Current water resources in Europe and Africa

Matching water supply and water demand

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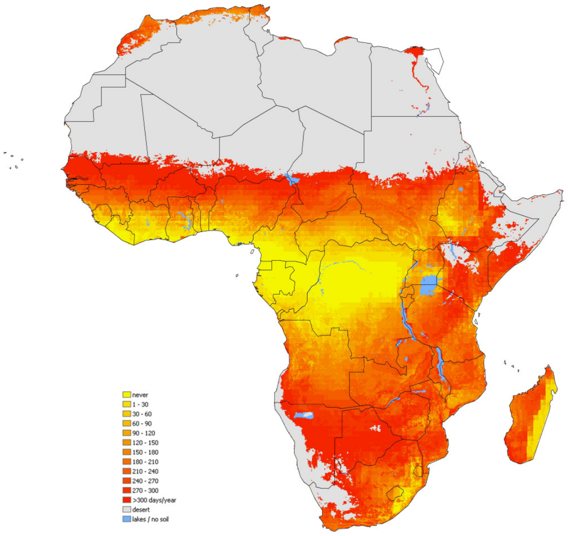

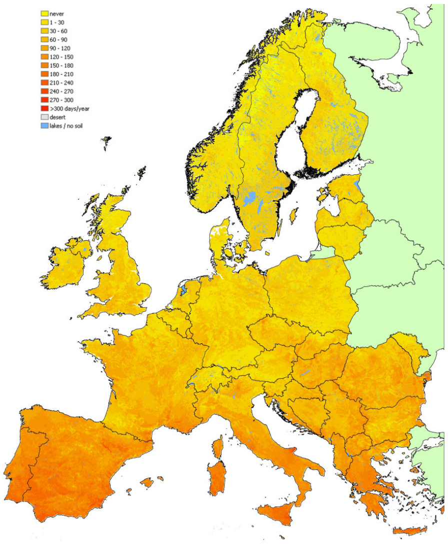

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Contents

Summary

An assessment for Europe on available water resources and a comparison with water demands from various economic sectors shows that freshwater availability over the European continent varies significantly. Large areas in Spain and Eastern Europe have on average less than 200 mm generated freshwater per year. At the same time, in parts of those areas annual water demand from the various sectors is equal or even larger than the freshwater generation. However, estimating water scarcity is not a straightforward exercise, since important parts of the 'puzzle' are missing, such as inter-riverbasin water transfers, detailed information on various storages in lakes and reservoirs, as well as the use of deep/fossil groundwater. Therefore, estimating water scarcity still includes many uncertainties, and the estimation made here needs further improvement.

In addition, although data needed for water resources assessment do exist in Europe, the access to these data to make a pan-European overview could still be improved - the public availability of observed river flows is still a particular concern. The availability of meteorological observations, together with increased availability of satellite observations, has greatly improved already.

An assessment of the African continent reveals large areas with less than 200 mm freshwater generation per year. Areas with freshwater generation larger than 200 mm are situated in Morocco, equatorial Africa, Southwest Ethiopia, Eastern South-Africa and Madagascar. Estimating water scarcity is again a challenging exercise. First of all, the most recent pan-African data on water abstractions date from the year 2000, which needs improvement. Next, as in Europe, information on large inter-riverbasin water transfers is not available.

There are many future research challenges, knowledge gaps, and data gaps in the field of water resources estimation. The lack of available observed river flow data for Africa, for example, creates a major bottleneck in calibrating and verifying hydrological models for this continent. Satellite data provide improved meteorological data for Africa, but data on water abstractions need to be updated more frequently. In general, information on long-distance water transfers - intra riverbasin, inter-riverbasin, or cross-border - is largely unavailable at continental and global level.

Introduction

Ensuring good quality water in sufficient quantities for all legitimate uses is a major policy aim of the European Commission, and the main aim of the the European Commission's "Blueprint to Safeguard Europe's Waters", which will be launched in 2012. The Blueprint is the EU policy response to emerging challenges in the field of water.

It is within this policy framework that the JRC carries out research on hydrological simulation modelling, aiming to provide scientific assessments of general available water resources and floods, droughts and water scarcity. The main aim of these research activities is to assess current and future water availability versus current and future water demands from different economic sectors.

Global warming is expected to account for about 20% of the global increase in water scarcity this century. Global water consumption increased sixfold in the past century - more than twice the rate of population growth - and will continue to grow in the coming decades. Given these trends, the equitable provision of adequate water resources for agriculture, industry and human consumption poses one of the greatest challenges of the 21st century (http://timeforchange.org/).

Before future challenges can be addressed, a thorough analysis of current water resources is needed. The scope of this study is to analyse current water resources in Europe and Africa, and to match water supply and water demand from various sectors.

Several attempts already have been made to assess European, African and global water resources. Recently, Haddeland et al. (2011) produced a multimodel estimate of the global terrestrial water balance at 0.5° spatial resolution. This has been achieved within the Global Water Availability Assessment (GWAVA), developed in the context of the EU-funded WATCH project (https://gateway.ceh.ac.uk).

Within another EU-funded project, GLOWASIS (Global Water Scarcity Information System), Utrecht University and Deltares are developing a global water scarcity map also at 0.5° spatial resolution, to be finished by December 2012 (http://glowasis.eu). First results are published in Van Beek et al. (2011). The JRC is a partner in this project to benchmark the global product with the higher resolution European and African assessments.

A further study was conducted by Hoekstra and Mekonnen (2011), assessing global water scarcity for the world's major river basins.

Other available information on global water resources are available from:

- FAO, Aquastat portal http://www.fao.org/nr/water/aquastat/globalmaps/index.stm
- UNEP: http://maps.grida.no/go/graphic/freshwater-availability-groundwater-and-river-flow
- Cleaningwater: http://cleaningwater.se/whats-new/geographical-distribution
- IWMI Institute: http://www.iwmi.cgiar.org/WAtlas/Default.aspx
- World Resources Institute: http://earthtrends.wri.org/maps_spatial/maps_detail_static.php?map_select=265&theme=4
- Monde diplomatique: http://www.monde-diplomatique.fr/cartes/disponibiliteeau
- GRID-Arendal (Africa): http://www.grida.no/publications/vg/africa/
- EEA (Europe): http://www.eea.europa.eu/data-and-maps/figures/annual-water-availability-per-capita-by-country-2001

In general, however, the analysis carried out on the products described above is undertaken at national scales, at relatively coarse spatial resolution (0.5^o), and using water demand data from the year 2000 or before, because more recent data are not yet available. The scope of the study presented here is to carry out a higher spatial resolution analysis for Europe (5 km ~ 0.05^o) and Africa (0.1^o), using a daily timescale for modelling, and using new JRC analyses of European water uses for irrigation, livestock, industry and energy, and domestic purposes. The analysis is carried out using the JRC LISFLOOD hydrological simulation model, supported by several other available models (EPIC, LUMP).

Hydrological modelling

LISFLOOD is a GIS-based spatially-distributed hydrological rainfall-runoff model developed at the JRC. It includes a one-dimensional hydrodynamic channel routing model (De Roo et al., 2000; Van der Knijff et al., 2010). LISFLOOD is currently used at the JRC for simulating water resources in Europe and Africa. Driven by meteorological forcing data (precipitation, temperature, potential evapotranspiration, and evaporation rates for open water and bare soil surfaces), LISFLOOD calculates a complete water balance at a daily time step and every grid-cell. Processes simulated for each grid cell include snowmelt, soil freezing, surface runoff, infiltration into the soil, preferential flow, redistribution of soil moisture within the soil profile, drainage of water to the groundwater system, groundwater storage, and groundwater base flow. Runoff produced for every grid cell is routed through the river network using a kinematic wave approach. Although this model has been developed with the aim of carrying out operational flood forecasting at the pan-European scale, recent applications demonstrate that it is well suited for assessing the effects of land-use change and climate change on hydrology (Feyen et al., 2007; Dankers and Feyen, 2009).

To account properly for land-use dynamics, some conceptual changes have been made to render LISFLOOD more land-use sensitive. Combining land-use classes and modelling aggregated classes separately is known as the concept of hydrological response units (HRU). This concept is used in models such as SWAT (Arnold and Fohrer, 2005) and PREVAH (Viviroli et al., 2009) and is now implemented in LISFLOOD on the sub-grid level. A forest fraction map, water fraction and direct runoff fraction have been derived from the 100m resolution land use Land Use Modelling Platform (LUMP) maps. The spatial distribution and frequency of each class is defined as a percentage of the entire 5 x 5 km grid. To address the sub-grid variability in land use, we model the within-grid variability by running the soil modules separately for fractions of land use.

