REPORT

High prevalence of breast cancer in light polluted areas in urban and rural regions of South Korea: An ecologic study on the treatment prevalence of female cancers based on National Health Insurance data

Yun Jeong Kim1,2, Eunil Lee1,2,3, Hyo Sun Lee1,3, Mari Kim1,3, and Man Sik Park4

1Department of Preventive Medicine, College of Medicine, Korea University, Seoul, South Korea, 2Department of Public Health, Graduate School, Korea University, Seoul, South Korea, 3Molecular, Cellular and Developmental Biology, Division of Biomedical Science, College of Medicine, Korea University, Seoul, South Korea, and 4Department of Statistics, Sungshin Women’s University College of Natural Sciences, Seoul, South Korea

It has been reported that excessive artificial light at night (ALAN) could harm human health since it disturbs the natural bio-rhythm and sleep. Such conditions can lead to various diseases, including cancer. In this study, we have evaluated the association between ALAN and prevalence rates of cancer in females on a regional basis, after adjusting for other risk factors, including obesity, smoking, alcohol consumption rates and PM10 levels. The prevalence rates for breast cancer were found to be significantly associated with ALAN in urban and rural areas. Furthermore, no association was found with ALAN in female lung, liver, cervical, gastric and colon cancer. Despite the limitations of performing ecological studies, this report suggests that ALAN might be a risk factor for breast cancer, even in rural areas.

Keywords: Artificial light at night, breast cancer, generalized poisson distribution, light pollution, treatment prevalence

INTRODUCTION

Light pollution refers to pollution caused by an excess of artificial light. It is one of the causes of energy waste, especially in populated regions including both commercial and industrial areas (Living Environment Information Center, 2012). Furthermore, excessive exposure to artificial light at night (ALAN) has been reported to have negative effect on health because it disturbs circadian rhythms and sleep patterns, which can cause problems related to the regulation of body temperature, blood pressure, the immune system, the circulatory system and the excretory system (Navara & Nelson, 2007; Pauley, 2004; SCENIHR, 2012).

In shift workers, the chronic disruption in the circadian rhythm has been reported to be connected to various cancers, including breast, endometrial, prostate, ovarian, colon, skin and blood cancers (Anisimov, 2006; Bass & Takahashi, 2010; Bauer et al., 2013; Bhatti et al., 2013; Boyce & Barriball, 2010; Davis et al., 2001; Haus & Smolensky, 2006; Kloog et al., 2008; Rana & Mahmood, 2010; Stevens et al., 2007).

Since most studies on circadian disruption had been implemented for female shift workers, a greater concern had been induced for female-specific cancers (Bonde et al., 2012; Costa et al., 2010). Women aged 50 and older who have experienced more than 3 years of shift work before the age of 30 have a risk for breast cancer that is 4.3 times higher than that for other women (Lie et al., 2006). These studies suggest that circadian disruption could influence carcinogenesis in breast tissue. In addition, shift workers who have worked for more than 20 years at night have a 1.48 times higher risk of endometrial cancer than non-shift working women (Viswanathan et al., 2007). The incidence of advanced and borderline ovarian cancer has been found to increase 24% and 49% in women who frequently work overtime at night, as compared to non-night shift workers (Bhatti et al., 2013). Many studies have reported the elevated risks of cancer in shift workers at night. However, the effects of ALAN on circadian rhythm have only been recently conducted for the general population. Furthermore, a few studies have found an association between ALAN and female cancer in the general population.
A study used the data provided by the Georgia Comprehensive Cancer Registry to further investigate the influence of ALAN on breast cancer in the general populations, and the results showed that women exposed to a high ALAN intensity are susceptible to a 12% increase in risk of breast cancer (2000–2007) (Bauer et al., 2013). Also the communities with the highest ALAN had a 73% higher rate of incidence of breast cancer relative to the communities with the darkest environments. They also found a significant association between ALAN and breast cancer after adjusting for ethnic makeup, birth rate, population density and local income levels (Kloog et al., 2008).

