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ORIGINAL PAPER

Nighttime light level co-distributes with breast cancer incidence worldwide

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Abstract Breast cancer incidence varies widely among countries of the world for largely unknown reasons. We investigated whether country-level light at night (LAN) is associated with incidence. We compared incidence rates of five common cancers in women (breast, lung, colorectal, larynx, and liver), observed in 164 countries of the world from the GLOBOCAN database, with population-weighted country-level LAN, and with several developmental and environmental indicators, including fertility rate, per capita income, percent of urban population, and electricity consumption. Two types of regression models were used in the analysis: Ordinary Least Squares and Spatial Errors. We found a significant positive association between population LAN level and incidence rates of breast cancer. There was no such an association between LAN level and colorectal, larynx, liver, and lung cancers. A sensitivity test, holding other variables at their average values, yielded a 30–50% higher risk of breast cancer in the highest LAN exposed countries compared to the lowest LAN exposed countries. The possibility that under-reporting from the registries in the low-resource, and also low-LAN, countries created a spurious association was evaluated in several ways and shown not to account for the results. These findings provide coherence of the previously reported case–control and cohort studies with the co-distribution of LAN and breast cancer in entire populations.

Keywords Breast cancer · Epidemiology · Geography · Light at night (LAN)

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Introduction

There is evidence that excessive exposure to light at night (LAN) may increase the risk of breast cancer (reviewed in [1, 2]). Possible mechanisms include the suppression of melatonin (MLT) secretion by the pineal gland leading to increased tumor growth [3, 4]; the adverse effects of LAN on thermoregulatory and immune functions [5, 6], and the direct disruption of circadian gene function in the suprachaismatic nuclei by LAN, leading to alterations of cell cycle regulation in the breast tissue [7, 8]. The original hypothesis was based on a suppression of melatonin. If this is a primary mechanism, then we predicted that LAN would be associated with hormone-dependent cancers (e.g., breast and prostate cancers), and not, or to a lesser extent, with non-hormone-dependent cancers (e.g., lung, colorectal, and larynx).

The "LAN–breast cancer" theory has been supported by the observation that shift-working women are at higher risk of developing breast cancer [9–12], while blind women [13–15] and long sleepers [16–19] seem to be at a lower risk. The studies in shift workers resulted in the classification of "shift work" as a 2A "probable human carcinogen" by the International Agency For Research on Cancer (IARC) [20].

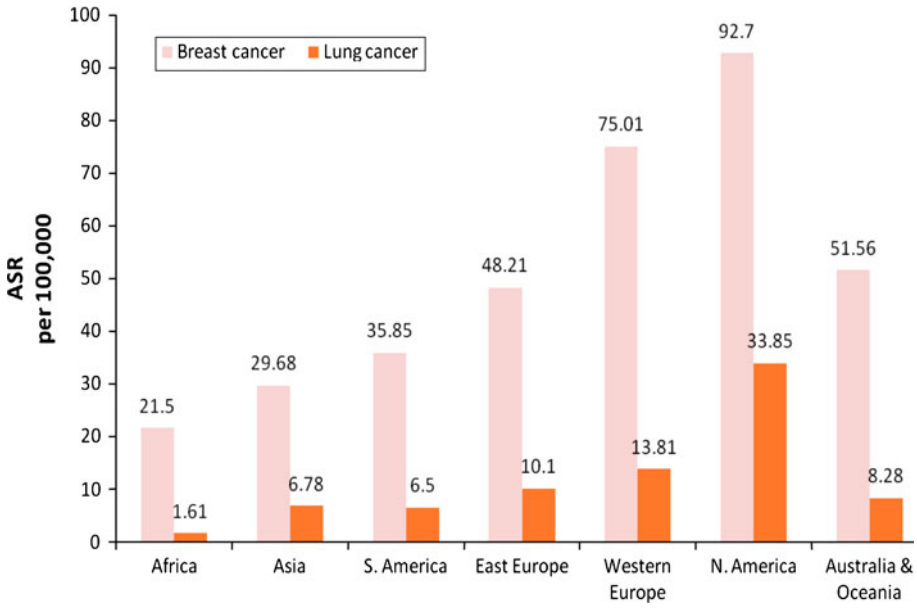

Fig. 1 Worldwide variation of breast and lung cancers incidence by continent *Note*: Age-standardized incident rates per 100,000 *Source*: Calculated using data from Ferlay et al. (2004)

Breast cancer is the second leading cause of cancer death in women (after lung cancer) and is the most common cancer among women worldwide, excluding non-melanoma skin cancers. According to the World Health Organization (WHO), 1,300,000 women are diagnosed with breast cancer annually and about 465,000 die from this disease every year [21].

