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An Investigation on the Relationship between Land Use Composition and PM10 Pollution in Iskandar Malaysia

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ABSTRACT

This paper discusses the relationship between land use composition and the degree of air pollution, specifically PM10, in Iskandar Malaysia. Aspires to be a low carbon region and a smart city, Iskandar Malaysia has to meet the social and economic needs of its growing population while taking care of all the environmental challenges that come with rapid urbanization. The occurrence of regional haze episodes in the past has shrouded this region with particulate matters including PM10, but the major cause of the haze was extensive agricultural open burning rather than land use change. Since there is no doubt land use change itself can be a significant contributor to local PM10 concentration, separating PM10 caused by the local (land use change) source from that of the regional source would enable us to investigate the trend in local PM10 pollution level. Therefore, a study on the Iskandar Malaysia's PM10 readings for the years 2002, 2006 and 2008 was carried out with the aim to identify the relationship between land use composition and PM10 concentration. The background concentration of the readings was extracted by using the base flow separation process commonly used in the hydrograph study. The extracted background concentration was then interpolated with the Terra MODIS level 2 product to identified the PM10 concentration for the whole Iskandar Malaysia region, spatially. Since data for land use changes are compositional data in nature, where the percentages of different land use coverages always add up to unity, the barycentric or ternary plot had been used to investigate the relationship between PM10 concentrations with the land use composition (urban:agriculture:forest) in Iskandar Malaysia. The results show that air quality as represented by PM10 concentrations are inevitably linked to the land use changes at the local level notwithstanding the more noticeable but intermittent influence of the regional haze episodes. The degree of air pollution is noticeably controlled by the percentage of urban land use with PM10 clearly affected by the size of commercial area.

KEYWORDS
PM10, land use composition, remote sensing, Iskandar Malaysia

1.0 Introduction

Particulate matter is often condemned as an agent that negatively affects global warming and health. Ramanathan and Carmichael (2008) stated that black carbon warmed the climate in two ways. The particulates warm the air by absorbing sunlight and generate heat in the atmosphere when suspended in the air. Iskandar Malaysia had faced air pollution either from regional source or local emission. Trans boundary pollution faced by this region is the haze episodes that intermittently shrouded Southeast Asia since 1972. Focusing on local emission, this study considered the regional sources of air pollution as noise variable. Separating PM10 caused by the local emission from that of the trans boundary pollution would enable us to clarified the definition of the relationship between local particulate matter emission and land use changes. Geo-information is a good platform to clearly study local particulate matter emission from a spatial perspective. The presence of particulate matter is best indicated using PM1, PM2.5, PM4 and PM10 concentrations. Focusing on PM10, Aerosol Optical Depth product of Moderate Resolution Imaging Spectroradiometer (MODIS AOD) were used in this study to verified the local particulate matter pattern, while land use changes were detected using satellite images, Landsat Thematic Mapper (1984 to 2008). Thus, this study denoted the relationship between those variables as the impact of land use changes towards air quality (PM10) in Iskandar Malaysia.

Based on the monitoring data and ambient air-quality studies, several large cities in Malaysia are faced with increasing level of air pollutants that are not always at acceptable levels (DOE, 2002). Due to this, the Department of Environment (DOE) Malaysia adopted the Air Pollutant Index (API) in order to revise their index system in 1996. The basis for the interpretation of the API had been explained in the Malaysian Ambient Air Quality Guidelines (Table 1: The “safe levels” for the listed concentration pollutant). Highlighted in this study, the average threshold limit concentrations for PM10 are 150µg/m3 and 50µg/m3 for 24-hour and 1-year averaging time respectively.

Table 1: Malaysian ambient air quality guidelines

Pollutant	Averaging Time	Malaysia Guideline	
		Ppm	**µg/m³**
Particulate Matter (PM10)	24h		150
	1 year		50
Carbon Monoxide (CO)	1h	30	35
	8h	9	10
Nitrogen Dioxide (NO_2)	1h	0.17	320
	24h	0.04	
Sulphur Dioxide (SO_2)	1h	0.13	350
	24h	0.04	105
Ozone (O_3)	1h	0.1	200
	8h	0.06	120

Source: Department of Environment, Malaysia (2002)

2.0 Method

Two main variables that had been used in this study are air pollution; denoted by PM10 readings, and land use changes; denoted by changes of land use accretion. As shown in Figure 1, those variables had been through several processes in order to clarify the relationship between air pollution and land use composition in Iskandar Malaysia. The air pollution involves two types of data which are in situ data; retrieved from Department of Environment, Malaysia (DOE), and spatial data; MODIS Aerosol Optical Depth data. Due to the limited number of monitoring stations, DOE’s in situ readings were used to interpolate with MODIS Aerosol Optical Depth value. This process is important to comprehensively speculate the whole Iskandar Malaysia region readings, spatially.