After formed the predictive hypothesis that the correlation between ALAN and breast cancer in 1987, several empirical studies have found that ALAN was cited as contributing to late sleep patterns and disruption to the circadian rhythms and melatonin production (Haim & Portnov, 2013; Stevens, 1987, 2011; Stevens et al., 2014; Wright et al., 2013). These results provide strong evidence that light pollution is currently emerging as a new risk factor for breast cancer.

Breast cancer is the only cancer that has been reported to be significantly associated with ALAN in the general population, but no study has yet compared the effects that ALAN has on the risk for different female cancers. It is very important to compare across different types of female cancers because cancers are heterogeneous diseases that have various genetic and environmental mechanisms (Anisimov, 2006; Bass & Takahashi, 2010; Bauer et al., 2013; Bhatti et al., 2013; Boyce & Barriball, 2010; Davis et al., 2001; Haus & Smolensky, 2006; Kloog et al., 2008; Rana & Mahmood, 2010; Stevens et al., 2007). Furthermore, no studies have been performed in East Asia to address the influence of ALAN on the risk for cancer.

South Korea is one of the most rapid industrializing countries and also light pollution has been severe rapidly. Furthermore, the gap in the lighting infrastructure between urban and rural areas is still large, but all areas, both urban and rural, are becoming brighter every year.

In particular, urban areas predominantly show a prevalence for cancer similar to that of developed countries (western style cancers), whereas in rural areas, cancers are similar to those of developing countries, that is, infection predominate cancers of developing countries (Korean Cancer Maps, 2004). However, a substantial increase in the incidence of breast cancer has been observed for Korean women in urban and rural areas over the past 20 years.

Therefore, this study evaluates the risk posed by ALAN for several female cancers, including breast cancer using the National Health Insurance Service with several environmental cancer risk factors. We also evaluated the risks posed by ALAN on female cancers in rural areas only to exclude possible effects on cancer risk of urban shift work.

**MATERIALS AND METHODS**

**Study design**
All research methods and procedures were performed ethically and based on the principles and standards of the journal (Portaluppi et al., 2010). We conducted this study as following the flow diagram of analysis process (Figure 1).

**Study area and population**
Target areas were located in South Korea (Figure 2), which has 248 administrative districts and total area of 99,720 km². The total population of South Korea was 48,955,203 according to the Central Intelligence Agency (CIA) in 2013 (CIA, 2013). Of these administrative districts, 163 were in urban areas and 85 were in rural areas in South Korea. An urban area is generally defined as an area whose population residing in the urbanized parts of the relevant area is more than 60% of the total population. In addition, its total population is more than 50,000 (Local Autonomy Act, Article 7, 1994). On the other hand, if it is not eligible for this condition, it is defined as a rural area.

**Prevalence of cancers and other variables**
The number of females for cancers in each district in 2010 was provided by the Department of Information...
FIGURE 2. Correspondence between breast cancer prevalence and light pollution patterns. Figure (A) shows the distribution pattern and the prevalence of breast cancer for each district, that is, 248 administrative districts containing 163 urban and 85 rural areas. Figure (B) shows the ALAN distribution pattern. (C) We merged breast cancer prevalence and ALAN intensity maps. Regions in the proximities of cities showed high prevalence of breast cancer and high ALAN intensities (green circles).
Management of the Korean National Health Insurance Corporation. The number of treated patients meant the number of patients that received health services regardless of the number of physician visits. We calculated prevalence rates in each district for various female cancers based on population data as previously described (Vanasse et al., 2012) after adjusting for age. Other data regarding obesity, alcohol consumption and smoking rates in each district were provided by the Korean Center for Disease Control and Prevention (Community Health Survey, 2010). Local light pollution data were obtained from light at night intensity data supplied by the U.S. Defense Meteorological Satellite Program (DMSP, 2010). We used mean ALAN intensity level from 2001 to 2010 by averaging ALAN intensity over 10 years because of the long incubation periods of cancers (Armenian, 1987). The average ALAN levels for each district were calculated using Arc-Geographic Information Systems from visible light intensity data supplied by the DMSP. The ratio of urbanized parts, such as commerce, residence, industries or other urban businesses areas in each district, was provided by the Korea Land & Housing Corporation (Korea National Housing Corporation’s Zoning Data, 2010). Air pollution data, including CO, NO2, SO2, O3 and PM10 levels, were provided by the Ministry of the Environment (National Air Pollutants Emission, 2010).

