Mapping Current and Future European Public Water Withdrawals and Consumption

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Abstract:

In Europe, public water withdrawals make up on average 30%, and in some cases up to 60% of total water withdrawals. These withdrawals are becoming increasingly important with growing population density; hence there is a need to understand the spatial and temporal trends involved. Pan-European public/municipal water withdrawals and consumption were mapped for 2006 and forecasted for 2030. Population and tourism density were assumed to be the main driving factors for withdrawals. Country-level statistics on public water withdrawals were disaggregated to a combined population and tourism density map (the "user" density map) computed for 2006. In order to forecast the map to 2030 we assumed the water withdrawals per user to remain constant in time, so that the future withdrawals reflected the projected population and tourism trends. The methodology was validated using actual *regional withdrawal statistics from France for 2006. The Total Absolute Error (TAE) calculated was proven to be reduced by taking into account the tourism density in addition to the population density. Our results show that although there are large variations from region to region, in general public water withdrawals will increase significantly over the period 2006 to 2030. The European average increase is 16%, with a maximal increase of 53% in Ireland.*

Keywords: water use; water consumption; mapping; population; tourism; Europe

1. Introduction

With increasing demographic pressure on available physical resources, there is a growing need to evaluate and monitor their usage. Public water withdrawals are those made by the municipal water distribution system, and are used mainly for household purposes, although usually they are also used in the commercial and even industrial sectors. In Europe, they account for, on average, 30% of total water withdrawals (EUROSTAT, 2012a). In northern Europe they can account for up to 60% of withdrawals. Understanding the spatial and temporal patterns in water withdrawals for public use is therefore an important step towards improving the efficiency of use of water resources and reducing water scarcity.

Globally, domestic demand for water has been extensively studied and there have been numerous attempts to describe and model demand (Arbues et al., 2003; Kostas and Chrysostomos, 2006; Wong et al., 2010; Worthington et al., 2006), although mainly at a local or regional level. At these scales, it is possible to take into account such factors as household income and size. There are also several existing models which describe water withdrawals for the public sector at a larger scale. The Global Water

Scarcity Information Service (GLOWASIS), (Wada et al., 2011a, Wada et al., 2011b), and the Water – Global Analysis and Prognosis (WaterGAP) (Alcamo et al., 2003) model describe the global monthly water demand for the year 2000 at 0.5° spatial resolution for the domestic sector. The Pan-European Atlas of Water Abstractions, Losses and Returns (Wriedt et al., 2008) disaggregated EUROSTAT public water withdrawal statistics to regional level (NUTS3[1]) using the total population. We aim to improve on previous models by providing higher resolution and more up-to date public withdrawal and consumption maps for Europe. Moreover, the objective is to take into account the impact of additional water withdrawals for the tourism industry, and provide a robust methodology to estimate future public water withdrawals. We propose a methodology based on a strong linkage with land use modeling, which allows us to map future water use trends up to 2030, which is the time horizon up to which the land use model can reliably forecast land use. We use 2006 as the reference year for our mapping and land use model as refined land use maps are available for this year. Additionally, available water withdrawal statistics for 2006 are more complete and consistent than for more recent years.

Figure 1 presents an overview of the terminology and approach used to assess sectorial water flows (definitions are adapted from the *3rd UN World Water Development Report (2009*). Water withdrawal is the gross amount of water extracted from any source in the natural environment for human purposes. Water use is the amount of water that is actually processed in a given sector. Water consumption refers to the part of the processed water that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, so heavily polluted that it is no longer suitable for use, or otherwise removed from the immediate water environment. From the total water withdrawal, a part is lost due to leakages during transportation/distribution processes, and thus returned to the natural environment. In

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[1] "NUTS (Nomenclature of Territorial Units for Statistics) is the European Union's official regional subdivision of member states, with three hierarchical levels (NUTS1, NUTS2 and NUTS3)"

addition, a part of the total used water can potentially be returned to the stock of available water. This share depends on the sector and on the installed capacity to treat water.

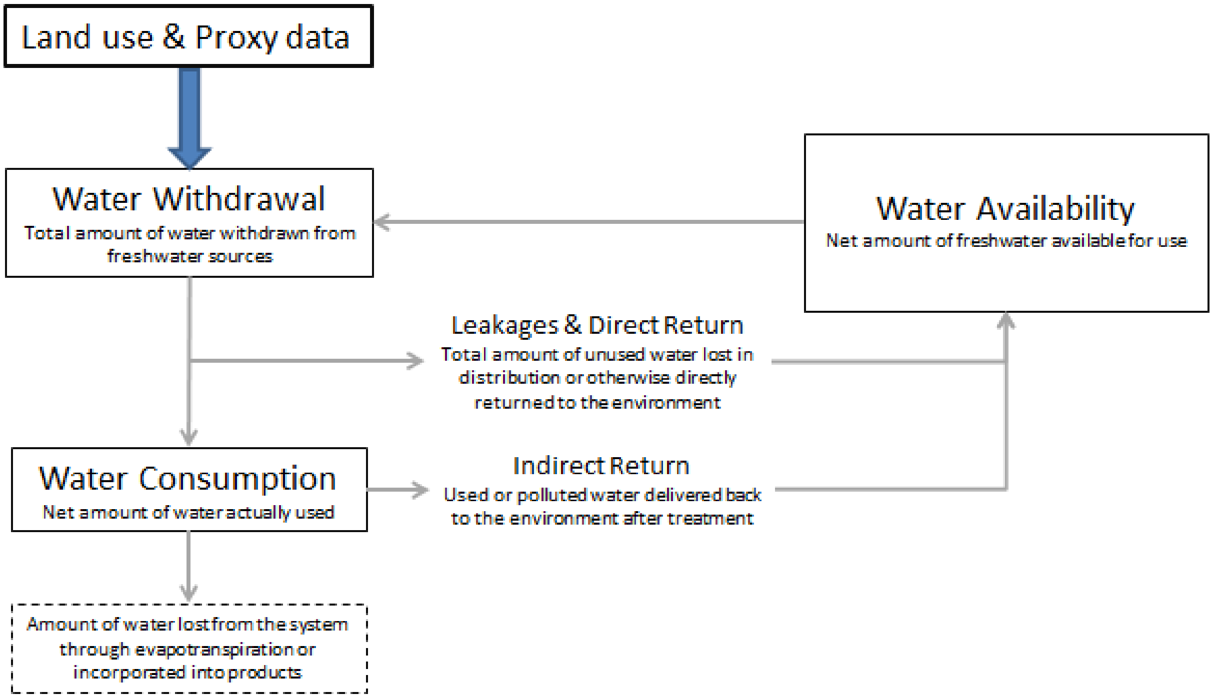

Figure 1. Conceptual model for the analysis of the water flows. Original definitions are based on the *3rd UN World Water Development Report (2009*).

