Official Statistics From Satellite Data – The example of Artificial Light Emissions in Ireland

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1. INTRODUCTION

A question asked with increasing frequency is whether high official statistics can be produced using satellite imagery, particularly from open source or low-cost data sources, and without the need for extensive computing or network infrastructure. This project wished to examine the availability and usefulness of data on artificial light.

In this project, satellite data is used in conjunction with open source R GIS packages to produce estimates of artificial light emissions in Ireland at national, regional and local level, Comparative data for locations in the UK, France, Germany, the Netherlands and Portugal are also provided. This project seeks to show how Big Data such as satellite imagery could be used to produce high-quality and relevant statistics. The project also included extensive quality assurance and result validation processes.

Light emissions are a matter of major public concern. In 2009, the UK Government's Royal Commission on Environmental Pollution published "Artificial Light in the Environment" [1] which raised concerns about the impact of artificial light on animal behaviour, human sleep patterns, energy waste and carbon emissions associated with the misuse of artificial light. It also included a useful definition of light pollution as "…the experience of light in the wrong place…", though it does not confine its analysis to light pollution but rather the question of increasing levels of artificial light in general. Likewise, this project does not seek to classify artificial light into "wanted" and "unwanted" categories but rather seeks to establish overall levels of artificial lighting in Ireland.

In recent years, concerns about excessive levels of artificial lighting have driven legislation in countries including France as well as leading to the EU, beginning the STARS4ALL programme. The United States National Oceanic and Atmospheric Administration (NOAA) published research in Nature in 2010 linking excessive use of artificial light in cities with increased levels of air pollution [2].

Satellite data on artificial light emissions has been collected and used to measure artificial light levels for a considerable period of time. The US Defence Meteorological Satellite Program (DSMP), a series of high-resolution military weather satellites, began publishing night light images of Earth from the early 1990s. This eventually led to Cinzano and Falchi's work in the early 2000s developing a World Atlas of artificial light measurements [3] using satellite imagery and instrumentation, which began with a map of artificial light in Europe. Therefore, while satellite imagery isn't the only way of measuring artificial light (ground measurements are also used), it is still a tried and tested method.

The NOAA's VIIRS-DND [4] [5] (Satellite Visible Infrared Imaging Radiometer Suite Day-Night Band) system superseded the DSMP data on artificial light emissions, which had been available from 1992 to 2013. The World Atlas was updated in 2016 to take

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account of improvements in satellite measurement of artificial light, including the VIIRS DNB dataset used in this project [6].

2. METHODS

The project involved analysing the existing VIIRS-DNB monthly datasets using open-source R Graphical Information System (GIS) packages in conjunction with Irish mapping and boundary data to extract summary statistics at various geographical levels.

2.1. Data Source

The monthly VIIRS-DNB datasets contains the following relevant variables:

1. Latitude and longitude of measurements at 1km x 1km grid resolution. This resolution means that extremely low geographical level analysis (such as street or Census small areas) is not feasible but given that it is not possible to identify buildings or individuals from this dataset, disclosure control concerns are also minimised.

2. The average monthly composite cloud-free radiance figure. The unit is nanoWatt per square centimetre per square radian (nW/cm2/sr). A typical value for a rural area may be less than 5, while a city centre may have values well above 50.

3. The number of cloud free days in each month. Statistics based on visual light range collected by satellite data (such as light emissions and land use analysis) are most accurate when clouds are absent ("cloud-free") from the sky.

In terms of technical specifications, the datasets are provided using the standard TIFF raster format which simplifies the analysis process associated with the data. Due to their standard format and structure, the datasets can be combined with other GIS sources to permit the production of detailed statistics both at a national and international level.

2.2. Methods used

The VIIRS-DNB dataset has already been classified and coded as monthly cloud-free averages based on nightly VIIRS-DNB measurements. These datasets were integrated with OSI boundary files (e.g. counties, settlements, electoral divisions etc.) using the 'SF' R package to permit geographical analysis. Next, the R raster package was used to generate summary light emissions statistics.

By overlapping the light emissions data points on the OSI boundary files it is possible to produce average artificial light estimates for the areas in these boundary files. Mapping files are also created in R using R temperature maps. These are graphical representations of the overlaid OSI and VIIRS-DNB datasets. The use of 'SF' and the 'Raster' R package allows processing of raster images.

R was chosen as it is open source and there are already widespread resources available on coding and analysing satellite imagery. It also allows for the use of an R server which makes it easier to process the VIIRS-DNB dataset, although this project was conducted on a desktop PC. The summary output files also exist in tabular CSV files, which also include the detailed EU light emissions statistics.

