EXAMINING THE CONNECTIONS BETWEEN LAND USE AND AIR POLLUTION FOR A TIME SERIES USING AERIAL PHOTOGRAPHS

Guan-jie Chen, Re-Yang Lee, Yi-ting Cai , Han-xiu Zhang,

Yu-fang Yen , Jian-wen Dong , Chia-Hui Hsu

e-mail:jessie850513@gmail.com

Department of Land Management , Feng-Chia University

No. 100 , Wenhwa Rd., Seatwen, Taichung, 40724 Taiwan (R.O.C.)

KEY WORDS：PM2.5, Land use regression,aerial photographs

ABSTRACT

Many studies on the impact of air pollution on land use development have neglected the existence of temporal variability and spatial instability. The scope of this study is to explore the relationships between the land use types and the concentration of air pollutants PM 2.5 for a time series. The Shalu town of central Taiwan, which is affected by the PM 2.5 , is selected as the study area. Air pollutants data for the Shalu site is obtained from Environmental Protection Administration of Taiwan (EPA). The land use types are acquired by the manual interpretation of the aerial photographs dated 2007 and 2009. Based on the land use types in these two year, Markov chain model is used to estimate the land use types for the years of 2011, 2013, and 2015. Land use regression (LUR) models are utilized to examine the relations for these 5 years. The results of regression analysis (Table 3) indicate the most relevant land use type with PM2.5 concentrations is hydraulic. The correlation coefficient is 43.6% (positive moderately correlation), followed by animal husbandry, the farmland and forest, residential and school, as well as temples and funeral. However, the explanatory power of the regression for nine land-use types and PM2.5 concentrations is only 26% (R2=26%). We could not only use nine types of land use to estimate completely the PM2.5 concentrations.

1. INTRODUCTION

With the development of industry and commerce, air pollution problems have become increasingly serious. Reducing air pollution to ensure environmental quality is a very important issue. Especially, the PM2.5 pollution problem has caused widespread concerns by the community. PM2.5 can penetrate the lungs of the human body, which in turn causes chronic diseases of the lungs and respiratory organs. It is extremely harmful to health. If the fine particles are attached with other contaminants, they will be more deeply harmful to the respiratory system (Schwartz, 1996). Several researches have indicated the relationship between the air pollution and human health (Brunekreef and Holgate, 2002; Brook et al., 2010). It has also been found that the land use types have a considerable relationship with the air pollution (LaGroJr and DeGloria, 1992; Jacobson and Mark, 2009). Hoek et al. (2008) used land use regression (LUR) model to assess the variability of air pollution in the city by using predictive variables obtained from geographic information systems. Sun et al. (2016) indicated that water, woodland, grassland, arable land, urban and unused land have impacted on the concentration of air pollutants. Therefore, the relationships between the land use types and PM2.5 pollutants is worth to be explored.

The satellite imagery, with the characteristics of multi-period, wide range, rapid acquisition of data, and lower cost than that of artificial ground survey, has been widely used to derived the data of land use (Singh, 1989; Jensen, 1996; Coppin et al., 2004; Lu et al, 2004; Liu et al , 2008; Dewan and Yamaguchi, 2009a, 2009b; Dewan et al, 2012; Wei et al, 2015). Different from previous researches, this study established the LUR model by utilizing the remote sensing technique to obtain the land use types for multi-years.

Due to the terrain and local atmospheric circulation in the Taichung area of Taiwan, pollutants tend to accumulate at lower temperatures in the case of weak weather patterns (Zeng, 2013). The Shalu region near the Central Taiwan Science Park, the main pollutants for this region are the materials from the industrial combustion. There is a comprehensive PM2.5 automatic monitoring station located since 2005. Considering the availability of the air pollution concentration data, the Shalu region and its surrounding areas within 3 km were selected as the study area. The aerial photographs dated October 14, 2007 and October 8, 2009 were used to derive land cover types for the LUR model. Nine land use types relating to the impact of air quality were used in the analysis including other land, farmland and forest, animal husbandry, hydraulic land, business, school, industrial land, temples and funeral, leisure.