Data analysis

Poisson distribution is a discrete probability distribution that expresses the probability of a given number of events occurring in a fixed interval of time and/or space if these events occur with a known average rate and independently of the time since the last event (Frank, 1967). The Poisson distribution can form the basis for some analyses of count data-like the number of treated patient because of cancer. In such case, Poisson regression may be used (Hutchinson & Holtman, 2005; Kim & Kriebel, 2009). Associations between ALAN intensity levels and cancer prevalence were determined by Poisson regression analysis using Statistical Analysis System (SAS) 9.1 version (SAS Institute; Cary, NC, USA) after adjusting for other variables.

RESULTS

Table 1 shows the average of ALAN intensity levels and variables in each metropolitan city and province, which were divided into 248 administrative districts. ALAN intensity level was the highest in Seoul (61.8), which was about 3–4 times higher than the lowest areas such as Jeollanam-do (14.5), Gyeongsangbuk-do (14.5), Gangwon-do (11.4) and Jeju-do (13.7). The smoking rate among Korean women is very low. Daejeoun (4%) and Gyeonggi-do (4.1%) showed the higher rates of 4%, whereas Jeollanam-do (1.7%) and Gwangju City (2.2%) showed the lowest rates.

Alcohol consumption rates in Seoul and Ulsan cities were the highest (at 43.7% and 43.1%, respectively). Obesity rates were similar (at <20%) to each other between cities and provinces, although Gangwon-do showed a relatively higher rate (at 23.9%).

We only included CO and PM10 for the best fit regression model among the environmental pollution variables (CO, NO2, SO2, O3 and PM10). Average CO and PM10 levels in Gyeonggi-do were slightly higher than those in Jeju-do (0.569ppm and 60.2µg/m3 versus 0.3ppm and 48.2µg/m3).

Next, we performed distributions of various female cancers in study areas. It is showed different distributions among the age-standardized prevalence of various female cancers in study cities and provinces. The

| Metropolitan cities and provinces (do) | No. of districts | ALAN intensity (%) | Smoking (%) | Alcohol consumption (%) | Obesity (%) | Urbanized parts (%) | CO (ppm) | PM10 (µg/m3) |
|--------------------------------------|-----------------|--------------------|-------------|------------------------|-------------|---------------------|----------|--------------|
| Seoul city                            | 25              | 61.8               | 3.8         | 43.7                   | 15.5        | 59.3                | 0.5400   | 49.4         |
| Busan city                            | 16              | 55.7               | 3.4         | 42.0                   | 17.8        | 32.6                | 0.4125   | 50.3         |
| Daegu city                            | 8               | 48.9               | 3.8         | 38.8                   | 15.0        | 38.1                | 0.5375   | 51.7         |
| Incheon city                          | 10              | 47.1               | 3.9         | 40.5                   | 19.6        | 25.2                | 0.5400   | 55.2         |
| Gwangju city                          | 5               | 48.2               | 2.2         | 41.1                   | 14.3        | 20.8                | 0.5300   | 44.8         |
| Daejeon city                          | 4               | 49.6               | 4.0         | 37.0                   | 14.5        | 18.7                | 0.5400   | 43.2         |
| Ulsan city                            | 5               | 45.4               | 2.4         | 43.1                   | 16.1        | 18.1                | 0.4800   | 48.2         |
| Gyeonggi-do                           | 44              | 51.5               | 4.1         | 40.5                   | 17.5        | 22.4                | 0.5690   | 60.2         |
| Gangwon-do                            | 18              | 11.4               | 3.2         | 37.2                   | 23.9        | 21.7                | 0.5056   | 43.2         |
| Chungcheongbuk-do                     | 13              | 21.4               | 3.9         | 33.7                   | 19.1        | 16.5                | 0.5154   | 51.8         |
| Chungcheongnam-do                     | 17              | 19.2               | 3.1         | 31.0                   | 17.4        | 16.8                | 0.5000   | 48.1         |
| Jeollabuk-do                          | 15              | 17.3               | 2.7         | 26.6                   | 18.2        | 17.3                | 0.4071   | 52.3         |
| Jeollanam-do                          | 22              | 14.5               | 1.7         | 26.9                   | 17.6        | 12.7                | 0.4795   | 42.2         |
| Gyeongsangbuk-do                      | 24              | 14.5               | 3.3         | 31.7                   | 19.8        | 16.6                | 0.5167   | 46.5         |
| Gyeongsangnam-do                      | 19              | 20.8               | 3.6         | 35.5                   | 17.9        | 13.9                | 0.3700   | 46.5         |
| Jeju-do                               | 2               | 13.7               | 2.7         | 39.2                   | 17.8        | 12.0                | 0.3000   | 48.0         |

