Measuring and Mapping Light Pollution at a Local Scale

MSc. Thesis; Stefan M. Bruehlmann (sb@dentaku.ch)
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15 to 20 min. presentation followed by questions
1. Introduction
Inquinamento luminoso in Svizzera
Pollution lumineuse en Suisse
Lichtverschmutzung in der Schweiz

La mappa mostra l'inquinamento luminoso in base alla diminuzione della visibilità delle stelle.
La carte montre la pollution lumineuse sur la base de la diminution de la visibilité des étoiles.
Die Karte zeigt die Ausdehnung der Lichtverschmutzung anhand der Abnahme der Anzahl sichtbarer Sterne.

Carlo Lapi (Italian Institute of Science and Technology)
LaPresse (IT)
EVTU (Tesi di Laurea in Ingegneria Ambientale)

Basis der Karte: Satellitenbilder (DMSP) / Base de la carte: photos satellites (DMSP)
Situation 1998 / Situation 1998
Revisione/Revision: Mappa Svizzera / Superposition de la carte Suisse / Überprüfung der Schweizerkarte

I livelli corrispondono ad una perdita di magnitudine
Les niveaux correspondent à une perte de magnitude
Die Stufen entsprechen einem Magnitudeverlust
(in magnitudine V x 5 magnitudine V/vis Magnitudine V):

Il numero di stelle visibili si dimezza grossomodo ogni circa 0.6 magnitudini perdute
Le nombre d'étoiles visibles diminue de 50% environ tous les 0.6 magnitudes perdues
Die Anzahl sichtbare Sterne wird pro ca. 0.6 verlorene Magnitude auf die Hälfte reduziert.
Light pollution is a local phenomenon

Available maps are very coarse and generalized

There are only a few light pollution maps existing at a local (neighborhood) level
2. Light Pollution
Light Pollution

**Definition**: «that part of light that ends up in the sky and is consequently not for functional use»
Detriment effects

- Health hazards
- Nocturnal insects
- Ecological consequences
- Bird migration
- Consequences for astronomers
- Loss of the night

Photo: Jim Richardson
3. Literature

Influencing studies:

Cinzano et al. (Università di Padova, Italy)
- World Atlas of the Night Sky Brightness
- Using satellite data and modelling techniques
- Large scale

Zamorano et al. (2011) (Universidad Complutense de Madrid)
- Field measurements & ISS image analysis
- Quality of ISS image
- Large scale

Kyba et al. (Freie Universität Berlin)
- Aerial photo survey
- Land use analysis
- Large scale

& several regional studies (Geneva, Hongkong, Japan, …)
4. Research question

What is a suitable set-up of a **GIS-based model** to produce an upward light emission map at a local scale and what **significance** can the map achieve?

- What are the spatial distribution and the parameters of the light sources?
- What accuracy can the model output reach?
- What are potential advantages and disadvantages of the model?
- What are potential fields of application?
5. Research method

Observation | Measurements | Modelling | Visualization | Validation | Improvement

- Desk / Field research
- ArcGIS

- Observation
- Measurements
- Modelling
- Visualization
- Validation

- Understanding light sources
- Propagation of light
  - Measurement equipment
  - Measurement strategy
  - Modelling of relevant features
  - Data quality and data processing

- Reference image
- Analysis

- Vector Data
  - Swisstopo; OSM, local Geoportals
Research Area

Source: map.geo.admin.ch
Research Area

![Map of Winterthur area with research area highlighted]

104.7 km²

Source: map.geo.admin.ch
5. Research method

**Observation** | Measurements | Modelling | Visualization | Validation | Improvement

Motorway | Residential street | Sports fields

*Photos: Stefan M. Bruehlmann*
5. Research method

**Observation** | **Measurements** | **Modelling** | **Visualization** | **Validation** | **Improvement**
--- | --- | --- | --- | --- | ---
Visual inspection of aerial photos | Data Input for modelling