The land use changes investigation in Iskandar Malaysia involves two types of data which are land use database; accessed from the Iskandar Region Development Authority, and LANDSAT Thematic Mapper satellite images; retrieved from the United States Geological Survey. Land use morphology had been extracted from those satellite images through supervised classification technique. The land use changes had been investigated by calculating the percentage of accretion changes. The calculation had been done by using change detection technique. Those processed data; air pollution and land use data, were used in the analysis process. The correlation between built-up area and monitoring station data (PM10) denotes the impact of urbanisation process towards air quality. The ternary plot used to identify the relationship between land use composition and air pollution level. Through those processes and analysis, the relationship between those variables clearly visualised the local air pollution scenario in Iskandar Malaysia.

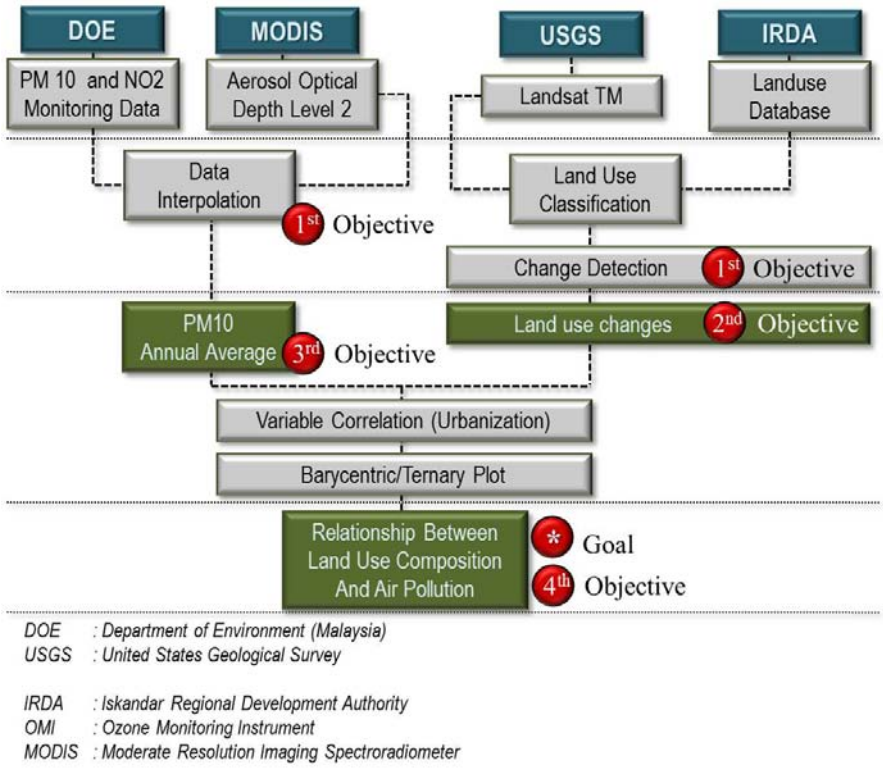

Figure 1: Method adopted in this study

3.0 Processed Data

As explained in previous section, there are several data that had been processed include the in situ data; DOE's monitoring stations data (PM10), satellite images; LANDSAT Thematic Mapper (1984-2008), and aerosol spatial data; MODIS Aerosol Optical Depth (2002-2008). Those data were required to show the significance of the relationship between particulate matter and land use changes.

3.1 MODIS Aerosol Optical Depth (2002-2008)

The air quality monitoring stations had monitored particulate matter, but lacked information spatially, since there were only three stations. Due to this limitation, MODIS Aerosol Optical Depth data were used to interpolate and comprehensively speculated the missing values, spatially. Iskandar Malaysia, the grid of the aerosol optical depth only consisted ten out of sixteen grids that covered Iskandar Malaysia (grid dimension: 0.2 degrees by 0.2 degrees). As shown in Figure 2, Terra Atmosphere Level 2 product data were used for this process.

As focused in this research, separation between haze episodes and local emissions should be performed for the MODIS AOD data. Therefore, the data during haze episodes was removed and the annual average for each year, cross-selected with land use data, was done to accurately analyse the relationship. The selected annual average readings were for the years of 2002, 2006 and 2008. There were about thirty grids of annual average data available that could be analysed with the land use distribution data. Particulate matter was an important variable under investigation. However, the data derived from the MODIS AOD grid value was not particulate matter concentration. Therefore, a correlation between those monitoring data needed to be identified in order to predict the PM10 readings for other uncovered areas. A close relationship had been identified between the MODIS AOD grid value and the monitored PM10 concentrations using mix effects model (Table 2).