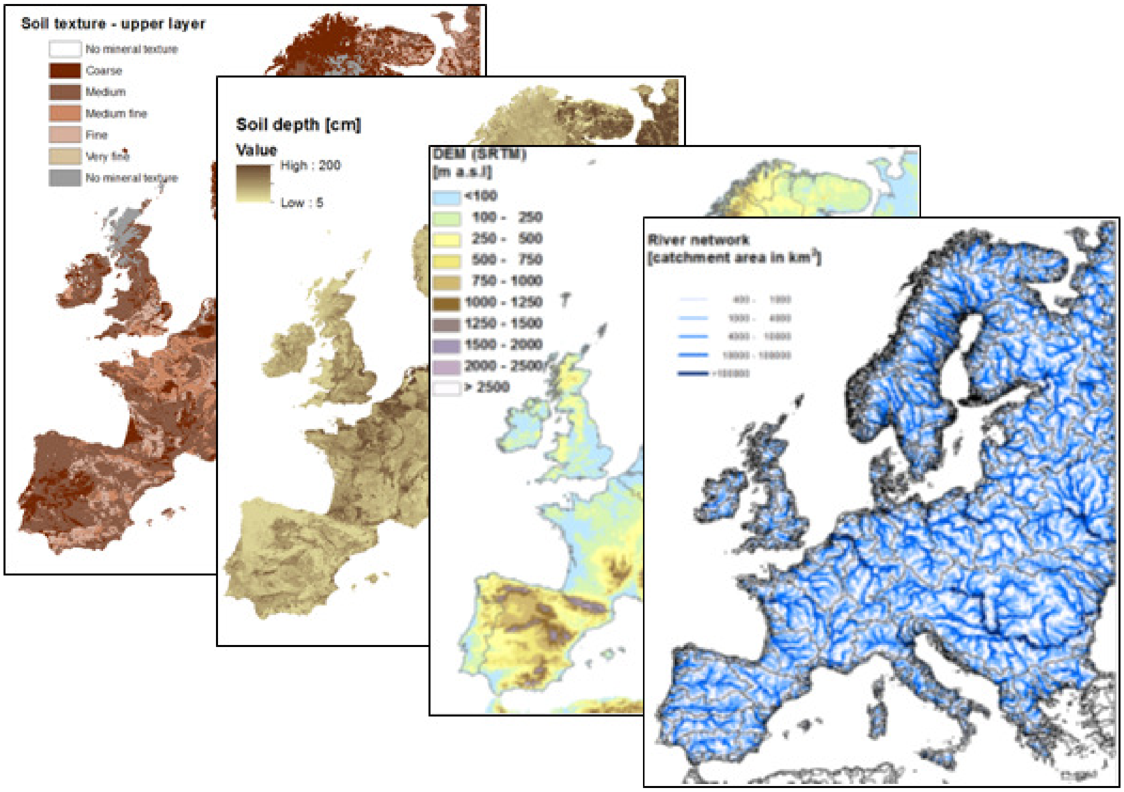

Figure 1 Input data used for the European LISFLOOD model setup

The model has also options to simulate lakes, reservoirs, and retention polders, which are relevant for low-flow analysis (as they tend to increase low flows) as well as for simulating flood protection during high flows. In the current setting for Europe, 173 lakes and reservoirs are included. Several large lakes and reservoirs are also included for Africa.

Model input data

The current pan-European setup of LISFLOOD uses a 5-km grid and spatially variable input parameters and variables obtained from European databases (Figure 1). Elevation data are obtained from the Shuttle Radar Topography Mission (SRTM) (Farr et al., 2007) and river properties were obtained from the Catchment Information System (Hiederer and de Roo, 2003). Soil properties were obtained from the European Soil Geographical Database (King et al., 1994) whereas porosity, saturated hydraulic conductivity and moisture retention properties for different texture classes were obtained from the HYPRES database (Wösten et al., 1999). Vegetative properties and land use cover were obtained from the JRC Land Use Modelling Platform (LUMP). The meteorological and hydrological data used are described in the next chapter.
For Africa, a 0.1-degree resolution is established.

Model output data

The LISFLOOD model output can be any internal variable calculated by the model, either as time series, summary maps or stacked maps over the complete time period. Examples of output are discharge hydrographs, summary maps of evapotranspiration, soil moisture or groundwater recharge.
For modelling water supply and water demand, the model output is the daily accumulated amount of surface and groundwater in millimetres for each grid cell (daily local runoff).

Model limitations

With a grid size of 5 x 5 km (Europe) and 0.1 x 0.1 degree (Africa), LISFLOOD is developed for simulating medium and large river basins. Satisfactory results can be obtained in basins of a few hundred km^2 up to the size of the entire Danube basin. A limiting factor is the availability of good, accurate and homogenous input data for the entire pan-European or pan-African scale, for example soil data or measured discharge data. Human influences (e.g. dams, reservoirs, polders, irrigation) also are difficult to quantify. This is an especially important factor for low-flow simulations.

Calibration and validation of the LISFLOOD model

With a 5-km grid resolution, the current European-wide model setup uses spatially variable parameters on soil, vegetation and land use derived from European datasets. The Shuffled Complex Evolution - University of Arizona (SCE-UA) algorithm (Duan et al., 1992) was selected for carrying out the calibration of the LISFLOOD model at the European scale. A set of 9 parameters that control infiltration, snowmelt, overland and river flow, as well as residence times in the soil and subsurface reservoirs, have been estimated for 479 catchments by calibrating the model against historical records of river discharge. The results of 435 of these catchments have been used to set up the model, while 44 were rejected because of unreliable data input. The calibration period varied between the different catchments depending on the availability of discharge measurements, but all spanned between 1 and 9 years between 1996 and 2009. A more detailed description of the calibration of LISFLOOD for different European catchments is given by Feyen et al. (2007, 2008).

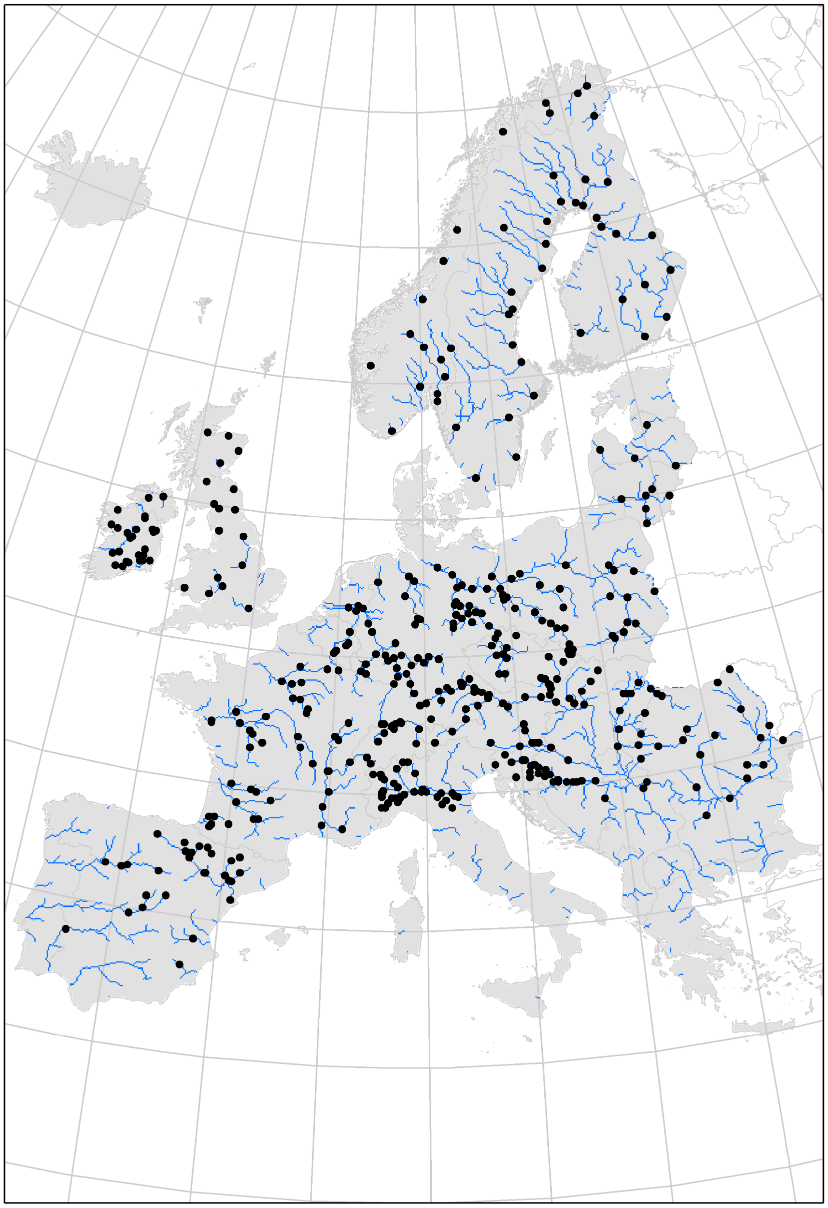

Figure 2 Location of the 435 discharge gauging stations used in the calibration of the hydrological model

The location of the stations used in the calibration and validation are represented by the black dots in Figure 2. This overview shows that the coverage is sufficient in most parts of northern and central Europe. For the Balkan area, Greece, southern Italy and parts the Iberian Peninsula, no discharge series were available at the time of the model calibration. For catchments where discharge measurements were not available, simple regionalisation techniques (regional averages) were applied to obtain the parameters.