In this paper we discuss in detail the methodology used and present the resulting public water withdrawal and consumption maps for 2006 in addition to comparing them to 2030. The methodology is also validated against actual regional statistics and the added value of the inclusion of tourism as a driving factor is also assessed.

1.1 Data availability

The OECD/EUROSTAT Joint Questionnaire on Inland Water provides country-level statistics on annual freshwater abstraction by source and sector and water use by supply category and user *(Nagy et al.,* *2007)*. The questionnaire covers the EU27 countries plus Iceland, Norway, Switzerland, Croatia, the Former Yugoslav Republic of Macedonia, Turkey, Bosnia and Herzegovina, and Serbia (although for these countries the datasets are not always complete). For the reference year 2006, we used the average sectorial water withdrawals for the period 2005-2007 from EUROSTAT, which was supplemented by the 2003-2007 average from FAO - AQUASTAT (2012) in case data was missing or inconsistent. Where there were still missing values the respective sectorial European average per capita was used. Figure 2 gives an overview of the public water withdrawal for the reference year 2006. The withdrawals have been normalized by the country total population in order to allow comparison between the countries.

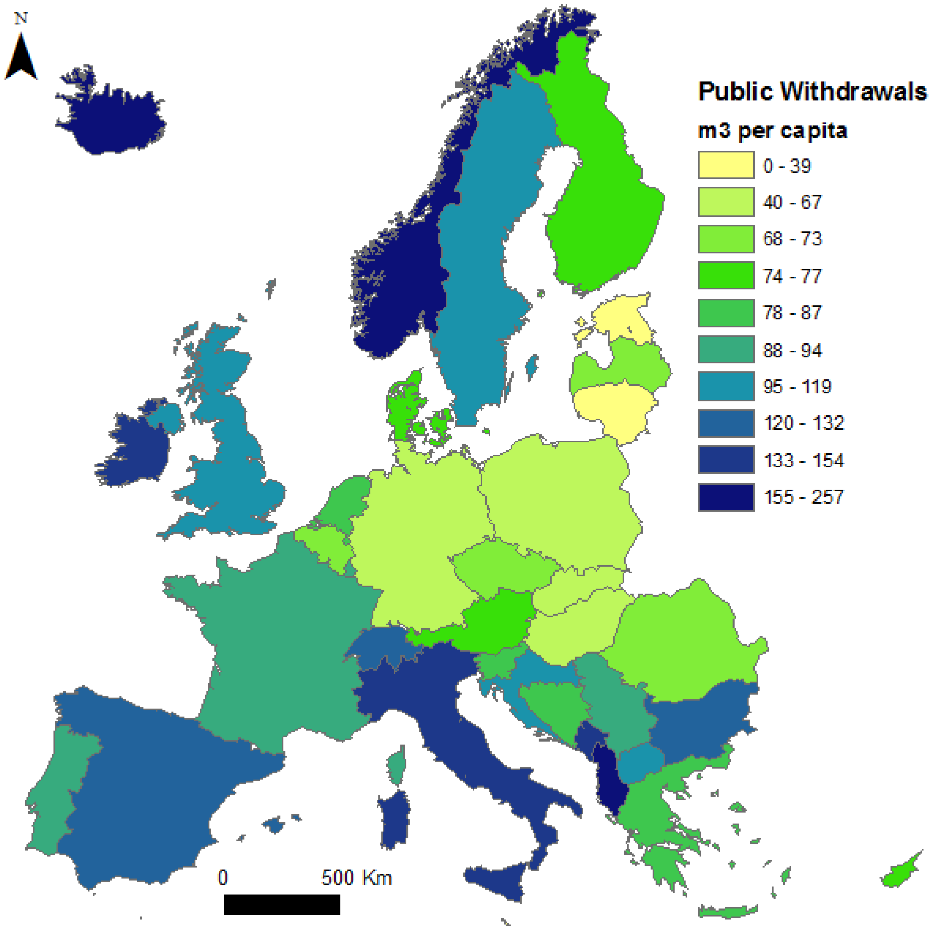

Figure 2. Map of public water withdrawals per country for the reference year 2006. Values were normalized by the country total population for comparability and are given in cubic meters per capita.

The data on “public water supply” as provided by the questionnaire is defined as: *“… (the) water supplied by economic units engaged in collection, purification and distribution of water… Experience from France: This service includes water for domestic use and water used at offices. It also includes small factories, municipal use …, and private garden watering.”* (Nagy et al., 2007). Statistics given on the public supply of water to the different sectors (EUROSTAT 2012a) show that, on average, some 79% of public water is used for domestic purposes. A further 17% is used for industrial purposes, and 4% for agriculture.

Figure 3 shows the relative proportions of public water withdrawals compared to withdrawals for other major water-using sectors. Interestingly, public water withdrawals make up more than 60% of the total in Northern countries such as the UK, Luxemburg, and Denmark, whilst agricultural withdrawals make up the majority of total withdrawals in the Mediterranean countries Portugal, Greece, and Spain. Industrial and particularly energy withdrawals (used as cooling water in thermal power plants) are especially important in eastern European countries.

