Earth by Night: Exploring Night Light Satellites Imagery for Water Management

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1 Introduction

1.1 Background

Integrated Water Resources Management requires a good understanding of supply and demand of water. On a global scale, the natural environment is the largest consumer of fresh water resources by evapotranspiration of landscapes and vegetation. The largest consumer of abstracted water by humans from rivers, lakes and groundwater is the irrigated agriculture. Remote sensing from satellites, planes and flying sensors (drones) can help to understand water supply and demand issues better, both for operational as well as strategic planning (Droogers et al., 2009; Wu et al., 2014). Over the last 50 years substantial progress has been made by observing water related characteristics from remote sensing and typical examples include crop status, growing stage, water deficit and water consumption by evapotranspiration e.g. (Droogers et al., 2012; Kite and Droogers, 2000) .

Imagery from satellites used are normally the day-light ones and the nigh-imagery are ignored. In fact, some satellites are orbiting in such a way that only day-light images are captured. However, there are a couple of satellites that based on the nature of their orbiting also acquire images during the night. Artificial night light has received some attention especially regarding the impact on ecology and human’s well-being (Gorelick et al., 2017; Proville et al., 2017), but usefulness for application in water management has not been explored so far.

So the objective of this explorative study is looking at the potential of satellites night imagery in providing additional information for water management.

1.2 Satellites and Sensors

Two satellites/sensors are used to observe night-light: DMSP (Pandey et al., 2017; Pok et al., 2017) and VIIRS (Levin and Zhang, 2017). A short description of those two is provided here, while the Appendix summarizes major features.

1.2.1 DMSP

The well-known older images of Earth at night (13) were based on an uncalibrated sensor from a defense satellite [Defense Meteorological Satellite Program (DMSP)], which had frequent and unrecorded changes in sensor gain and an intrinsic spatial resolution of 5 km and the more recent resolution of 1 km. DMSP satellites operated in a sun-synchronous orbit; passing over the north and south poles, the satellite would see different strips of the Earth at the same local time each day. The DMSP satellites had periods of roughly 101 minutes, so they would orbit the Earth 14.3 times in 24 hours. This period combined with the sun-synchronous orbit would have the satellite pass over the whole surface of the planet twice a day. The actual sensor that is used for the night light is the Operational Linescan System (OLS). A total of 18 DMSP satellites has been launched, while the last one (number 19) failed on its launch in 2014. It is unclear whether more DMSPs will be launched. Data from 1992 (F10) up to 2013 (F18) can be obtained from NOAA (see Appendix).

From the various bands and products it was decided to use the 'stable_lights' one, which is scaled between 1 and 63.

1.2.2 VIIRS

Visible Infrared Imaging Radiometer Suite (VIIRS) is the successor of the DMSP used for night light imagery. In fact, VIIRS is the sensor onboard of the Suomi National Polar-orbiting Partnership (Suomi NPP) weather satellite. VIIRS is capable of generating two data processing streams that result in two different sets of land products. One is produced by NOAA, and provides operational data for use by the National Weather Service. These are known as environmental data records (EDRs). The other stream is from NASA, and is intended to contribute to the larger scientific community. These are known as Earth System Data Records (ESDRs) (source: Wikipedia). Images that can be used for night light are acquired by the so-called nighttime sensor (also called the Day/Night Band, or DNB).

From the various bands and products it was decided to use the 'avg_rad' one from the Stray Light Corrected Nighttime, which has unit (nanoWatts/cm2/sr).

1.3 Methodology

The Google Earth Engine has been used to obtain the images and to do the first preliminary analysis. Google Earth Engine is a cloud computing platform for processing satellite imagery and other Earth observation data (Gorelick et al., 2017). It provides access to a large warehouse of satellite imagery and the computational power needed to analyze those images. The script used is shown in the Appendix.

Additional equations and coloring were undertaken by QGIS with special focus on the raster calculator.

2 Results

2.1 Netherlands

There is a substantial difference in images obtained by DMSP and VIIRS in terms of accuracy and resolution. DMSP has an intrinsic resolution of 5 km although data have been resampled to 1 km; resolution of VIIRS is 500 m. Moreover, DMSP imagery is not calibrated so only relative values are presented, while VIIRS has physical meaningful units (Watts/m2/sr). Moreover, DMSP images are obtainable from 1992 to 2013, while VIIRS started in 2014.