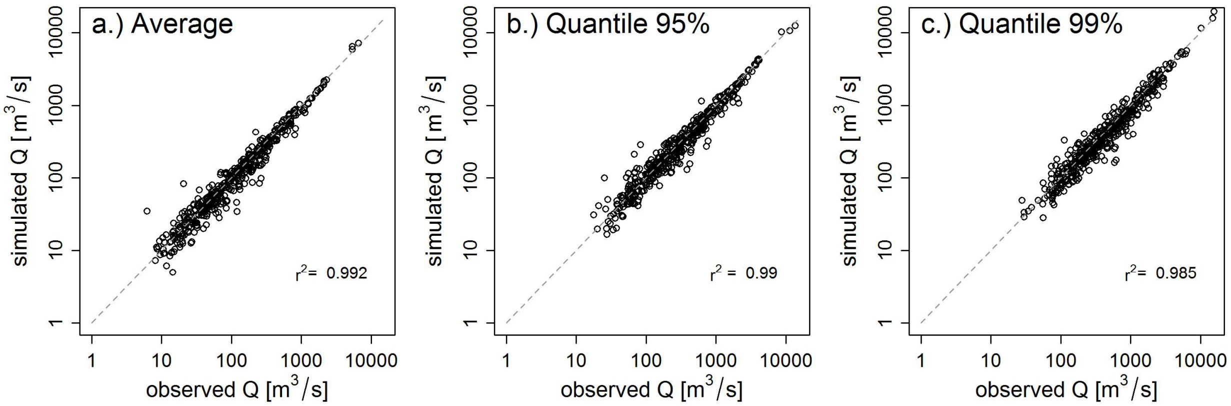

Figure 3 Observed versus simulated averages, 95% and 99% discharge for each of the 435 calibration stations for a 3-year validation period

Figure 3 shows observed versus simulated averages, and 95% and 99% discharge for each of the 435 calibration stations shown in Figure 2, for a 3-year validation period. This period varyies between the different catchments depending on the availability of discharge measurements but includes the latest available data. Visual inspection and the values for the coefficient of determination (r2) show that the observed flow statistics are reasonably well reproduced by the LISFLOOD simulation with a general tendency towards better performance for average flows and with increasing catchment size. Notwithstanding the overall good agreement between the observed and simulated flow statistics, large discrepancies do occur at a small number of stations. Deviations from the observation-based statistics may be attributed to errors in meteorological forcings, the spatial interpolation of meteorological data, as well as to errors in the hydrological model, its static input and the calibration of its parameters. Some of the differences may also be due to manmade modifications of flow regimes in many catchments, which are not accounted for in the hydrological model.

Meteorological and hydrological data

Europe

The meteorological variables of precipitation, minimum/maximum/average/dewpoint temperature, wind speed, potential evapotranspiration, and evaporation rates for open water and bare soil surfaces for driving LISFLOOD are derived from various data sources for the period 1/1/1990 until 31/12/2010. These data sources include the JRC MARS database (http://mars.jrc.ec.europa.eu/mars/), data obtained from MeteoConsult, SYNOP data, as well as data from the European Climate Assessment & Dataset (ECA&D, http://eca.knmi.nl/). An overview of the definitions of the different meteorological variables and the data sources used for those variables is given in Table 1.

Variable	Definition	Data Sources
ws	Mean daily wind speed at 10 metres/second (m/s) from 0-24 UTC	JRC MARS, SYNOP, ECA&D
pr	Precipitation (mm) between 6 UTC on the day specified and 6 UTC on the following day	JRC MARS, SYNOP, ECA&D, MeteoConsult
tn	Minimum temperature (C) between 18 UTC and 6 UTC (i.e. during the preceding night)	JRC MARS, SYNOP, ECA&D
tx	Maximum temperature (C) between 6 UTC and 18 UTC (i.e. during daytime)	JRC MARS, SYNOP, ECA&D
td	Average of all available dewpoint temperature measurements between 6 UTC on the day specified and 6 UTC on the next day.	SYNOP
ta	If the daily maximum temperature (tx) and the daily minimum temperature (tn) is known, mean daily temperature is calculated as ta = (tx + tn) / 2.	JRC MARS, SYNOP, ECA&D
e0	Penman potential evaporation from a free water surface (mm/day)	JRC MARS
et	Penman potential transpiration from a crop canopy (mm/day)	JRC MARS
es	Penman potential evaporation from a moist bare soil surface (mm/day)	JRC MARS

Table 1 An overview of the observed meteorological variables as used in LISFLOOD and LISVAP

All meteorological variables are interpolated on a 5 x 5 km grid using inverse distance weighting with a weight of d^{-2} and a maximum number of 5 points for the interpolation. Temperature variables are first corrected using the elevation obtained from a DEM with a resolution of 1 x 1 km and using a constant lapse rate of 0.006 (0.002 for dewpoint temperature) and are then interpolated onto the 5 x 5 km grid. An example of the spatial distribution of precipitation observations is given in Figure 4.

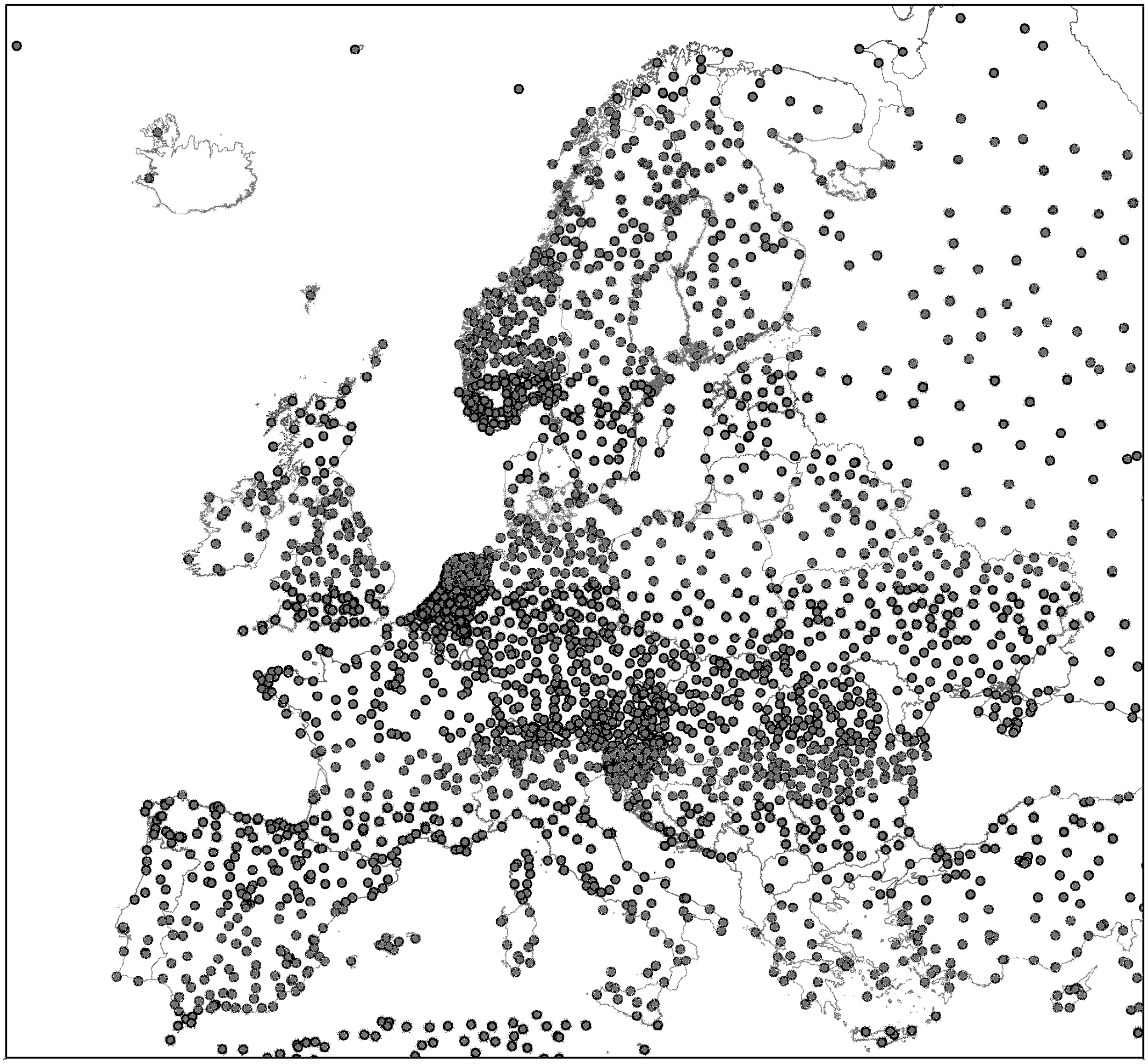

Figure 4 Spatial distribution of available precipitation observations on 15 Dec 2010.

