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To cite this article: X Zhou et al 2017 IOP Conf. Ser.: Earth Environ. Sci. 57 012021

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NPP-VIIRS DNB-based reallocating subpopulations to mercury in Urumqi city cluster, central Asia

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Abstract. Accurate and update assignment of population-related environmental matters onto fine grid cells in oasis cities of arid areas remains challenging. We present the approach based on Suomi National Polar-orbiting Partnership (S-NPP) -Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB) to reallocate population onto a regular finer surface. The number of potential population to the mercury were reallocated onto 0.1x0.1 km reference grid in Urumqi city cluster of China’s Xinjiang, central Asia. The result of Monte Carlo modelling indicated that the range of 0.5 to 2.4 million people was reliable. The study highlights that the NPP-VIIRS DNB-based multi-layered, dasymetric, spatial method enhances our abilities to remotely estimate the distribution and size of target population at the street-level scale and has the potential to transform control strategies for epidemiology, public policy and other socioeconomic fields.

1. Introduction

Mercury (Hg) is a highly potent neurotoxin that readily elevate potentially toxic levels to affect human and environmental health [1, 2]. About one third of the world’s land surface is arid and semi-arid. There are not specific study on the environmental impacts of Hg in developing areas with rapid urbanization in these remote regions [3]. Urumqi city cluster is an emerging competitive key areas of central Asia. Over the past 35 years, its population grew from 1.02 to 3.11 million and its gross domestic product (GDP) increased from 0.82 to 245 billion Yuan. Coal-based industrial sector is a major source of Hg in the city cluster, especially coal-based polyvinyl chloride (PVC) manufacture [4-6]. The coal-based PVC production of the city cluster is also one of the most significant consumers of Hg in China [5]. Considerable concerns about the adverse impacts of Hg-containing wastes and fly ash related to the manufacture on environmental and human health. However, accurate and update assignment of population-related environmental matters onto grid cells within cities remains challenging.

High-resolution spatiotemporal population data can be particularly difficult to access for remote areas and low-income areas due to methodological insufficiencies [7,8]. In general, methods of
Censuses and surveys to measure human population can yield dramatic discrepancies when calculating important health metrics and interventions. Combining across data sources can improve population estimates in accuracy and spatiotemporal resolution. For example, the Gridded Population of the World (GPW) [9], the Global Rural Urban Mapping Project (GRUMP) [10], LandScan [11], and WorldPop [12]. Recently, mobile phone data are introduced to measure movement, but access to phone data is highly restricted [13].

Daily, serial satellite images of nighttime lights provide a direct, quantifiable indicator of human presence [14, 15]. These products mainly include Defense Meteorological Satellite Program (DMSP) – Operational Linescan System (OLS) nighttime stable light product and Suomi National Polar-orbiting Partnership (S-NPP) – Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB). The DMSP – OLS nighttime stable light data is limited in its application to local and within city scales due to its coarse spatial resolution (3 km pixels), overglow (the “spilling” of light from built-up areas into non-lit areas), saturation in urban areas and intra-sensor calibration problems [16]. The NPP/VIIRS–DNB launched in October 2011 overcomes saturation problem in nighttime light data. As a new-generation nighttime light data, the NPP-VIIRS data have a wider radiometric detection range and a higher spatial resolution (0.74 km pixels) compared with the DMSP-OLS data, supporting a more accurate fine-scale estimations [17].

This study proposes the NPP/VIIRS-DNB-based multi-layered, dasymetric, spatial approach to reallocate population onto 0.1 × 0.1 kilometer (km) reference grid, improving population estimates in accuracy and spatial resolution within the city cluster of the remote arid region.

2. Methods

2.1. Site description
Xinjiang Uygur Autonomous Region (XUAR) is the China’s largest administrative unit and is a valuable resource hub in the central and western Asia. Urumqi, capital of the XUAR, has been an emerging area in rapid urbanization and industrialization over the most recent decade. The air quality in the Urumqi city ranked as the second poorest in China and the 61st poorest in 1,600 cities worldwide from 2010 to 2013, reported by the World Health Organization’s (WHO’s). Thus, the Urumqi city cluster (e.g., Urumqi and adjacent Wujiaqu and Fukang city) is one of key regions launched by the China 12th Five-Year Plan to reduce air pollution. In addition, more than 40% of soil Hg is released from coal-based chemical industries [4-6]. There is a deep concern on the particulate matter re-suspension in the windy seasons of the arid environment.

