Landuse Changes Tendency and Environmental Quality Indicators Development for Air and Water Pollutions Monitoring in Chiang Mai Comprehensive Plans Boundary, Thailand

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Abstract

Urbanization is a growing process in both developed and developing countries as the proportion of the world's population is increasing. Land use changes are dynamic process that linked to natural and human systems especially in build-up regimes including Chiang Mai Comprehensive Plans boundary (CMCP) of northern Thailand. Consequently, the measurement of land use transitions and environmental effects are needed and the environmental quality indicator models for air and water pollutions monitoring and implementation for the CMCP boundary were developed for this study. The main objective of this study is to clarify the causal relationship between technocracy urbanization processes within CMCP boundary and their environmental consequents. Accordingly, the research methodology was developed to apply and analyze the results from spatial dynamics simulation of cellular automata models which have been effectively used to predict physical urbanization trends in correlation with environmental quality indicators development which is also hypothesized to be effective co-technique in order to understand the spatial dynamics impact from urbanized area of interested. The study result showed a tendency of CMCP urban growth to increase over time. The environmental indicators conclusive prediction trends from this study during 2000 to 2030 inform long-term deteriorate environmental qualities of air, water, and landuse changes while seasonal patterns revealed diverse characteristic for each indicator. The future aspect from this study is to enable the city's administrators to implement the model as additional reference in decision making which are anticipated toward sustainable patterns of the CMCP environmental monitoring and enhancement strategies.

Keyword: Urban Expansion, Land Use Changes, Pollutions Monitoring, Environmental Quality Indicators, Chiang Mai Comprehensive Plans Boundary

Introduction

Land use changes are a complex dynamic process that links between the human and natural systems which related to many environmental issues including social-ecological complex landscape, municipal air and water pollutions, municipal's air ventilation, and water drainage regimes alteration (Lebel, 2005; Lebel et al., 2008; Tan-kim-yong et al., 2005). A rapid urbanization has led to landuse changes into human settlements (Sangawongse et al., 2012). As Chiang Mai city is expanding, the necessity of environmental quality indicators model development to monitor air and water pollutions are required to utilize the model results as

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technical reference for government executives and decision makers toward municipal action plan enhancement. This study aimed to utilize the SLEUTH model output for landuse changes mapping spatial and temporal dimensions of urban growth which was developed in 2010 (Sangawongse et al., 2011) and relate the output to air and water quality indicators for assessing the impact of urbanization on the environmental quality from 2000 to 2030. The expecting short-term and long-term implementations of the environmental indicators model are the relationship between the air and water qualities as seasonal indicators and landuse changes as CMCP area environmental improvement.

Preceding Context

The spatially open simulation SLEUTH model (Slope, Land Use, Exclusion, Urban Extent, Transportation, and Hillshade) of urban growth patterns was applied toward CMCP landuse changes investigation through the project "Impact Assessment of Urbanization on Environmental Quality in Chiang Mai-Lumphun Valley, Northern THAILAND" (Sangawongse et al., 2011). SLEUTH can simulate four types of urban land-use changes: spontaneous growth, new-spreading center growth, edge growth, and road-influenced growth. Moreover, SLEUTH also has a functionality termed `self-modification' which allows the growth coefficients to change throughout the course of a model run and which is intended to simulate more realistically the different rates of growth that occur in an urban system over time. The inclusive output from the model consists of 2 parts: (1) SLEUTH model and (2) Land use Classification (see Figure 2 and 3). The prediction results generated statistical files and simulated images, which can be used for analysing future trends in urbanization and land use change. The simulated images of urban growth in CMCP in 5 years interval are represented in Figures 2. From the analysis of statistical files, the number of growth pixels generated throughout the prediction period for CMCP is 55931.65 pixels. Figures 3 represents simulated images of land use changes in CMCP of 5 years interval. The different color schemes in Figure 3 represent the probability of pixels for urbanization. The yellow pixels are referred to the original urbanized areas in 1973, having 100 % probability and other coloured pixels can be classified as urbanization probability percentage as follows: the light green 40-60 %, the dark green 60-70 %, the dark orange 70-80 %, the violet red 80-90 %, and the dark red 90-100 %. The different color schemes in Figure 4 represent the land use changes probability and associated color pixels. The dark-red pixels represent urban area, the yellow pixels represent agriculture area, the orange pixels represent orchard area, the green pixels represent forest area, the blue pixels represent water area, the white pixels represent bare-land area, and the pink pixels represent other-types area. the inclusive existing information and prediction of land use types by percentage in CMCP from 2000-2030 illustrates in Table 1.