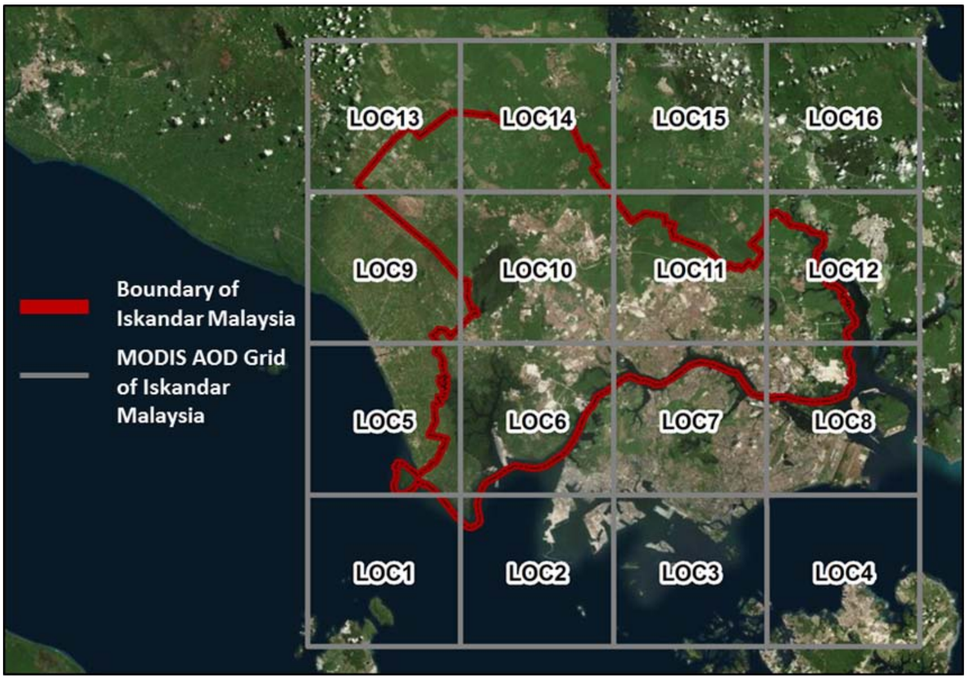

Figure 2: MODIS AOD grid of Iskandar Malaysia

Table 2: Calculated PM10 value, predicted using MODIS AOD grid values

YEARS	LOCATION		MODIS AOD Grid Value (annual average)	Predicted PM10 Value (annual average)
2002 y = 0.0882x + 7.8111	LOC5	Pulau Kukup	265.852116	31.25915667
	LOC6	Gelang Patah & Nusajaya	291.023543	33.47927655
	LOC7	Johor Bahru & Permas	375.798186	40.95640002
	LOC8	Pasir Gudang	306.735493	34.86507056
	LOC9	Tmn Putri, Kulai	264.577092	31.14669954
	LOC10	Skudai & Senai	284.554563	32.9087125
	LOC11	Ulu Tiram	287.461924	33.16514177
	LOC12	Kg Delima, Pasir Gudang	280.480070	32.54934222
	LOC13	Kg Sri Paya, Kulai	267.763567	31.42774664
	LOC14	Sedenak	278.375440	32.36371389
2006 y = 0.0496x + 29.843	LOC5	Pulau Kukup	227.989497	41.15127903
	LOC6	Gelang Patah & Nusajaya	268.232292	43.14732166
	LOC7	Johor Bahru & Permas	286.768519	44.06671852
	LOC8	Pasir Gudang	293.092130	44.38036962
	LOC9	Tmn Putri, Kulai	251.578150	42.32127623
	LOC10	Skudai & Senai	237.942550	41.64495046
	LOC11	Ulu Tiram	254.157788	42.44922628
	LOC12	Kg Delima, Pasir Gudang	247.558929	42.12192285
	LOC13	Kg Sri Paya, Kulai	253.300562	42.40670789
	LOC14	Sedenak	251.142598	42.29967287
2008 y = 0.0472x + 33.532	LOC5	Pulau Kukup	296.384091	47.52132909
	LOC6	Gelang Patah & Nusajaya	407.743827	52.77750864
	LOC7	Johor Bahru & Permas	425.944444	53.63657778
	LOC8	Pasir Gudang	343.856790	49.7620405
	LOC9	Tmn Putri, Kulai	293.486688	47.38457169
	LOC10	Skudai & Senai	351.439394	50.11993939
	LOC11	Ulu Tiram	399.612500	52.39371
	LOC12	Kg Delima, Pasir Gudang	352.167154	50.15428967
	LOC13	Kg Sri Paya, Kulai	254.961689	45.56619176
	LOC14	Sedenak	304.413874	47.90033487

