that the new residential areas, as a result of the land alteration, would generate traffic from the newly emerged areas, as transportation has been acknowledged as one of the most important components of the urban growth (Taylor, 2002). Transportation and urban expansion are growing simultaneously toward the achievement of citizen's aspiration. Hence

transportation would continue to grow in line with the growth of urban areas, particularly in a city where the private transportation is predominant. In such a case, the upshots would be beyond the thoughts of citizens.

Studies in some developing countries of various sources of air pollution impacts on human health revealed that economic and environmental losses have been major threats. Alberini and Krupnik (2000) found that in Taiwan the ratio between cost of illness, in terms of respiratory illnesses, and willingness to pay was 1.61 to 2.61, it may indicate that the level of respiratory illness was significant. With certain level of welfare, Bangkok citizens were willing to pay a relatively higher share to protect their health from air pollution related symptoms (Chesnut et al., 1997), while a study in Delhi (Cropper et al. 1997) found that peak effects on health due to air pollution occur between the age of fifteen to forty-four, it implies that death associated with air pollution causes more life-years to be lost. Larson et al (1999) reported that air pollution related mortality risks in Volgograd Russia, was about 960 to 2667 per million of population per year. These studies reflect non-negligible effects of air pollution on human health, and at the same time show the importance of air quality issues elsewhere particularly in developing world including Indonesia. The importance of the issues has encouraged us to seek for the clarification on the correlation between land use changes and air quality degradation. Permana et al. (2015) clearly depicted the linear correlation between urban growth and climate changes through the nexus of urban growth – land use changes – traffic generation – air pollution – energy uses – and climate changes as shown in Figure 1.

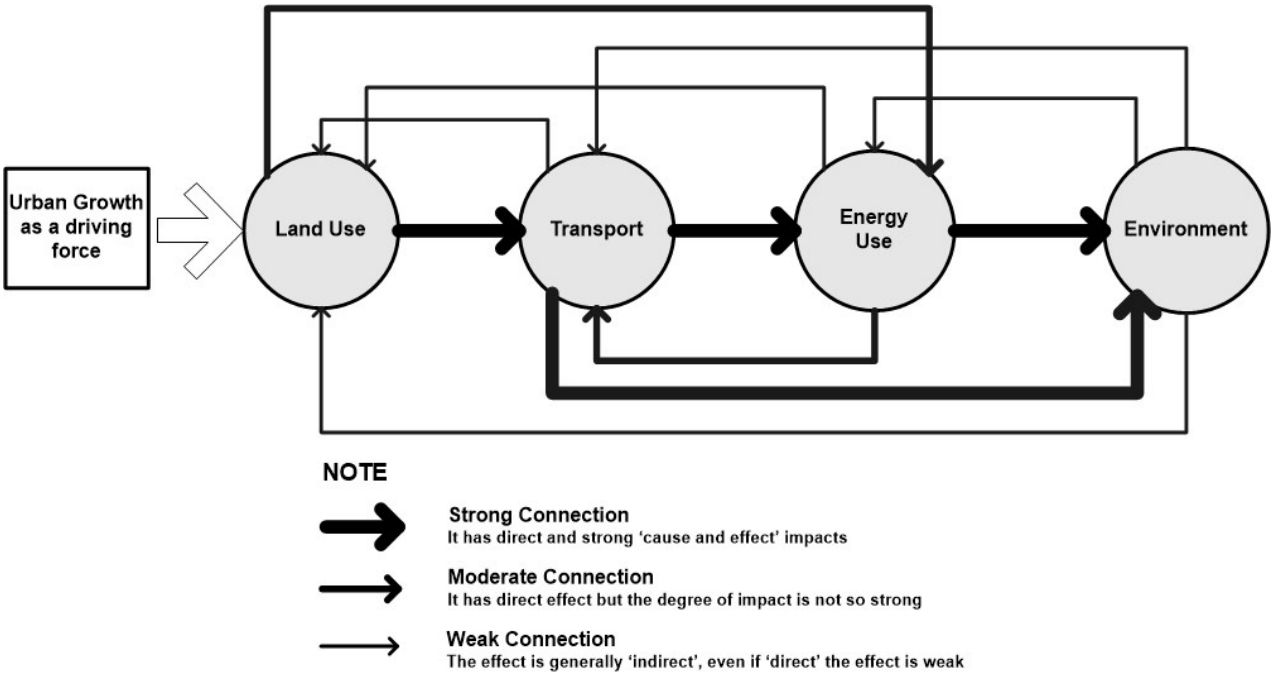

Figure 1: The Nexus of Urban Growth and Environmental Issues

This study investigates the correlation between land use changes, in terms of changes from natural environment to built-up areas, by observing the extent of the changes in unit area and computing the single equivalent traffic volume generated by that changes at immediate collector roads. Simultaneously, the correlation between traffic volume and concentration of air pollutants with traffic as a single main source was also investigated. To establish this correlation, the concentrations of air pollutants were measured, and traffic volume was simultaneously counted. The measurement of air quality was carried out by employing mobile air quality monitoring system, which capable of operating at anytime and anywhere.

Land use changes were examined through the observation of changes of the landscape from natural areas to built-up areas, particularly development of residential area. A historical data of land use changes due to development of residential area was analyzed to predict generated traffics.