Parkin and colleagues [22–24] conducted several comprehensive studies of worldwide differences in cancer rates. During this ongoing research, the estimates of prevalence, mortality, and incidence of 26 most common cancers were collected for 20 geographic regions of the world. The rates of breast cancer in women appear to differ widely across the globe, being generally higher in developed countries than in the developing ones. Thus, in North America age-standardized rates (ASR) of breast cancer incidence are 92.7 per 100,000, compared to Africa where breast cancer ASR are 21.5 per 100,000 (see Fig. 1). Global variation of lung cancer is also large with ASR reaching 33.85 per 100,000 in North America vs. 1.61 per 100,000 in Africa.

However, to the best of our knowledge, no studies carried out to date have attempted to investigate the possibility that the above disparities in female cancer incidence rates are associated with country-specific LAN emissions (light pollution), thus testing a prediction of the LAN–cancer theory.

In the present analysis, we investigate whether exposure to LAN is associated with cancers in women, using ASR of common cancers in women available for 164 world countries obtained from the GLOBOCAN 2002 database. This analysis is a continuation of our previous studies showing a significant co-distribution of LAN and prostate cancer worldwide but not with lung and colorectal cancer in men [25] and an extension of previous studies which detected a positive association between LAN and breast cancer within Israel [26].

If LAN is significantly associated with hormone-dependent cancers, then an elevated incidence of breast cancer with elevated levels of LAN can be expected, but not elevated risk of colorectal, larynx, liver, and lung cancer, the cancers which are not hormone dependent and thus included in the present analysis as negative controls.

The limitations of population level, or ecological, studies are well known and include exposure misclassification and missing confounder bias. However, such studies are important in providing context for research among subpopulations of people using case–control and cohort designs. If no association is found at the population level in a study with good statistical power, then that would be evidence against a strong effect of a putative risk factor. A positive association is thus a necessary, but not sufficient condition for there to be a large effect of a common exposure on risk in society at large.

Methods

Cancer data

Data on cancer ASR in women for the present analysis were obtained from the GLOBOCAN 2002 database, maintained by the IARC [23]. The IARC cancer data are reported for individual countries of the world for the period of 1998–2002 [22]. These data have been previously used widely in epidemiological research (e.g., [27, 28]).

The data were obtained for breast, lung, and colorectal cancers (three of the most common cancers in women) as well as for larynx cancer and liver cancer the main risk factors for which are well known (smoking for larynx cancer and hepatitis B virus (HBV) or hepatitis C virus (HCV) for liver cancer).

Explanatory variables

Several development indicators of the world countries were included in the present analysis as potential predictors of country-specific cancer incidence rates and perhaps as confounders of any possible LAN effect.

GDP per capita ($US) is a commonly used measure of population welfare that reflects differences in the diet and lifestyles of different socio-economic strata [29, 30]. Risk of breast cancer tends to be higher among high-income groups than across low-income strata and is significantly higher in the developed countries than in the developing ones [31].

Percent urban population

Living in cities is often associated with a considerable amount of physiological stress associated with high residential densities, traffic congestion, and air pollution, which may increase cancer risk [32]. In addition, residents of urban areas are exposed to more environmental smoking, due to high residential densities thus also creating passive smokers under these conditions, which is another cause of cancer [33]. Dietary differences and reduced physical activities associated with urban living may also play a role in the development of cancer.

Electricity consumption (kWh per capita)

Electricity consumption may be an indicator of socio-economic development and industrial emission of gaseous substances associated with electricity production [34, 35].

Fertility rates (average number of births per woman)

Fertility is negatively associated with breast cancer risk [36]. Fertility rates used in the analysis, to account for this effect, are total fertility rate (TFR), which is a more accurate measure of fertility than crude birth rates, since they refer to the average number of births per woman, rather than to average natural growth for population as a whole [37].