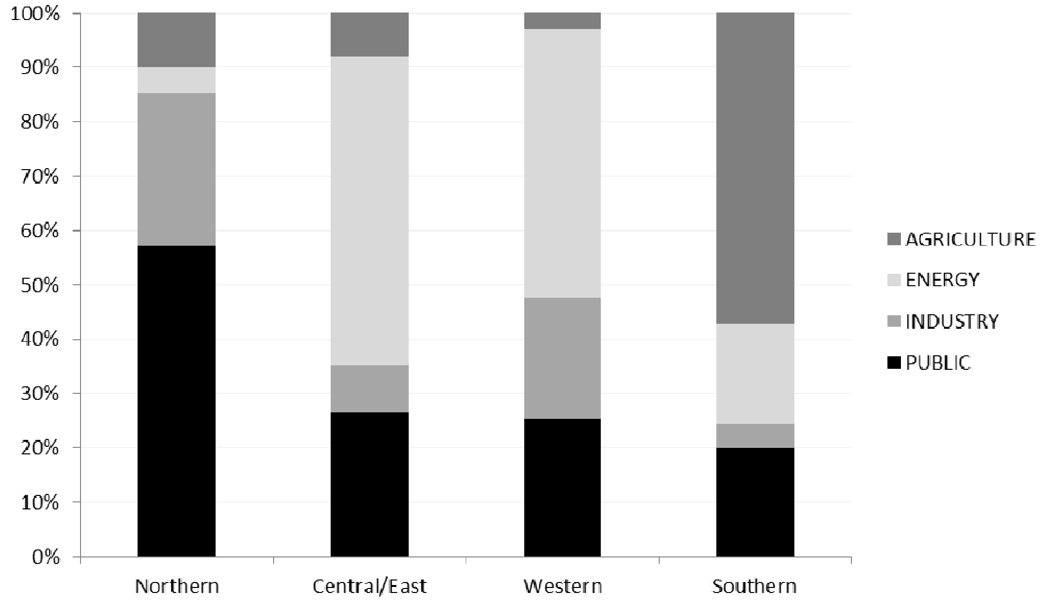

Figure 3. Sectorial water withdrawals as a percentage of the total withdrawals across European countries for 2006.

In order to supplement the country-level data provided by Eurostat, we collected regional sectorial water withdrawal statistics (at NUTS2, NUTS3 or basin-level) from various sources, including each country's National Statistical Institute and environmental agencies. As the sectorial regional dataset for all EU27 countries is incomplete, further analysis has been carried out on the country-level data. Where available, the country-level statistics were verified with the regional totals. Since detailed and verified NUTS3 level data was available for France for 2006 (SOeS, 2012), we confirm our public water withdrawal map for France, produced by disaggregation from the country-level statistics, with actual regional statistics.

2. Methodology

We assume the public water withdrawal to be the total water withdrawn in urban areas. Although some commercial/service areas may be included in the land use class, the use is assumed to be mostly domestic, therefore covering the water needs of the resident population within a given area at any time. Since tourism has a large impact in some of the most water scarce areas, we have taken the influence of additional tourist presence into account.

2.1 Land use proxy approach

Our approach links land use data to public water withdrawals. In order to do this for the base year maps we used the 2006 refined version of the CORINE Land Cover (CLC_r) (Batista e Silva et al. 2012). The land use needed to map the following years, up to 2030, was modeled using the Land Use Modelling Platform (LUMP). The land use/cover model EUClueScanner (EUCS100), developed at the Joint Research Centre

(JRC) Ispra is the core component of this platform which incorporates several data sources and models (Lavalle et al. 2011). Future land use claims are driven mainly by the CAPRI model (Common Agricultural Policy Regionalized Impact Modelling System), Eurostat data (EUROPOP2008) and Corine Land Cover trends. As yet, the model is only calibrated for the EU27 member states. The close linkage with the relevant land use classes allows us to both spatially disaggregate the withdrawals at high resolution (100 m), and to forecast withdrawals based on changing urban land use patterns as simulated by EUClueScanner. As resident and touristic water use was assumed to be present in urban areas, both were assigned to the relevant urban land use classes. We additionally assign touristic water use to the land use class ‘sport and leisure facilities’, so taking into account extra water used to maintain these infrastructures. Proxy data is used to disaggregate to pixel level and to refine the approach.

An initial analysis of possible proxy data influencing public withdrawals at both country and regional level gives high R^2 correlations for total population (0.92) and number of nights spent by tourists (0.82). Hence, these variables are selected as being most appropriate to explain public withdrawals at pixel level. Public water withdrawals are therefore assumed to be those made by residents and tourists in urban areas, so that the spatial distribution of the withdrawals is directly related to the combined population and tourist density. Our first step is to compute both the population and tourism densities at the highest resolution possible.

We used a detailed European population density map for 2006 (Batista e Silva et al. 2013), which was produced by disaggregating resident population counts at commune level originating from EUROSTAT to a grid of 100 m x 100 m cells. The disaggregation approach consisted of redistributing the population totals of each commune among the urban fabric cells as reported in a refined version of the CORINE Land Cover (CLC_r) (Batista e Silva et al. 2012). In addition, the redistribution was weighted proportionally to the average imperviousness of each urban fabric class, which was used as a proxy for housing density and, therefore, for population density. The source for these data was the European Environment Agency's Soil Sealing Layer 2006[2].

Tourist density maps are created using the number of nights spent by non-residents at NUTS2 level (EUROSTAT 2012b, corrected with ESPON data). This data is further disaggregated to NUTS3 level using the number of bedplaces (EUROSTAT 2012b). The monthly distribution of tourism is calculated using the country-level percentage of nights spent per month. In both cases, national statistics or regional averages are used where data is missing, always taking the closest available year to 2006. The total number of tourists per month (calculated as the total number of nights spent / 365 days) at NUTS3 level for each country is disaggregated to the CLC_r refined CORINE classes 111 and 112 (urban fabric), and 142 (sport and leisure facilities) to create a map of tourism density at pixel level (100m). To correct for outbound tourism, the number of nights spent abroad by residents (EUROSTAT 2012b) per quarter year is also calculated and subtracted from the population density maps. Tourists have a higher water use than residents, which can be explained by the additional water needed to maintain the additional recreational facilities required by tourists, and the higher consumption of water by holiday-makers. The tourist density maps are given a greater weight, by multiplying by a factor of 300/160 (derived from Gössling et al., 2012) when actually assigning the water withdrawals to the users (residents + tourists), so assuming that tourists use almost twice the amount of water as residents do.