The process validation had three elements – (a) detailed study of theoretical basis of the VIIRS-DNB dataset; (b) consultation with an external advisor on the approach taken and (c) comparison of the light emissions with pre-existing data. For example, satellite

estimates areas of Ireland designated as low emissions "Deep Sky Reserves" areas were extremely low, as expected. Likewise, city centre areas showed high emission.

3. RESULTS

The following table shows Irish Local Electoral Areas (population of roughly 30-40,000) with high and low average artificial light emissions

Table 1. LEAs with highest and lowest average light emissions (nW/cm^2/sr)

LEA - Top 5	COUNTY	January 2019 Light Emissions nW/cm^2/sr
PEMBROKE SOUTH DOCK	Dublin	69.940
NORTH INNER CITY	Dublin	59.147
CRUMLIN KIMMAGE	Dublin	38.811
RATHGAR RATHMINES	Dublin	31.855
TALLAGHT CENTRAL	Dublin	26.713
LEA – Bottom 10		
WEST CORK	Cork	0.484
BALLINAMORE	Leitrim	0.471
CONAMARA	Galway	0.457
WEST MAYO	Mayo	0.453
SOUTH AND WEST KERRY	Kerry	0.418

Figure 1. Artificial Light Emissions mapped by Dublin Electoral Divisions January 2019 Unit nW/cm^2/sr

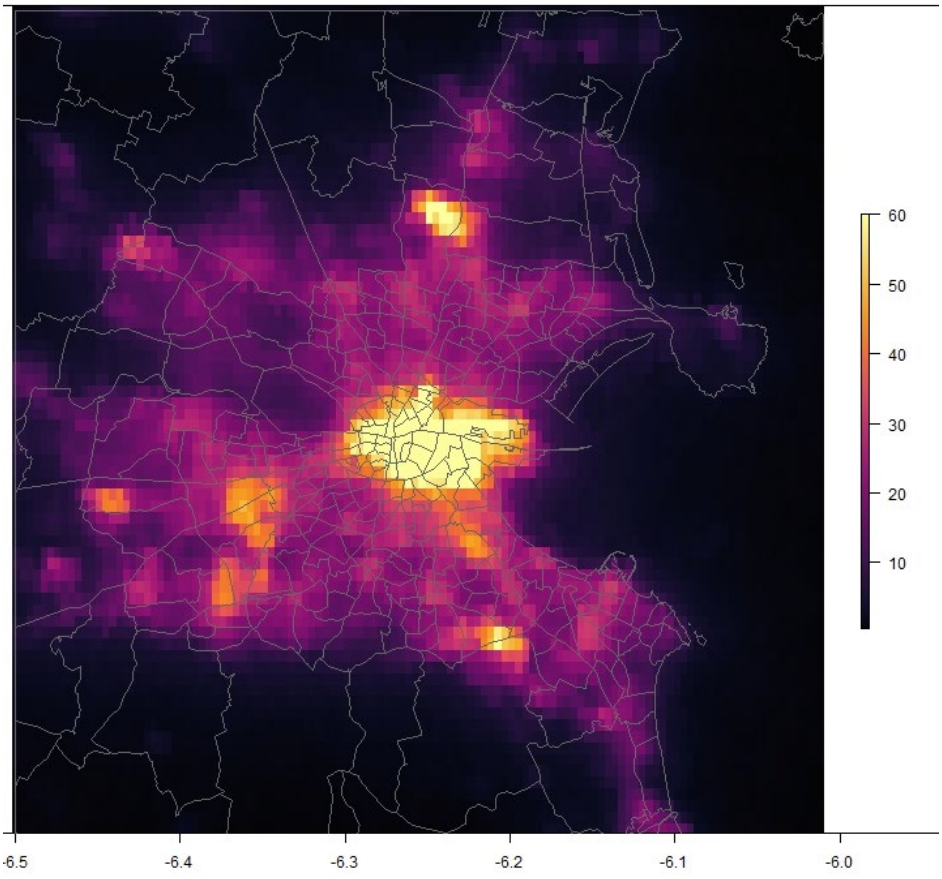
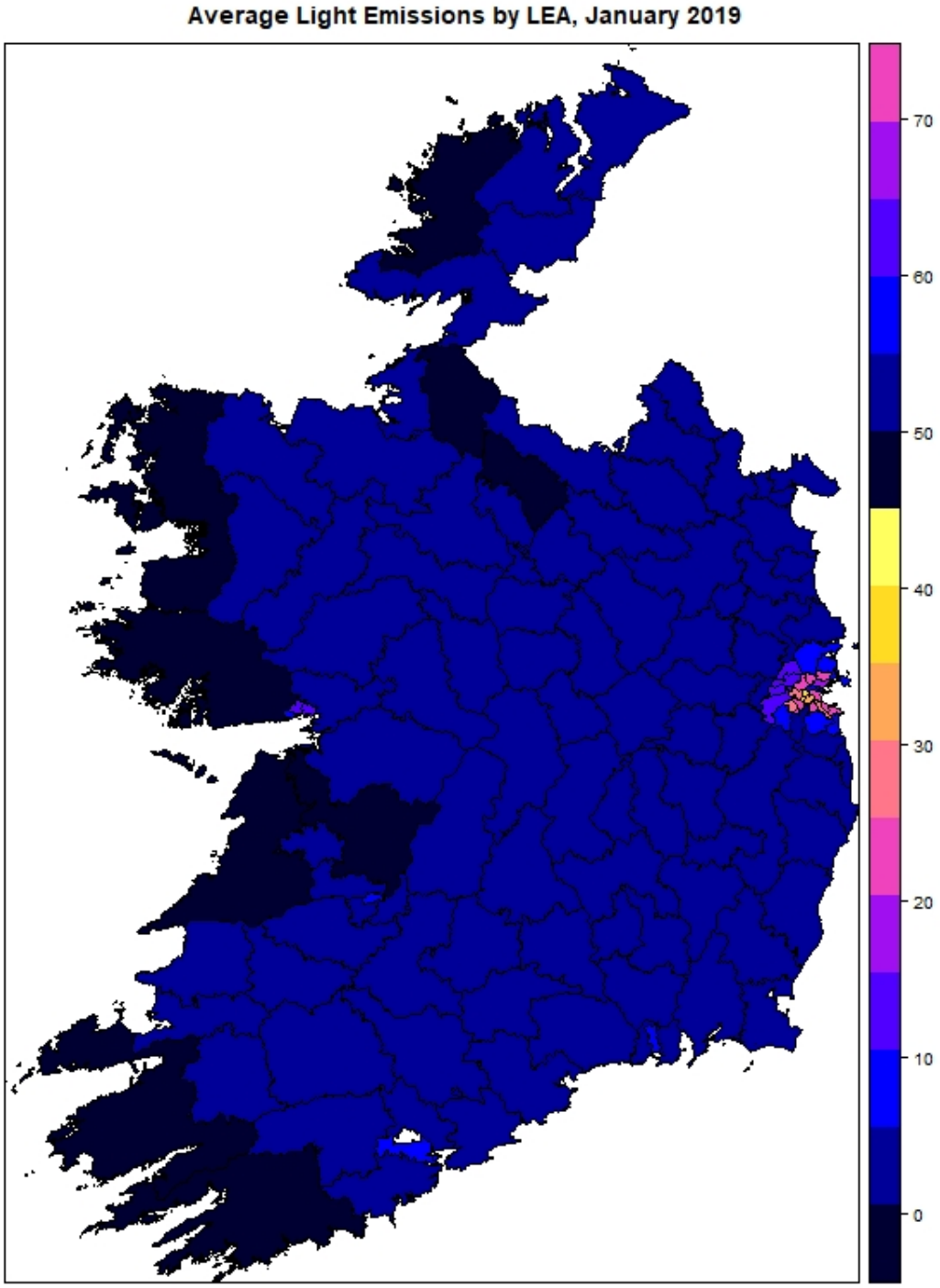