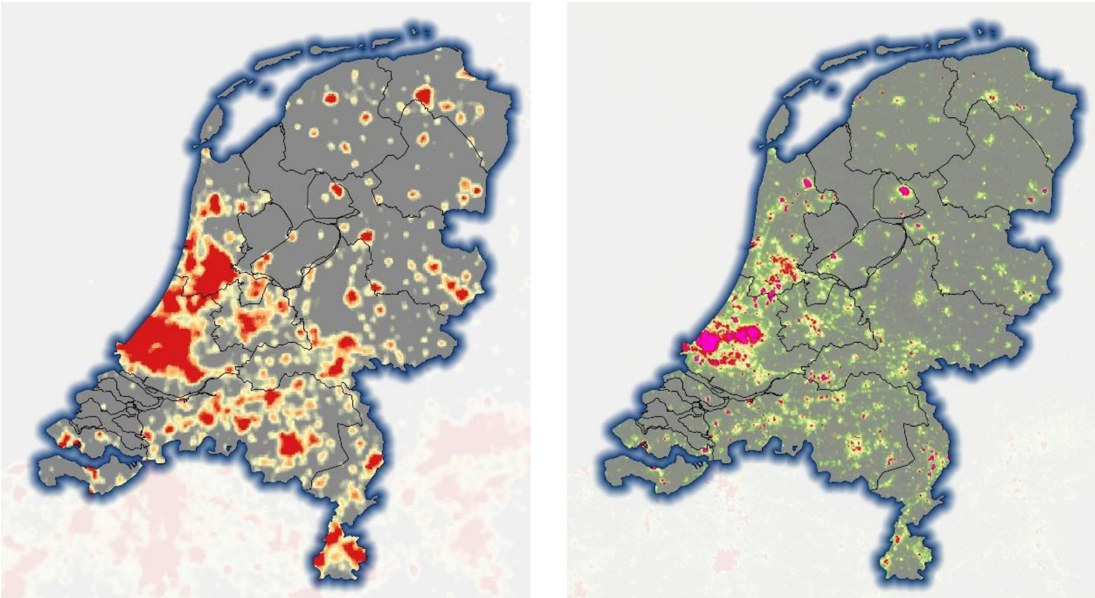

Figure 1. Comparison between DMSP (left) and VIIRS (right). For DMSP the Stable Lights composite 1992 is shown (no units). For VIIRS the Stray Light Corrected Nighttime composite 2016 is shown (nanoWatts/cm2/sr).

To increase the resolution of the DMSP images in order to get the same (higher) resolution as the VIIRS images a downscaling process has been performed. The relative difference between two DMSP images has been taken and this relative difference has been subsequently applied to the VIIRS images. This has been done using the Raster Calculator in QGIS. The following equations were used:

```
"NL_1992@1" / "NL_2013@1" * "NL_2014@1"
```

Where

`"NL_1992@1"` is the DMSP composite of 1992
`"NL_2013@1"` is the DMSP composite of 2013
`"NL_2014@1"` is the VIIRS composite of 2014

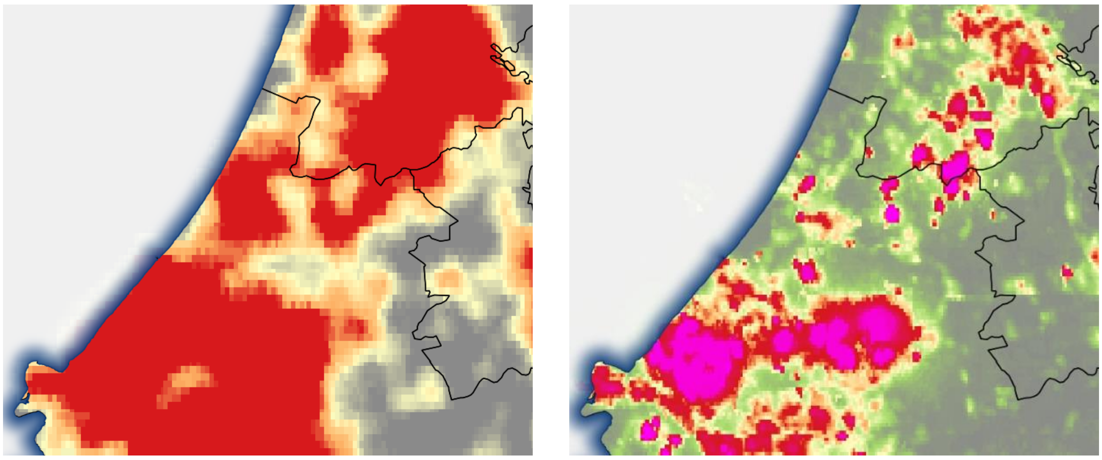

Figure 2. Result of the imagery sharpening showing the original DMSP 1992 composite (left) and the resampled 1992 one (right).

Based on these resampled imageries the evolution of night light over a period of about 25 years has been calculated (1992 to 2016). For this the absolute difference in night light is calculated using QGIS Raster Calculator:

```
"NL_2016@1" - "NL_1992@2"
```