2 The observations

We observed three primary variables i.e. the changes from natural environment to be built-up environment, traffic volume at immediate collector roads where the land use took place, air quality of the area, to corroborate our statement on the correlation between the land transformation and degradation of air quality in Bandung City, a city with, hard to argue, natural growing characteristics rather than a well-planned city. With an annual population growth of 1.6 to 2.4 percent, the city suffered from the pressures on lands, infrastructure and services. The urban areas of Bandung were beyond the administrative boundary of Bandung City. It has been expanding about five times of the original area of the city, because of conurbation process to include surrounding cities, which were sub-urban areas. Within the Bandung city itself, the urban expansion took place particularly to the east, as natural constraints i.e. flood problems and natural reserves were exist in the south and north.

2.1 Land Use, Its Changes and Traffic Connectivity

The term of "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 change was particularly manifested by the development of residential or commercial areas on the previously natural environment. With this understanding, knowledge on urban expansion with respect to different types of land use changes, particularly development of residential area, was required. Land use changes in Bandung City are illustrated in the Table 1, the changes were started with the year of 1970 as a baseline data, since national development of Indonesia, including Bandung City, was also commenced in 1970. A ten-year interval land use development was presented. Observation were focused on the development of residential area, particularly on where the development was located and when the development has undergone. The "where" and "when" inquiries were important to confirm the traffic volume increases due to that development.

Table 1: Land Use Development in the Administrative Area of Bandung City

Land Use Category	Area in 10-year Interval (hectares)											
	1970		1980		1990		2000		2010		2020	
	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%
Low Residential	2,557	40.0	2,796	30.0	3,579	35.0	8,792	52.4	9,671	57.7	11,452	68.3
Industry	64	1.0	280	3.0	307	3.0	610	3.6	610	3.6	610	3.6
Mixed Use, Commercial	469	7.3	656	7.0	902	8.8	988	5.9	1,037	6.2	1,120	6.7
Military Area	300	4.7	300	3.2	348	3.4	348	2.1	348	2.1	348	2.1
Institutional Area	250	3.9	373	4.0	409	4.0	557	3.3	613	3.7	650	3.9
Roads and Rivers	400	6.3	450	4.8	580	5.7	933	5.6	1,294	7.7	1,740	10.4
Conserved and Reserved Area	952	14.9	3,266	35.0	3,101	30.3	3,802	22.7	2,457	14.7	1,197	7.1
Greenery	1,400	21.9	1,200	12.9	1,000	9.8	737	4.4	737	4.4	650	3.9
TOTAL	**6,392**	**100**	**9,320**	**100**	**10,226**	**100**	**16,767**	**100**	**16,767**	**100**	**16,767**	**100**

Table 1 shows considerable development of low-density residential area over time, from 2,557 ha in 1970 to 11,452 ha in 2020 or about 4.5 times. Based on an approximate projection as depicted in Figure 1, it seems that Bandung City must change their policy on low-density residential areas abruptly toward high-density e.g. property development with the apartments and condominiums connected by public transport, or else Bandung

City would face urban environmental disasters, which actually have already been undergoing, for example, more frequent urban flooding, severe traffic congestions, urban dilapidations, uncollected urban wastes.

Based on year-long casual observation that leads to preliminary conclusion reveals that this development has brought into the substantial increase of traffic volume in some collector roads. It shows that there is a correlation between land use and mobility variables. This result supported by some studies in developed countries which conclude comparable supposition on the association between pattern of the land use and mobility variables. Kitamura et al. (1997), Sun et al. (1998), Hong et al. (2014), and Chen et al. (2016) found that spatial factors do explain some variations in travel behavior and travel patterns. However, Snellen (2002) contradictorily concluded from a study in Southern California that there is no evidence that land use variables influence travel behavior, and Hanson (1982) found that socio-demographic variables outweigh spatial variables.