In addition, LAN exposure was measured in the analysis using satellite image data, as further detailed in the "Data Sources" and "GIS Analysis" sections. In particular, the worldwide satellite image for 1996/97, used in the analysis, was to compare with 2002 cancer incidence rates, the latest available, thus helping to account, at least to a some extent, for the latency period between exposure and the onset of cancer.

Descriptive statistics of the research variables used in the analysis are presented in Appendix 1.

Data sources

Data for the present analysis were obtained from the following two main sources:

- Country-level data on per capita gross domestic product (GDP), percent of urban population, and per capita electricity consumption for 1998–1999 were obtained from the ESRI ArcGIS ™ database, and country-specific fertility rates were obtained from the CIA World Fact Book [37, 38].
- Data on nighttime illumination (LAN) were obtained from the U.S. Defense Meteorological Satellite Program (DMSP) [39]. The DMSP satellite provides continuous reading of the entire Earth surface during nighttime as it cycles around the globe. The satellite image for 1996/97, used in our analysis, was constructed by the DMSP by averaging daily readings of the satellite sensors and removing cloud cover. [Reported in nanowatts per centimeter squared per steradian.]

Geographic information systems (GIS) analysis

GIS has been used extensively in recent years as an important research tool for cancer-related studies [26, 40–44].

In the present study, GIS technology was used for matching country-specific cancer incidence rates with the LAN levels obtained from satellite images. The task was performed using the "spatial join" tool in the ArcGIS 9.x™ software, which joins data from two geographic layers by appending attributes from one layer to another, based on the relative location of features in the layers [45].

The "spatial join" between two data sources was performed as follows: At the beginning, a worldwide radiance-calibrated satellite image of nighttime illumination, comprised of average nightlight intensity in 1996/97 and measured in light radiance units (i.e., nanowatts/cm2/sr), was imported to the ArcGIS 9™ software. The image reflects the fraction of light escaped into space and detected by the satellite's sensors.

Although these satellite measurements are a magnitude lower than actual LAN levels detected on the ground, they represent accurately the *relative levels* of nightlight intensity observed in different localities [26], thus reflecting the

levels of nighttime illumination from various outdoor sources to which local residents are exposed.

The original nighttime illumination image was converted into a vector map using ArcGIS 9.x™ "raster-to-feature" conversion tool. The conversion resulted in a polygon layer containing approximately 3,800,000 polygons characterized by various LAN intensities (with a minimum LAN value of 0 (no illumination) and the maximum value of 255 nanowatts/cm^2/sr (maximum illumination).

Using the average LAN exposure in a country may result in a bias caused by a country's differences in geography and population structure. For example, countries with large unpopulated areas (such as e.g., Canada or Sweden) are likely to exhibit disproportionately low average LAN estimates. To minimize this bias, we used a previously developed novel method of adjusting LAN exposure, which takes into account both a country's geographic distribution of population and its local LAN intensities [46]. To perform this adjustment, the map of LAN intensity polygons was overlapped with another map containing places worldwide with a population greater than 1,000 residents. Each city was mapped using its "central reference" point, normally represented by the location of the city hall or the central post office. Average LAN values were then calculated for each populated place by obtaining LAN values from the LAN intensity polygon into which the populated place falls. Representing big cities by their "central reference points" may potentially lead to a certain overestimation of the calculated average LAN exposures due to the fact that cities' central areas are normally more lighted up than their peripheral neighborhoods. However, it is unlikely to cause a substantial bias in the comparative analysis since the same procedure was applied to all localities in all countries under study. Moreover, this approach may be considered compensatory for the exclusion of populated places with less than 1,000 residents, omitted from the analysis due to restrictions on data availability.

The difference between simply averaged and population-adjusted LAN estimates can be considerable. For example, calculating the LAN exposure for Canada by simple averaging values of LAN polygons (that is, without accounting for the skewed geographic patterns of the country's population), results in relatively low LAN estimates of 6.57 nanowatts/cm^2/sr, giving the country rank of 133 (out of 164 countries in our sample). Concurrently, the population-weighted LAN estimate for Canada is 122.84 nanowatts/cm^2/sr which gives it the second rank among 164 countries in our sample, which reflects better the country's high development status and the elevated per capita LAN exposure of its residents. Another example is Sweden, whose unadjusted LAN estimate is 6.08 nanowatts/cm^2/sr (rank 128), while population-adjusted LAN is 94.23 nanowatts/cm^2/sr, giving it the rank of 5 among 164 countries in the sample.