Where

`"NL_2016@1"` is the VIIRS composite of 2016

`"NL_1992@2"` is the resampled DMSP composite of 1992

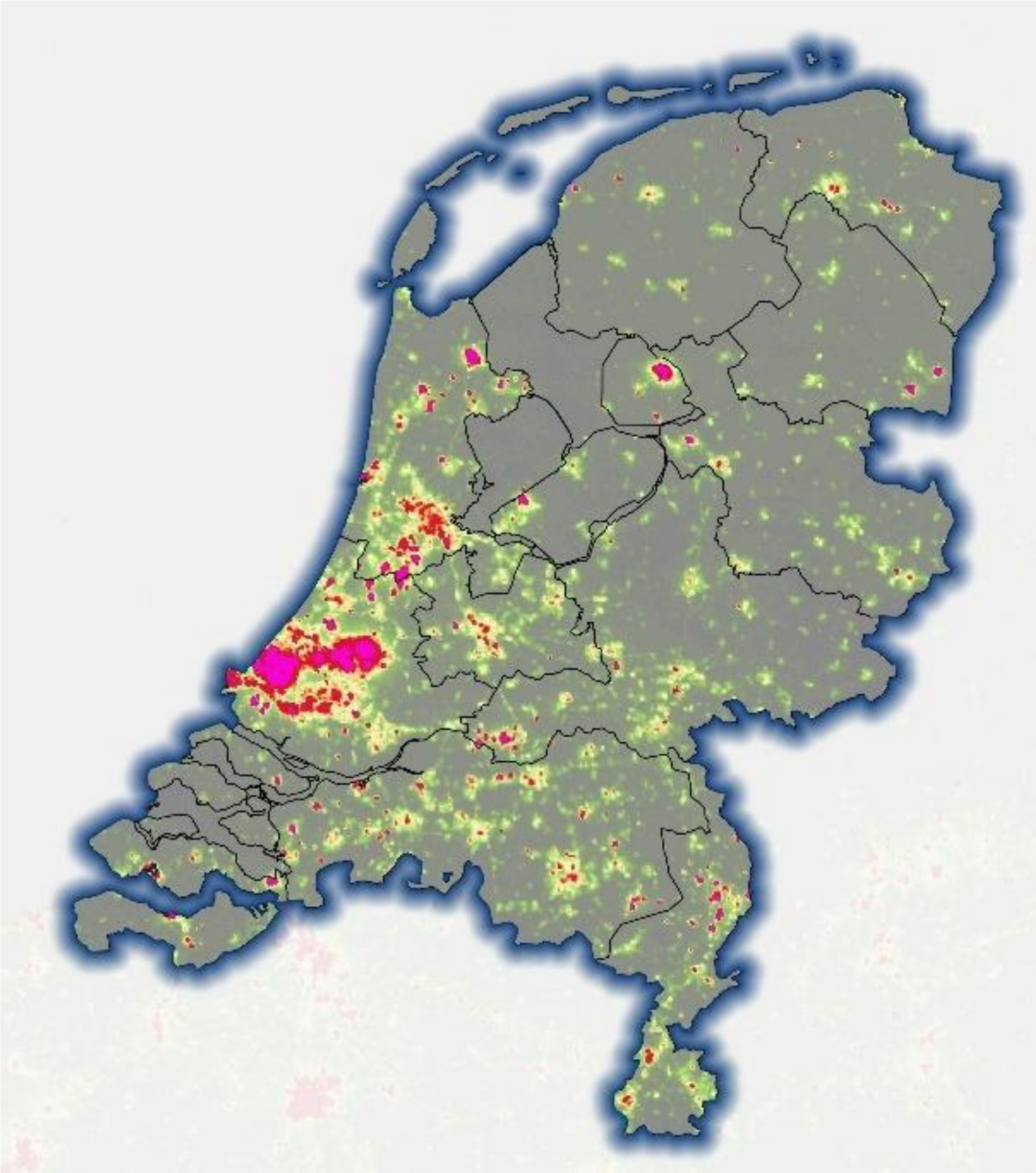

Figure 3. Artificial night light in the Netherlands in 2016 based on VIIRS satellite product Stray Light Corrected Nighttime.