ALAN intensity: light intensity at night from DMSP 2010 data (unit: nW/cm²/sr). Urbanized parts: The ratio of urbanized parts – the commerce, residence, industries or other urban businesses areas in each district.
prevalence of breast cancer, cervical cancer, colon cancer, lung, liver and gastric cancers in Seoul, Gangwon-do, Jeollanam-do and Gyeongsangnam-do was the greatest (Table 2).

The areas with high levels of ALAN showed a higher prevalence of breast cancer (Tables 1 and 2). Seoul (the most light polluted area) had a 34.3% (Seoul is 454 and Ganwon-do is 338) higher breast cancer prevalence than Ganwon-do (the lowest light polluted area).

Figure 2 shows that the distributions of average ALAN intensity and the prevalence of breast cancer in the 248 districts. A similar distribution is shown when the distribution of ALAN and that of breast cancer prevalence are overlapped.

In particular, large cities with a high ALAN intensity level like Seoul, Busan and Ulsan showed high prevalence of breast cancer. Furthermore, the areas adjacent to metropolitan cities, such as the Seoul/Daejeon axis, showed a high prevalence of breast cancer and high ALAN intensity levels. However, the prevalence of other cancers such as lung, liver, gastric, cervical and colon cancers did not show any correlation with ALAN intensity levels (Figure 3).

A Poisson regression analysis, which was performed to identify variables that might affect the prevalence of cancers, showed that ALAN was the most significant variable associated with the prevalence of breast cancer, together with obesity, the percentage of urbanized parts and PM10 (Table 3). However, ALAN was not found to be significantly associated with the prevalence of other cancers. In fact, significant factors differed for lung, liver, cervical, gastric and colon cancers.

The significant variables for lung cancer were smoking rate, PM10 and the percentage of urbanized parts. For colon cancer, the significant variables were CO and PM10, obesity rate, smoking rate and the percentage of urbanized parts. For cervical cancer, the significant variables included the obesity rate, alcohol consumption rate and the percentage of urbanized parts.

For liver cancer, the obesity rate was the only significant factor, and no significant variables were identified for gastric cancer.

The Poisson regression analysis was performed only for urban areas and rural areas since we wanted to assess the connection between ALAN and breast cancer risk after taking into account the differences between the urban areas and the rural areas in terms of artificial lighting, lifestyles and infrastructure.

The variables that were significant for breast cancer risk in urban areas are shown in Supplementary Table 1, and those for rural areas are shown in Table 4.

Table 4 shows that ALAN is the most significant variable for breast cancer risk and also obesity and PM10 are significant variables for breast cancer risk in rural areas. The relative risk (RR) of ALAN is 1.017, the RR of obesity is 1.03 and the RR of PM10 is 1.002 in rural areas. In fact, ALAN is the risk factor for breast cancer among all areas (RR: 1.007), urban (RR: 1.007) and rural areas (RR: 1.017).