The locality-specific LAN values obtained were then multiplied by the population size of localities and summed up for each country under study and later divided by the total population size of the country's populated places. This resulted in the average LAN exposure estimate per person in each country under study. Several countries are reported in Appendix 2.

Statistical analysis

To identify and measure the significance of factors affecting the selected cancer rates, several statistical techniques were used. We started with an ordinary least squares (OLS) model. During the analysis, multicollinearity and normality were tested, and their results were found satisfactory (Tolerance > 0.27). The tolerance statistic estimates the degree of inter-collinearity between independent variables, with values approaching zero, indicating that a strong multicollinearity may be present. In econometric studies, tolerance values greater than 0.1 are considered to be satisfactory [47]. The tolerance value of 0.27 we obtained is considerably higher than 0.1, thus indicating that the multicollinearity between the explanatory variables is well within acceptable limits.

The analysis was performed separately for each cancer type using the following linear model:

$$\begin{aligned}\text{Cancer incidence rate} = {} & B0(\text{constant}) \\ & + B1 * (\text{Electricity consumption}) \\ & + B2 * (\text{GDP per capita}) \\ & + B3 * (\text{LAN}) \\ & + B4 * (\text{Percent of Urban population}) \\ & + B5 * (\text{fertility rate}) \\ & + \varepsilon(\text{random error term})\end{aligned}$$

where $B0, \ldots\ldots, B5$ are regression coefficients.

The residuals of the OLS model were tested for the presence of spatial autocorrelation using the Moran's I test statistic. The test showed significant clustering of residuals (Moran's indicator: (0.366–2.461, $p < 0.001$) which necessitated the use of spatial dependency (SD) models, to take the spatial dependency of residuals into account and improve the robustness of regression estimates [48]. The spatial dependency (SD) regression modeling was performed in the GeoDa™ spatial analysis software [49]. [It should be noted that the results of the SD modeling were found to be essentially similar to the OLS estimates and are not reported in the following discussion, for brevity's sake, and can be obtained from the authors upon request. In

addition, a weighted analysis using the country population was also conducted and made no meaningful difference in the parameter estimates].

Results

Table 1 shows factors associated with cancer incidence rates. The multicollinearity of all variables was tested and found within tolerable limits (Tolerance > 0.27). All models in Table 1 are OLS, estimated separately for the following five cancer types: breast, colorectal, larynx, liver, and lung. Two regression models (1 and 2) are reported separately for breast cancer incidence rates. These models differ in that Model 2 omits the five "outlier" Gulf States.

The models for breast, lung, and colorectal cancers provide good fit ($R^2 = 0.571$–0.648) and have a high degree of generality ($F = 41.975$–59.893, $p < 0.01$), while the liver and larynx models present poor fits (0.018–0.125), thus implying that predictors included in these models do not explain well the variability of these cancer types across the globe.

Among all the cancer types analyzed, only breast cancer exhibited a significant positive association with LAN exposure ($b = 0.150$, $t = 2.365$; $p < 0.05$). For all other cancer types, LAN exposure was found not to be statistically significant.

Per capita *GDP* (ln) is also positively associated with ASRs of breast, lung, and colorectal cancer ($p < 0.01$), while it is inversely associated with liver cancer, albeit the association is not significant ($p > 0.05$).

Fertility rates are negatively associated with breast cancer as well as lung and colorectal cancer ($p < 0.01$), but not with larynx and liver cancer ($p > 0.3$), as could be expected.

To investigate whether the LAN–breast cancer association differs by countries with different reproductive patterns, the ANOVA analysis was run. For the analysis, the countries in our sample were grouped into low, medium, and high fertility based on Jenk's 'natural breaks' method [50]. This method determines the best arrangement of values into classes by comparing the sum of squared differences of values from the means of their classes and thus identifies "break points" in the data values by picking the class breaks that best group similar values and maximize the differences between classes. The fertility cut-points were less than 2.67 children per woman (low-fertility group), 2.67–4.58 children per woman (medium-fertility group), and greater than 4.58 children per woman (high-fertility group). Notably, the LAN/breast cancer connection is much stronger in the low-fertility group ($F = 16.91$, $p < 0.001$), to which most developed countries of the world belong, than in high-fertility group ($F = 1.24$, n.s).