3.2 LANDSAT Thematic Mapper (1984-2008)

In order to measure the urbanisation process in Iskandar Malaysia, LANDSAT TM satellite images were used to differentiate the built-up area and non-built-up area. This classification derived the increased built-up area as weightage for the urbanisation process. Figure 3 showed the urbanisation process of Iskandar Malaysia (1984 to 2008), which was processed from LANDSAT TM satellite images using supervised classification in ENVI software. As shown in figure, the built-up area of Iskandar Malaysia had rapidly increased from 1990 to 1997, which evidently proved that Malaysia started rapid urbanisation during the 90's, when the government focused on the industrial sector; increase 5712.13 acres per year. The areas of built-up areas in Iskandar Malaysia started at 29,486.33 acres during 1984, and continuously increased to include a total area of 110,050.86 acres during 2008. The process itself provided many great opportunities in the economic sector, but was still a major contributor towards air pollution.

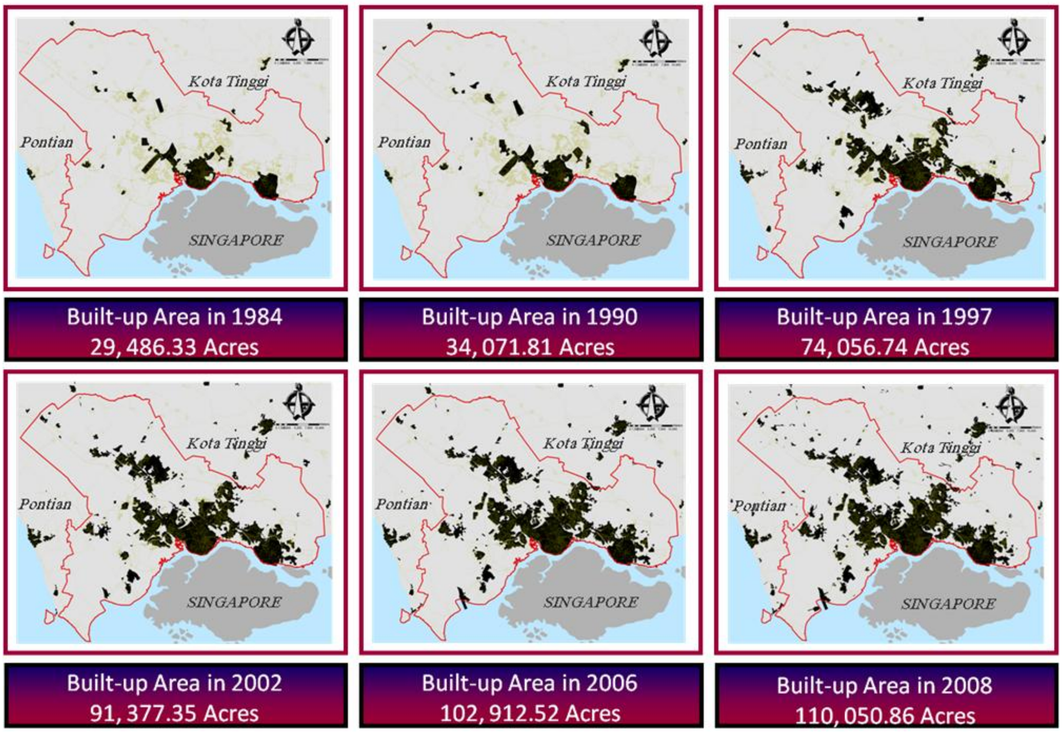

Figure 3: Urbanisation process of Iskandar Malaysia, 1984-2008

According to the extracted urbanisation process of Iskandar Malaysia, the increasing acreage of built-up area had been of significance towards particulate matter emissions. Therefore, a more detailed analysis of the built-up area was performed to analyse the effect of built-up area towards particulate matter emission. A cross-tabulation between built up area and the land use database was done to measure the land use changes periodically. Figure 4 shows land use change map of Iskandar Malaysia from 1984 to 2008. According to the measured rates of land use change, the highest rate of change was observed between 1990 and 1997; built-up area increase 5,712.13 acres per year. As a concern in this research, the land use changes were not an indicator to prove that Malaysia was growing economically, but as an indicator of land use influence towards the degradation of air quality in Iskandar Malaysia.