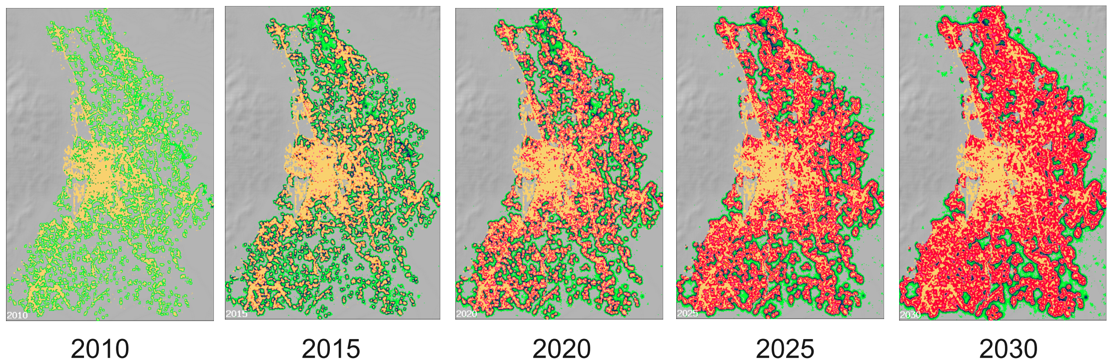


Figure 1 Prediction of urban growth for CMCP of 5 years intervals from the year 2010 to 2030 (Excerpted from Sangawongse et al., 2011)

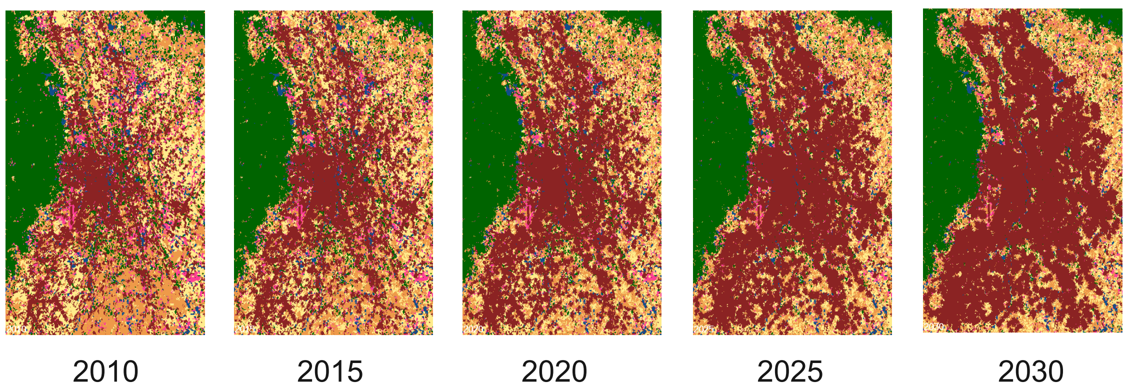


Figure 2 Simulated images of land use change in CMCP of 5 years interval from the year 2010 to 2030 (Excerpted from Sangawongse et al., 2011)

Table 1 Existing Information and Prediction of Land Use Types by percentage in CMCP from 2000-2030

CMCP Land Use Type	Percentage Proportion (%)					
	2000	**2009**	**2015**	**2020**	**2025**	**2030**
Urban	12.09	18.27	31.51	38.70	45.61	51.27
Agriculture	29.19	18.99	16.06	14.06	12.21	10.39
Orchard	24.93	24.53	20.35	18.41	15.79	13.59
Forest	22.54	24.86	22.83	21.65	20.74	20.08
Water	0.39	4.08	3.16	2.76	2.40	2.12
Bare-land	0.10	0.18	0.09	0.05	0.03	0.02
Other	10.76	9.09	6.00	4.38	3.22	2.53