The results of land interpretation in 2007 and 2009 were then used to estimate the land use situation in 2011, 2013 and 2015 by using Markov Chain model. The air pollutant concentration data for 2007, 2009, 2011, 2013 and 2015 were obtained from the air monitoring station in Shalu. The regression analysis was executed to analyze the relationships between various land use areas and the pollutant concentration data.

2. MATERIALS AND METHODS

2.1. Study Area

The study area, Shalu, is located in Taichung City, Taiwan, with a total area of about 40.46 square kilometers Figure 1). There are many factories in the territory and close to Taichung City Science and Technology Park, which envelops many pollutants produced by industrial combustion. In this study, we chose the Shalu station at Taichung Municipal Beishi Junior High School. Since the land use variables were assumed that the maximum buffer distance of 3000m (Su et al., 2009), the land use types which circular buffer with radius of 3000m around the monitoring station was interpreted using aerial photographs.

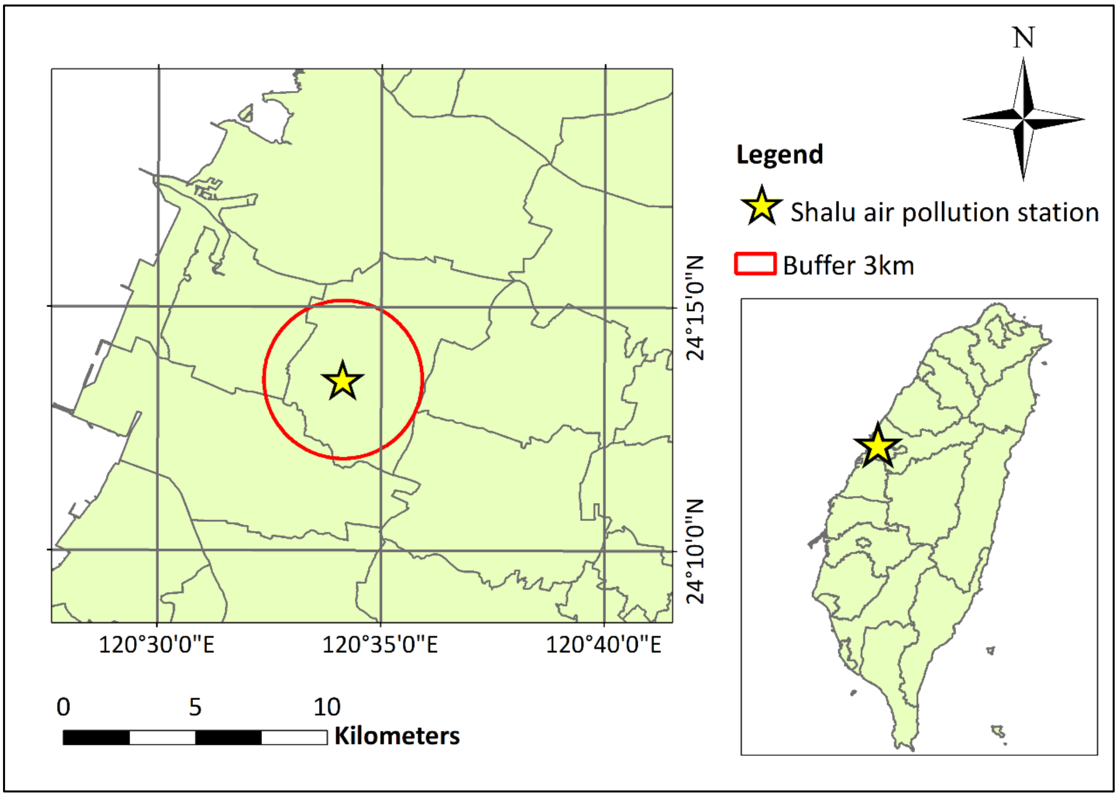

Figure 1. The location of the Shalu study area.