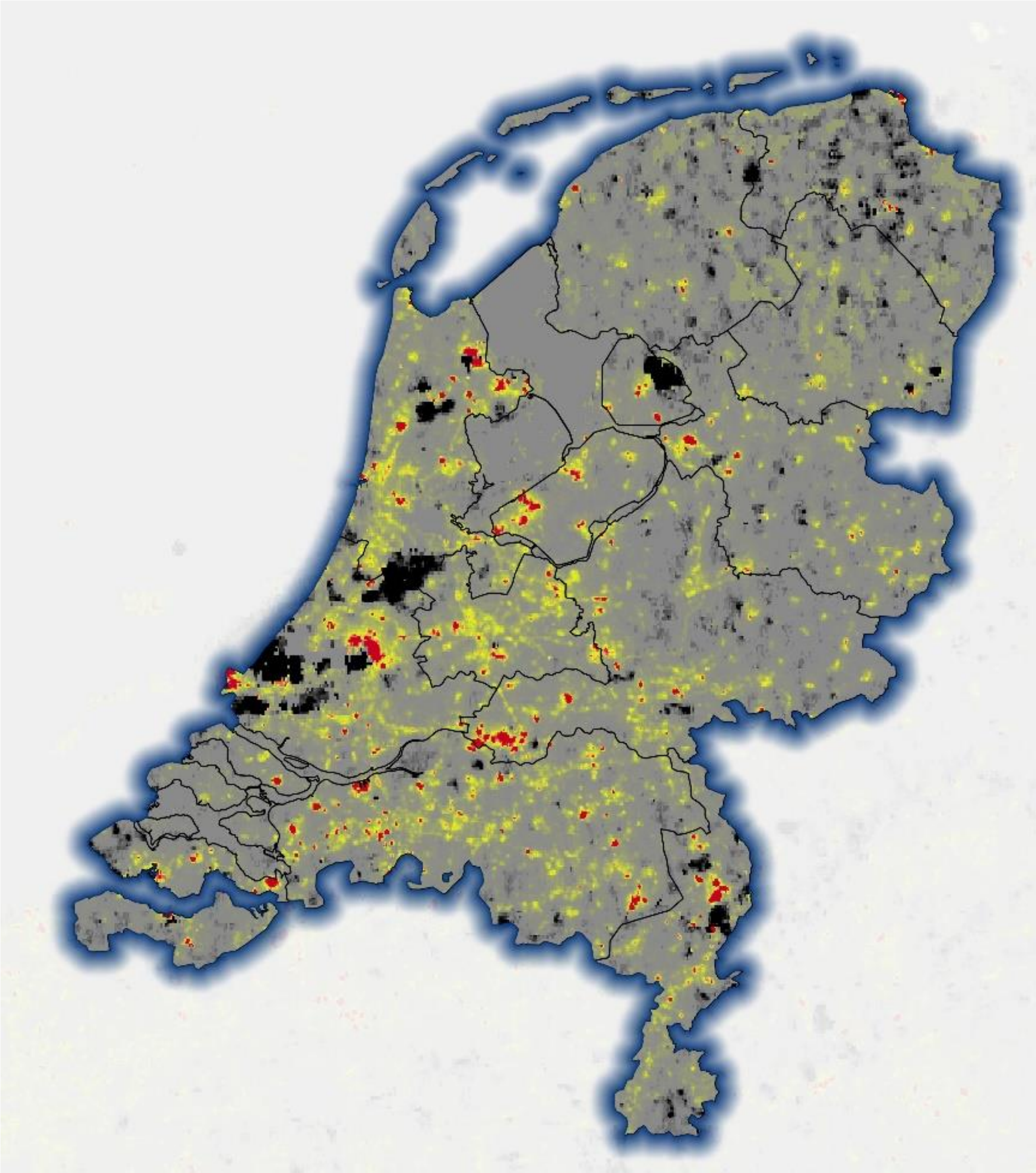

Figure 4. Changes in night light between 1992 and 2016 based on the resample DMSP-1992 and the original VIIRS-2016 composites. Black colors indicate less night light in 2016 compared to 25 years back; grey no substantial changes, yellow more and red substantial more night light today compared to 25 years ago.