The monthly maps of weighted number of users of public water per pixel, or 'user density', are calculated as:

$$\textit{User density} = (P - T_o) + 300/160 * (T_i) \qquad (1)$$

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[2] http://www.eea.europa.eu/data-and-maps/data/eea-fast-track-service-precursor-on-land-monitoring-degree-of-soil-sealing-100m-1

Where $\boldsymbol{P}$ is the population density (annual map); $\boldsymbol{T_o}$ is the number of nights spent abroad by residents (quarterly maps); and $\boldsymbol{T_i}$ is the number of nights spent by tourists (monthly maps). Finally, the country-level total public water use is disaggregated according to the user density maps.

$$PWW_i = PWW_c * \text{User density}_i / \sum_i \text{User density}_i \tag{2}$$

Where *PWW* is public water withdrawal; *i* is the pixel indicator per country; *c* is the country

2.2 Forecasting to 2030

The public water withdrawals are forecasted up to 2030. We combine the land use map, modeled up to 2030, with projected population statistics, and take country-specific tourism growth rates into account. The actual water withdrawal per capita per country is kept constant. Figure 4 shows the trends in public water withdrawals for the period 1970 to 2005 for several countries where consistent datasets were available for all years (EUROSTAT, 2012a). The evolution of public water withdrawals per capita differs greatly depending on the country, and no clear general trend could be identified. It can be assumed that water withdrawals per capita should decrease in time with improving efficiency of water use linked to a combination of increasing information dissemination, water pricing, and technological improvements. However, at the present time we do not feel we have sufficient data to support and quantify this assumption, and therefore retain the constant per capita withdrawal value for 2006. This means that the future withdrawal trends are directly determined by the population and tourism projections.

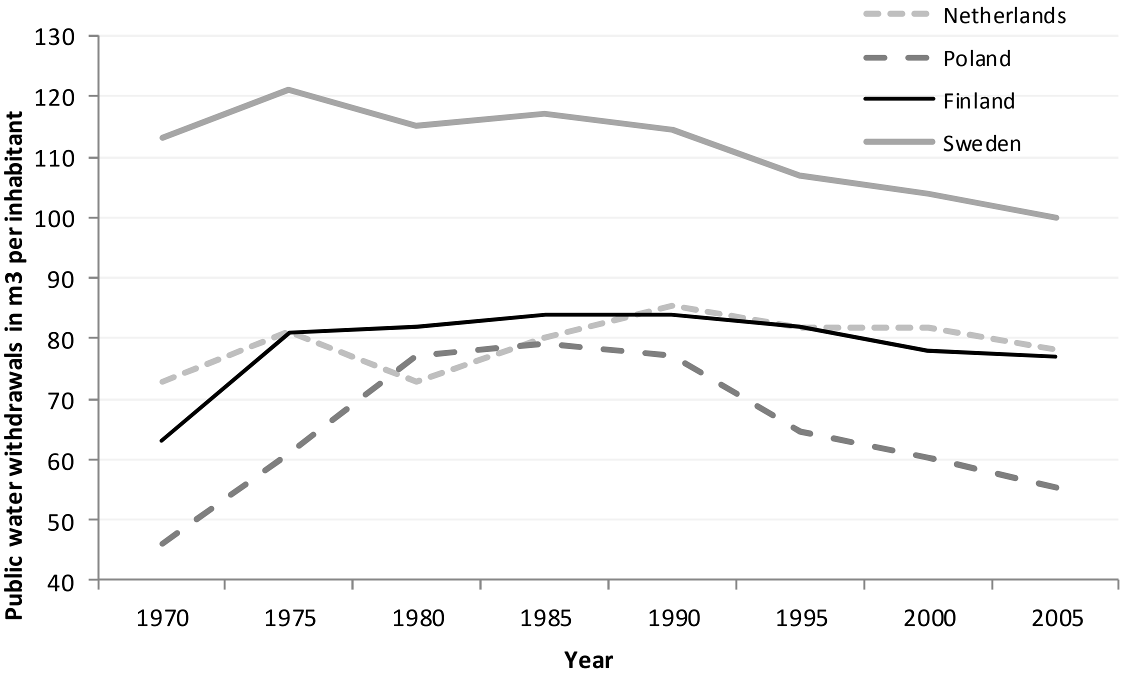

Figure 4. Trends in Public water withdrawals per capita from 1970 to 2005 (EUROSTAT, 2012)

Figure 5 summarizes the methodology applied to map the withdrawals for both 2006 and 2030. The projected land use for 2030 is modeled using EUClueScanner. Forecasted population density maps are created using population projections from EUROSTAT (EUROPOP), and the tourism density maps are re-calculated according to the tourism growth forecasts (at country level) from the Europe vision 2020 report (WTO, 2000). We assume the tourism growth rate for the period 2006-2030 to be equivalent to that predicted for 2010-2020 in the report. Since insufficient data is available on both the regional and monthly distribution of tourism, the 2006 patterns are used. The public water withdrawal per capita is also kept constant, using the 2006 statistics. Therefore the total public water withdrawals for 2030 directly reflect the projected population and tourism densities.