Table 1 Factors affecting most common cancer incidence rates in women worldwide (method: ordinary least square (OLS) regression)

Variable	Breast(1)[a]	Breast(2)[a]	Lung[a]	Colon[a]	Larynx[a]	Liver[a]	Tolerance[b]
(Constant)	−25.038 (−1.394)	−46.559 (−2.721)***	−2.613 (−0.509)	−16.896 (−2.426)**	1.735 (2.392)**	11.415 (1.604)	
Light at night (LAN) (nanowatts/cm^2/sr)	0.150 (2.365)**	0.277 (4.330)***	0.032 (1.772)	0.026 (1.061)	−7.55E–006 (−0.003)	−0.006 (−0.227)	0.702
Electricity consumption (kWh per capita)	0.006 (1.317)	0.002 (0.603)	0.006 (5.351)***	0.002 (1.420)	8.50E–005 (0.496)	0.619 (0.703)	0.911
Urban population (%)	0.115 (1.541)	0.187 (2.689)***	0.016 (0.743)	0.032 (1.126)	0.003 (0.951)	−0.003 (−0.099)	0.475
GDP per capita (ln), $US	7.882 (3.817)***	9.314 (4.824)***	1.465 (2.483)**	3.981 (4.974)***	−0.127 (−1.517)	−1.016 (−1.242)	0.271
Fertility rates (per 1,000)	−2.939 (−2.759)***	−1.080 (−1.035)	−1.233 (−4.052)***	−1.757 (−4.255)***	−0.042 (−0.971)	0.585 (1.386)	0.424
Number of obs.[c]	164	159	164	164	164	164	
R^2	0.571	0.648	0.575	0.655	0.018	0.105	
F	41.975***	56.219***	42.777***	59.893***	0.574	3.689***	
Moran's I[d]	3.775***	5.130***	3.031***	2.461**	0.336	−1.101	

[a] Regression coefficient (*t*-statistic in the parenthesis)

[b] Tolerance (multicollinearity diagnostic)

[c] Number of valid observations list-wise

[d] Moran's I index of spatial association of regression residuals

** Indicates a 0.05 significance level; *** indicates a 0.01 significance level

Breast(1): Breast cancer OLS model; all countries in the sample

Breast(2): Breast cancer OLS model; five "outlier" Gulf States are omitted

However, in the high-fertility group, five countries had relatively high LAN exposure, and these were all oil producing Gulf states–Saudi Arabia, Oman, United Arab Emirates, Qatar, and Kuwait (see Appendix 1-B). When these are removed from the analysis, the strength of association between LAN and breast cancer of all countries combined ($n = 159$) considerably increased (from $t = 2.365$; $p < 0.05$ (Breast(2) Model) to $t = 4.330$; $p < 0.001$ (Breast(3) Model; see Table 1).

Sensitivity test

To estimate the relative contribution of LAN to breast cancer ASRs, we split all the countries in our sample into three groups—countries with minimal LAN exposure (less than 15 nanowatts/cm^2/sr); countries with average LAN exposure (15–57 nanowatts/cm^2/sr), and countries with the highest LAN exposure (greater than 57 nanowatts/cm^2/sr). The Jenks "natural breaks" method was used to classify countries into the groups. Next, the values of all other variables from the second model (apart from LAN) were set constant to the average values observed in each group, and a sensitivity test of breast cancer ASRs to changes in LAN values was run, using the "breast cancer" model reported in Table 1. The results of the sensitivity test are reported in Table 2.