2.2. Calculations of Land Use Areas

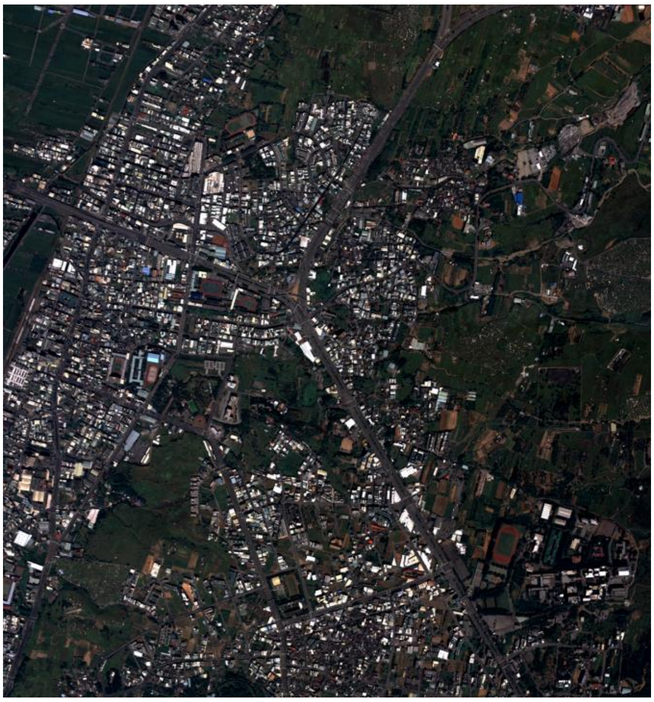

Figure 2. The example of the Shalu aerial photo on October 14, 2007

7 color orthorhombic aerial photographs around the Shalu station were purchased from the Forestry Bureau Aerial Survey Office (Figure 2). These photos included Dazhuang (95213002), Gonming (95213004), Qingshui (95214093), Longjing (95213012) Taiwan Suger Lin House Farm (95213014), Shalu (95213003) and Puzih (95213013). In order to acquire obvious changes of the land use in Shalu, we selected the interval of two years instead of a year of aerial photos. Considering the availability of the aerial photographs, two dates, October 14, 2007 and October 8, 2009, were used.

2.3. Air Pollution Measurement Data

The fine particle concentration data of the monitoring station was provided by the EPA Taiwan. In order to be able to exclude outliers of the diurnal variation of fine suspended particles data, we used the median for each October. We first sorted the daily average concentration data according the level of order and took the intermediate values as the median (Table 1). The medians were then used as the dependent variables to build LUR models.

Table 1. The medians of fine sediment concentration (μg / m3) data for each October of the Shadu station.

Year	2007	2009	2011	2013	2015
PM2.5	28.46	25.63	26.29	33.46	19.25

2.4. Classification Procedures

9 types of land use were manual interpreted using aerial photographs for two years, including farmland and forest, animal husbandry, hydraulic, business, residential and school, industry, temples and funeral, as well as leisure (Figure 3). The areas of each land use type were then calculated. The results were converted to transitional probability matrix and the chi-square test (χ^2 - test) was used to evaluate whether the transfer matrix had Markovian properties. Finally, the Markov Chain analysis was used to estimate the areas of each land use category for 2011, 2013, and 2015. The land use areas and the corresponding air pollution data were then utilized for regression analysis to explore the relationship between land use and air pollution.