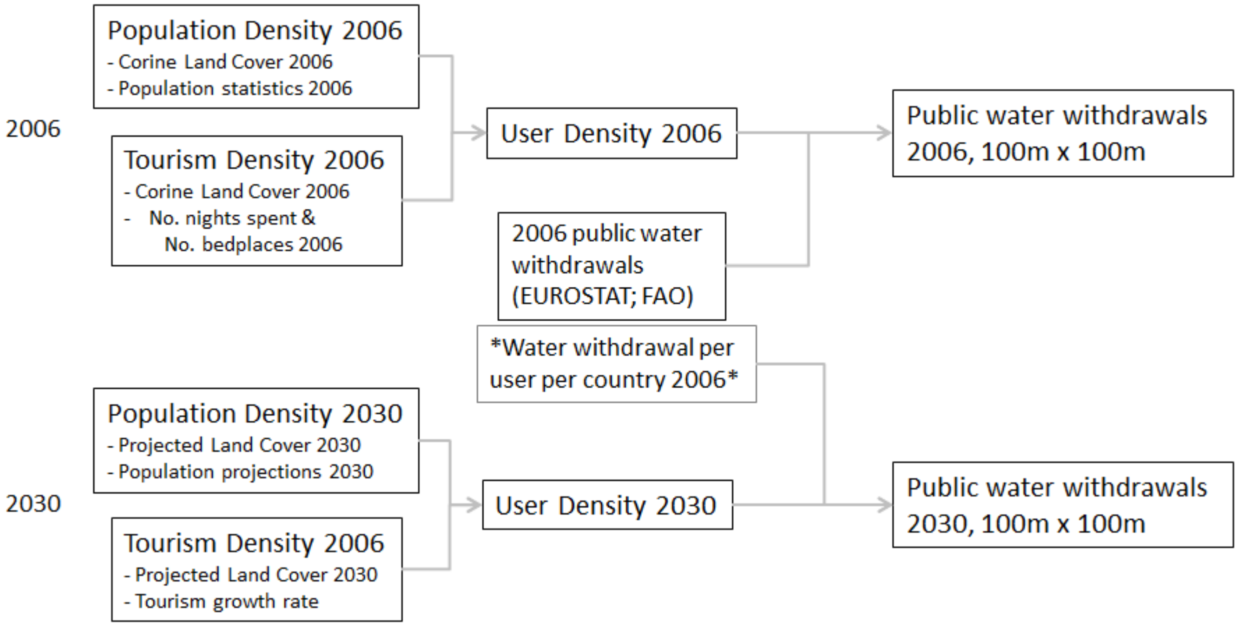

Figure 5. An overview of the methodology used to map 2006 and 2030 public water withdrawals

3. Results

3.1 Confirmation of methodology

In order to confirm our methodology we use detailed and verified NUTS3 level data for France, which is available from the Service de l'observation et des statistiques (SOeS, 2007). We compared the actual 2006 total public water withdrawals to those given by summing the estimated withdrawals per NUTS3 region. In order to assess the influence of taking tourism into account in our model, we recalculated the public water withdrawal map based on a disaggregation of the country total water withdrawals directly to the population density, and also compare the NUTS3 totals derived from this map to the actual statistics. Figure 6 compares the regional estimates derived by these two methodologies to the actual statistics.

The Total Absolute Error (TAE) is calculated for both cases as:

$$TAE = \sum_i |\text{Measured Value}_i - \text{Modelled Value}_i| \tag{3}$$

The resulting error is 26.56, or 13.3% including the tourism density, and a TAE of 27.42, or 13.7% using only the population density maps. This shows that, although population density is the main factor contributing to the spatial disaggregation of the statistics, taking the tourism density into account does, in fact, improve the end result.

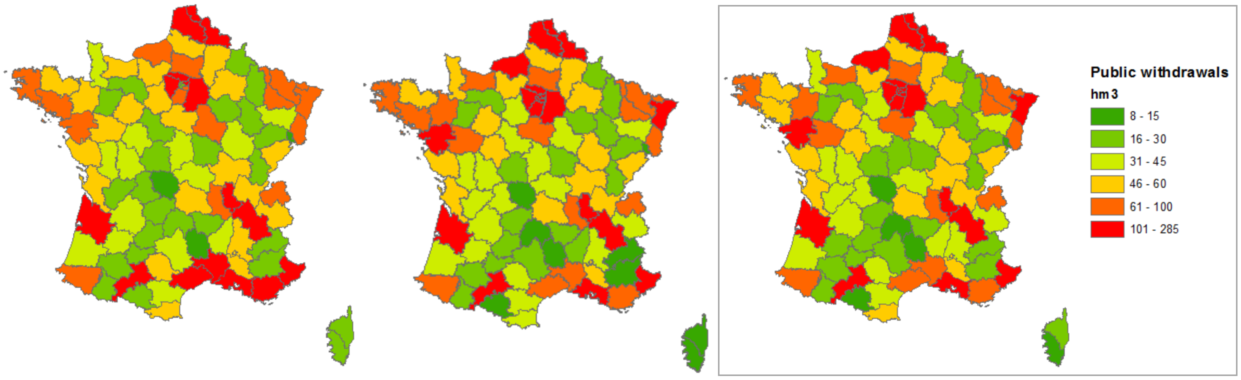

Figure 6. Public water withdrawals given in hm3 for France at NUTS3 level for 2006. Left: NUTS3 totals derived from our model; Center: NUTS3 totals derived from disaggregation of water use directly to the population density; Right: actual statistical data available from the SOeS.

3.2 Public Water withdrawals in 2006

Public water withdrawals are mapped at 100 m resolution at a Pan-European scale for the period 2006 to 2030. Figure 7 shows the withdrawal map for 2006, which has been aggregated to 5 km resolution for improved visualization. Within each country, the most densely populated areas have the highest water withdrawals, with the greatest withdrawals therefore being in major cities like London, Paris, Madrid, and Berlin. The Benelux area and northern Italy also stand out. The influence of tourism water withdrawals is seen especially in the high withdrawals along the coastal Mediterranean towns in Spain, Italy, and Croatia.