2.2. Sampling, test and data collection

2.2.1. Sampling
Sampling sites of this study were selected according to the basic type of land use from China Code for Classification of Urban Land Use and Planning Standards of Development Land (GB 50137-2011), and come from urban development land (residential, green space, municipal utilities, industrial and manufacturing, street and transportation, commercial and business facilities, administration and public services, logistics and warehouse) and non-development land. The interval of measurement be <5 km to ensure the enough high accuracy of spatial analysis. Accordingly, the average sampling grid was designed a square mesh with sampling points at approximately 5.0 km × 5.0 km with the actual sampling sites randomly selected near the target sampling sites in each grid cell. The samples were located in GPS of ArcGIS10.2 by the connection of Landsat 7 satellite images and hand-held GPSs.

Topsoil samples of the whole study area were collected from 0-20 cm depth with a steel sampler and a wooden shovel. Each sample, approximately 2 kg composite soil was collected into plastic bags prior to the laboratory processing. The soil samples were air-dried, grinded, and then sieved through <1.7 mm nylon sieve to remove stones, coarse materials, and other debris. A sub-sample of the sieved soils were grounded to < 0.15 mm by an agate grinder for total mercury (THg) analysis of the bulk soils.

2.2.2. Testing of total mercury concentration
THg in bulk soil were analyzed by a Lumex RA 915+ mercury analyzer (Lumex Ltd., Russia). The detection limit for THg was 0.5 ng·g⁻¹. Quality control for THg analysis was addressed using certified reference material (GBW07426, Xinjiang Soil), with an average recovery of 98.0 ± 1.8% (2σ, n=5). Quality assurance and quality control of THg determinations were carried out using duplicates and certified reference materials.

2.2.3. Data collection
The NPP-VIIRS data were obtained from website of NOAA/NGDC (http://ngdc.noaa.gov/eog/viirs). Landsat-8 imagery were obtained from website of USGS (http://landsat.usgs.gov). Population census and other auxiliary information were available from National Bureau of Statistics of China and Bureau of Statistics of XUAR.

The NPP-VIIRS imagery is a preliminary product, containing lights from cities, towns, transportation corridors, gas flares, biomass burning and background noise, and the reflectance of light from bright surfaces. The highest DN value of 235.13 is used as a threshold to correct the outliers [16]. The pixels whose DN value is larger than 235.14 in the NPP-VIIRS data are assigned as a new value. The new value is the maximal DN value within the pixel’s immediate eight neighbours. The pixels with negative DN values in NPP-VIIRS data are assigned the value of 0. Data of built-up regions of the Landsat-8 Operational Land Imager (OLI) imagery are classified using the approach of Support Vector Machine.
2.3. **Downscaling and data integration**

The physical exposures are represented through the inventory of buildings in urban and rural areas called built-up environment. A multi-layered, dasymetric, spatial approach is used to reallocate population onto a regular finer surface (reference grid) by the following workflow:

**Step1: Define population of built-up environment**

The mask based on the Landsat-8 OLI imagery are used to delimit the cells representing the built-up areas. It was employed to extract the NPP-VIIRS DNB-based population data. A regression model is used to estimate population using the satellite images of nighttime lights in this study (Equation 1)

\[
P_{\text{census}} = f \left( \sum R_{\text{VIIRS}} \right)
\]

where \( P_{\text{census}} \) is the statistical population of per administrative unit, \( \sum R_{\text{VIIRS}} \) denotes the total radiometric of NPP-VIIRS nighttime light of per administrative unit, \( f \) is the regression coefficient.