Study Area

The study area is located in the Monsoon Asian region of the Chiang Mai-Lamphun Valley, northern Thailand. Chiang Mai Comprehensive Plans boundary (CMCP) is one of the most developed regions in Thailand. CMCP has been undergoing a rapid urbanization within the past 20 years which are most likely become twin cities with Lamphun city in the near future (Sangawongse, 2006). Urbanization process plays a significant impact on environment, landuse changes, and policy play important roles in how urban regions developed. From Figure 3, the left side map represents boundaries of Chiang Mai provinces and the right side map represents the boundaries study area of CMCP which were designated by the Department of Public Works and City Planning (DPWCP) for land use zoning. The comprehensive plan is a guide for the city's future growth that includes the future land use plan, transportation plan, and recommended goals with objectives to carry out the plans. The CMCP area includes 7 administrative districts including Muang, Mae Rim, Sansai, Saraphi, Hangdong, Sankumphaeng and Doi Saket with total area of 408 square kilometers. The topography of the study area is characterized as a broad valley. Elevations in CMCP and its surroundings range from 300 m MSL to about 1,650 m MSL.

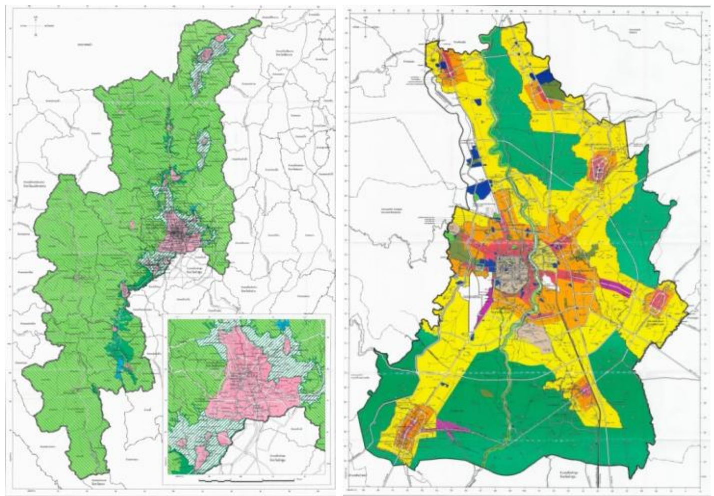


Figure 3 Left: the study area of Chiang Mai Comprehensive Plans boundary (the pink area) inside Chiang Mai province administrative boundary (the green area) and Right: the zoning details of CMCP

Methodology

This study utilized the results from the developed landuse changes prediction trends (Sangawongse et al., 2011) and conjoined the information with environmental quality indicators model development to monitor air and water pollutions. The Particulate Matter with diameter less than 10µm (PM10) was selected as CMCP air quality database was obtained from the Thai Pollution Control Department. Total suspended solids (TSS) representing CMCP water quality database was obtained from the Royal irrigation department's hydrology and water management center for upper northern region. Both databases were arranged, and developed into air and water quality prediction trends using regression analytical procedure. In addition, the CMCP landuse changes prediction trend were obtained from the output of spatially open simulation models of urban growth patterns called the SLEUTH model (Clarke, K.C.et al., 2007).