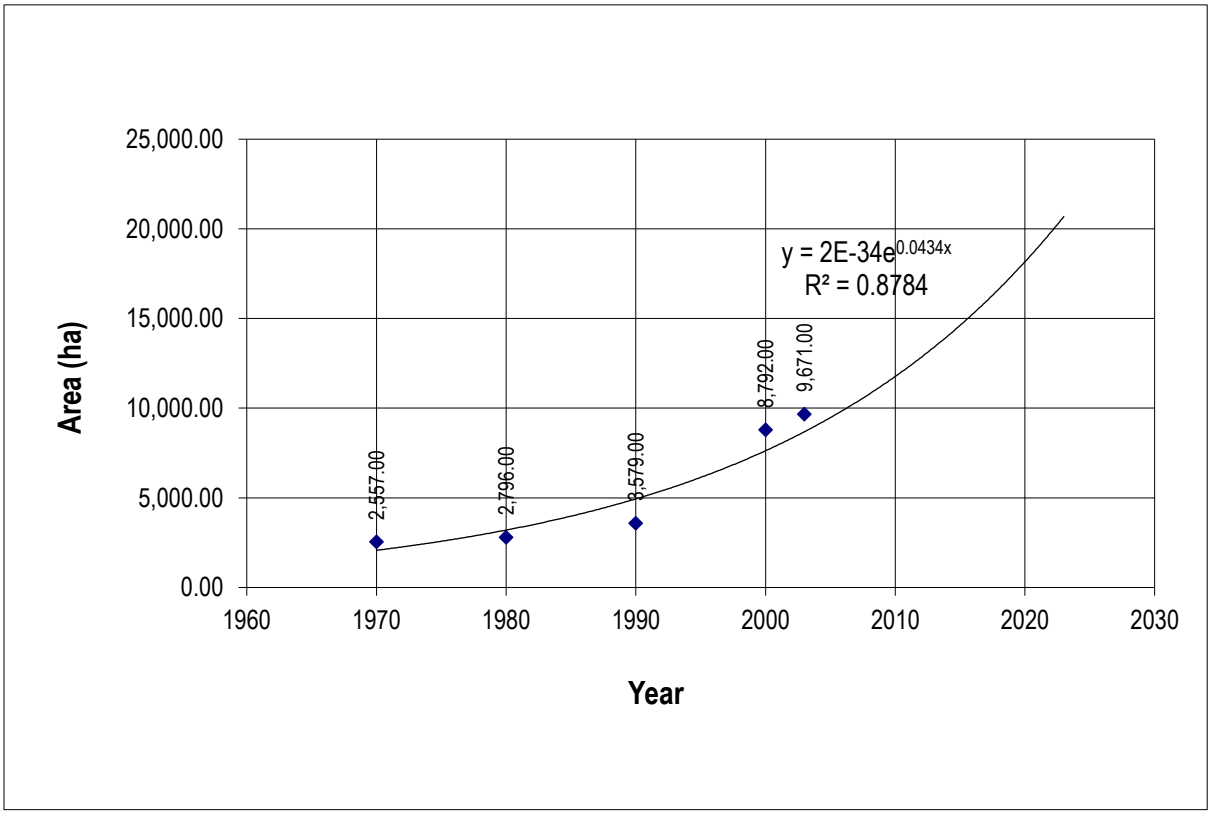

Figure 2: Development Trends of Low-density Residential Areas in Bandung City

Figure 2 confirmed that, based on a projection, in 2020, the low-density residential areas Bandung City exceeded the area of the itself, just for single category of land use. It is far from an idealistic land use of a sustainable city. A sustainable city in combination with smart city principles, the high-density residential areas must be between 15-30 percent with less than 5% of the low-density residential areas. The predominant use is supposed to be natural environment, recreational areas, public spaces, urban utilities and amenities. What we observed in Bandung City these days, based on subjective views of the authors during the survey, are sea of congestion, metro-pollutant, uncollected garbage and urban floods.

Another fact on the naturally grown Bandung City is the uncontrolled growth of built-up areas against natural environment as exhibited in Figure 3. This fact confirms that the city is not in a correct pathway to sustainable city, as the low-density residential areas is exponentially increasing while the natural environment is steadily decreasing. The city is sprawling without a proper effort to prevent the process. Now, one can observe that the

urban sprawling process has generated another issue on the conurbation among the Bandung city and the surrounding urban areas. One of the consequences is that the hardscape has replaced the natural scape, and hydrologically increasing the run-off coefficient, which causes the frequent urban floods. The problem is exacerbated by the attitude of the most citizens, which is not at all compatible with the prevention of urban floods. The strong population pressures in the city and surrounding urban areas have brought to numerous adverse impacts from the viewpoints of sustainability and sustainable city principles. It seems that business-as-usual approach, which has currently been doing by the city authority, to cope with this complexity, would not be able to solve the issues. A radical tactic with strong leaderships of the authority would be needed. Given that strategic plans along with a share vision of the citizens are in place.