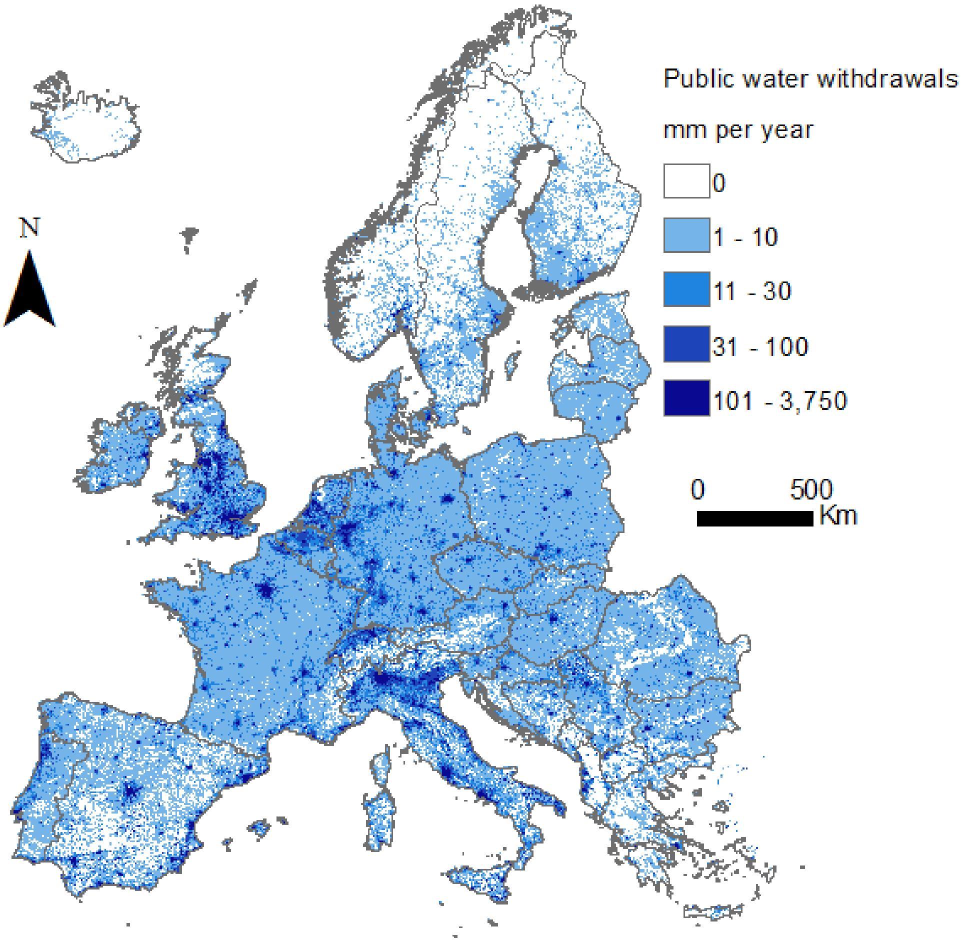

Figure 7. Public water withdrawal at 5 km by 5 km resolution for 2006 in millimeters per year.

Tourism density can vary significantly depending on the region and the season. Figure 8 shows the tourism density maps for January and August of 2006 calculated for Italy. These months were selected to represent the peak winter and summer tourism. The Alps and the major towns retain high tourism densities for both seasons. In general, tourism is much greater in summer, with more tourists present in most regions, and an especially high concentration along the coastal towns. Summer tourism is especially high in the Veneto region of Italy and along the Croatian coast.

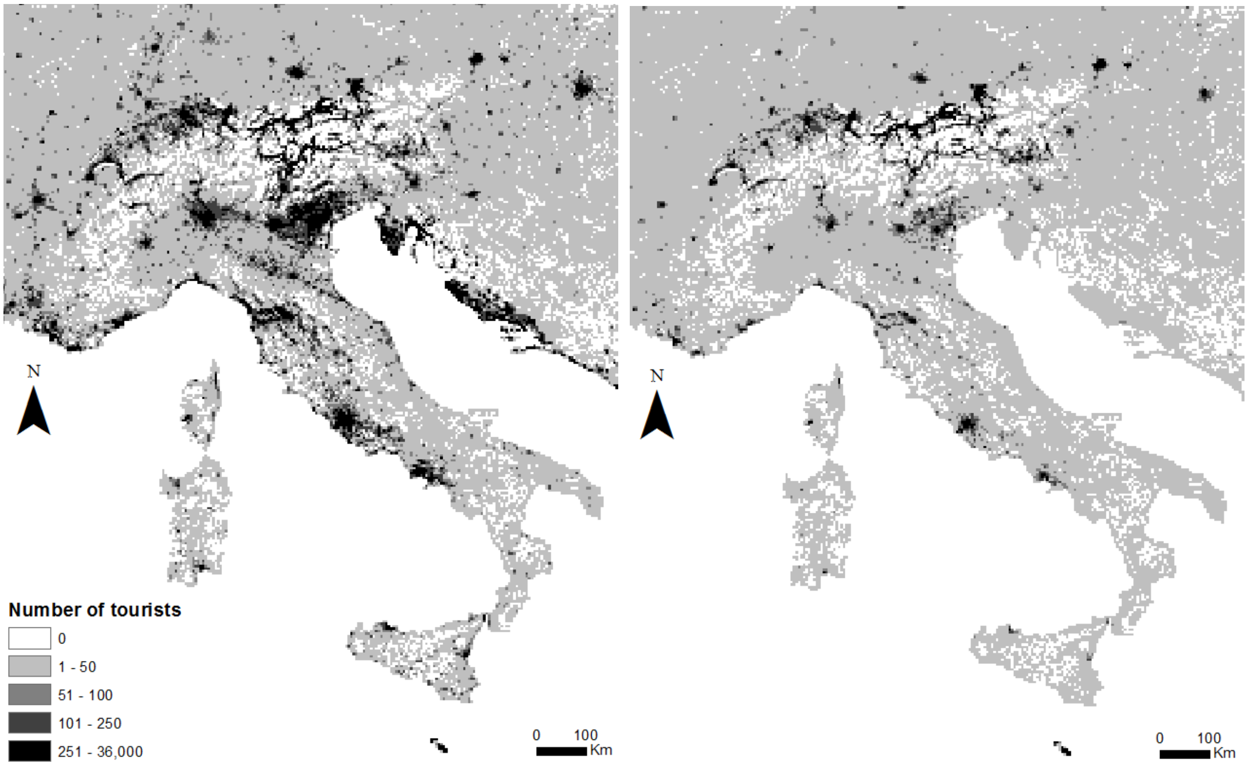

Figure 8. Tourism density (number of tourists per 5 km pixel) for August 2006 (left), and January 2006 (right)

3.3 Forecasted Public Water withdrawals for 2030

Figure 9 shows the percentage changes in public water withdrawals for the EU27 countries as compared to the EU27 average change. As yet, non-EU27 countries are not modeled by EUClueScanner. Since forecasted land use was unavailable for these countries, we could not compute the 2030 water withdrawals. The predicted trend in water use is dictated first and foremost by the projected trends in population growth, with some slight influence by the tourism growth rate.