As a matter of fact, except for the percentage of urbanized parts and the PM10, there were no differences between the risk factors for breast cancer among all areas, including both urban and rural areas.

**DISCUSSION**

In 2007, the International Agency for Research on Cancer (IARC) classified shift work that involves

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**TABLE 2. Prevalence of patients the light pollution for breast, lung, liver, cervical, gastric and colon cancer.**

| Cities and provinces | Breast cancer | Lung cancer | Liver cancer | Cervical cancer | Gastric cancer | Colon cancer |
|----------------------|---------------|-------------|--------------|----------------|---------------|--------------|
|                      | No. of treated patients | Prevalence | No. of treated patients | Prevalence | No. of treated patients | Prevalence | No. of treated patients | Prevalence | No. of treated patients | Prevalence | No. of treated patients | Prevalence |
| Seoul city           | 23838         | 454         | 3190         | 62            | 2574          | 50           | 6048         | 119          | 8325          | 161         | 9230          | 177         |
| Busan city           | 7526          | 437         | 1166         | 71            | 1179         | 79           | 2338         | 140          | 3537          | 219         | 3130          | 195         |
| Daegu city           | 5213          | 408         | 822          | 67            | 735          | 61           | 1539         | 123          | 2614          | 213         | 2283          | 191         |
| Incheon city         | 5465          | 404         | 768          | 73            | 578          | 50           | 1673         | 126          | 1849          | 154         | 2089          | 167         |
| Gwangju city         | 2386          | 336         | 578          | 82            | 406          | 59           | 845          | 128          | 1251          | 179         | 1061          | 157         |
| Daejeon city         | 3187          | 422         | 466          | 65            | 360          | 50           | 869          | 115          | 1379          | 187         | 1261          | 171         |
| Ulsan city           | 1872          | 337         | 329          | 63            | 253          | 47           | 509          | 96           | 970           | 178         | 798           | 143         |
| Gyeonggi-do          | 25142         | 411         | 3957         | 70            | 3102         | 56           | 6816         | 117          | 9625          | 164         | 9973          | 172         |
| Gangwon-do           | 3088          | 338         | 647          | 91            | 563          | 85           | 1109         | 154          | 1535          | 222         | 1639          | 238         |
| Chungcheongnam-do    | 2914          | 376         | 707          | 115           | 450          | 70           | 925          | 126          | 1725          | 255         | 1784          | 275         |
| Chungcheongnam-do    | 4033          | 410         | 1048         | 127           | 798          | 89           | 1368         | 138          | 2648          | 297         | 2301          | 262         |
| Jeollabuk-do         | 3049          | 359         | 854          | 141           | 601          | 89           | 1025         | 137          | 2267          | 347         | 1701          | 250         |
| Jeollanam-do         | 3114          | 317         | 1295         | 165           | 1111         | 134          | 1319         | 143          | 2838          | 350         | 2107          | 260         |
| Gyeongsangbuk-do     | 5171          | 409         | 1156         | 110           | 1076         | 104          | 1738         | 138          | 3684          | 335         | 3214          | 287         |
| Gyeongsangnam-do     | 5601          | 337         | 1378         | 117           | 1193         | 95           | 1917         | 134          | 3633          | 297         | 2914          | 228         |
| Jeju-do              | 860           | 298         | 168          | 61            | 205          | 74           | 389          | 135          | 487           | 180         | 451           | 179         |

ALAN: light intensity at night from DMSP 2010 (nW/cm²/sr). Prevalence: treatment prevalence of age-standardized per 100 000 inhabitants.
circadian disruption as “probably carcinogenic” (Group 2A). Such work leads to cancer development when biological rhythms do not function properly due to temporal changes in the environmental, such as shift work at night (Anisimov, 2006; Blask et al., 2005; Straif et al., 2007).