First, water quality database were analysed toward water quality indicator (WQI) development using the stream's total suspended solid (TSS) which defined as solid particles transported in a fluid media by flowing water. Suspended solid concentration in a water body can be affected by many factors. In rivers, the concentration depends on the water's flow rate, turbidity, soil erosion, urban runoff, and wastewater and septic system effluent. For the Chiang Mai Mae Ping River discharge and precipitation action are the largest contributors of River Suspended Solid. Consequently, TSS is selected as the key indicator of river water quality. Suspended Solid block light from reaching submerged vegetation and slows down ecology photosynthesis leading to less dissolved oxygen to be released into the water by the plants and in extreme cases, resulted in death of the aqua-plants and living habitat. Moreover, suspended solids absorb heat from sunlight and increase water temperature. Altering the depths of river is also one of the effects caused by Suspended Solid when their flocculation phenomenon occurred. Thai Royal Irrigation Department (RID) has been collecting TSS water quality data using "Depth Integrating" suspended sediment sampling protocol. At least 10 years of monthly Chiang Mai valuable data in part per million units (ppm) was kindly provided to our project from the year 1993 -2010. These data were converted into ranked water quality indicator (WQI), ranging from 0-100 point scale using the conversion chart from total suspended solids (ppm) into ranked WQI illustrated in Figure 4.

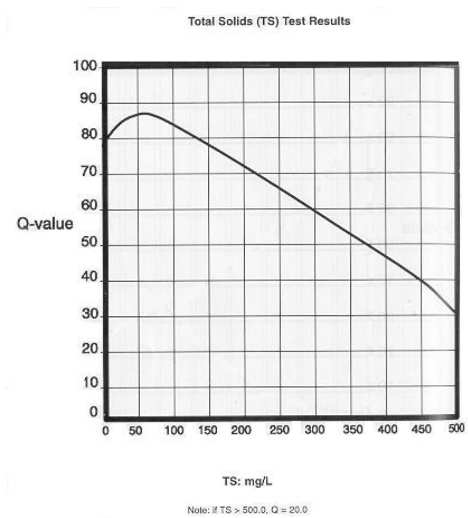
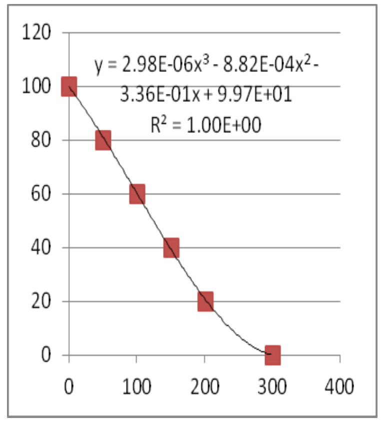


Figure 4 The conversion chart from total suspended solids (ppm) into ranked WQI
Note: If total solids are greater than 500 ppm, the water quality index equals 20
Source: USEPA (http://www.water-research.net/watrqualindex/waterqualityindex.htm**.)**

Second, air quality database were analysed toward air quality indicator (AQI) development. The respirable particulate matter (PM10) is particles with a diameter of 10 micrometers or less. Compared with Thailand's Pollution Control Department (PCD) daily concentration standard of 120 µg/m^3, USEPA's health-based national air quality standards for PM-10 are 150 µg/m^3 (measured as a daily concentration) and 50 µg/m^3 (measured as an annual mean). Major concerns for human health from exposure to PM-10 include: effects on breathing and respiratory systems, damage to lung tissue, cancer, and premature death. The elderly, children, and people with chronic lung disease, influenza, or asthma, are especially sensitive to the effects of particulate matter. Acidic PM-10 can also damage human-made materials and is a major cause of reduced visibility in many parts of Thailand (Pengchai et al., 2009). The Respirable Particulate Matter PM10 data acquired from PCD were converted into the Air Quality Index (AQI) which is nationally uniform index (ranked 500-0), established by the United states Federal Environmental Protection Agency (USEPA). AQI used to provide the public with information on air pollutants. The AQI may be used to provide information on pollutant concentrations for ground-level ozone as indicated in Figure 5a. The air quality data was converted into AQI standardized 0-100 ranked data using the following polynomial conversion chart from Figure 5b.