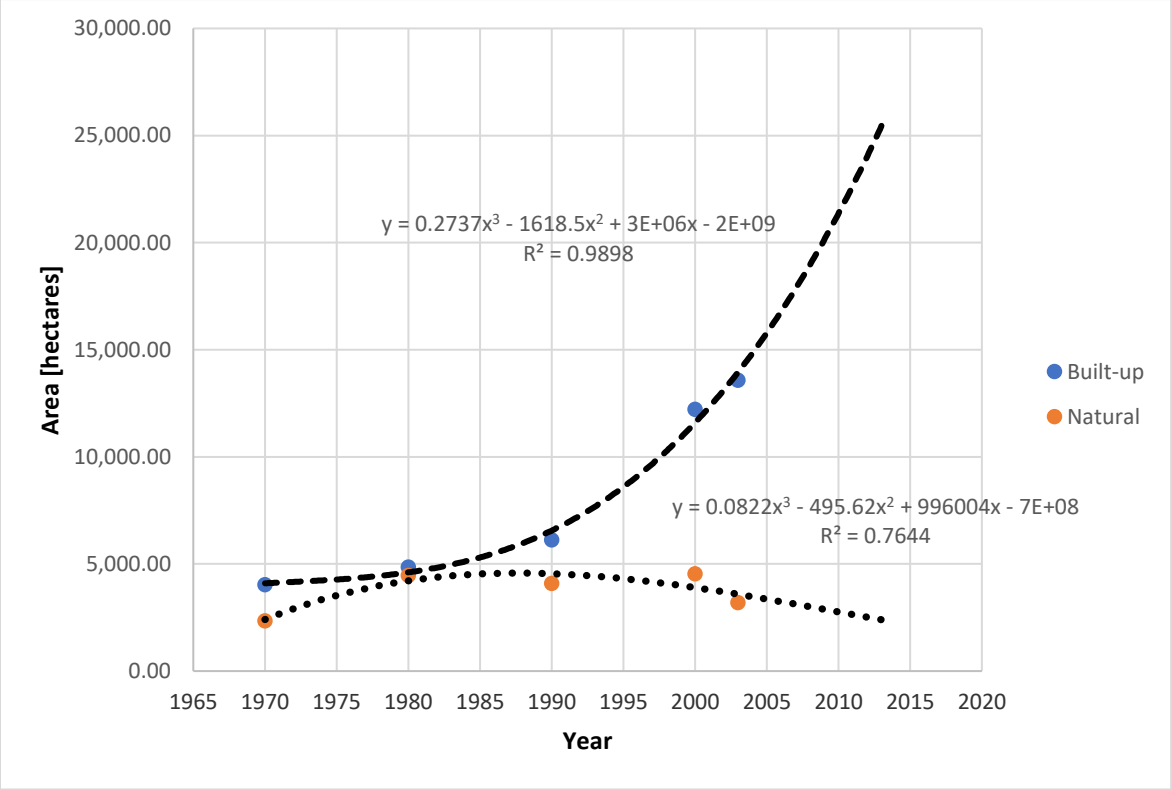

Figure 3: Diametrically Opposite Trends of Built-up Areas and Natural Environment

2.2 Urban Air Quality

Present Indonesian national policy instruments have a potential to provide sufficient guidance toward better air quality. However, implementation of the instrument is insufficient, since law enforcement is the weakest points among the process. With insufficient law enforcement the environmental degradation is steadily decreasing over time. This is among other reflected in the degradation of urban air quality. In addition, some other instruments do not clearly guide toward the objectives of improving urban air quality and environmental condition in general. Example of the weakness is the implementation of Blue-Sky Policy. This policy is a half-hearted-like policy, since the implementation was only in the form of appealing and encouraging people. Yet the implementation of this policy was in voluntarily basis. Another example was emission test. The test was undertaken intermittently without clear plan to continue this good practice. The emission test was also compulsory for public transport, but numerous polluting bus and other public transport vehicles are still hitting the road. All of these show that appropriate policy instruments with adequate implementation system are required.

Previous studies on air quality issues have used various kinds of urban form measures to capture the effects of the land use changes on travel behavior. It has been quite typical to consider only a single variable to measure the urban form, to name some examples a single measure of density has been used in a study undertaken by Bhat and Singh (2000), Dunphy and Fisher (1996), Bay and Lehmann (2017), and Xu et al. (2020). For the purpose of comprehensive perception on the relationships between air pollution, transportation and land use changes, understanding on land use changes and traffic connectivity as well as traffic generated by land use changes must be acquired. Following sections discuss the correlation between land use changes and traffic.

Study conducted in nine Asian developing cities as well as their counterparts in developed countries (Barter, 1999) implied that there was strong association between urban form and mobility pattern, while mobility pattern was formed by origin and destination shortest path problem (Kodialam and Orlin, 1992). With this basis, the association was then described by employing this origin-destination shortest path movement. It is strongly argued that urban form would certainly dictate physical mobility pattern. Barter (1999) further argued that non-motorized transport as percentage of journey-to-work is dictated by urban density. It was understood if efforts to modify travel behavior were carried out by employing land use policy, for this reason, much has been written about the prospects for using land use policy to influence travel behavior. One of them is a study undertaken by Boarnet and Sarmiento (1998). They further explained that the goals of the New Urbanism are, in fact, multi-faceted, the land use elements most often purported to be associated with reduced automobile use were grid-oriented streets, inviting pedestrian environments, mixed land uses that created short distances between residences and shopping or entertainment destinations, and sometimes parking restrictions or other policies intended to raise the cost of driving. Similarly, transit-oriented developments (TODs) were designed to cluster residences, employment, and shopping around mixed-use, pedestrian-oriented rail transit stations, all in an attempt to encourage persons to walk to the train rather than drive to their destination.

The most observable correlation between land use and traffic can be examined from the proximity of origin (e.g. residential area) to destination (e.g. commercial or civic or government area), if the location of residential area is in the periphery of the urban area while the destination was usually located in the urban center, with very long distances from urban center it might influence the frequency of journeys, particularly for more discretionary journeys such as social or entertainment purposes (Williams, 2000). The proximity of origin and destination is generic idea to reduce motorized travel needs. However, this issue would be valid with the support of standardized complement of public facilities as identified by Friedman (1996) and size of settlement as studied by Williams (2000). She argues that the mixing land uses may affect the physical separation of activities and therefore influence travel demand, although some evidence suggests that this influence is not as strong as that imposed by density. Nevertheless, the level of mixed use may contribute to travel demand, particularly through the decentralization of less specialized employment. To achieve an appropriate proximity of origin and destination in such a way that travel behavior of the citizens could be modified toward an ideal condition with respect to the reduction of motorized travel needs, city revitalization and redevelopment should be undertaken in Bandung. This proposal was raised since extensive development of low-density residential areas in the absence of sufficient public facilities exists.