**Step2: Aggregation onto the 0.1 km × 0.1 km reference grid**

There are different between the estimated population and the population census of each administrative unit due to error of the linear regression. Therefore, the percentage of the statistical population and the total population to the grid cell in administrative units is calculated using the following Equation 2 and the total population are successively corrected onto the 0.1 km × 0.1 km reference grid (Equation 3).

\[
w_A = \frac{P_{\text{census}}}{\sum_{(A)} Pop(x,y)}
\]

\[
\text{Grid} \sum_{(A)} Pop(x,y) = \text{Grid} \sum_{(A)} Pop(x,y) \times w_A
\]

where: \( w_A \) is the percentage of the statistical population and the total population to the grid cell in per administrative unit, \( P_{\text{census}} \) is the census population of per administrative unit, \( \sum_{(A)} Pop(x,y) \) denotes the total population living the grid cell per administrative unit, \( \sum_{(A)} Pop(x,y) \) denotes the corrected total population living the grid cell per administrative unit.

**Step3: Dasymetric of the population distribution per the element at risk**

The following algorithm employs to downscaling a DPE to the grid cell for evaluating the number of potential population damage related to the elements at risk (Equation 4).

\[
DPE(x,y) = Pop(x,y) \times E(x,y)
\]

where: \( DPE(x,y) \) is population per the element at risk per cell at x,y position, \( Pop(x,y) \) denotes the corrected population living per cell, \( E(x,y) \) denotes the element at risk per cell at x,y position.

After the above operation, each cell represents the number of potential exposed persons for the element at risk in a portion of built-up areas.
3. Results and Discussion

As shown the scatter diagram of linear regression analysis (Figure 1.), the DNB-POP relationship were evaluated in the district and town units. The $R^2$ value of the corrected NPP-VIIRS DNB and POP data was 0.8689. The spatial distribution of gridded street-level population was allocated (Figure 2. Left). The Monte Carlo modeling indicated that the range of 0.5 to 2.4 million people was reliable (Figure 2. Right). The polluted area of soil THg reached 425 square kilometer ($km^2$), which concentrations exceed the GradeII limits (for pH $> 6.5$) (GB15618-1995) (EQSS). Based on the above operations, the subpopulation to Hg at risk were reallocated onto 0.1 km $\times$ 0.1 km reference grid. The hotspots of subpopulation to Hg were traced in the Urumqi inner city and industrial areas (Figure 3).

**Figure 1.** The scatter diagram of linear regression analysis between the total nighttime light of corrected NPP-VIIRS data and the population census.

**Figure 2.** The spatial distribution of the gridded street-level population (Left) and Monte Carlo modeling (Right).

Unlike the DMSP-OLS data, the varied DN values in NPP-VIIRS data can reflect human activities and provide a more accurate population estimations. The more reasonable estimated results within the cities mainly benefit from the higher resolution and radiometric detection range of NPP-VIIRS nighttime light data. The overestimation population of the study area may affects the accuracy.
of the population size due to deserts, dry riverbeds, mining fields and the original noises of NPP-VIIRS data. Some methods have been proposed for removing the noise or detecting wildfires from NPP-VIIRS data [17]. Those works would benefit to improve the quality of the new-generation nighttime light data in wider fields in the future.

![Figure 3](image)

**Figure 3.** The gridded map of Hg concentration exceed the GradeII limits (Left) and the number of the subpopulation to Hg at risk were reallocated onto 0.1 km × 0.1 km reference grid (Right).

### 4. Conclusions

Gaining an understanding of local subpopulation sizes and patterns helps make informed changes in the planning of epidemiology, public policy and other socioeconomic aspects. The characteristics of target susceptible subpopulations at the street-levels scale can be remotely measured with widely available NPP/VIIRS satellite imagery of anthropogenic lights, and can be applied to other health efforts in areas without detailed spatial epidemiological data. The empirical relationship between the nighttime light data and population cannot be viewed as an absolute law. The reliability of statistical data is also a major factor affecting the reallocating accuracy. There is still room for improving the data quality, and more methods could be applied to the correction process of the emerging data source in wider fields.

### Acknowledgements

This project was jointly supported by the National Natural Science Foundation of China (Grant No. 21207155), the Science Foundation of the Chinese Desert Meteorology (Grant No.Sqj2015014), and the West Light Foundation of the Chinese Academy of Sciences (Grant No. RCPY 201104).

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