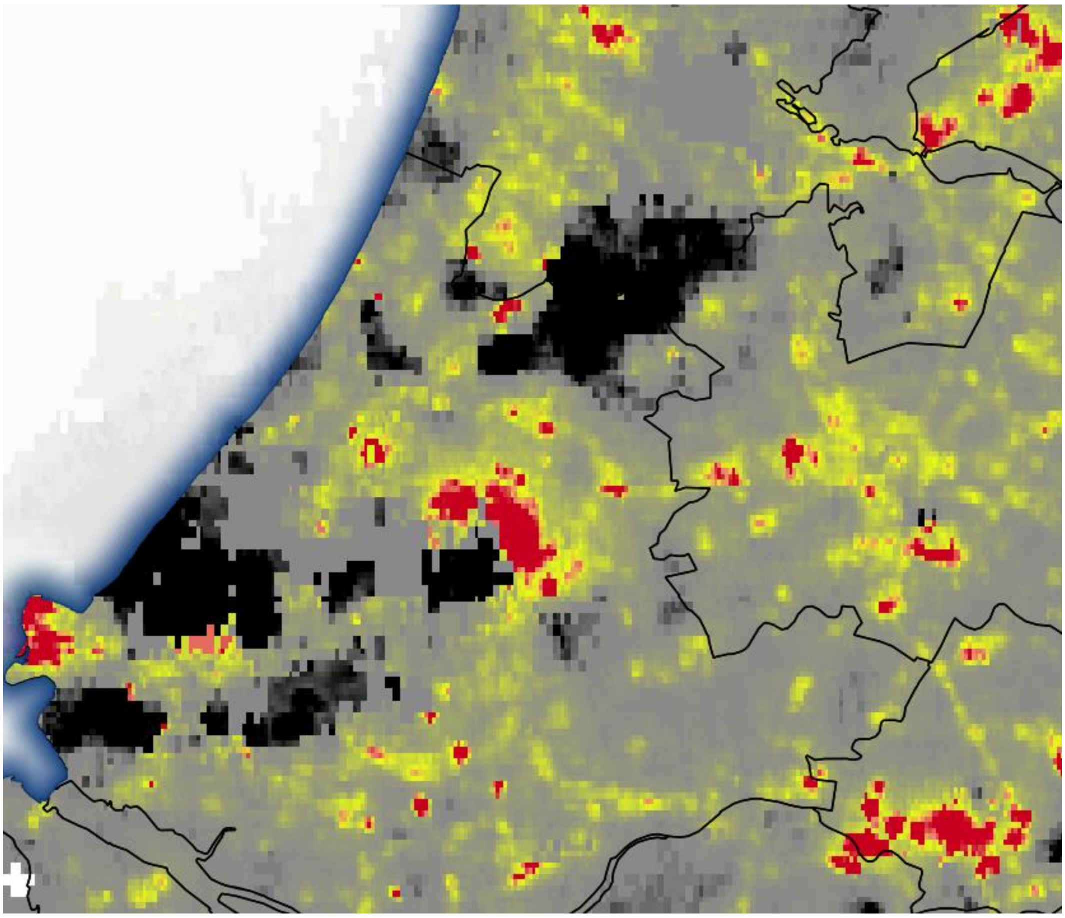

Figure 5. Detail of Figure 4 showing western part of the Netherlands. Black colors indicate less night light in 2016 compared to 25 years back; grey no substantial changes, yellow more and red substantial more night light today compared to 25 years ago.

Main conclusions of the analysis for the Netherlands based on Figure 3 to Figure 5 can be summarized as:

- There is a substantial amount of artificial nightlight in the country. Origin of this light is urban areas and predominantly light from greenhouses. The northern and eastern part of the countries have lowest artificial lights.
- Changes in artificial night light over the last 25 years are quite significant. Despite being still the largest emitters of artificial light, greenhouse artificial light has been reduced drastically[1]. Urban areas itself have not experiences increase in artificial light, but new developments around cities are clearly visible.

2.2 Greater Europe

The same analysis and approach as described for the Netherlands in the previous section was applied to the “greater” Europe region: Europe, North-Africa and West-Asia. Artificial night light from most recent and the 25 years old satellites images were compared.