From previous discussions it is acknowledged that transportation and land use pattern mutually affected one another. Roads network, transit system, and other transportation components shape 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 changes, therefore, alters travel behavior of the road user. The behavior of road users were affected by numerous conditions and purposes such as housings and jobs location (Waddell, 2000), technological advance of transportation system (Cera, 2001), automobile and ownerships, land use, socio-economic and demographic (Kenworthy and Hu, 2002), 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 varieties of travel behavior and purposes are fundamental factor of prediction of traffic generation caused by land use changes with the premise that travel purposes are governed by land use form e.g. because of origin and destination separation (US-EPA, 1999), and in turn, the traffic generates air pollution.

3 Discussions and Results

To corroborate the direct relationships between land use changes and air quality degradation, we observed historical land use changes and traffic volume at two collector roads of *Jalan A Yani* and *Jalan Buah Batu* (refer to Figure 4). Traffic generation is counted by employing origin-destination with shortest distance (Kodialam and Orlin, 1992; Ostrovsky-Berman, 2003), and it has been confirmed with travel survey from residential areas in the region of the city (origin) and central business district (destination). In the same fashion, the correlation between traffic volume and concentration of the air pollutants was established by employing a non-linear regression.

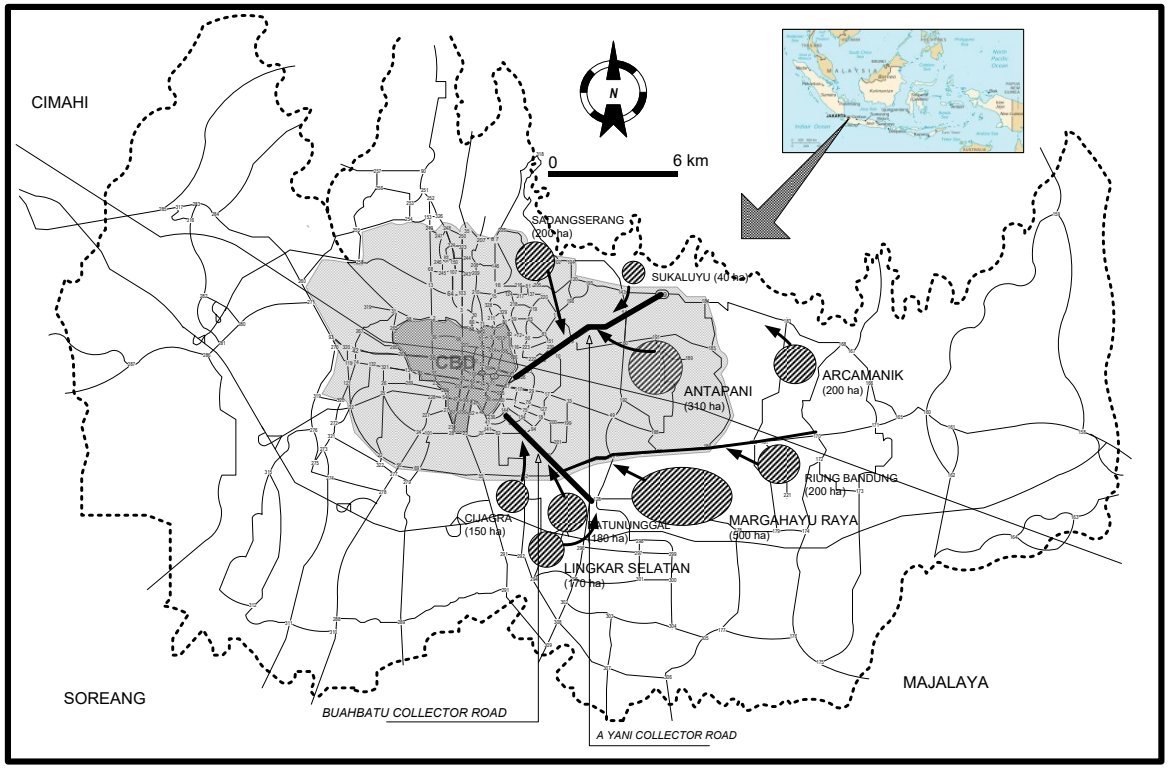

Figure 4: Two Collector Roads Observed

3.1 Traffics Volume and Land Use Changes

Land use changes were longitudinally recorded in the areas of the city where the traffic volume due to these changes were expected to affect the two collector roads of *Buah Batu* and *A Yani*. The changes were recorded in terms of the expansions of the residential areas with Year 1970 as the baseline information i.e. equal to 1.0. The following years after 1970 are the changes, which is multiplication of the baseline year (1970). Figure 5 shows a very clear and obvious correlation between the land use changes from natural environment to be built-up areas i.e. residential and commercial areas and traffic generated by the changes. It can be explained from the facts that (a) the residential and commercial development in Bandung city were rarely integrated with the sufficient public transport system (b) The public transport system in Bandung City is served mostly by 10-seat van-like car, called *angkot*. The public transport system is owned privately by individual citizens and few private transport companies, with rudimentary quality (c) The number of vans, which serve public transport system in the city might be sufficient, but quality-wise is insufficient. Thus, it could not attract all strata of citizens to shift from private transport to public transport.