Figure 5 shows the temporal distributions of the different meteorological variables from 01.01.1990 until 31.12.2010. On average more than 2000 5 x 5 km pixels have at least one precipitation observation and more than 1,200 have a temperature or wind speed observation for the time period between 1990 and 2003. Since about 2004 on average more than 2,500 5 x 5 km pixels for precipitation and more than 2,000 for temperature and wind speed are observed at least once.

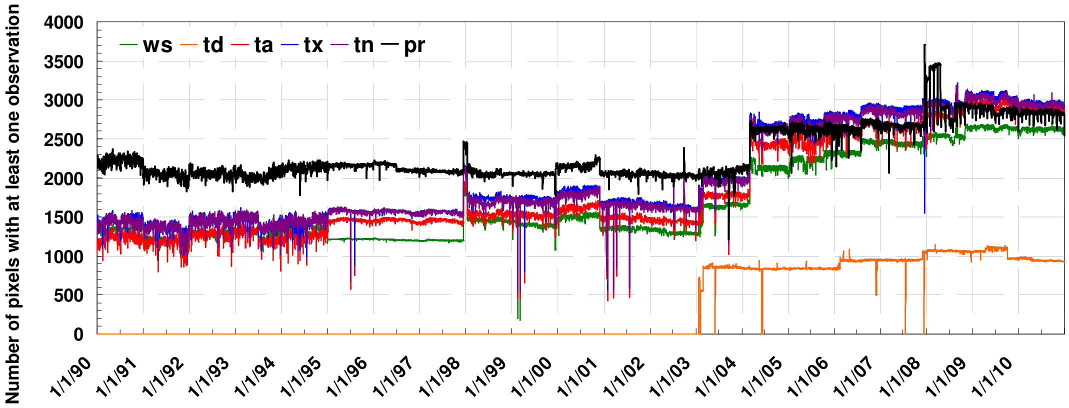

Figure 5 Temporal distribution of the number of observations available for the interpolation of precipitation, minimum/maximum/average/dew point temperature, and wind speed.

Potential evapotranspiration, and evaporation rates for open water and bare soil surfaces, are calculated in two different ways during the 21-year time span. For periods before 23/01/2003 e0, et and es are taken from the JRC MARS database directly and interpolated as described above. However, from 23/01/2003 onwards, LISVAP (van der Knijff, 2008), an evaporation pre-processor for LISFLOOD, is used to derive the maps using the observed variables minimum daily temperature (tn), maximum daily temperature (tx), dewpoint temperature (td) and windspeed (ws). Figure 6 shows the annual average precipitation for Europe, computed from the data we have available for this study.

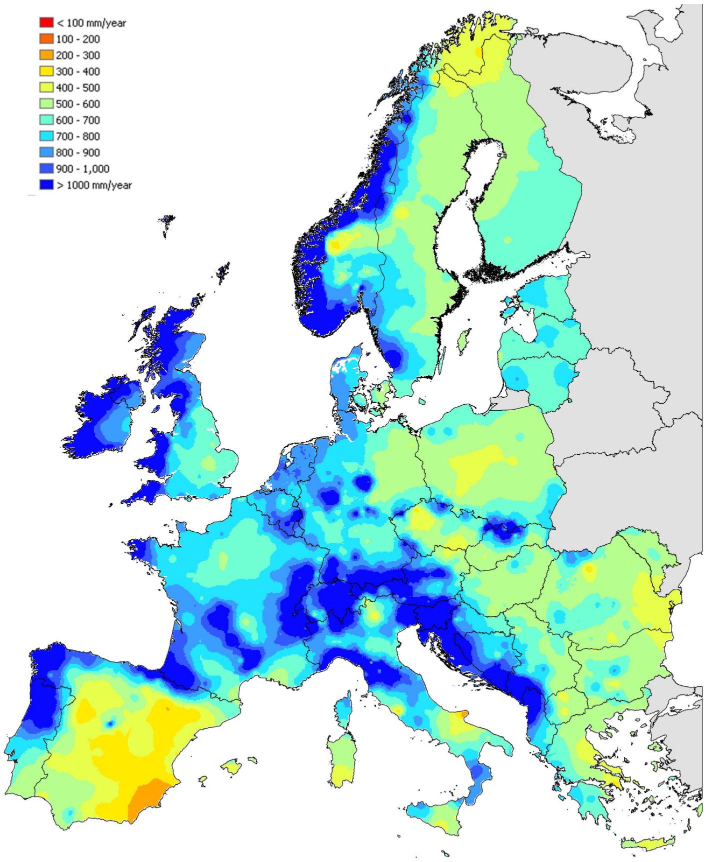

Figure 6 Annual average precipitation (mm) (1990-2010), based on spatially interpolated ground station measurements, using the JRC CGMS/Mars database and the JRC EUFloodGIS database. Source: JRC / Salamon, Burek (2011).

Africa

For Africa, we also used the spatially distributed hydrological rainfall-runoff LISFLOOD model for discharge simulation. Driven by meteorological forcing data, LISFLOOD calculates a complete water balance at every (daily) time step and every grid cell defined in the modelled domain. The current pan-African setup of LISFLOOD uses a 0.1^{o} degree grid. Spatially variable input parameters and variables were obtained from different databases when available. The source of processed digital elevation models was the Shuttle Radar Topography Mission (SRTM) elevation data (URL: http://dds.cr.usgs.gov/srtm). The Local Drain Direction maps of the African river basins were developed using a sequence of upscaling operations performed on the flow network derived from a high resolution SRTM-based elevation model of Africa. Manual modifications were needed at several crucial locations. Soil properties (soil texture, soil depth) were obtained from the Harmonized World Soil Database (HWSD). For soil texture, sand, silt and clay content in percentage was derived on topsoil and subsoil levels with the condition of the three components was 100%. Forest fraction and land use cover were obtained from the Global Land Cover 2000 (GLC2000) dataset (JRC, 2003). In addition to land cover, the vegetative properties (Leaf Area Index) were obtained from the VGT4AFRICA Project (MEDIAS/POSTEL). All the datasets were resampled to 0.1^{o} degree horizontal resolution. A more detailed description of the static input maps for Africa is given by (Bódis, 2009). For this study, we ran a LISFLOOD model of the pan-African domain for the period 1/1/1989 until 31/12/2010.

To drive the LISFLOOD model for the pan-African domain, the ERA-Interim reanalysis dataset was used. The ERA-Interim reanalysis dataset contains a physically consistent atmosphere and surface analysis produced by ECMWF (http://www.ecmwf.int/research/era/do/get/era-interim). ERA-Interim covers the period from 1989 until present. More information of the full ERA-Interim reanalysis products can be found in Simmons et al. (2007). Gridded data products of ERA-Interim include a large variety of surface parameters and upper-air parameters. Here we retrieved 3-hourly or daily estimates of wind speed, minimum and maximum temperature, dewpoint temperature, and solar and thermal radiation at a grid of 0.25 degrees from the original Gaussian reduced grid (about 0.7 degree). However, all the forcing data are projected on a 0.1 degree regular lat/lon grid used by LISFLOOD at the pan-African scale for the period of 1/1/1989 until 31/12/2010. The input variables (potential evapotranspiration, and evaporation rates for open water and bare soil surfaces) to force LISFLOOD are obtained using the Penman-Monteith formula calculated with a LISVAP pre-processor.