[1] http://www.platformlichthinder.nl/thema/wetgeving/

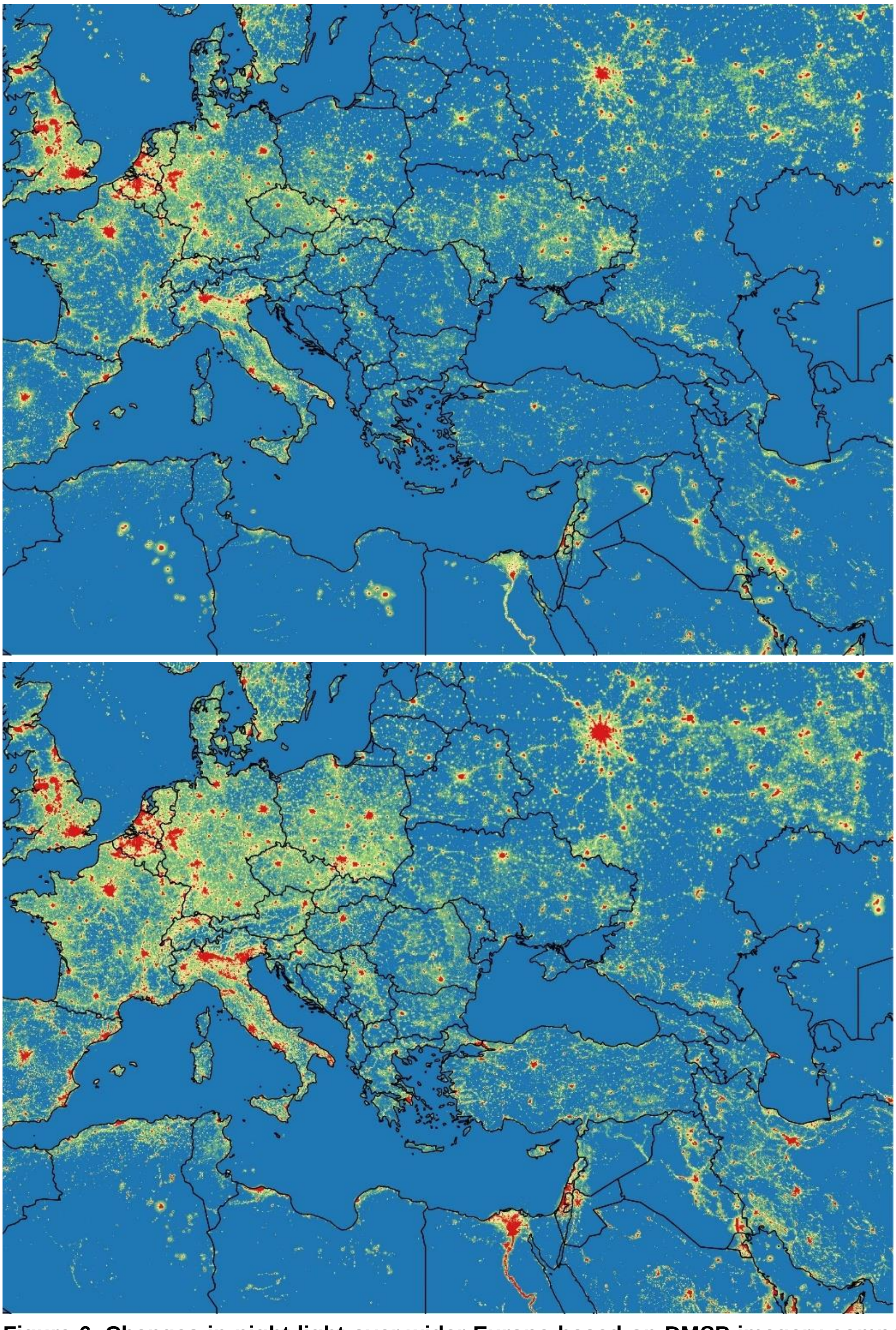

Figure 6. Changes in night light over wider Europe based on DMSP imagery composites 1992 (top) and 2013 (bottom).

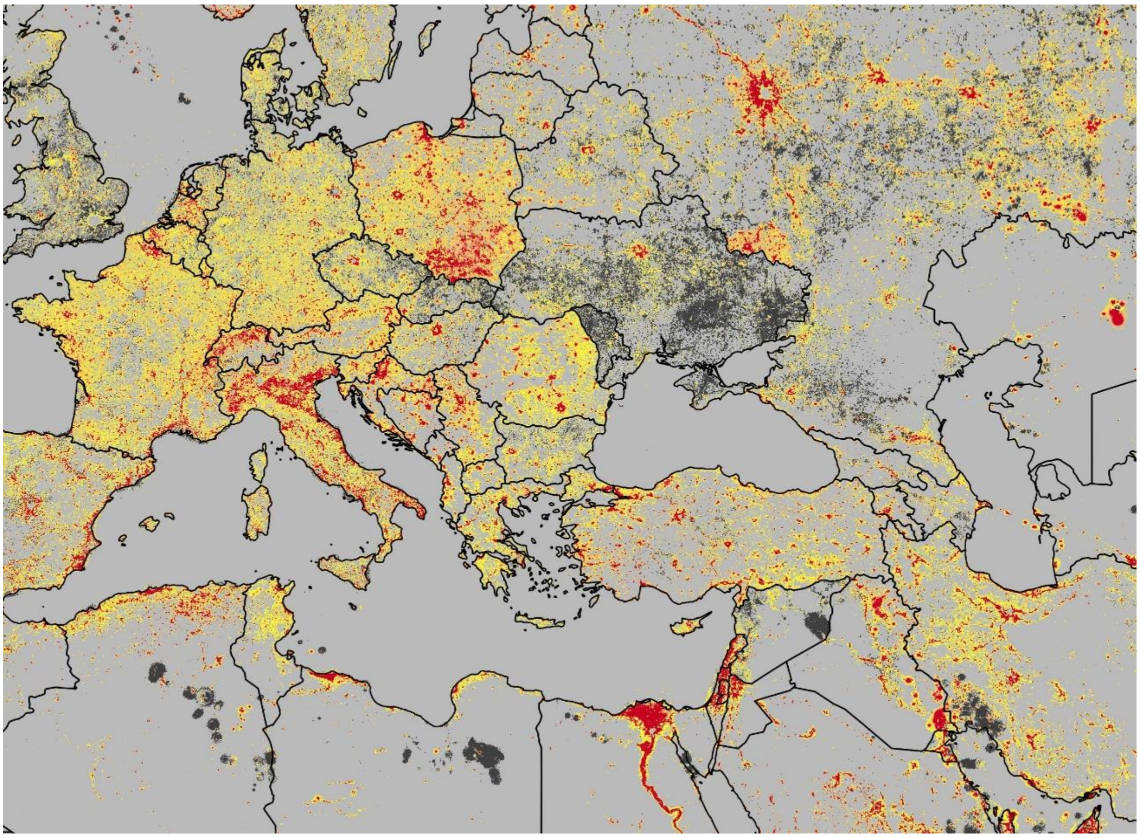

Figure 7. Changes in night light between 1992 and 2013 based on the DMSP annual composites. Black colors indicate less night light in 2013 compared to 1992; grey no substantial changes, yellow more and red substantial more night light in 2013 compared to 1992.

Comparing the 1992 DMSP images to the 2013 ones some striking differences can be observed. Some of the more striking differences are:

- The Nile Delta and the banks of the Nile have had a substantial increase in artificial night light in those 25 years. Developments in the overall economy and especially the intensification of the irrigation sector have led to this increase in night light. Obviously, the water demand by this intensification of irrigated agriculture in the region will be substantial. Over exploitation and falling ground water levels are reported frequently.
- Development and intensification of rural areas can be spotted in a wide-range of areas by the increase in night-light. Most likely this will have major implications for water use in the agricultural sector as better and more reliable access to electricity for pumping groundwater is available.
- Ukraine shows a remarkable decrease in night light. The contrast with some of the neighboring countries is striking and the geographical borders are sharply visible. Main reason is the decline in rural activities and the agricultural sector. The associated impact on water consumption by agriculture are likely. Note that the internal conflict cannot be attributed to this decline in night-light, as the conflict started in 2014 while the images compared are 1992 and 2013.
- The major conflict areas in Syria can be clearly seen where night light has been reduced substantially. Especially the Euphrates valley near the Iraqi border shows a substantial decline.