PM10 HEALTH EFFECTS GUIDE			
Air Quality Index	**Health Effects Statements**	**Air Quality Index (AQI)** An AQI of 100 corresponds to EPA's air quality standard	**PM10 Concentration** (micrograms per cubic meter) 24-hour average unless noted
Good	No health effects are expected when air quality is in this range.	0 to 50	0 to 54
Moderate	No health effects are expected when air quality is in this range.	51 to 100	55 to 154
Unhealthy for Sensitive Groups	Increasing likelihood of respiratory symptoms and aggravation of lung disease, such as asthma.	101 to 150	155 to 254
Unhealthy	Increased respiratory symptoms and aggravation of lung disease, such as asthma; possible respiratory effects in general population.	**151 to 200**	255 to 354
Very Unhealthy	Significant increase in respiratory symptoms and aggravation of lung disease, such as asthma; increasing likelihood of respiratory effects in general population.	**201 to 300**	355 to 424
Hazardous	Serious risk of respiratory symptoms and aggravation of lung disease, such as asthma; respiratory effects likely in general population..	**301 to 500**	425 to 604
Sensitive Groups: When the PM10 AQI exceeds 100 the sensitive groups most at risk are people with respiratory disease.			

(5a)



(5b)

Figure 5 (a) PM10 health effects guide and (b) Polynomial conversion chart
Source: USEPA (http://www.epa.gov/airtrends/aqtrnd95/pm10.html)

After Chiang Mai comprehensive plans boundary landuse changes tendency during the year 2000 to 2030 were processed and analysed in to yearly landuse quality changes prediction trend, the air quality and water quality pollutions databases were processed and analysed in to corresponsive seasonal-monthly and yearly prediction trends.

Findings

From the selected metrics and five growth parameters obtained from the overall SELUTH calibration result was compared and used for determining urban growth patterns of CMCP area over the period 1973 to 2009. Table 2 shows three selected metrics (r2 Pop, r2 Edges and Lee-Sallee) by resolutions from overall calibration process and Figure 5 shows the urban growth patterns of CMCP. From Table 2 and Figure 6 the Diffusion coefficients in CMCP decreased from coarse to fine calibration while Spread coefficients decreased from coarse to fine, and slightly increased from fine to final calibration. It is noted that "Breed" growth is much increased from fine to final showing a good adjustment of model to the actual growth. This result corresponds to Xialou et al., 2009 who suggested that before 1980, the development of urban center in Chiang Mai city was low. After 1980s, there was a tremendous diffusive area sprawling outward. As for the Slope factor, it decreased over the calibration phase, showing less significant for the growth in CMCP. Road growth is much increased during the final calibration showing that road influence is a significant factor for urban growth in CMCP. This result coincided with the recent construction of new roads in Chiang Mai. Regarding urban area tendency, the result of land use changes prediction in CMCP from 2000 to 2030 shows that urban areas increased, but agricultural areas decreased over time as illustrated in the preceding context Table 1. The landuse evaluation results from Geographic Information System analysis of the year 2000 to 2030 for CMCP illustrated as the landuse evaluation indicator summary plots shows the decline trend of landuse quality indicated in Figure 7 from 60.60 in 2000 to 47.30 in 2030 corresponding with the CMCP urban area expansion.

Table 2 Complete calibrations by resolutions and urban growth patterns for CMCP (Excerpted from Sangawongse et al., 2011)

Score /resolution	**Coarse 89 * 120**	**Fine 179 * 241**	**Final 358 *482**
r^2Pop	0.908	0.863	0.831
r^2 Edges	0.999	0.889	0.767
Lee-Sallee	0.239	0.216	0.213
Diffusion	49.24	16.17	3.87
Breed	46.79	31.93	51.64
Spread	47.29	16.31	29.05
Slope	26.56	2.7	1.03
Roads	55.03	41.76	64.89

r^2Pop: modeled urbanization compared with actual urbanization for the control years
r^2 Edges: modeled urban edge counts compared with actual urban edge counts of the control years
Lee-Sallee: shape index, calculated by taking a ratio of the intersection and the union of the simulated and actual urban areas (Clarke and Gaydos, 1988)