Figure 2. Artificial Light Emissions mapped by Local Electoral Area January 2019 Unit nW/cm^2/sr



4. CONCLUSIONS

This project shows that high quality statistics can be produced for light emissions using open-source satellite data and limited IT resources (one desktop PC). There have already been numerous studies establishing the viability of satellite measurements in determining light levels. In a 2012 study of Pakistani cities, Butt examined the relationship between satellite light measurements and light pollution [7]. Simons and Travicore showed a strong correlation between atmospheric light measurements and satellite measurements, while noting the possibility of variance [8].

The VIIRS-DNB dataset has a reputation as a high quality publicly available dataset. A detailed quantitative analysis in 2014 by Cao and Bia [5] measured it for accuracy and concluded that "light radiant power computed from the VIIRS DNB data matched relatively well with independent assessments based on the in situ light installations", while noting the potential limitations of the dataset with relation to measuring certain blue light wavelengths which may lead to reduced sensitivity for LED lighting [5].

In conclusion, while subject to caveats, satellite imagery, in particular the VIIRS-DNB datasets, seem to provide a viable approach for measuring artificial light levels. Its usefulness is enhanced by the fact that the VIIRS-DNB dataset is regular, long-term, open source data imagery with the associated advantages in terms of cost and transparency. Moreover the VIIRS-DNB dataset is based on a particular satellite system and it is quite probable that any new system will lead to further improvements in data quality. Of course, at that point a full evaluation of the project would be needed, particularly for discontinuities it introduced into any time series.

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