The majority consumers of the public van are low-income citizens (d) Private cars are the most preferred transport system for middle and upper strata of the citizens (e) The residential development in the city never consider the pedestrian-driven principles, because of many factors. These factors have driven the increasing or generating traffic volume when new residential or commercial areas were developed. It is then not a surprise when there is very distinct correlation between land use changes and traffic volume in most cities in Indonesia. The most planners and the city authorities in Indonesia are incapable of creating a city with less motorized transport dependent, less energy consumption, less destruction to the environment. The urban development in Indonesia was wrong from the beginning, as concentric land use zoning is the prevailing school of thoughts in urban planning in Indonesia. It is not very surprising if the residential development is not well planned, rather driven by economic motive and other interests.

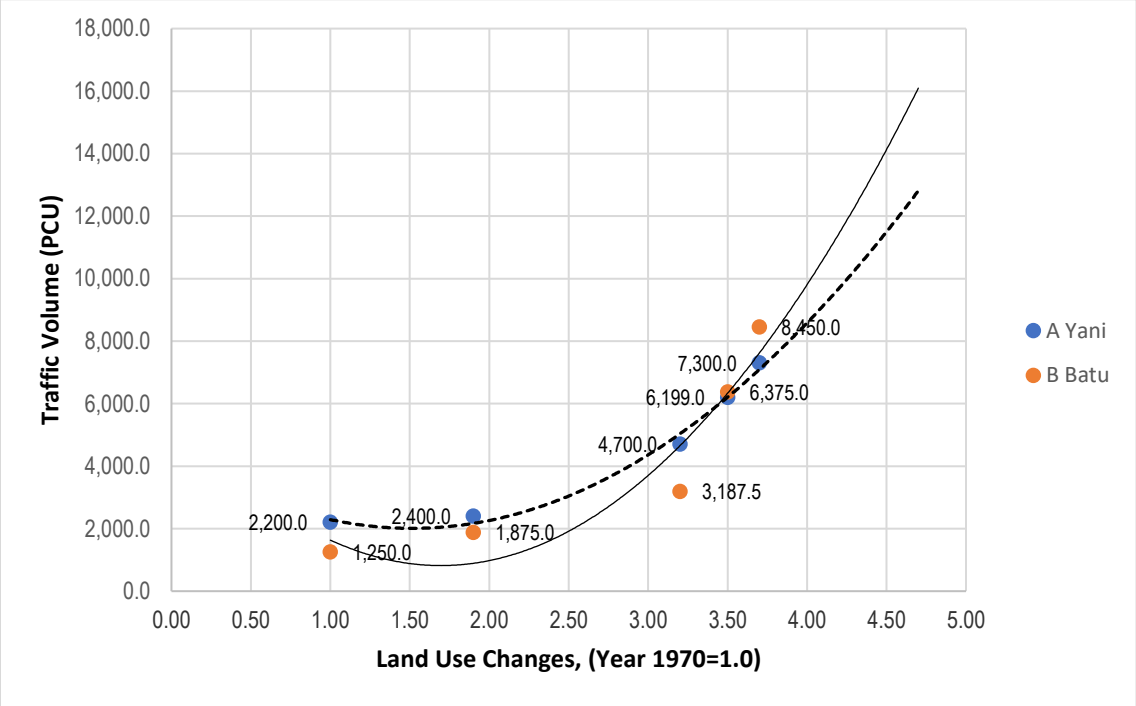

Figure 5: Land Use Changes and Traffic Volume at Two Collector Roads

3.2 Traffic Volume and Air Pollutants Concentration

To develop a quantitative correlation between land use, transportation and air quality, relationship between traffic volume and three principal air pollutants with traffic as major source were established. The establishment of correlation between traffic volume and air pollutants was undertaken by employing historical data on traffic and air pollution measurement. There eighteen data set available for analysis. Few studies attempted to correlate directly traffic volume with air pollutants concentration by road-side measurement, some of them were done by Kim et al, (2004), Keuken (2002), and Ohnishi and Namikawa (2001).

Air pollution data was monitored by means of mobile air quality monitoring laboratory. The data were acquired by parking the mobile air quality monitoring at the road-side, and then the air quality was observed. At the same time traffic volume was simultaneously counted. This procedure expects correlation between traffic volume and air quality can be established. Measurement of ambient air quality was carried out eight hours continuously daily at certain point and time. The ambient air quality was monitored in hourly basis during 8:00 to 16:00, therefore

there would be eight-hour interval data samples, with minimum, maximum, and average parameters. There are eight air pollutants were monitored. Those are: SO, CO, O_3, HC, Non CH_4, CH_4, SPM and SO_x. However, analysis is only undertaken on two principal air pollutants, those are sulfur dioxide (SO_2), and carbon monoxide (CO).

A study conducted by 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:

$$E_p = \sum_{i=1}^{n} L \times N_i \times F_{pi} \qquad \text{(Eq. 1)}$$

Where E_p Emission intensity of a line segment (gram/hour/km)
L Length of road researched (km)
N_i Traffic flow, number of vehicles of type *i* passing through the road segment (vehicles/km)
i Vehicle type (1 to n)
F_{pi} Emission factor of vehicle type *i* (g/km)

The major difference between the study conducted by Zonghan et al. (2002) and this study is that Zonghan's consider the quantity of emission in a "line domain" while this study observes a "point domain" to assess the quantity of emission.