<table>
<thead>
<tr>
<th>Category</th>
<th>Interval [m]</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Class A Road</td>
<td>50.0</td>
<td>lux</td>
</tr>
<tr>
<td>2. Class 1 Road</td>
<td>30.0</td>
<td>lux</td>
</tr>
<tr>
<td>3. Class 2 Road</td>
<td>30.0</td>
<td>lux</td>
</tr>
<tr>
<td>4. Class Q Road</td>
<td>30.0</td>
<td>lux</td>
</tr>
<tr>
<td>5. Residential Buildings</td>
<td>15.0</td>
<td>lux</td>
</tr>
<tr>
<td>6. Industrial Buildings</td>
<td>15.0</td>
<td>lux</td>
</tr>
<tr>
<td>7. Train station area</td>
<td>30.0</td>
<td>lux</td>
</tr>
<tr>
<td>8. Sports pitch</td>
<td>25.0</td>
<td>lux</td>
</tr>
<tr>
<td>9. Parking</td>
<td>20.0</td>
<td>lux</td>
</tr>
<tr>
<td>10. Old Town</td>
<td>15.0</td>
<td>lux</td>
</tr>
</tbody>
</table>
5. Research method

Observation | **Measurements** | Modelling | Visualization | Validation | Improvement

① Measurement procedure in the field

Illustration: Stefan M. Bruehlmann

② Data processing

Illustration:

③ Data processing

Illustration:
Vector Base Data

Observation | Measurements | **Modelling** | Visualization | Validation | Improvement

**VECTOR25**

VECTOR25 reproduces man-made and natural features in a flexible vector format and is especially suitable for applications in geographic information systems (GIS)

Road network  
Other traffic  
Primary surfaces  
Hedges and trees  
Single objects  

Railway network  
Hydrological network  
Buildings  
Facilities

Source: swisstopo
5. Research method

Observation | Measurements | **Modelling** | Visualization | Validation | Improvement

**Polyline:** ‘Streets’, ‘Buildings’

**Polygon:** ‘Parking’, ‘Sports fields’
5. Research method

Observation | Measurements | **Modelling** | Visualization | Validation | Improvement

1. Euclidean Distance

2. Application of ‘lux’ and ‘spread’
5. Research method

Observation | Measurements | Modelling | Visualization | Validation | Improvement

Albedo reflectance
- Asphalt
- Vegetation
- Bare ground
5. Research method

Observation | Measurements | Modelling | Visualization | Validation | Improvement

<table>
<thead>
<tr>
<th>Category</th>
<th>Light points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Class A Road</td>
<td>418</td>
</tr>
<tr>
<td>2. Class 1 Road</td>
<td>2'097</td>
</tr>
<tr>
<td>3. Class 2 Road</td>
<td>6'051</td>
</tr>
<tr>
<td>4. Class Q Road</td>
<td>6'518</td>
</tr>
<tr>
<td>5. Residential Buildings</td>
<td>67'710</td>
</tr>
<tr>
<td>6. Industrial Buildings</td>
<td>2'714</td>
</tr>
<tr>
<td>7. Train station area</td>
<td>583</td>
</tr>
<tr>
<td>8. Sports pitch</td>
<td>738</td>
</tr>
<tr>
<td>9. Parking</td>
<td>601</td>
</tr>
<tr>
<td>10. Old Town</td>
<td>1’179</td>
</tr>
<tr>
<td>Total</td>
<td>88’609</td>
</tr>
</tbody>
</table>
5. Research method

Observation | Measurements | Modelling | **Visualization** | Validation | Improvement

RGB Aerial photo of Geneva

*Source: Ville de Genève*
5. Research method

Observation | Measurements | Modelling | Visualization | Validation | Improvement

Source: esa
Current ISS position: http://iss.astroviewer.net/index.php
5. Research method

Observation | Measurements | Modelling | Visualization | Validation | Improvement

Source: Google Earth
6. Results & Analysis
Modelled:
City of Winterthur

Orthophoto:
City center Geneva

Source: Light Pollution Model

Source: Ville de Genève
6. Results & Analysis

**Comparison ISS | Hotspots**

![RGB image 'green band']