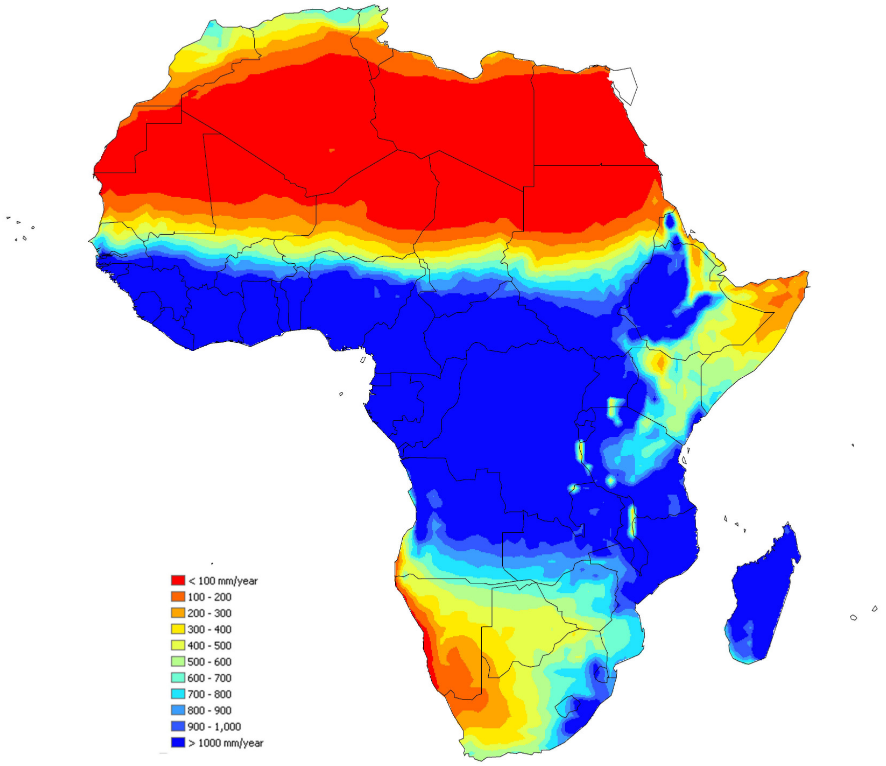

Figure 7 Annual average precipitation (mm), based on ECMWF corrected ERA-Interim data (1989-2010). Source: JRC / Bisselink, DeRoo (2012).

For precipitation we used a corrected ERA-Interim product (Figure 7). A scale-selective rescaling procedure that corrects the original ERA-Interim precipitation is performed by Balsamo et al. (2010) in order to match the monthly accumulated precipitation provided by the Global Precipitation Climatology Project (GPCP v2.1) product. It is expected that the rescaling improves the accuracy by combining the advantages of the observation-based GPCP v2.1 product with those of the original high resolution ERA-Interim data.

Hydrological data

Observed river flow data at gauging stations from Europe and Africa were used from the Global Runoff Data Centre (GRDC). These daily observed data have been used to calibrate and validate the LISFLOOD model setups for Europe and Africa. For Europe, historical river flow data from 435 stations (Figure 2) have been used for model calibration and validation.

For Africa, data from 51 stations are available to us for model verification. It should be noted that the density of available observations for Africa needs improvement in order to improve the accuracy of the African assessment.

Water use and demand data

Europe – Irrigation water requirements

A detailed description of the methods used to derive irrigation requirements for Europe can be found in Wriedt et al. (2008, 2009).

The generation of the irrigation map followed a two-step procedure. First, irrigated area was distributed to crop categories at sub-regional level (NUTS3) based on statistical information and distribution rules. Next, the regional information was disaggregated to a high resolution dataset based on the crop distribution and a global irrigation dataset (Siebert et al., 2005). Based on crop growth, soil water and the EPIC nutrient model, we estimated irrigation water requirements on a daily basis at a 10 x 10 km grid scale using automatic irrigation under different strategies, including unlimited irrigation, various water stress thresholds, and a 'no irrigation' strategy. We then chose the irrigation strategy that yields at least 80% of the yield obtained under the unlimited irrigation strategy, while also minimising water use. Selecting different irrigation strategies allowed us to adapt irrigation more specifically to soil conditions and crop growth. For rice we took a fixed irrigation strategy applying an amount of 3,500 mm per year. The calculated average irrigation requirements for irrigated crops range from a minimum of 13 mm/yr in Switzerland to 900 mm/yr and more for Spain, Portugal, Greece and Italy. Figure 8 shows the annual irrigation requirements for EU-27.

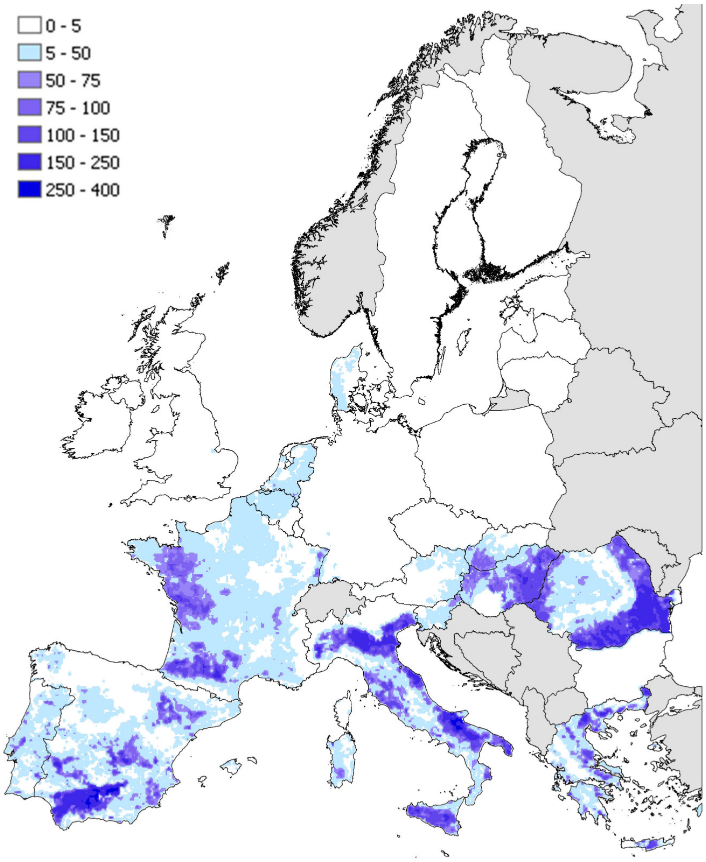

Figure 8 Average annual irrigation water requirements for Europe (mm per 25 km^2 grid). Source: JRC/Bouraoui, Wriedt (2008).

Europe – Water use for Livestock, Industry and the Domestic sector

Maps of EU-wide sectoral water withdrawals were produced for the reference year 2006, based on the disaggregation of Eurostat sectoral withdrawal statistics to a 5 x 5 km grid using proxy values. The OECD/EUROSTAT Joint Questionnaire on Inland Water (tables 4 & 5) provides country-level statistics on sectoral water supply and abstraction for the EU-27. We have extracted the average sectoral water withdrawals for the period 2005-07, which we assume to be representative of the year 2006, while excluding any extreme values. Since detailed and verified NUTS3 level data was available for France for 2006, this country was used as a test case to find correlations between sectoral water withdrawals and proxy parameters which could then be extrapolated to model water withdrawal for the countries where detailed regional data was not available or was unreliable. The following sectors were mapped:

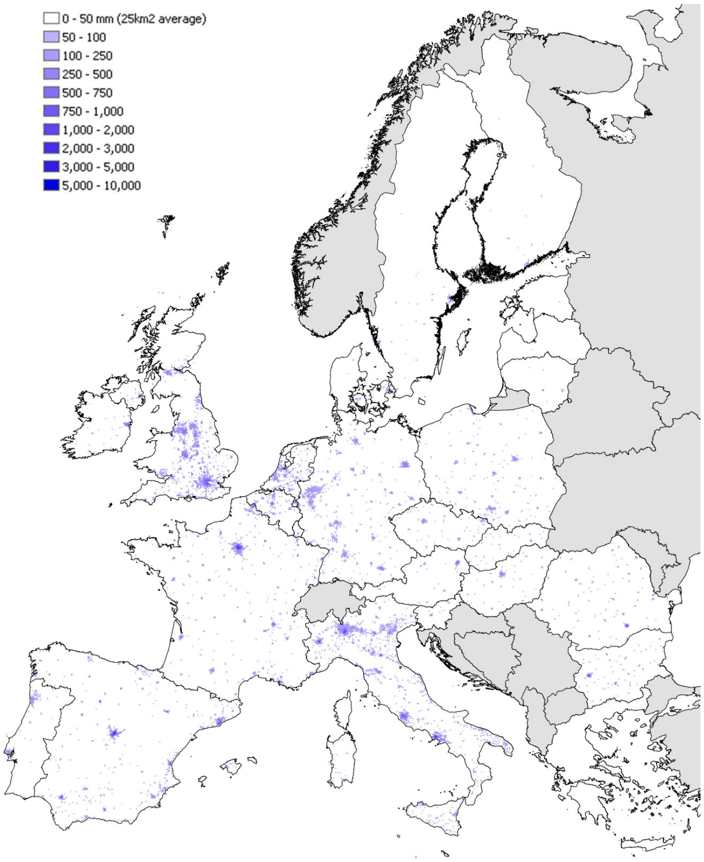

Figure 9 Average annual public water withdrawl for Europe (2005-2007) (mm/yr per 25 km2 grid). Source: JRC/Mubareka, Vandecasteele, Bianchi (2012).