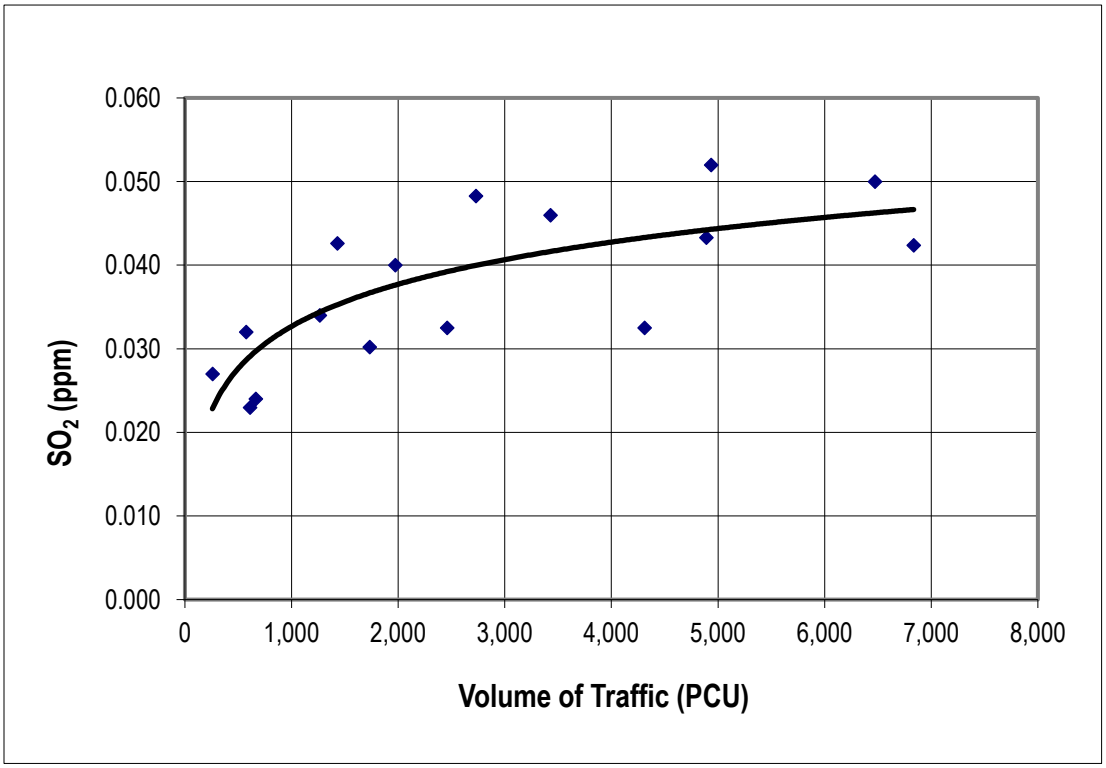

Figure 6: Correlation between Traffic Volume and SO_2

The reduction of number of vehicles operating on road, the use of low emission fuels, traffic management to reduce traffic volume, urban planning to reduce motorized travel needs, provision of good public transportation system to reduce the use of private cars, are also major factor governing the urban air quality in the city. Current efforts of the City Government to improve urban air quality with respect to those plans seems insignificant, however city government plan to develop city monorail was a good initial attempt to response to the need of improvement of urban air quality.

Even though it is predominant, but traffic is not the only source of air pollution in ten Asian Cities. Unlike in Bandung, it makes impossible to directly correlate traffic volume and concentration of air pollutants in other Asian cities. The unique source of air pollution in Bandung makes possible to model the city with a line-source air pollution modeling. Discussion on the correlation between traffic volume and concentration of air pollutants can be regarded as a preliminary empirical model of line source air pollution in the study area prior to more complex mathematical model which can support the decision or policy making in improving urban air quality. By combining Figure 5, 6 and 7, we can conclude that the land use changes in a natural grown i.e. not well-planned city, and where the public transport is insufficient, do have the influence the urban air quality. This is a precaution for the city authority that the alteration of natural environment particularly from the forestry to built-up environment would likely bring the multiple consequences as reflected by Figures 5-6-7 and 1. These figures exhibit very clear message on the consequences of land transformation in urban areas.