Extracted from the land use change map, the acreage of changes in Iskandar Malaysia was plotted in the graph (Figure 5). The processed data indicated that the major land use change was the change from agricultural activities to residential and industrial activities, with total acreage changes of 4937.17 acres/year and 1562.122 acres/year, respectively, for the whole period. Even though the highest change was from agricultural to residential, still, the second highest change was industrial activities. In addition, the figure showed that there were very low practices of brown field and infill development in Iskandar Malaysia, since the major change happened from agricultural and forest, undeveloped land use types.

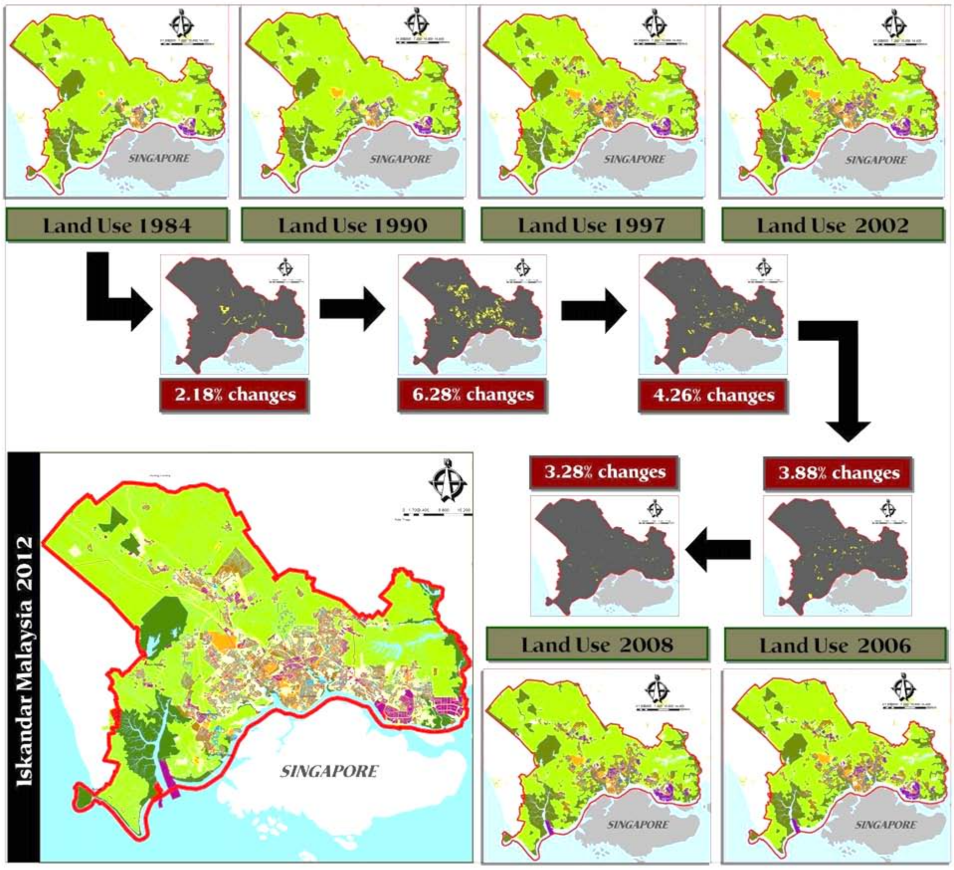

Figure 4: Map of land use changes in Iskandar Malaysia, 1984-2008

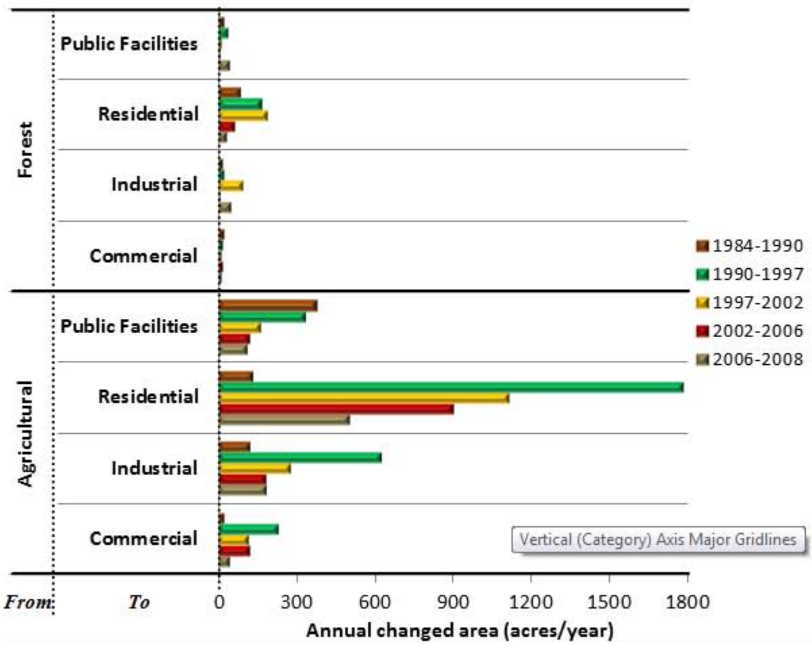

Figure 5: Land use changes process in Iskandar Malaysia, 1984-2008

4.0 Analysis and Findings

As the final process in this study, the analysis of the processed data will be discussed in this section. The first analysis that had been discussed is about the correlation of the urbanisation process and the background concentration of particulate matter, which led to another analysis process. According to the research framework, the variables that were identified were the particulate matter and the composition of land use activities in Iskandar Malaysia, based on the selected years. Therefore, in order to define the relationship between those variables, the ternary plot was adapted.

4.1 Impact of Urban:Agriculture:Forest Land Use Composition on PM10

Every land use composition involved in this research was plotted against the air pollutants. As the axes are limited to only three composition, several mix composition had been considered to indicate the scenario. Figure 6 showed the pattern of PM10 for the composition of urban:agriculture:forest. The urban proportion made up the majority of urban land use in Iskandar Malaysia; consist of