Public water withdrawal

Eurostat provides data on "Public water supply", which is defined in the metadata (Nagy et al., 2007) as: "Water supplied by economic units engaged in collection, purification and distribution of water..." We assume that the public water withdrawal is the total water withdrawn in urban areas. Although some commercial/service areas may be included, the use is assumed to be mostly domestic. Since public water withdrawal was seen to be highly correlated to the total population, both at country and regional level, we used population density, based on the refined population grid calculated by Batista e Silva et al. (submitted) as a proxy to describe the withdrawals spatially. Multiplying the per capita water use (based on the country totals from Eurostat) with the population density gave a first draft map of annual public water withdrawal at 5 km resolution. The influence of tourism (total number of nights spent, collected from the national statistical websites) was also taken into account, especially as it closely reflects the seasonal variation in public withdrawal.

Industrial water withdrawal

For this first draft of the water withdrawal maps, we consider industrial abstraction to include both withdrawals for both the manufacturing industry and the energy sector. Industrial withdrawals are highly correlated to Gross Value Added (GVA) for industry and employment in industry. For the disaggregation to a 5 x 5 km grid, however, the number of industrial units per cell was calculated from the EPRTR dataset, and this was used as a proxy value. Indeed, for France, the number of industrial units showed the highest correlation to industrial water withdrawals at NUTS3 level. The average water use per industrial unit was multiplied by the total number of industrial units in each cell to give an approximation of the total annual industrial water withdrawal per cell. A next step is the identification and increased/weighted allocation of withdrawals to the most water-intensive industries. The water withdrawal for energy production at country level is highly correlated to energy consumption, for which statistics are being collected at the regional level. This would be a good proxy, combined with the number of thermal combustion plants per NUTS3 region, which can be derived from the EPTPR dataset. Once the dataset is complete it can also be used to improve the disaggregation and models applied for public and industrial withdrawals. For the moment, however, we do not differentiate water withdrawal for energy production from the total industrial withdrawal.

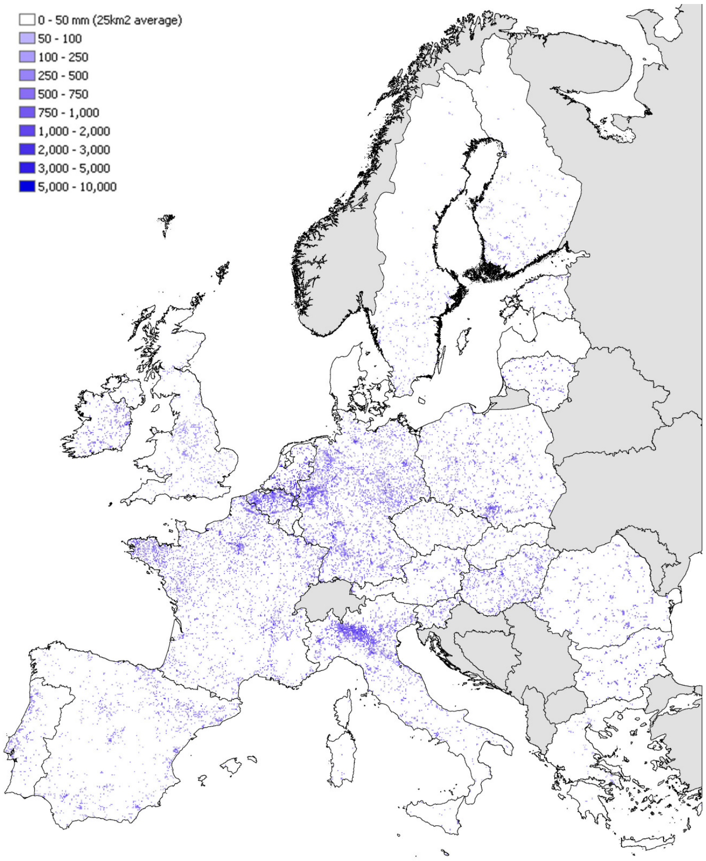

Figure 10 Average annual Industrial water withdrawal (2005-2007) (mm/year per 25km2 grid). Source: JRC/Mubareka, Vandecasteele, Bianchi (2012).

Livestock water withdrawal

Daily maps of livestock water withdrawal were calculated using the Food and Agriculture Organization (FAO) livestock density maps and output from the CAPRI agricultural model. The water use was calculated based on the specific water requirement (taken from literature) and spatial distribution of each type of livestock (cattle, pigs, poultry, sheep and goats). A temperature function was derived and applied to describe daily variations in water use for each livestock group.

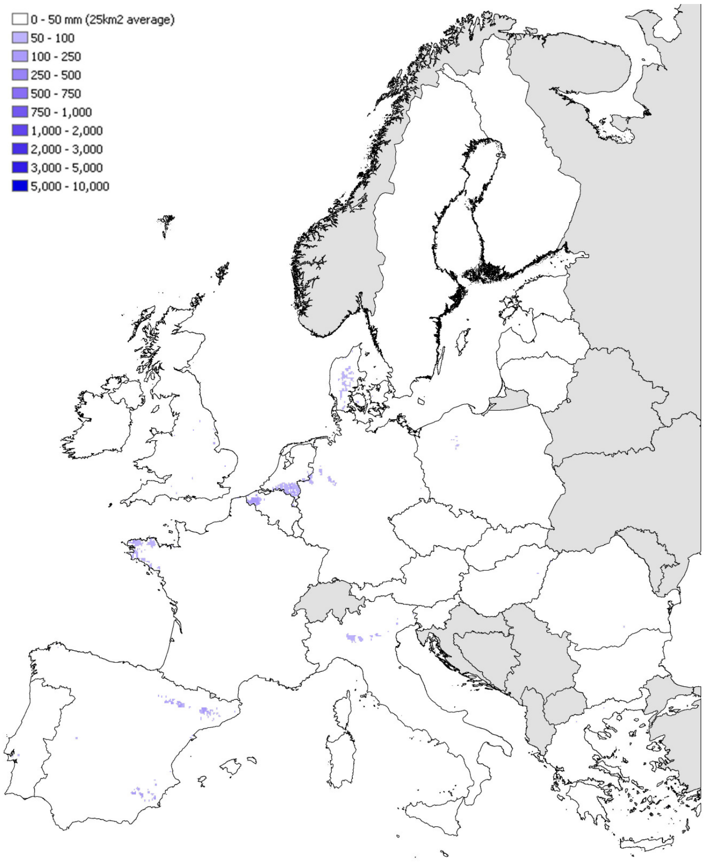

Figure 11 Average annual livestock water withdrawal (2005-07) (mm/yr per 25 km^2 grid). Source: JRC/Mubareka, Vandecasteele, Bianchi (2012).

Figure 12 shows the sum of the water abstractions for irrigation, industry, livestock and domestic purposes.

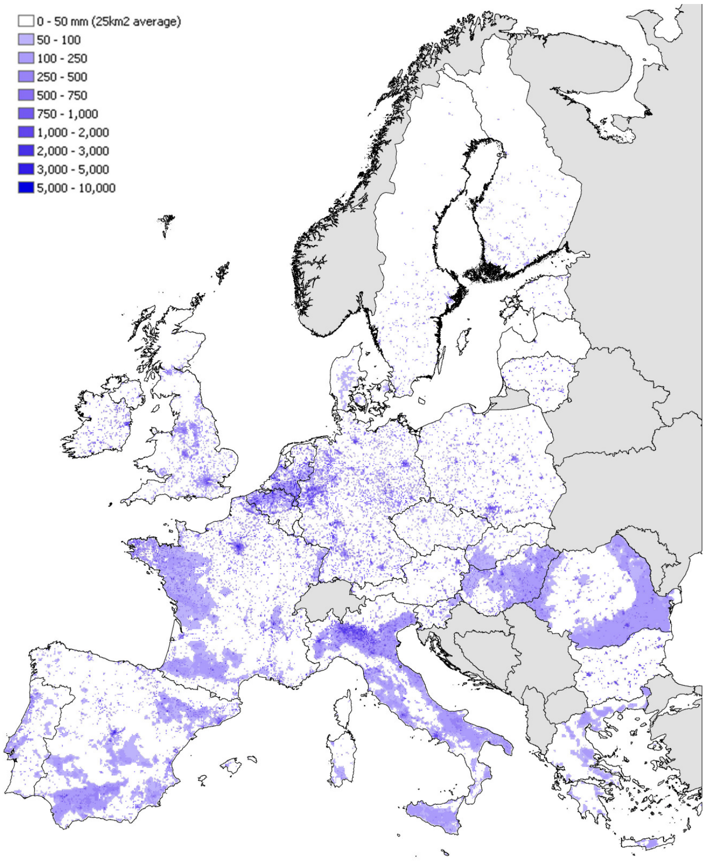

Figure 12 Total average annual water demand in Europe for irrigation, livestock, industry (manufacturing and energy production) and the domestic sector. Source: JRC/Bouraoui, Wriedt, Mubareka, Vandecasteele, Bianchi (2012).