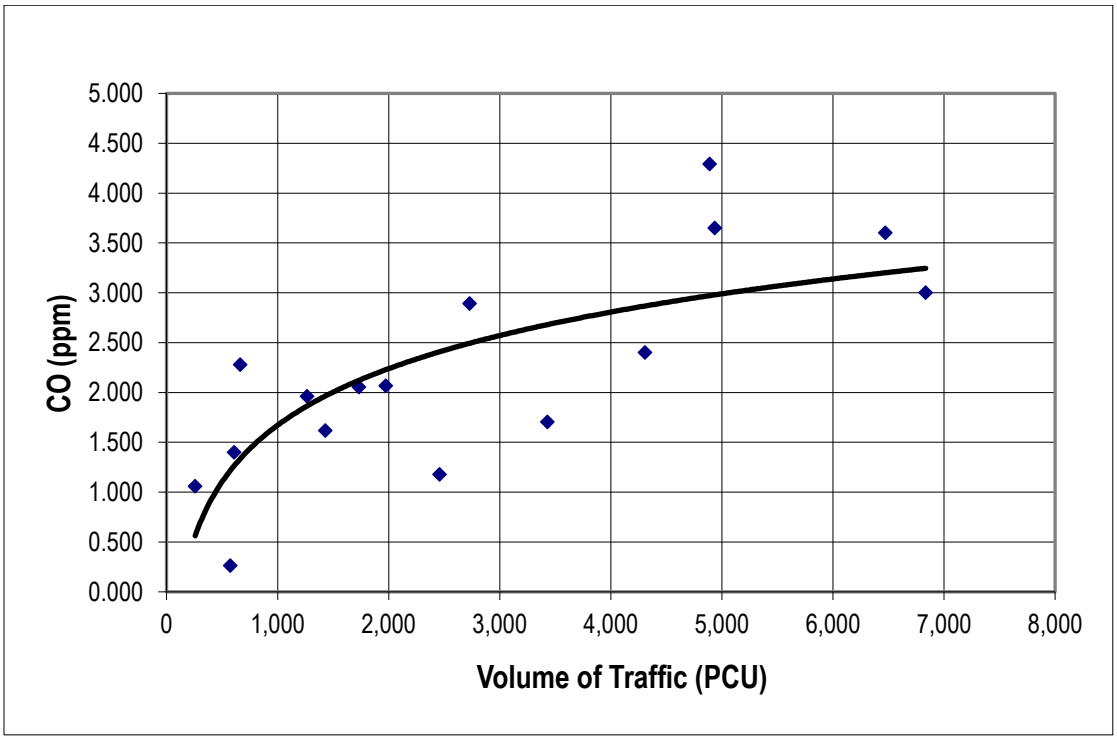

Figure 7: Correlation between Traffic Volume and CO

From the discussion on the urban air quality impacted by traffic, it has been recognized that urban air quality in the study area is steadily decreasing as urban area expanding and traffic volume increasing. Sets of policy instruments are necessary to deter such urban air quality degradation; otherwise more severe impacts on urban and living environment will strike the study area in the near future. For this reason, some possible sets of coping strategies for the city with present situation related to the degradation of urban air quality can be highlighted.

4 Implications on the Necessary Coping Strategies

Previous studies on urban air quality related coping strategies have recommended various policy instruments which are principally related to three key determinants, those are: land use, transportation and air quality. Some of the studies propose integrated, comprehensive and simultaneous approach to cope with urban air quality issues (Molina, 2005; Evarts, 2002, GTZ, 2002; Ahearn, 1997). Urban planning, land use and spatial related policy instruments are also proposed by studies conducted by GTZ (2002), US-EPA (1999), Wheaton (1998), Smith and

Raemakers (1998), Pharoah (1996), and Friedman (1996). Traffic management and traffic reduction emphasized coping strategies have also been proposed to improve urban air quality (Keuken, 2002; Jeon, 2003). World Bank (2001) has emphasized the strategy on public transport; it argues that with an appropriate public transport, the use of private cars will be reduced and consequently air pollution is reduced. Economic instruments are the most favorable tools to cope with urban air quality degradation for most of economists as, among others, proposed by Alberini and Krupnick (2000), Anas and Xu (1999), McCubbin and Delluchi (1999) and Field (1997). The provision of air quality standards is also acknowledged as suggested by Haq and Han (2002) and Evarts (2002). The need of cleaner production and encouraging integrated environment management with more flexible and outcome-oriented approaches is also offered by Ahearn (1997) to deal with urban air quality degradation with various sources of air pollutants.

The need of integrated and wide-range coping strategies has been a common demand to improve urban air quality in many developing world cities including the study area, however, since those strategies have long been exist for many years in developed and developing world cities, therefore in the case of Bandung city, the strategies to cope with urban air quality issues are extended to only specific and locally genuine strategies and/or are being planned for implementation in the city. This is also undertaken to limit the discussion to avoid unnecessary explanation.

This strategy aims at doing something strategic and doable interventions those genuine or vernacular to the city of Bandung. This intervention may be developed locally with local genius or local wise or adopted from other places that culturally adaptable, technically possible, and economically feasible. The approach is employing three key determinants, this is required since synergistic and comprehensive approach is inevitable toward the improvement of urban air quality while improving urban environmental of the city as a whole. Fractional, discontinuous and scattered interventions will only lead to the ineffectiveness of programs toward the achievement of the objectives. Considering previous studies as discussed earlier, the strategies could cover land use and urban planning, traffic management and air quality management.

5 Conclusions and way forward

Three urban development determinants, which are land use, traffic and air quality has proved an empirical and quantitative correlation between land use changes and traffic volume, as well as between traffic volume and the concentration of air pollutants, providing the unique condition of the study area that traffic is the only source of air pollutants. Changes of land use from previously natural environment to built-up areas particularly residential areas along with other governing variables are positively associated with the increase of traffic volume. And simultaneously, traffic volume is also positively associated with two principal urban air pollutants those are SO_2 and CO. This trilateral linkage exposes the need of interconnected strategies whenever efforts to improve urban air quality due particularly to traffic are necessary. City specific and locally undergoing coping strategies are necessary to address the currently undergoing degradation of urban air quality in Bandung City. Since empirical correlation is produced, and few similar studies particularly in developing cities were conducted, therefore further studies with the support of mathematical modeling might be necessary.

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