industrial, residential, commercial and public facilities. It was found that these air pollutants had a different pattern. According to the figure, the main causation for increasing PM10 pollution was 'urban'. As the urban proportion increased, the annual average of PM10 concentration tended to increase. In general, this fact proved that urban activities were the main factor of PM10 local emissions in Iskandar Malaysia.

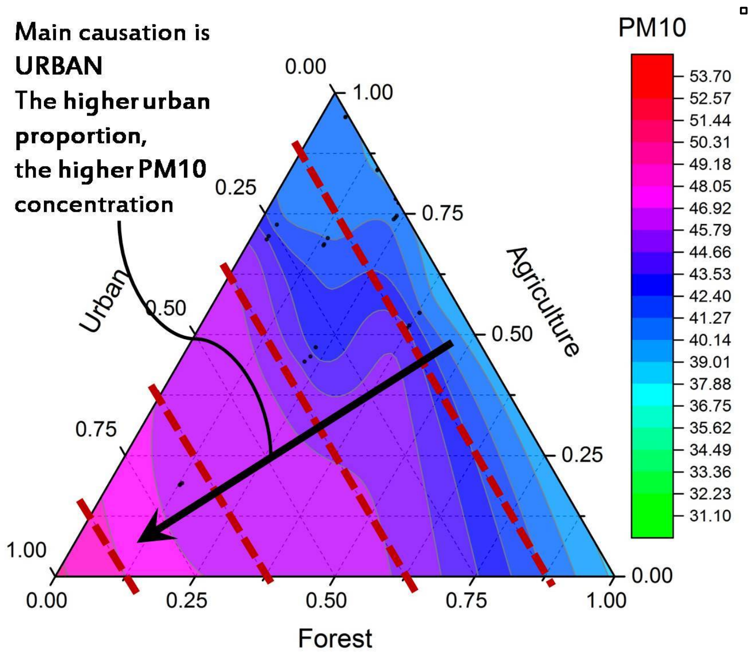

Figure 6: PM10 pattern for urban:agriculture:forest land use composition in Iskandar Malaysia

4.2 Impact of Industry:Commercial:(Residential+Public Facility) Land Use Composition on PM10

As concern in this study, a detail analysis had been done to identify the land use in urban area that highly contributed to the degrading of air quality. As shown in Figure 7, the pattern of PM10 for the composition of the land use in Iskandar Malaysia's urban area clearly illustrated that the commercial sector was the main causation for the PM10 annual average concentrations. As a matter of fact, if the commercial proportion increased, the PM10 annual average concentration will tend to increase also. This was not as expected, because industrial activities are usually blamed as the main source of air pollutants. The collected data suggested that the emissions from commercial activities were the main contributor to air pollution, and not industrial activities. On deeper examination, this scenario happens because the major contributor for PM10 was transportation activities in commercial areas.

Commercial areas in Iskandar Malaysia were smaller in accretion, but higher in transportation activities. This was due to unpractised low carbon lifestyle by the community in Iskandar Malaysia. The community in Iskandar Malaysia preferred to use private vehicles rather than walking or other green modes of transportation. This was supported by the fact that commercial areas usually attracted a large number of people, in addition to transportation activities that were not environment-friendly.