Africa – Irrigation water requirements

A detailed description of the methods used to derive irrigation requirements for Africa can be found in Pastori et al. (2011).

The irrigation requirements have been estimated using the GISEPIC AFRICA GIS system which integrates the biophysical continuous simulation model EPIC (Williams et al., 1995) with an SQL Server 2008 database that allows for the simulation of nutrient and water cycling as affected by agricultural practices and crop growth at the African continental scale. The system is mainly composed of the following components: the EPIC model, the spatial geodatabase, the dll component and the GIS interface. EPIC is a biophysical, continuous, field scale agriculture management model. It simulates crop water requirements and the fate of nutrients and pesticides as affected by farming activities such as the timing of agrochemicals application, different tillage practices, crop types and varieties, crop rotation, irrigation strategies, etc., while also providing a basic farm economic account. The main components can be divided into the following: hydrology, weather, erosion, nutrients, soil temperature, plant growth, tillage, plant environment control and economics. Complete and detailed information and a description of each component are given by Williams et al. (1995).

The latest version of the global map of irrigated areas from the FAO (Siebert et al., 2005, 2006 and 2007) was used as the main reference to identify the area for which irrigation has to be considered in the EPIC simulations. Irrigation reports from the FAO were used to identify crops or groups of crops that are irrigated in different countries (FAOe, 2009). When some discrepancies with reported data from the FAO map were observed, the Global Irrigated Area Map of the World map (Thenkabail et al., 2008) was used to provide the missing data. The Global Irrigated Area Map of the World is a map developed for year 1999 using multiple satellite sensors and secondary data such as rainfall series, land use data, DEM and others (see Thenkabail et al., 2008 for details). The final product is a 10-km resolution map with 28 classes covering the entire globe. Finally, irrigation reports from the FAO (FAOf, 2009) were mainly used to identify crops or groups of crops that are irrigated in different countries. Other information was available from other FAO statistic databases (FAOf, 2009).

A table was designed in the database to store all the required information: the presence or absence of irrigation, which crops are actually irrigated, the relative percentage of irrigated area (crop selective irrigation) and the maximum amount of water that can be applied.

When irrigation is active, the automatic EPIC scheduling option is used. This model automatically schedules the irrigation and the amount applied is calculated according to daily plant water stress. Different parameters can be used to control the irrigation scheduling and to parameterise the irrigation according to regional and local practices. In our application, the maximum total volume by year, the type of irrigation (furrow or sprinkler) and the time between different water applications are defined for each site and for each crop. The irrigation requirements are summarised in Figure 13, where the average annual irrigation requirement is shown.

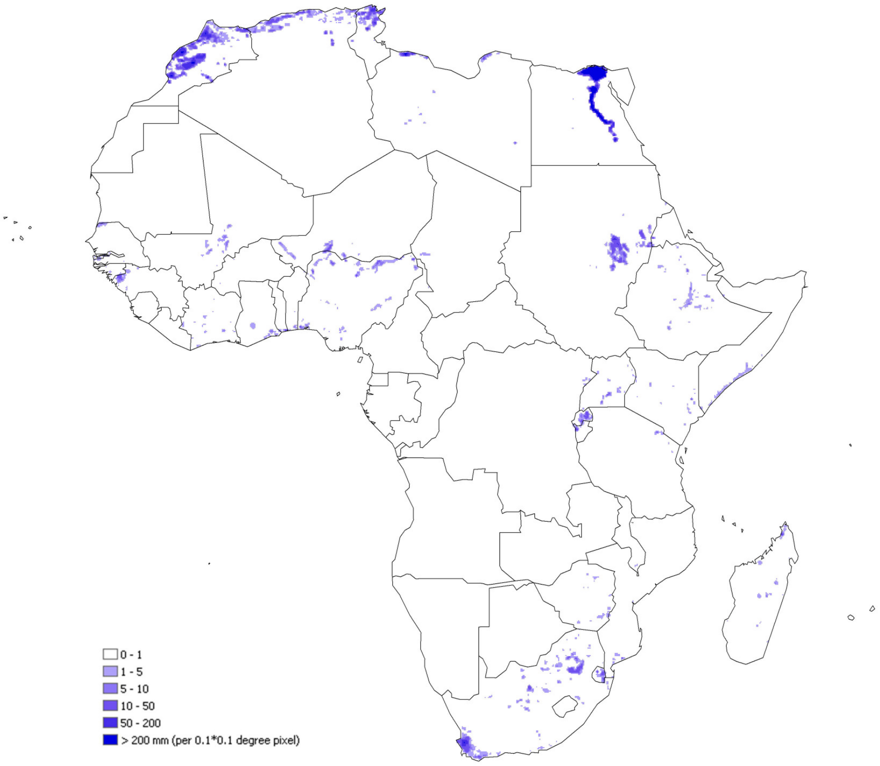

Figure 13 Average annual irrigation water requirements. Source: JRC / Bouraoui, Pastori (2011).

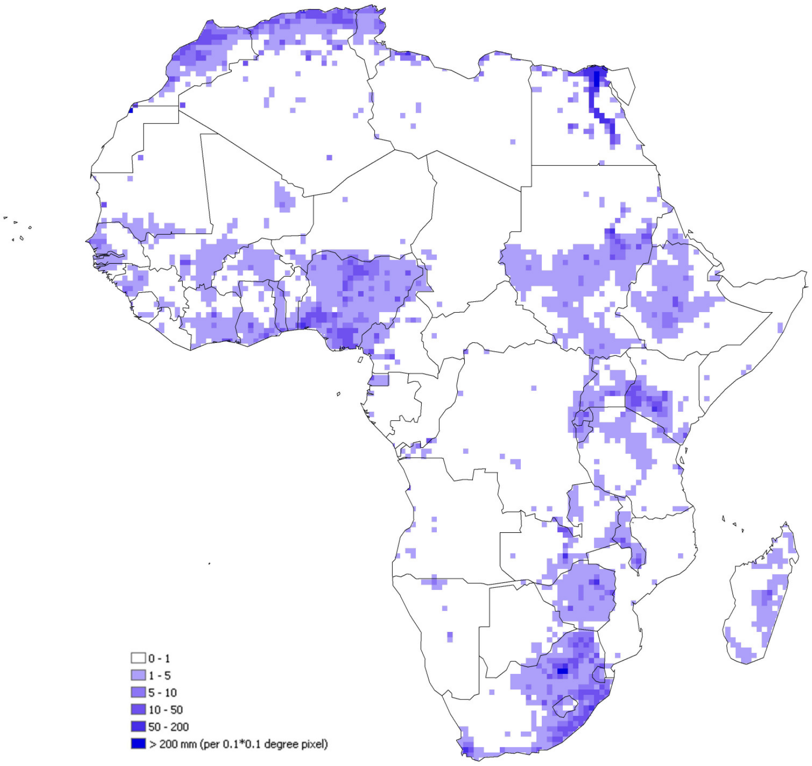

Figure 14 Average annual water use in Africa for the industry, households and livestock sectors (mm per 0.1 x 0.1 degree grid). Source: Utrecht University (Van Beek et al., 2011; Wada et al., 2011).

Africa – Water use for the Livestock, Industry and the Domestic sectors

For the other water use data for Africa (figure 14), we used the global data produced by Van Beek et al. (2011) and Wada et al (2011), made available by Utrecht University within the EU-project GLOWASIS. The global monthly water demand for the livestock, industrial and domestic sectors were estimated using various data such as livestock densities and population. Here, the water demand is defined as net water demand, the potential consumption of surface freshwater resources. Consequently, it is lower than gross water demand as water withdrawn for industrial and domestic sectors is recycled and returned to the river networks while part of gross irrigation water demand is met by green water availability (i.e., soil water). The year 2000 is taken as benchmark while the long term climate variability is characterised by the 44-year period from 1958 until 2001. Monthly livestock, industrial and domestic water demand are estimated for the year 2000. For the livestock water demand, the gridded data of global livestock density in the year 2000 and the specific daily water consumption were obtained from the FAO (2007) and Alcamo et al. (1997) respectively. For an extensive description of the methods, we refer to Van Beek et al. (2011) and Wada et al. (2011b). To estimate the net industrial water demand, the industrial water withdrawals which were taken from the WWDR-II dataset (Shiklomanov, 1997; WRI, 1998; Vörösmarty et al., 2005) are multiplied by a recycling ratio. The gross domestic water demand is obtained by multiplying the number of persons in a grid cell by the country-specific per capita domestic water withdrawal for the year 2000. The gridded global population for 2000 was obtained from the History Database of the Global Environment (HYDE; Klein Goldewijk and van Drecht, 2006). The country-specific per capita domestic water withdrawal was taken from the FAO AQUASTAT database.