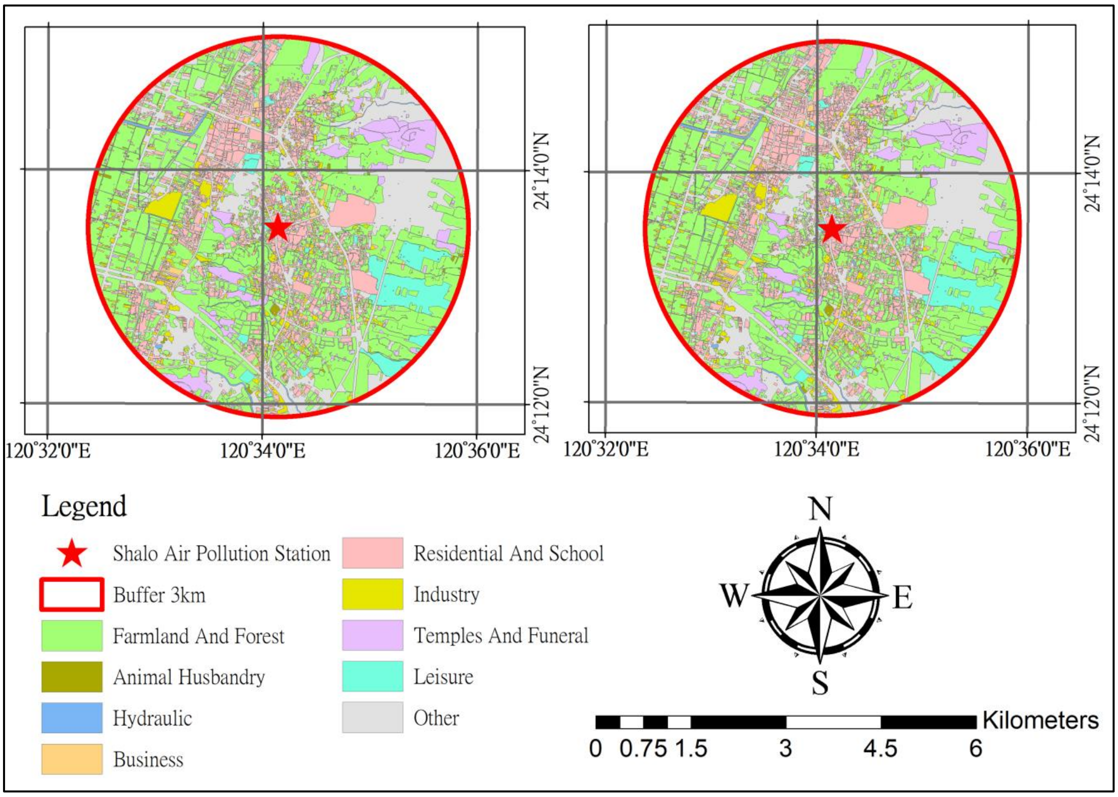

Figure 3. Maps of the manual interpreted land use.

3. RESULTS AND DISCUSSION

This study investigated the relationship between land use and air pollution, using Markov chain model in prediction of the land use. The areas of multi-year land use areas and PM2.5 concentrations were then analyzed using statistical analysis to explore the relationship between them.

3.1 Markov chain model and land use

Table 2 demonstrates the areas of land use from the interpretation of aerial photos for 2007 and 2009, and the estimates using Markov chain transfer matrix for 2011, 2013, and 2015. These areas were then utilized in the statistical analysis.

Table 2. The areas (Ha.) of land use types for five years

Years / Land Use Type	2007	2009	2011	2013	2015
Farmland & forest	8.3	8.2	8.2	8.1	8.1
Animal husbandry	25.9	25.9	25.9	25.8	25.8
Hydraulic	38.7	39.2	39.7	40.2	40.7
Business	412.7	410.3	408.0	405.7	403.5
Residential & school	123.5	129.1	134.8	140.4	146.1
Industry	155.5	150.6	146.0	141.8	137.7
Temples & funeral	117.5	119.1	120.7	122.3	123.9
Leisure	1176.8	1171.3	1165.8	1160.4	1155.0
Other	807.5	812.5	817.1	821.5	825.5

3.2 Land use and air pollution

The results of regression analysis (Table 3) indicate the most relevant land use type with PM2.5 concentrations is hydraulic. The correlation coefficient is 43.6% (positive moderately correlation), followed by animal husbandry, the farmland and forest, residential and school, as well as temples and funeral. PM2.5 concentrations, however, were negatively related to industry, leisure, business, and others.

Table 3.

Land use	Pearson correlation coefficient
Others	-.309
Farmland & forest	.324
Animal husbandry	.325
Hydraulic	.436
Business	-.325
Residential &school	.323
Industry	-.325
Temples & funeral	.310
Leisure	-.325

Since the season of Images used in this study is fall, most farmlands in this region are dry farming or fallow, the sands of river channel exposed with less water, animal husbandry is usual on the dry land, and temple generates air pollutants. All these factors increases PM2.5 concentrations, thus the correlation coefficients are positive. On the other hand, PM2.5 concentrations are negatively related to several patterns of land use, such as business and industry. Theoretically, for the increase of areas of these land use types, PM2.5 concentrations should be higher. However, the results are negatively related, differing from this general knowledge. F

or the overall statistical results, the explanatory power of the regression for nine land-use types and PM2.5 concentrations is only 26% (R2=26%). It means we could not only use nine types of land use to estimate completely the PM2.5 concentrations.