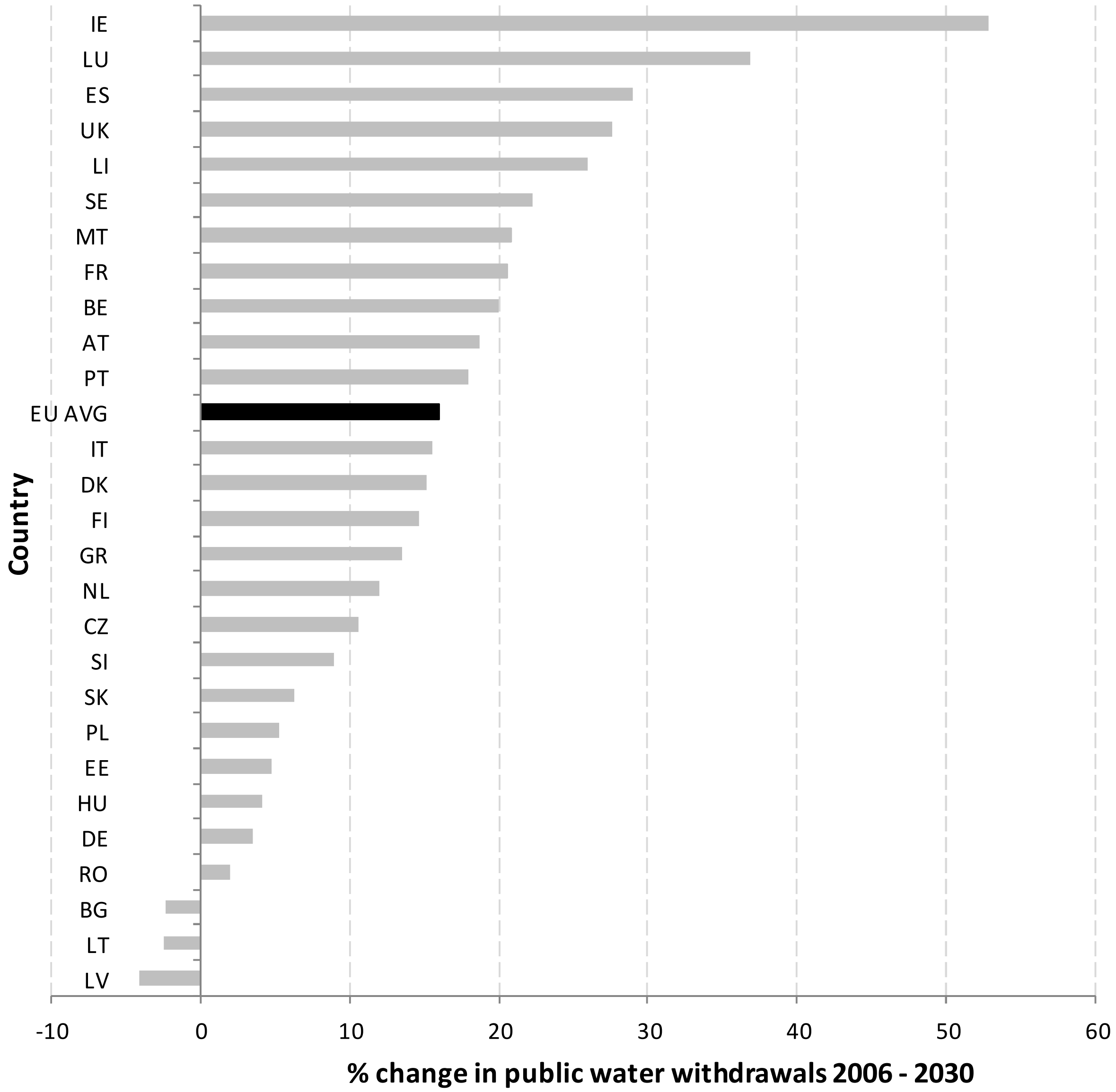

Figure 9. The percentage change in annual public water withdrawals for 2030 as compared to 2006 for the EU27 countries.

Figure 10 shows the evolution in public water withdrawals for each NUTS2 region of the EU27 countries, calculated over the period 2006 to 2030. The difference in water withdrawals for 2030 to those made in 2006 varies from a decrease of up to 23% in central Germany and several regions in Poland, Hungary, Romania, Bulgaria, Latvia, Lithuania and Sweden, to an increase of up to 63% in southern Spain and France, northern and central Italy, the UK, and some regions of central and northern Europe.

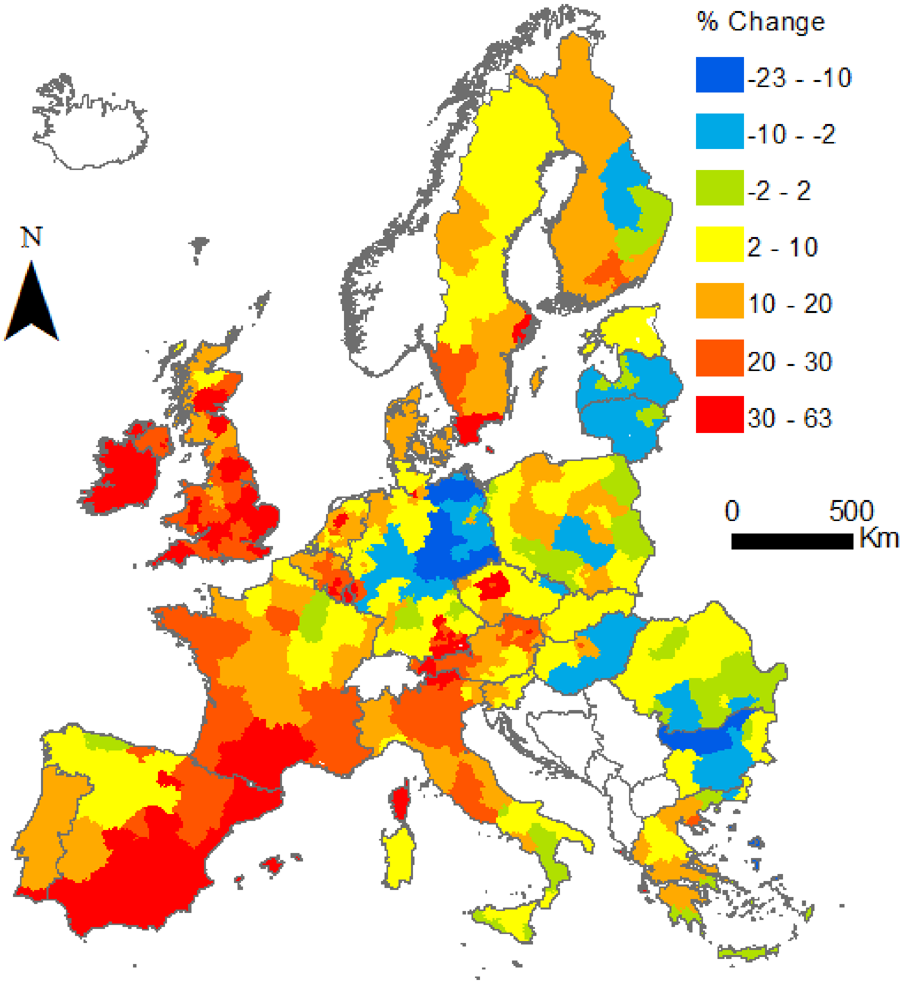

Figure 10. The change in total public water withdrawals per NUTS2 region over the period 2006 to 2030 for the EU27 countries, given as a percentage increase or decrease.