As Table 2 shows, when the values of all other variables are fixed, the increase of LAN from 8.60 nanowatts/cm2/sr (the average LAN value in the group of countries with minimal LAN exposure) to 28.95 nanowatts/cm2/sr (countries with average LAN exposure) corresponds to an increase of 7.2% in breast cancer ASR. A further increase in LAN value to 99.21 (the maximum LAN exposure) corresponds to an increase of 23.25% in breast cancer ASR. There were five countries that had high fertility but also very high LAN exposure; these were all five Persian Gulf States (Saudi Arabia, Oman, United Arab Emirates, Qatar, and Kuwait). When these five "outlier" Gulf States are omitted (Breast (2) model), the estimated breast cancer ASRs rise by about 50% from the highest to the lowest LAN countries.

We also fitted the model to the 80 countries with a per capita GDP of > $3,000 in order to partially control for a possible bias in the quality of the registries in the GLOBOCAN database. Parameter estimates were virtually unchanged compared to the full analysis of all 164 countries.

Table 2 Sensitivity test of breast cancer ASR to plausible changes in the ground LAN intensity

LAN level	Average LAN value (nanowatts/cm2/sr)	Estimated ASR (per 100,000 residents)	Percent change (%)
Breast (1) model (see Table 1)			
Low	8.60	40.47	–
Medium	28.95	43.39	7.20
High	99.21	53.43	23.25
Breast (2) model (see Table 1)			
Low	8.60	44.45	–
Medium	28.95	50.08	12.70
High	99.21	69.54	38.85

ASR-Age-standardized rates per 100,000 residents

The values of the fixed variables were set constant as follows: GDP per capita = $US 9,000 (the average value for the "high-resource" countries under study); Urban population = 65.3%, Electricity consumption per capita = 131.870 kWh, fertility rate = 3.4 per 1,000 births

Discussion

The results of the present study are consistent with those of previous studies of LAN and risk [1], and those obtained on a national scale of breast cancer incidence in Israel [26]. Similar results were also obtained for another hormone-dependent (prostate) cancer on a worldwide scale for men [25].

We found a significant positive association between country LAN level and breast cancer incidence, yet no such association was found for the other cancer types (colorectal, larynx, liver, and lung) which were used as negative controls. The results of our analysis also revealed a significant association between breast, colorectal, and lung cancer and per capita GDP, which is consistent with the fact that the relative risk of contracting cancer is positively associated with average income of local residents [29, 30]. Part, but not all, of this excess is probably due to better access to medical and diagnostic procedures in the "high-resource" societies [51–53]. Ecological studies have well-documented limitations, but they also have strengths. The analysis included 164 countries of the world and data on several potentially important co-variables. Due to limitations on data availability, other risk factors, including occupation, alcohol consumption, and specific reproductive factors such as age-at-first birth, were not available for the analyses though the per capita income variable may capture some of their effects; in addition, fertility rate may also more specifically capture some of the inter-country variability in reproductive factors. Smoking may be partly covered by the percent urban variable and the per capita income variable, although for breast cancer, if smoking increases risk, it probably has a very modest effect. Studies have shown that greater urbanization increases smoking

[33] and that smoking is strongly linked with socio-economic status [54, 55]. It should, however, be noted that dynamics in population movement as well as behavioral patterns that limit exposure to LAN were also not assessed by this study. Such information can be obtained by studies carried out on a smaller scale such as localities within an urban space, but not on a global level. Another limitation is in the completeness of cancer registration in the developing world where LAN exposure is low and national incidence is extrapolated from data obtained from small incidence registries within the country. Parkin et al. [56] conducted a detailed analysis of cancer registration in Kampala, Uganda over the period 1994–1996 and concluded that "…it gives reassurance that published incidence rates are reasonably accurate." However, Curado et al. [57] caution that the cancer registries in low- and medium-resource countries are more susceptible to underreporting than those in high-resource countries. We addressed this limitation in several ways. First, we also analyzed four other cancer types which should also suffer from this possible bias, yet only breast cancer showed a strong association with LAN. Second, we restricted analysis to the 80 countries with per capita GDP greater than $3,000 and found that the change in parameter estimates was negligible. We also restricted analysis to the 73 lowest fertility countries and again found a significant association of LAN with breast cancer incidence.

When low-fertility countries are analyzed separately as a group, there is a stronger association of LAN with breast cancer incidence than among the high-fertility countries. Two aspects of this analysis are important to note. First, the variability of both LAN and breast cancer incidence is greater in the low-fertility group of countries ($n = 73$) than in the high-fertility group of countries ($n = 48$), perhaps providing a better opportunity to observe an effect should one exist. Second, given the legitimate concern of lower quality registries in the high-fertility countries, the strong finding in the low-fertility group lessens the concern about reporting bias accounting for our results.