- Some countries and regions had a substantial increase in night light over this period of 21 years. Typical examples include Poland and northern Italy. Most likely this is a direct effect of economic development in those regions.
- Similarly, some countries show a substantial decrease in night light. For most countries, this can be explained by changing economics, either decline or sectorial changes (e.g. less agriculture so decline in rural area activities). Typical examples include Moldova and Slovakia.

3 Conclusions and Recommendations

This explorative study looked the usefulness of artificial night light imagery from satellites in water resources management. The most relevant conclusions and recommendations can be summarized by:

- The current explorative study is the first in its kind that looks at trends in night light emittance.
- The preliminary analysis indicates that the resulting maps reveals a lot of information on the economic status and development of countries and regions. Expected changes are confirmed by the maps.
- The somewhat less obvious changes in current light emittance and in trends can be explained in many cases, helping to better understanding developments.
- The resolution enhancement of the older DMSP images is useful to better explore trends.
- The current trend analysis is based on two time slices: current and 1992. It would be interesting to explore a fuller set of historic images.
- Expanding the analysis to Africa and Asia would reveal probably clearer developments given the transitions those continents have experienced over the last 25 years.
- The link with water resources issues is in some cases very clear (greenhouses, irrigated areas development, changes in rural development), but a further exploration is needed.

4 References

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5 Appendix: Datasets

5.1 DMSP-OLS Nighttime Lights Time Series Version 4

The Defense Meteorological Program (DMSP) Operational Linescan System (OLS) has a unique capability to detect visible and near-infrared (VNIR) emission sources at night.

Version 4 of the DMSP-OLS Nighttime Lights Time Series consists of cloud-free composites made using all the available archived DMSP-OLS smooth resolution data for **calendar years**. In cases where two satellites were collecting data - two composites were produced. The products are 30 arc second grids (~ 1 km), spanning -180 to 180 degrees longitude and -65 to 75 degrees latitude.

Data availability (time)
Jan 1, 1992 - Jan 1, 2014

The following bands are available:

- avg_vis: The average of the visible band digital number values with no further filtering.
- stable_lights: The cleaned up avg_vis contains the lights from cities, towns, and other sites with persistent lighting, including gas flares. Ephemeral events, such as fires have been discarded. The background noise was identified and replaced with values of zero. Data values range from 1-63. Areas with zero cloud-free observations are represented by the value 255.
- cf_cvg: Cloud-free coverages tally the total number of observations that went into each 30 arc second grid cell. This image can be used to identify areas with low numbers of observations where the quality is reduced.
- avg_lights_x_pct: The average visible band digital number (DN) of cloud-free light detections multiplied by the percent frequency of light detection. The inclusion of the percent frequency of detection term normalizes the resulting digital values for variations in the persistence of lighting. For instance, the value for a light only detected half the time is discounted by 50%. Note that this product contains detections from fires and a variable amount of background noise.

Google Earth Engine ImageCollection ID
NOAA/DMSP-OLS/NIGHTTIME_LIGHTS

5.2 DMSP-OLS Global Radiance Calibrated Nighttime Lights Version 4

The Defense Meteorological Program (DMSP) Operational Line- scan System (OLS) has a unique capability to detect visible and near-infrared (VNIR) emission sources at night. This collection contains global nighttime lights images with no sensor saturation.

Data availability (time)
Mar 16, 1996 - Jul 31, 2011
Each image in the collection contains the following bands:

- avg_vis: Average digital band numbers from observations with cloud-free light detection.

- cf_cvg: Cloud-free coverages, the total number of observations that went into each 30 arc second grid cell. This image can be used to identify areas with low numbers of observations where the quality is reduced.

Google Earth Engine ImageCollection ID
NOAA/DMSP-OLS/CALIBRATED_LIGHTS_V4

Data can be downloaded from:
https://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html

5.3 VIIRS Nighttime Day/Night Band Composites Version 1

Monthly average radiance composite images using nighttime data from the Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB).

This product spans the globe from 75N latitude to 65S with a resolution of 15 arc-seconds (~500m / pixel).

Data availability (time)
Apr 1, 2012 - Sep 2, 2017

Each image in the collection contains the following bands:

- avg_rad (nanoWatts/cm2/sr): Average DNB radiance values.
- cf_cvg: Cloud-free coverages; the total number of observations that went into each pixel. This band can be used to identify areas with low numbers of observations where the quality is reduced.

Google Earth Engine ImageCollection ID
NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG

Data can be downloaded from:
https://ngdc.noaa.gov/eog/viirs/download_dnb_composites.html

5.4 VIIRS Stray Light Corrected Nighttime Day/Night Band Version 1

Monthly average radiance composite images using nighttime data from the Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB).