4. CONCLUSIONS AND SUGGESTIONS

Previous researches using the statistical analysis to study the relationship between land use and air pollution, mostly use existing survey data. This study first used remote sensing technology to interpret aerial photographs to derive the land use information for 2007 and 2009. Markov chain transition matrix was then employed to estimate areas of land use types for 2011, 2013, and 2015. The five-year land use areas and air pollution data were used to explore the correlations between land use and air pollution.

The results of regression analysis (Table 3) indicate the most relevant land use type with PM2.5 concentrations is hydraulic. The correlation coefficient is 43.6% (positive moderately correlation), followed by animal husbandry, the farmland and forest, residential and school, as well as temples and funeral. However, the explanatory power of the regression for nine land-use types and PM2.5 concentrations is only 26% (R2=26%).

The possible reason may be this study only used pollution values from one air pollution monitoring station. However, the air pollution is affected by several factors, including seasons, climate, winds and others. The use of only one station’s data cannot estimate completely the values of air pollution using LUR model.

In future studies, it is recommended to increase the number of samples by using data from more monitoring stations. Other air pollutants, such as NO2, CO, SO2, etc., can be used to explore the relationships with various land use types.

5. REFERENCES

Aguilera, I., Sunyer, J., Fernández-Patier, R., Hoek, G., Aguirre-Alfaro, A., Meliefste, K., Bomboi-Mingarro, M.T., Nieuwenhuijsen, M.J., Herce-Garraleta, D., Brunekreef, B., 2008.Estimation of outdoor NO(x), NO(2), and BTEX exposure in a cohort of pregnant women using land use regression modeling. Environ Sci Techno, 42(3), pp.815-21.

Brunekreef, B., Holgate, S.T., 2002. Air pollution and health. Volume 360, Issue 9341, Pages

1233-1242.

Chan, C.Y., 2012. Using Satellite Remote Sensing Multi-Spectral Image for Classification of Forest Fire Severity and Vegetation Recovery in Huanshan Area of Taichung.

Chang, Y.H., 2014. Detection of Forest Land Cover Changes Using Multi-temporal Satellite Images.

Chen, W.S., 2014. Social Housing Location Indicators - A Case Study of the Original Taichung City.

Chuang, C.W., Lin, C.Y., Chien, C.H., 2010. Simulation of Vegetation Restoration by Using Markov chain model at Chiufenershan Landslide Areas .Journal of Soil and Water Conservation, 42(3), pp.329-344 .

Chung, W.T.,2017. Applying land use regression model to evaluate associate between air pollution and Systemic lupus erythematosus: Apopulation based prospective cohort study in Taiwan.

Hector A.Olvera., MarioGarcia., Wen-WhaiLi., HonglingYang., HonglingYang., OrrinMyers., Scott W.Burchiel., MarianneBerwick., Nicholas E.PingitoreJr.,2012. Principal component analysis optimization of a PM2.5 land use regression model with small monitoring network. Science of the Total Environment,425,pp.27-34

Hu, Y.Z., 2006.A Study on the Urban Land-use Development Simulation-Local Spatial Autocorrelation and Neighborhood Characteristics.

Lee, J.H., 2015. The Application of Land Use Regression Models to Estimate Spatial Variation of PM10, PM2.5, PM2.5 Absorbance, and PMcoarse in Taipei Metropolis

Li, P., 2015. The study on location of the Earth God and Village Evolution of Neipu district Via Geographic information system.

Liao, Y.W., 2013. Utilizing Markvo model to study the land use transition in Taichung City.

Lin, C.S., Chiao, K.M., 1997. Study on the Change Detection of Ecological Environment by Using the Remotely Sensed Data-An ㄒ Illustration of Tainan District. Journal of Photogrammetry and Remote Sensing, 2(3),pp.37-46.

Liu, C.Y., 2015.Temporal and spatial pattern of land use simulation – A Case Study of Central Taiwan Scientific Parsk Specific Plan area

Mark Z. Jacobson, 2008.Review of solutions to global warming, air pollution, and energy security . Energy Environ. Sci., 2,pp. 148-173.