A lot of studies have shown that a disruption in circadian rhythm, specifically for shift work at night, is correlated with an increase in the risk for breast cancer. According to a meta-analysis of published papers on female night shift workers, among high quality studies, shift work was associated with a 1.4-fold increased risk of breast cancer. Furthermore, the duration of work at night was found to be associated with a greater risk of breast cancer (Jia et al., 2013). Such work disturbs hormonal rhythms due to exposure to ALAN for long periods of time because breast cancer is a representative hormone-related cancer, and hormonal imbalance may

FIGURE 3. ALAN and the distribution pattern of various cancers.
| TABLE 3. Significant variables affecting the prevalence of cancers in each district by Poisson regression analysis. |
|---------------------------------------------|
| Column | Breast | Lung | Liver | Cervical | Colon |
| Estimate | RR (95% CI) | Estimate | RR (95% CI) | Estimate | RR (95% CI) | Estimate | RR (95% CI) | Estimate | RR (95% CI) |
| Constant | 5.5961 | (3.8560, 7.2920) | 4.0707 | (3.4707, 4.6854) | 0.0011 | (0.0000, 0.0022) | 0.3901 | (0.3519, 0.4303) | 0.2864 | (0.2376, 0.3452) |
| Smoking | 0.0029 | (0.0003, 0.0055) | 0.0032 | (0.0007, 0.0056) | 0.0001 | (0.0000, 0.0003) | 0.0001 | (0.0000, 0.0002) | 0.0001 | (0.0000, 0.0002) |
| Alcohol consumption | -0.0037 | (-0.0067, -0.0007) | -0.0048 | (-0.0078, -0.0018) | 0.0009 | (0.0003, 0.0015) | 0.0006 | (0.0002, 0.0010) | 0.0004 | (0.0001, 0.0007) |
| Obesity | 0.0012 | (0.0000, 0.0025) | 0.0004 | (0.0000, 0.0008) | 0.0001 | (0.0000, 0.0002) | 0.0001 | (0.0000, 0.0002) | 0.0001 | (0.0000, 0.0002) |
| CO | 0.0153 | (0.0050, 0.0257) | 0.0189 | (0.0030, 0.0348) | 0.0004 | (0.0000, 0.0009) | 0.0001 | (0.0000, 0.0002) | 0.0001 | (0.0000, 0.0002) |
| PM10 | 0.0016 | (0.0007, 0.0025) | 0.0033 | (0.0015, 0.0051) | 0.0000 | (0.0000, 0.0000) | 0.0000 | (0.0000, 0.0000) | 0.0000 | (0.0000, 0.0000) |
| Urbanized parts | 0.0018 | (0.0002, 0.0034) | 0.0003 | (0.0000, 0.0006) | 0.0001 | (0.0000, 0.0002) | 0.0001 | (0.0000, 0.0002) | 0.0001 | (0.0000, 0.0002) |

ALAN intensity: light intensity at night from DMSP 2010 data (unit: nW/cm²/sr). Urbanized parts: the ratio of urbanized parts – the commerce, residence, industries or other urban businesses areas in each district. RR: relative risk ratio, CI: credible interval. Bold font represents a value $p < 0.05$.

Breast cancer has increased by approximately 91% over 10 years in Korea as compared to a 21% increase in Japan, which had the second highest growth rate as was reported by the GLOBOCAN report (GLOBOCAN, 2008).

According to Korean National Health Insurance Service reports, breast cancer has been increasing year by year. The total number of new breast cancer patients treated from 1999 to 2010 was 201 375, which equated to an incidence of breast cancer patients of 25.2 per 100 000 women per annum (Incidence of Breast Cancer, 2010). The reasons for this rapid increase in breast cancer incidence in Korea are probably related to well-known risk factors of breast cancer such as late marriage and delayed childbirth (GLOBOCAN, 2008).

The numbers of Korean women are participating in social activities and work has been increasing continuously (Population Census, 1992–2010). Furthermore, the mean age of marriage is now 30.2 years old, which represents an increase of 2.3 years over the past 10 years. In addition, the mean maternal age for first childbirth increased from 26.4 years in 1995 to 30.5 in 2010, and the ratio of women who give birth for the first time after an age of more than 35 years has increased from 4.8% to 18.7% over the same period (National Fertility and Family Health and Welfare Survey, 2010). In addition, the Korean total birth rate is 1.15 persons, which is the lowest rate among OECD countries. Also, almost all areas (both urban and rural) in Korea have low birth rate (National Fertility and Family Health and Welfare Survey, 2010).