Figure 11 compares the water withdrawal maps for 2006 and 2030 for Warsaw, Poland at the original resolution of 100 m pixel size. Total public water withdrawals for the administrative region of Warsaw increase from 79.73 hm^3 in 2006 to 81.65 hm^3 in 2030, an increase of about 2.4%. This increase is directly related to the growth in population and tourism. The related, significant increase in urban areas is clearly visible when comparing the maps.

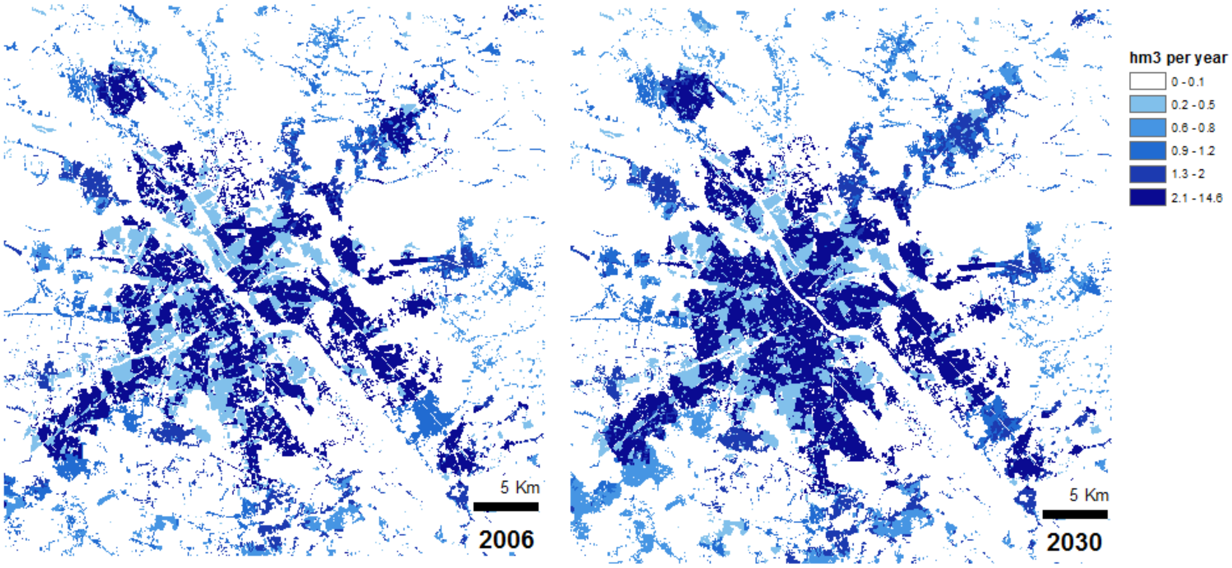

Figure 11. Public water withdrawals modeled at 100 m resolution for Warsaw, Poland. The figure compares the withdrawals for 2006 (left) to those for 2030 (right).

The statistics used so far concern only total water withdrawals. For each land use and region, there will be a fixed water demand, a portion of water permanently consumed, and a portion returned to the environment. For most sectors, there is a large return of water to the environment, and very little consumed. For the public sector, consumption is estimated at between 10 and 20 % of abstractions (UN WWDR, 2009).

4. Discussion and Conclusion

European public water withdrawals are mapped for the years 2006 (figure 7) and 2030 based on available land use, population and tourism data for 2006 and projections thereof to 2030. The monthly variation in public water withdrawals is also taken into account – this variation is especially noticeable in terms of tourism densities, which are significantly higher in the summer, especially in coastal regions (figure 8). Public water withdrawals already account for a substantial proportion of total water withdrawals in Europe – about 30% - and the forecasted withdrawals to 2030 show that in most countries there will be considerable increases. The European average increase in withdrawals for the period 2006 to 2030 is 16% (figure 9). Most of central and Eastern Europe show reasonably stable withdrawals, with overall decreasing trends predicted in Latvia, Lithuania and Bulgaria. These countries show relatively high tourism growth rates, but have strongly declining population trends resulting in overall decreasing water demand. Water withdrawals in southern Spain and France, northern Italy, and the UK are, however, predicted to increase considerably (figure 10). These are the regions with the highest combined relative population and tourism growth, where increasing pressure is predicted on the available resources. In these regions measures should be taken to reduce the impact of increasing water demand, especially considering the already limited supply of freshwater in the Mediterranean areas. Moreover, decreasing rainfall due to climate change might have an additional negative impact on resources.

The main limitation faced was the availability of detailed and up-to-date water withdrawal statistics. In the present study we used country-level data for public withdrawals as available regional data is limited in its consistency and comparability. We did, however, confirm the estimated withdrawals using actual regional statistics for France (figure 6). The Total Absolute Error is 26.56, or 13.3 %. Taking tourism into account reduces this error and improves the estimated withdrawals spatially. It also means that additional, high water withdrawals are assigned to leisure facilities (which are often highly water use intensive), which would otherwise not be included if disaggregation was only done based on the population density.

Leakages in the distribution network may also play an important role, and should be taken into account in the future. Total losses vary greatly between countries, but are mainly due to leakages in the distribution system, and to a lesser extent to evaporation. Bulgaria, Greece, Malta, Ireland and the UK all show losses much higher than the average of 7.7% (EUROSTAT). Also, a limitation is that we assume the whole population to be connected to the public water supply, while the average EU-27 connectivity is only 91% for 2006, and countries such as Romania and Estonia have connectivities as low as 49% and 73% respectively. An additional important consideration would be to take into account improved water use efficiency with time; it can be assumed that with time the amount of water used by each person will reduce as a result of technological improvements and increased awareness, especially in areas already prone to water scarcity. In the presented methodology improved water use efficiency is not accounted for, meaning that the presented water withdrawals for 2030 may be overestimations.

Finally, it should be noted that although we present a robust methodology to forecast future public water withdrawals, there are many uncertainties involved, especially considering that the methodology is dependent on land use, tourism, and population projections, which in turn have their own model uncertainties.

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