Beelen, R.,Hoek, G., Vienneau, D.,Eeftens, M .,Dimakopoulou, K.,Pedeli, X.,Tsai, MY.,Kunzli,N., Schikowski,T.,Marcon,A., Eriksen,KT.,Raaschou-Nielsen,O.,Stephanou,E.,Patelarou,E.,Lanki,T .,Yli-Tuomi,T.,Declercq,C., Falq,G.,Stempfelet,M., Birk,M.,Cyrys,J ., vonKlot,S.,Nador,G.,Varro,MJ.,Dedele,A.,Grazuleviciene,R.,Molter,A.,Lindley,S.,Madsen,C.,Cesaroni,G.,Ranzi,A.,Badaloni,C.,Hoffmann,B., Nonnemacher,M.,Kraemer,U.,Kuhlbusch,T.,Cirach,M., deNazelle,A.,Nieuwenhuijsen,M.,Bellander,T.,Korek,M.,Olsson,D.,Stromgren,M.,Dons,E.,Jerrett,M.,Fischer,P.,Wang,M.,Brunekreef, B.,de Hoogh, K.,2013. Development of NO2 and NOx land use regression models for estimating air pollution exposure in 36 study areas in Europe -The ESCAPE project. Atmospheric Environment,72,pp.10-23

Brook,RD.,Rajagopalan,S.,Pope,CA.,Brook,JR.,Bhatnagar,A.,Diez-Roux,AV.,Holguin,F., Hong,YL., Luepker,RV.,Mittleman,MA.,Peters,A.,Siscovick,D.,Smith,SC.,Whitsel,L., Kaufman,JD.,2010. Particulate Matter Air Pollution and Cardiovascular Disease,An Update to the Scientific Statement From the American Heart Association. AHA SCIENTIFIC STATEMENT, Volume 121, Issue 21.

Tsai, P.H., 2009. The Effect of Zoning to Urban Land Use Change

Van Johnson, 2000. Pattern of land use change in Hualien city and it"s vicinity area James A. LaGroJr,Stephen D. DeGloria,1992. Land use dynamics within an urbanizing non-metropolitan county in New York State (USA). Landscape Ecology, Volume 7, Issue 4, pp 275–289.

Vu, T.T., 2016. Using the Time Series Landsat Images to Detect the Land Use/Land Cover Changes in Dong Trieu District, Quang Ninh Province,Vietnam.

Weng, Q.H., Yang, S.H., 2006. Urban Air Pollution Patterns, Land Use, and Thermal Landscape: An Examination of the Linkage Using GIS. Environmental Monitoring and Assessment, Volume 117, Issue 1–3, pp 463–489

Wu, C.F., Lin, H.I., Ho, C.C., Yang, T.H., Chen, C.C., Chan, C.C., 2014.Modeling horizontal and vertical variation in intraurban exposure to PM2.5 concentrations and compositions. Environmental Research,133,pp.96-102.

Xia Meng, Li Chen, Jing Cai, Bin Zou, Chang-Fu Wu, Qingyan Fu, Yan Zhang, Yang Liu, Haidong Kan, 2015. A land use regression model for estimating the NO2 concentration in shanghai, China. Environmental Research ,137 ,pp. 308–315

Xu, G., Jiao, L., Zhao, S., Yuan, M., Li, X.M., Han, Y.Y., Zhang, B., Dong, T., 2016.Examining the Impacts of Land Use on Air Quality from a Spatio-Temporal Perspective in Wuhan, China. Atmosphere, 7(5), pp.62

Xu, X.Y., 2012. A Study on the Urban Land Use Change Model from Perspectives of Location and Socio-economics -- A Case Study of Land Consolidation in Taichung.

Yang, T.H., 2009. Characterizing Population Exposures to Particulate Matter and Nitrogen Oxides in an Urban Area: Comparison of ISC3, AERMOD and Land Use Regression Models

Zeng, W.Z., 2013. A Coastal Area Study of Landuse Transition and Management in Yunlin.

Zhang, Z.L., 2006.Markov Chain Model In the use of geography research, New knowledge of national religion, Volume 53, Issue 1, 72-86