The other possible reason for the high incidence of breast cancer in Korea is the increasing number of female shift workers. Approximately 10.2–11.2% (1 270 000–1 340 000 persons) Korean employees currently work in shifts. Women shift workers now account for 2.7–3.9% (340 000 persons) of Korean employees (Korea Labor Institute Report, 2008). Moreover, most shift workers are employed in metropolitan areas and ALAN levels in metropolitan areas are higher. In the...
present study, these areas showed higher prevalence of breast cancer. The significant association between ALAN and breast cancer found in this study suggests ALAN disrupts biorhythms, which might lead to the development of breast cancer. However, this association might be due to the large number of female shift workers in these areas.

Interestingly, the present study also showed a more significant association between ALAN and breast cancer in rural areas, which suggests that the effects of ALAN are substantial in both rural and metropolitan areas. These results suggested that urban and rural regions in South Korea were affected by ALAN despite different lighting conditions and infrastructures. In addition, these results are interesting as the ALAN effect was found to have an increasing trend, although the urban area with marriage age in the rural area 0.4 years younger than that of the urban areas (Korean Vital Statistics, 2010).

To the best of our knowledge, this study is the first study to show that ALAN affects breast cancer incidence in the general rural population. The levels of light pollution in South Korea have increased year-by-year, with a 2.4-fold over the period of 1999–2010 (Supplementary Figure 1). Furthermore, light polluted areas such as Seoul were found to have a 34.3% higher breast cancer prevalence than areas with the lowest ALAN intensities.

In rural regions, breast cancer prevalence showed an 11.4% increase for high ALAN areas relative to low ALAN areas (Supplementary Figure 2). When compared to two previous studies in Israel (73%) and Georgia (13%), our results for rural areas are in agreement with those of the breast cancer incidence study in Georgia (Bauer et al., 2013; Kloog et al., 2008).

One of the limitations of the present study is that satellite data were used to evaluate the ALAN exposure, which may be different from that of the actual values. However, the satellite data showed average levels of ALAN in different regions, which could be correlated with average real ALAN exposures. However, the real ALAN exposure is difficult to measure due to the high number of variables that are involved, such as lighting types, life style, usage of personal video display terminals (VDT) and activities. In particular, Koreans have been reported to have an exposure to VDT for 367 min/day, with 80% of respondents in the questionnaire having a personal VDT (KISDI Premium Report, 2010). VDTs emit a large amount of blue light (short wavelength from 450 to 495 nm), which has been reported to be harmful (Grimm et al., 2001; Kuse et al., 2014).

Long-term light pollution caused by VDT affects personal health, and the VDT exposure rate of Koreans is quite high. However, it is difficult to determine the effect of VDT in an ecological study.

One difference between our study and those presented by Georgia or Israel’s study is that we used prevalence data and not incidence data. We did this data because patients treated under the Korean National Health Insurance Service are representative of all Korean female cancer patients, since this service was made available to all citizens from 1 July 1989.

Admittedly, incidence data provide a better source for epidemiological studies. We did find a significant association between ALAN and prevalence data. Furthermore, when we compared the strength of the association between ALAN and breast cancer using both incidence and prevalence data in Gwangju city and Jeollanam-do, both data sets showed a significant association although the regression coefficient was higher for the incidence data (data not shown).

In addition, our study showed no effect of ALAN on other types of cancers, including cervical cancer, lung cancer, liver cancer, gastric cancer and colon cancer. Furthermore, our findings concerning the risks of previously reported significant variables such as smoking, alcohol consumption rates, obesity, CO and PM10 concurred with other studies. Obesity and smoking rates have been reported as causal factors or risk factors of cancers in many studies, such as obesity in breast cancer and smoking in colorectal cancer (Basen-Engquist & Chang, 2011; Hannan et al., 2009).