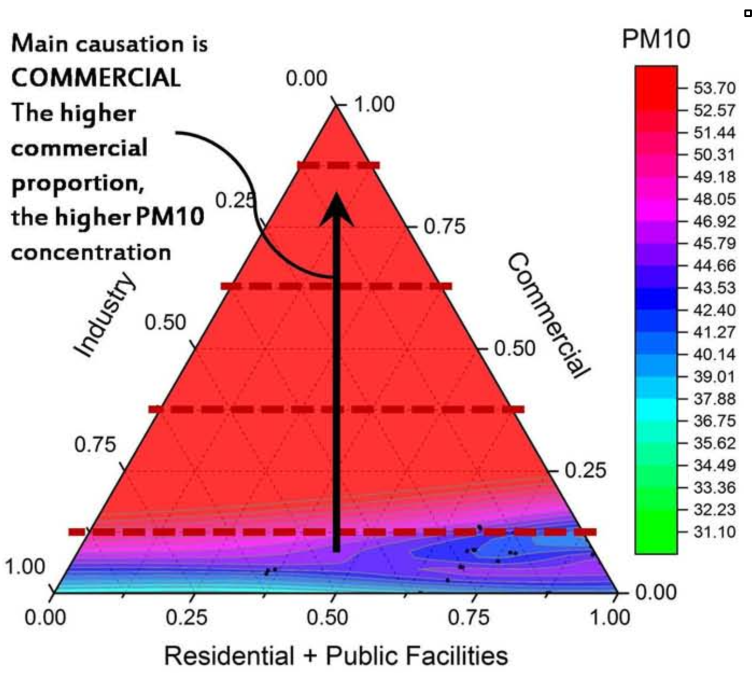

Figure 7: PM10 pattern for industry:commercial:(residential+public facilities) land use composition in Iskandar Malaysia

In order to closely analyse the results, another composition of the (urban land uses):forest:agriculture was plotted, but separately by each urban main land use type which were commercial, industry and residential (Figure 8). The results showed that all the ternary contours had the same pattern, but with different scales. As shown in Figure 9, the scale for commercial:forest:agriculture composition for PM10 was found to be greater than other compositions. This figure supported and strengthened the results from the previous ternary plot (Figure 8). Even though the commercial area had the highest contribution towards air pollutant emissions, industrial activities were not far behind commercial activities. Therefore, authorised parties should focus on controlling transportation in commercial and activities in industrial areas. As shown in Figure 9, the residential compositions presented the smallest influence towards the annual average concentration of those air pollutants. Even though residential compositions had the highest population, transportation activities were not very frequent and condensed compared to commercial areas. This may be the reason why the residential proportion had the smallest influence towards air pollutant emissions.

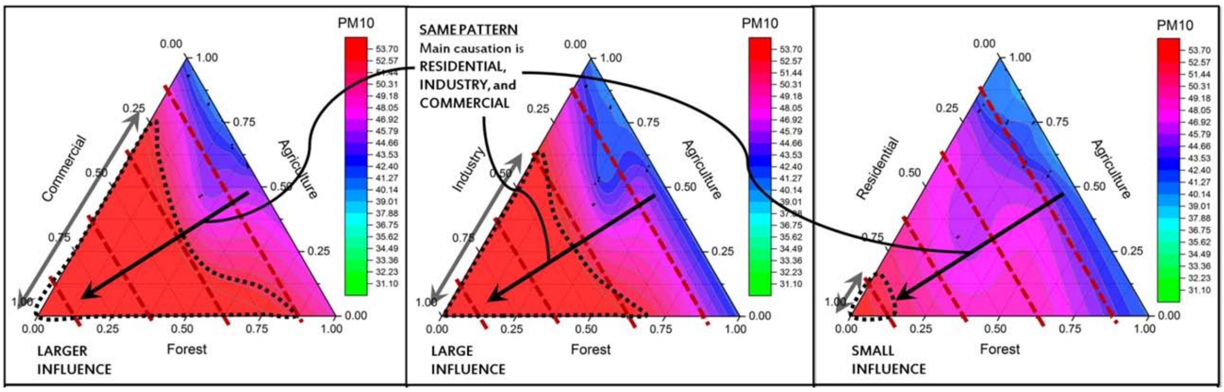

Figure 9: PM10 pattern for (urban land use):agriculture:forest land use composition in Iskandar Malaysia.

5.0 Conclusion

As a result of data processing and analysis, several results and findings were discussed. Part of the data processing had produced the local emission index of PM10, which was very useful to spatially identify the emission of particulate matter in Iskandar Malaysia (Figure 10). From this process, the map shows higher emissions of PM10 that had been identified in urban areas, especially emissions from industrial areas such as Pasir Gudang, Johor Bahru city centre, Skudai, Senai and Kulai. Therefore, several green and low-carbon approaches should be promoted by local authorities, so that the emission index will not increase rapidly in the future.