The lack of a strong association of LAN and incidence of colorectal cancer (CRC) is interesting in light of the fact that one strong epidemiological study found a significant association of shift work with CRC [58]. This study was based on evidence that melatonin influences risk in experimental and clinical models. Another consideration is that timing of feeding has been shown to have a strong synchronizing effect in the gut independent of light; whereas daytime feeding in nocturnal mice reset circadian gene expression in the gut, the SCN was unaffected and remained synchronized to the light cycle [59]. The relation of circadian disruption, from lighting and from meal timing, and CRC deserves more attention.

LAN is increasing rapidly in developing countries but also in developed countries. In order to save on energy consumption on the one hand and lower CO_2 production on the other, there is a global trend in industrialized countries like the EU to shift to low-energy consuming non-incandescent lamps. This shift while indeed saving energy may cause an increase in nighttime light exposure since these new lamps produce more light per watt of electricity, particularly in the blue range of the spectrum. This issue should be addressed by the policy makers in each country.

To the best of our knowledge, the present analysis is the first study to investigate the relationship between LAN and the incidence of several common cancers in women worldwide. No single study, ecological or otherwise, can 'prove' an association is causal. We view this analysis as an important piece of the evidence based on whether and to what extent LAN explains the global breast cancer burden. As per the IARC Classification paradigm, causal inference requires many different kinds of studies from different designs and perspectives, all evaluated together by the scientific community that may or may not eventually come to consensus.

Appendix 1

See Table 3.

Table 3 Descriptive statistics of the research variables

Variable	Measurement unit	Minimum	Maximum	Mean	SD
A. All Countries in the sample*					
Dependent variables					
Breast cancer	ASR[a] per 100,000	3.9	101.1	37.527	22.928
Colorectal cancer	ASR[a] per 100,000	0.9	42.2	11.935	9.911
Larynx cancer	ASR[a] per 100,000	0.0	4.1	0.721	0.612
Liver cancer	ASR[a] per 100,000	0.2	57.3	4.949	6.291
Lung cancer	ASR[a] per 100,000	0.1	36.1	6.824	6.589

Table 3 continued

Variable	Measurement unit	Minimum	Maximum	Mean	SD
Explanatory variables					
Electricity consumption per capita	*kWh* per capita	0.01	3,367.42	75.66	295.29
Fertility rates	average number of births per woman	1.14	7.41	3.403	1.722
GDP per capita	US$	463	32,021	6,545.73	7,315.17
Light at Night	nanowatts/cm^2/sr	0.00	143.34	8.23	22.43
Urban population	% of residents living in urban areas	6.16	100.00	55.16	23.31
B. Subsample of the Gulf States**					
Dependent variables					
Breast cancer	ASR[a] per 100,000	13.20	33.30	25.420	7.974
Colorectal cancer	ASR[a] per 100,000	3.1	17.50	10.100	5.201
Larynx cancer	ASR[a] per 100,000	0.0	0.90	0.460	0.336
Liver cancer	ASR[a] per 100,000	0.60	8.90	3.940	3.349
Lung cancer	ASR[a] per 100,000	2.30	6.0	4.180	1.578
Explanatory variables					
Electricity consumption per capita	*kWh* per capita	6.24	102.42	31.862	40.248
Fertility rates	average number of births per woman	2.79	5.72	4.216	1.365
GDP per capita	US$	7,535	22,123	14,185.21	6,134.46
Light at Night	nanowatts/cm^2/sr	24.26	115.39	57.210	37.305
Urban population	% of residents living in urban areas	72.51	97.57	86.460	9.50

*Total number of countries–164

**Number of countries–5

[a] Age-standardized rates per 100,000

Appendix 2

See Table 4.

Table 4 Average LAN exposure in selected countries

Country	Average LAN exposure per person (nanowatts/cm^2/sr)
Bhutan	0.001
Senegal	0.022
India	0.059
Peru	0.554
Egypt	2.028
Argentina	4.501
Israel	10.707
United States	57.540

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