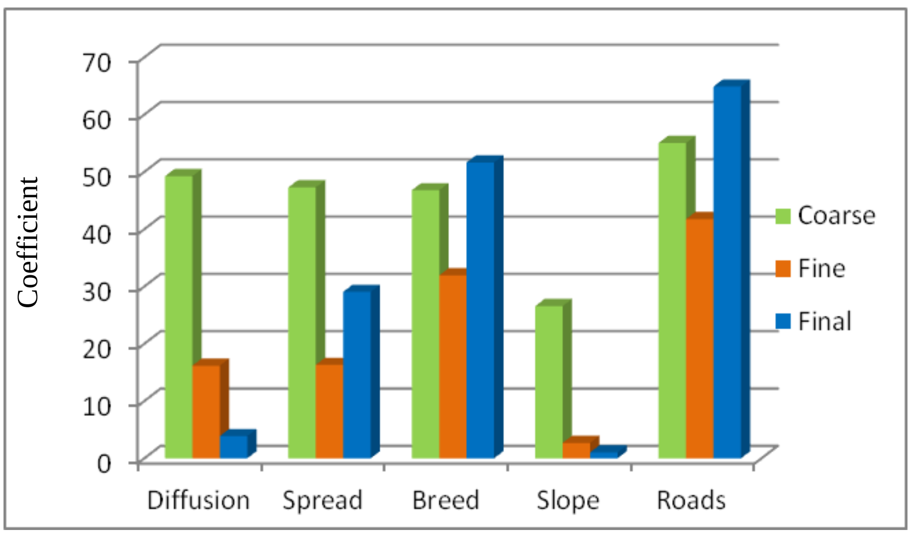


Figure 6 Urban growth patterns for CMCP (Excerpted from Sangawongse et al., 2011)

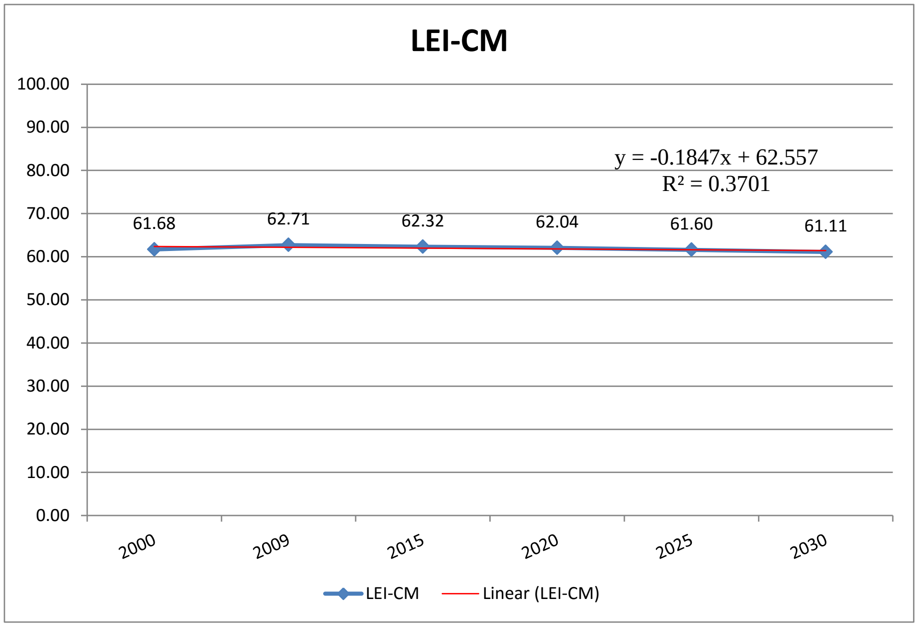


Figure 7 The landuse evaluation indicator summary plots for CMCP from Year 2010 to 2030

The seasonal-monthly air quality and water quality indicators using the information from year 1995 to 2010 CMCP air quality and water quality databases were processed and analyzed into seasonal-monthly prediction trends for the year 2010 - 2030. Figure 8 shows the monthly PM10 trend as seasonal air quality indicator and Figure 8 shows the monthly TSS WQI trend as seasonal water quality indicator. From both environmental model outputs, the monthly Particulate Matter PM10 trend form Figure 7 indicates seasonal CMCP air quality deteriorates at the beginning of dry season (December) and reached its peak in March before decreased by the end of April which correspond to other results from a previous study (Pengchai et al., 2009). Conversely, the monthly TSS trend form Figure 9 indicates seasonal CMCP water quality deteriorates at the beginning of rainy season (July) and reached its peak in August before decreased by the end of October.