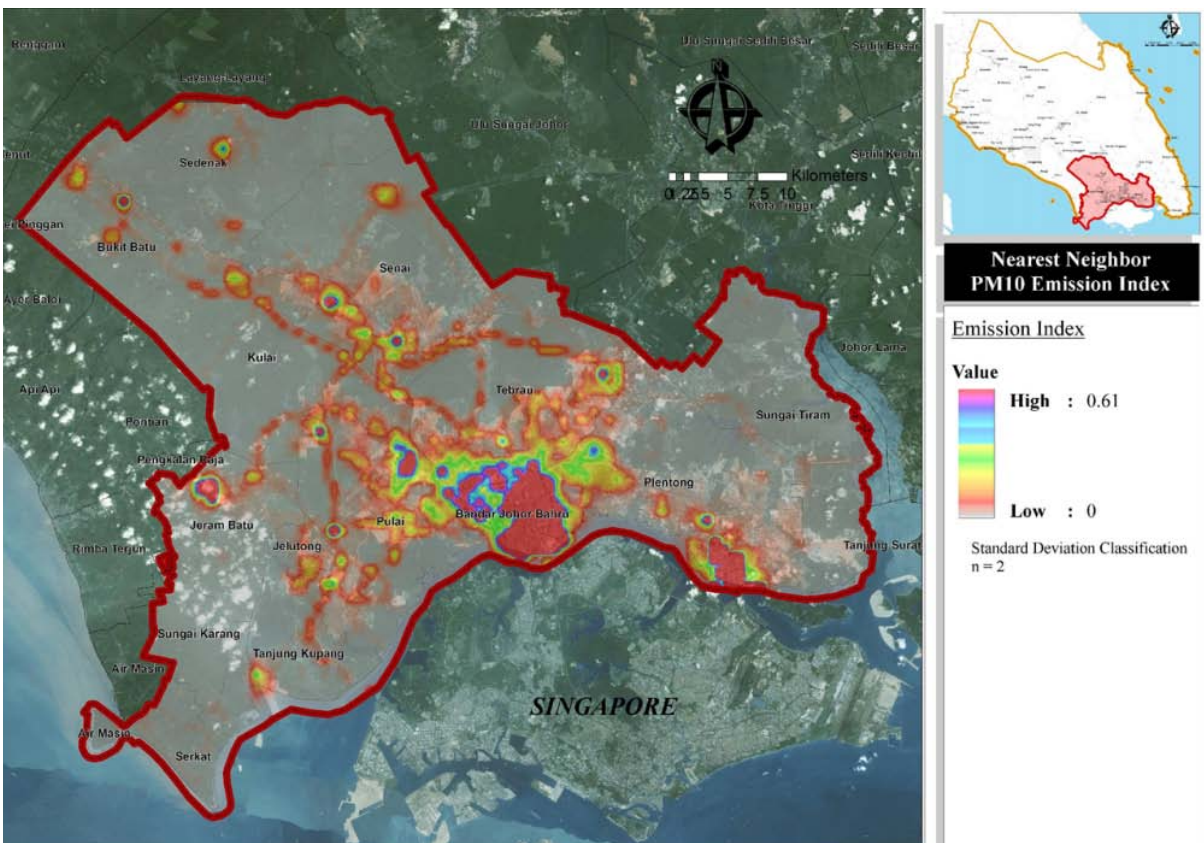

Figure 10: Map of local PM10 emission index in Iskandar Malaysia

A contour ternary diagram was adapted to visualise the composition of land use against air pollutants. The plotted data was observed to have a similar pattern. The results showed that air quality as represented by PM10 and NO2 concentrations were inevitably linked to land use changes at the local level, notwithstanding the more noticeable but intermittent influence of the regional haze episodes. The degree of air pollution was noticeably controlled by the percentage of urban land use, with NO2 and PM10 clearly affected by the size of commercial area, followed by industrial activities. Therefore, from those findings, several alternatives were listed in order to control air pollutant emissions.

This study had generated important findings towards the relationship between land use changes and the local emission scenario in Iskandar Malaysia. The result showed that air quality, as represented by PM10 and NO2 concentrations, was inevitably linked to land use changes at the local level, notwithstanding the more noticeable but intermittent influence of regional haze episodes. The degree of air pollution is noticeably controlled by the percentage of urban land use with PM10 clearly affected by the size of commercial area. Iskandar Malaysia, therefore, needs to be aware of the air pollution at its doorstep, while keeping an eye out for haze from neighbouring countries.

Acknowledgments

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