One of the interesting points is that breast cancer is affected both ALAN and obesity in our study. As empirical previous studies reported, obesity is strong risk factor for breast cancer (Benedetto et al., 2015; Crispo et al., 2015; Elkum et al., 2014; Gonzalez-Jimenez et al., 2015) due to the high levels of estrogen, which is secreted from the adipose tissue and promotes the growth of the tumors in breast cancer (Grossmann et al., 2008). However, ALAN also could effect changes in the daily patterns of food intake and activity, resulting in increases in body mass (Fonken et al., 2010). Therefore, obesity could be an independent risk factor of breast cancer or outcome factor by ALAN. The association between obesity and breast cancer could have mixed effects as causal factor of breast cancer and outcome.
factor of ALAN. However, it is difficult to explain influences of ALAN to obesity in this ecology study.

In Israel (Kloo et al., 2011), alcohol consumption was found to be a causal risk factor of cancer (Boffetta et al., 2006; Testino, 2011). The Israel study has reported that alcohol consumption could reduce breast cancer incidences because alcohol consumption in Israel is mostly limited to red wine that has protective effect against the development of breast cancer (Damianaki et al., 2000; Soleas et al., 2002).

However, most alcoholic beverage in Korea is spirits. In addition, alcohol intake in Korea is different from Israel. The amount of alcohol consumption is very high in Korea. The incidence of liver cancer shows a correlation with alcohol consumption (Global Status Report on Alcohol and Health, 2014). Air pollutant has been connected to risk of cancers, such as CO in colon cancer, and PM_{10} in breast cancer (Basen-Engquist & Chang, 2011; Choi et al., 2013; Hu et al., 2013; Kampa & Castanas, 2008; Yin et al., 2014). Many studies have addressed the relation between breast cancer and melatonin levels, which sharply increase when individuals are exposed to ALAN. In fact, melatonin levels are lower in breast cancer patients than in normal subjects (Sanchez-Barcelo et al., 2012; Viswanathan et al., 2007). Blind women and long sleepers are reported to have lower breast cancer risk (Hahn, 1991; Wu et al., 2008). Most studies about shift worker in women have reported low levels of 6-sulfatoxymelatonin (Bhatti et al., 2014; Davis et al., 2012). These results suggest that the suppression of melatonin secretion can lead to increased tumor growth (Blask et al., 2005; Srinivisan et al., 2008). Melatonin has been reported to be a modulator of estrogen to regulate cell proliferation and the expressions of several proteins, such as growth factors and proto-oncogene (Cos et al., 2008; Martinez-Campa et al., 2006). Melatonin also down-regulates the expression of ER-alpha and inhibits the binding of estradiol and ER complex to estrogen response element in DNA (Sanchez-Barcelo et al., 2003). Thus, reductions in melatonin secretion by light pollution could significantly impact cancer’s prevalence (Bhatti et al., 2013; Davis & Mirick, 2006; Schernhammer et al., 2003; Schoenfeld et al., 2003; Snedeker, 2006).

This study is the first to report an association between light pollution and breast cancer in East Asia. Despite its limitations, it shows a significant association between ALAN and breast cancer after adjusting for important significant risk factors. Furthermore, the findings of this study are consistent with other studies as it also shows a significant association between breast cancer and ALAN but no association between ALAN and other cancers, including lung cancer. No study has assessed the health effect of light pollution before this study in South Korea except several reports for architectural lighting or light pollution prevention act in South Korea (Ha & Kim, 2010; Won, 2012). Our study also suggests a possible reason of the rapid increase in breast cancer experienced over the past 10 years. Preventive measures can include reducing light pollution at night. Further studies are needed to examine the effects of light pollution on male-specific cancers, such as prostate cancer in East Asians, and to develop biomarkers for breast cancers, such as oxidative stress and immune markers for ALAN.

**DECLARATION OF INTEREST**

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Supplementary material available online
Supplementary Table 1 and Figures 1 and 2.