This product is an alternative configuration of the VIIRS DNB using a procedure to correct for stray-light. The correction procedure extends visible areas closer to the poles and improves dynamic range. It should be noted some artifacts are introduced due to the procedure used in twilight regions.

This product spans the globe from 75N latitude to 65S with a resolution of 15 arc-seconds (~500m / pixel).

Data availability (time)
Jan 1, 2014 - Sep 2, 2017

Each image in the collection contains the following bands:

avg_rad (nanoWatts/cm2/sr): Average DNB radiance values.
cf_cvg: Cloud-free coverages; the total number of observations that went into each pixel. This band can be used to identify areas with low numbers of observations where the quality is reduced.

Product generated by the Earth Observation Group, NOAA National Geophysical Data Center.

Google Earth Engine ImageCollection ID
NOAA/VIIRS/DNB/MONTHLY_V1/VCMSLCFG

Data can be downloaded from:
https://ngdc.noaa.gov/eog/viirs/download_dnb_composites.html
https://www.ngdc.noaa.gov/eog/viirs/download_dnb_composites.html

6 Appendix GEE script

```
//=================================================================================
// Get Night Light data
// Peter Droogers; p.droogers@futurewater.nl; Dec-2017
//=================================================================================

var StartYY = 1992;
var EndYY   = 2016;

var Box = ee.Geometry.Rectangle(3, 50.5, 7.5, 53.5)  // NL

// Add bands (=years) to an image (so not creating a imagecollection)
var GetAllYears = function(year) {

// Source are two ImageCollections for different years
  if (year >= 1992 && year <= 2013) {
    var NightLight = ee.ImageCollection('NOAA/DMSP-OLS/NIGHTTIME_LIGHTS') // available
1992-2013
      .filterDate(ee.Date.fromYMD(year, 1, 1), ee.Date.fromYMD(year, 12, 31))
      .select('stable_lights')
  }
  else if (year >= 2014 && year <= 2016) {
    var NightLight = ee.ImageCollection('NOAA/VIIRS/DNB/MONTHLY_V1/VCMSLCFG') //
available 2014, 2015, 2016
      .filterDate(ee.Date.fromYMD(year, 1, 1), ee.Date.fromYMD(year, 12, 31))
      .select('avg_rad')
  }
  else {
    print('wrong year')
  }
// From ImageCollection to Image (for DMSP sometimes more than one image for a year)
var Night = NightLight.max().rename([String(year)])

  return Night.toByte(); //cast as DMSP is byte and VIIRS is float
} // end of function GetAllYears


// Create empty image
var NightLight_img = ee.Image([]);
// Add all years
for (var year = StartYY; year <= EndYY; year++) {
  NightLight_img = NightLight_img.addBands(GetAllYears(year));
}


var plot_palette =['#2b83ba', 'green', 'yellow', 'orange', 'red'];
var plot_scale = {min: 0, max: 50, palette: plot_palette};

// Map all bands = all years
for (var year = StartYY; year <= EndYY; year++) {
  Map.addLayer (NightLight_img.select(String(year)), plot_scale, String(year))
}

print (NightLight_img)

var Box = ee.Geometry.Rectangle(3, 50.5, 7.5, 53.5)  // NL
Map.addLayer (Box)
Map.centerObject(Box)
```

```
Export.image.toDrive({
  image: NightLight_img,
  description: 'NL',
  scale: 500,
  region: Box
});
```

Result is one image with 25 bands (NOTE: in GeoTiff in QGIS these are numbered from 1 to 25)

```
bands: List (25 elements)
0: "1992", unsigned int8, EPSG:4326
1: "1993", unsigned int8, EPSG:4326
2: "1994", unsigned int8, EPSG:4326
3: "1995", unsigned int8, EPSG:4326
4: "1996", unsigned int8, EPSG:4326
5: "1997", unsigned int8, EPSG:4326
6: "1998", unsigned int8, EPSG:4326
7: "1999", unsigned int8, EPSG:4326
8: "2000", unsigned int8, EPSG:4326
9: "2001", unsigned int8, EPSG:4326
10: "2002", unsigned int8, EPSG:4326
11: "2003", unsigned int8, EPSG:4326
12: "2004", unsigned int8, EPSG:4326
13: "2005", unsigned int8, EPSG:4326
14: "2006", unsigned int8, EPSG:4326
15: "2007", unsigned int8, EPSG:4326
16: "2008", unsigned int8, EPSG:4326
17: "2009", unsigned int8, EPSG:4326
18: "2010", unsigned int8, EPSG:4326
19: "2011", unsigned int8, EPSG:4326
20: "2012", unsigned int8, EPSG:4326
21: "2013", unsigned int8, EPSG:4326
22: "2014", unsigned int8, EPSG:4326 => VIIRS
23: "2015", unsigned int8, EPSG:4326 => VIIRS
24: "2016", unsigned int8, EPSG:4326 => VIIRS
```

Values for the DMSP are between 0 and 63 (years 1992-2013)
Values for the VIIRS are between 0 and 41 (years 2014-2016)