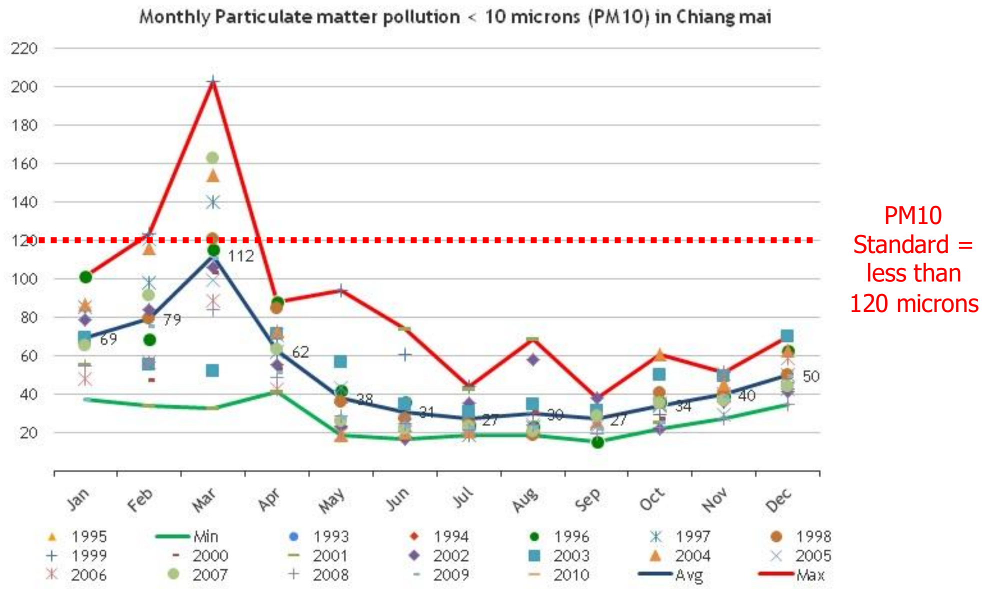


Figure 8 Monthly PM10 trend as seasonal air quality indicator

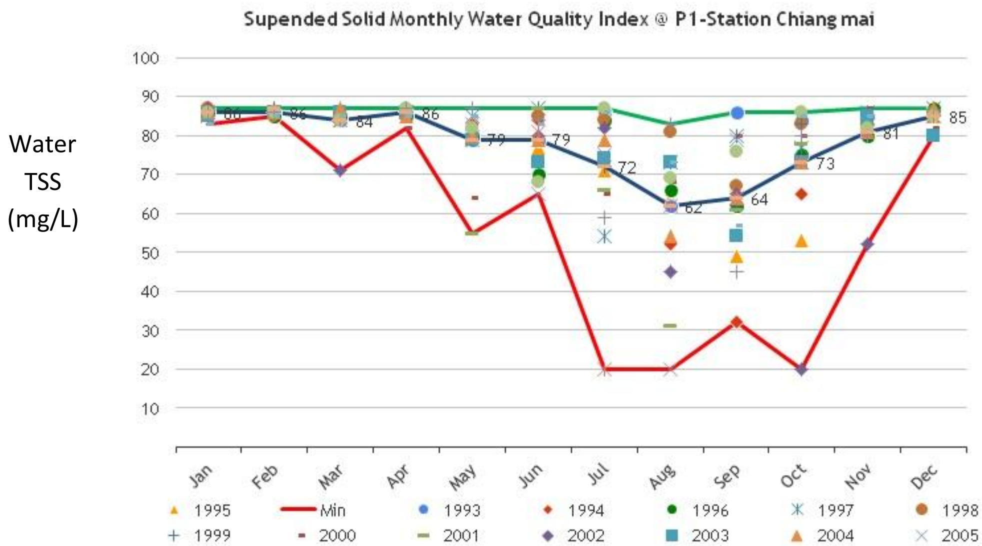


Figure 9 Monthly TSS WQI trend as seasonal water quality indicator

Finally, the conclusive long-term prediction trends for air quality, water quality, and landuse evaluation indicators (score 0-100) from Figure 10 illustrate prediction trends of environmental indicators from 2000 to 2030 which notify the long-term environmental quality decline for air indicator from 85.04 in the year 2000 to 78.17 in the year 2030, water indicator from 78.00 in the year 2000 to 75.57 in the year 2030 , and landuse evaluation from 61.68 in the year 2000 to 61.11 in the year 2030.

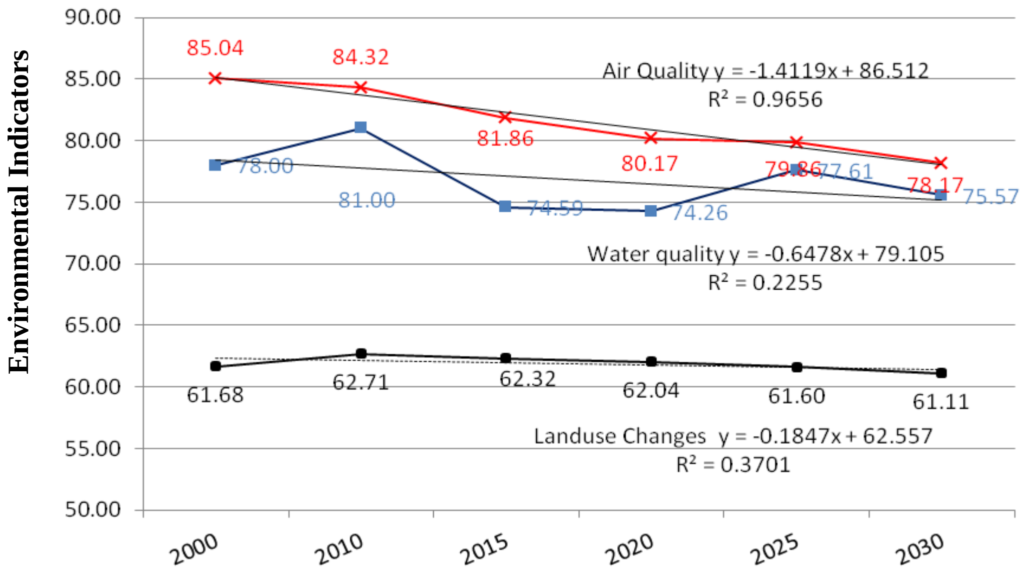


Figure 10 Conclusive long-term prediction trends of air, water, and landuse changes environmental indicators from 2000 to 2030

Conclusions

Results from the year 2010 to 2030 SLEUTH and environmental indicators models indicated that urban growth of CMCP has a tendency to increase over time while both air quality and water quality have tendency to decline. Urban growth patterns are best captured by road influenced while the slope factor plays less role in shaping the urban landscape for CMCP. There is a need for both government and the local residents in Chiang Mai municipal to closely monitor the impact of urbanization on land use changes on a regular basis. The impacts from urbanization and land conversion have deteriorated the environmental quality at a considerable rate. SLEUTH model provided reasonable result for mapping urbanized areas and land use changes from historic time (1973-2009) to the future time (2010-2030) for this study. The result of this study can be effectively applied to government and non-government agencies, including other agencies that are concerned with urban-environmental management and planning. It is expected that the outcome from this study can be used by public, land use planners, policy makers, and resource managers for various decision making implementations including municipal land use planning and environmental policy making. Future research prospects of environmental quality indicators model for air and water pollutions management in CMCP for both short-term and long-term are the utilization of water quality and air quality indicators model toward seasonal predictions and land use changes should be conjointly used as CMCP zoning and infrastructures management. The additional remark from this research is only scientific approach of database and analytical procedures were developed. For future aspects, additional factors including national and local policies shifting, political influences, land values, global warming and climate changes should also be considered toward more effective environmental management.

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