<table>
<thead>
<tr>
<th>RGB image 'green band'</th>
<th>Model output</th>
<th>Intensity classification</th>
<th>Reclassified Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>255</td>
<td>max Lux</td>
<td>high</td>
<td>5</td>
</tr>
<tr>
<td>0</td>
<td>min Lux</td>
<td>medium/high</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>medium</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>medium/low</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>low</td>
<td>1</td>
</tr>
</tbody>
</table>

![Model output]

![RGB image]
6. Results & Analysis

Comparison ISS | Hotspots
## Results & Analysis

**Comparison ISS | Hotspots**

<table>
<thead>
<tr>
<th>Deviation Class</th>
<th>Description</th>
<th>Pixel count</th>
<th>Pixel [%] of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>-4</td>
<td>Very high (ISS image is brighter)</td>
<td>80</td>
<td>0.2</td>
</tr>
<tr>
<td>-3</td>
<td>high</td>
<td>391</td>
<td>1.1</td>
</tr>
<tr>
<td>-2</td>
<td>moderate</td>
<td>1,417</td>
<td>4.0</td>
</tr>
<tr>
<td>-1</td>
<td>small</td>
<td>4,996</td>
<td>14.0</td>
</tr>
<tr>
<td>0</td>
<td><strong>none</strong></td>
<td><strong>27,012</strong></td>
<td><strong>75.7</strong></td>
</tr>
<tr>
<td>1</td>
<td>small</td>
<td>1,240</td>
<td>3.5</td>
</tr>
<tr>
<td>2</td>
<td>moderate</td>
<td>388</td>
<td>1.1</td>
</tr>
<tr>
<td>3</td>
<td>high</td>
<td>145</td>
<td>0.4</td>
</tr>
<tr>
<td>4</td>
<td>Very high (model output is brighter)</td>
<td>4</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>35,710</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>
6. Results & Analysis

Comparison ISS | Hotspots
6. Results & Analysis

Comparison ISS | Hotspots
6. Results & Analysis

Comparison ISS | Hotspots

[B1/a image]

[B1/b image]

[B1/c image]
7. Conclusions
7. Conclusions

- Current satellite imagery does not provide a sufficient detail to map light pollution at a local scale.
7. Conclusions

- Satellite imagery is currently not sufficient for the visualization of light pollution at a local scale.

- A modelled approach proves to be promising.

- Knowledge about the local situation is crucial.

- Dealing with temporal exceptions is an issue.

- Integration of other tools (e.g. Calculux) could be beneficial.
8. Applications

### Awareness

<table>
<thead>
<tr>
<th>Application</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make the light pollution issue known</td>
<td>Media coverage</td>
</tr>
<tr>
<td>Inform the citizens</td>
<td>Layer in Geo-portals</td>
</tr>
</tbody>
</table>

### Special interest groups

<table>
<thead>
<tr>
<th>Application</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astronomers</td>
<td>Night sky brightness map</td>
</tr>
<tr>
<td>Conservationists / Biologists</td>
<td>Input for analysis (example Geneva)</td>
</tr>
</tbody>
</table>

### Optimizing light emissions

<table>
<thead>
<tr>
<th>Application</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting scenarios</td>
<td>Visualize different lighting policies (e.g. LED)</td>
</tr>
<tr>
<td>Calculation of energy consumption</td>
<td>Optimize energy use</td>
</tr>
</tbody>
</table>
9. Further research

- Acquire further knowledge on characteristics and spatial distribution of light sources.

- Include a more sophisticated pattern of ‘light spread’ using specific light planning tools (e.g. Calculux)
9. Further research (2)

- Enhance model by comparing it to a ‘high quality’ image from the ISS (or orthophoto)

- Translate the modelled results into a ‘Night Sky Brightness’ map
Night Sky Brightness Map (measured with Sky Quality Meter)

Measurements/Cartography: Stefan M. Bruehlmann

Natural unpolluted starry sky