Modelling the match of water supply and demand

The process of modelling to match water supply and water demand is carried out using a simplified daily hydrological model, using the following inputs:

- Daily local runoff (mm) (simulated using the LISFLOOD model)
- Monthly irrigation water use (mm/area)
- Average annual industrial water demand (mm/area)
- Daily (Europe) or monthly (Africa) livestock water demand (mm/area)
- Average annual household water demand (mm/area)

The available water is routed along the river network in such a way that available river discharge and local runoff is known for every location. Large lakes and reservoirs are taken into account in the model where the data are available.

A map of 'water intake regions' is used, in which regions are defined from which water is supplied. For the European analysis described in this report, it is assumed that these regions consist of single large river basins within a country (Figure 15). Smaller coastal catchments are merged into one unit. For the African analysis (Figure 16), smaller sub-basins are used for the assessment, based on the assumption that water supply is more regional - it is assumed that no major water transfers above the normal river flow take place between countries in Africa. Obviously, major water transfers do take place, but given the lack of continental data on these transfers, they are not taken into account.

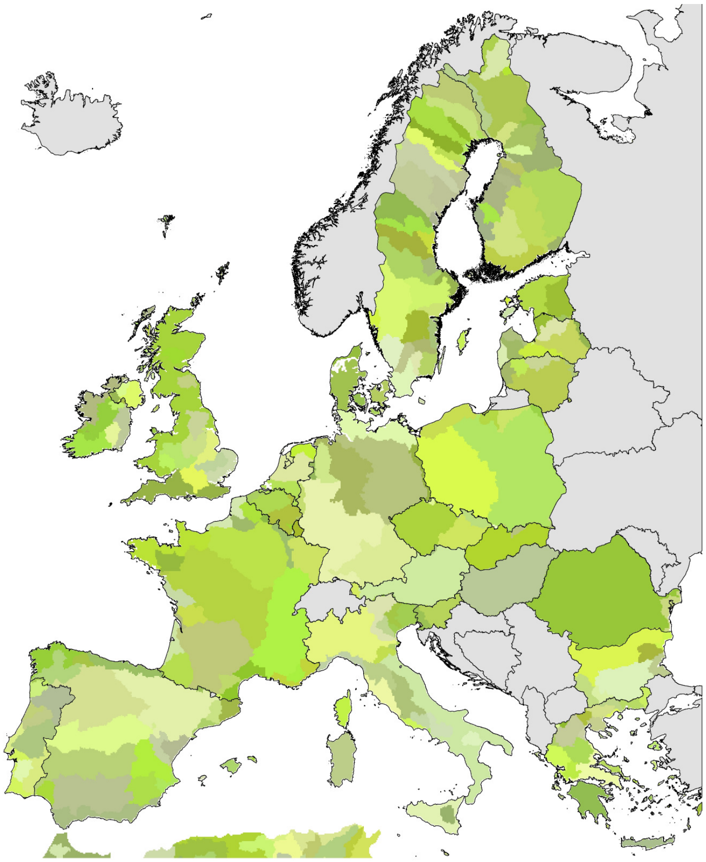

Figure 15 Regions used for the European assessment for matching water supply and water demand.

Assumptions and limitations of the approach

To match water supply and water demand, the following assumptions are made:

- Water can be used from the defined river (sub)-basin - no water transfers between river basins are taken into account, because of a lack of continental data on this; this assumes potential long-distance water transfers in some cases, for large countries and large rivers (e.g. Rhine-Germany, Loire/Rhone-France), which might not be realistic;
- Water can be used only from within the country, so no major water transfers take place between countries above the normal cross-border river flow;
- Groundwater recharge volumes are included in the analysis, but fossil (non-renewable) groundwater is not included;
- Freshwater generation through desalinisation is not taken into account;
- Water can be temporarily stored in lakes and reservoirs to cover the water requirements of a user-defined period; for Europe we used a longer period and larger storage capacity than we did for Africa - future work is required for this information to be more precise;
- Restrictions on water abstraction are built into the model to mimic the concept of environmental flow.

Figure 16 Regions in Africa used for matching water supply and demand.

The model concept is shown in Figure 17. From meteorological input data, together with data on topography, land use, soils and river networks, the LISFLOOD model computes daily freshwater fluxes, broken down into surface and subsurface fluxes. For the purpose of this study, the fluxes that flow on a daily basis into the river network are combined.

Water needed for local irrigation is first subtracted from the local freshwater flux. If the amount of water is not sufficient to cover the irrigation requirement, water is used from the river network or several stores in the region (lakes, reservoirs). A restriction of abstraction is built in to mimic minimum environmental flow.

Next, the model checks if sufficient water is available to cover the other needs, and flags occurrences where the water supply is not sufficient.

Finally, the model includes daily river routing, providing realistic flow propagation through the river basin, and including outflows from lakes and reservoirs.

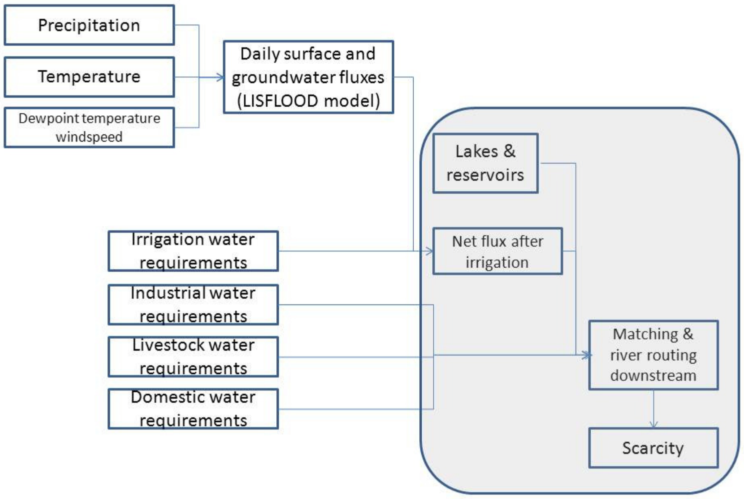

Figure 17 Conceptual water scarcity model applied in this study

Available water resources in Europe

Using the 21-year meteorological dataset (1990-2010) described previously, daily water fluxes have been estimated at a 5 x 5 km grid scale for Europe with the LISFLOOD model. These daily water fluxes have been accumulated on an annual basis, resulting in Figure 18. The figure shows the average annual freshwater availability in mm/year. It basically reflects precipitation and snowfall minus evapotranspiration and deep groundwater losses. As the model setup has been calibrated and validated, and uses data from approximately 500 river flow gauging stations, the accuracy of this assessment is considered to be relatively high.

The results indicate significant differences between European regions, with reduced freshwater availability in Spain, Southern Portugal, parts of France, Italy and Greece, and in Eastern European countries.

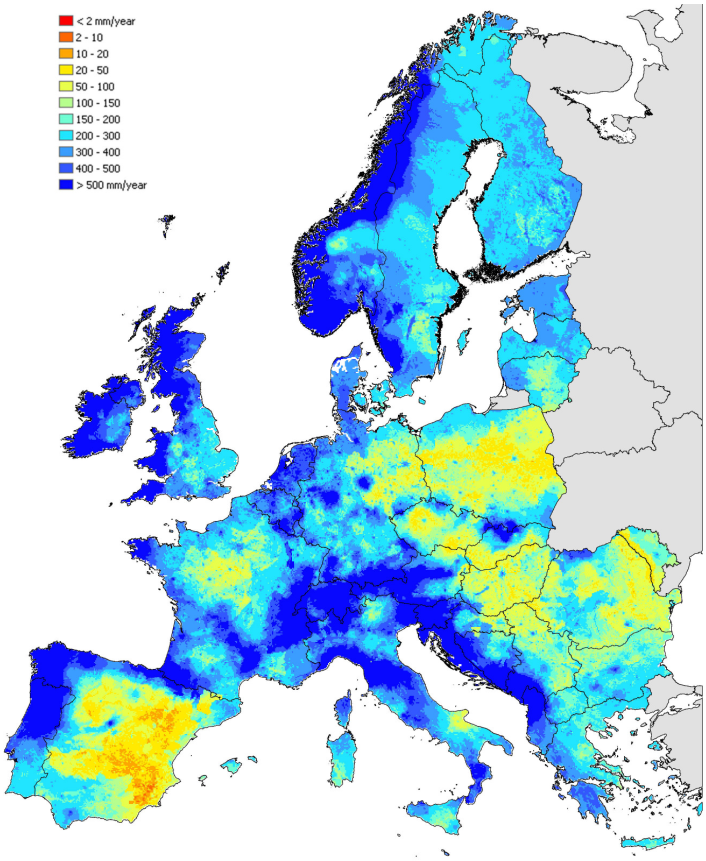

Figure 18 Average annual net runoff (freshwater availability) (1990-2010), simulated using the LISFLOOD model. Source: JRC/Bisselink, Burek, Zambrano, DeRoo (2011).

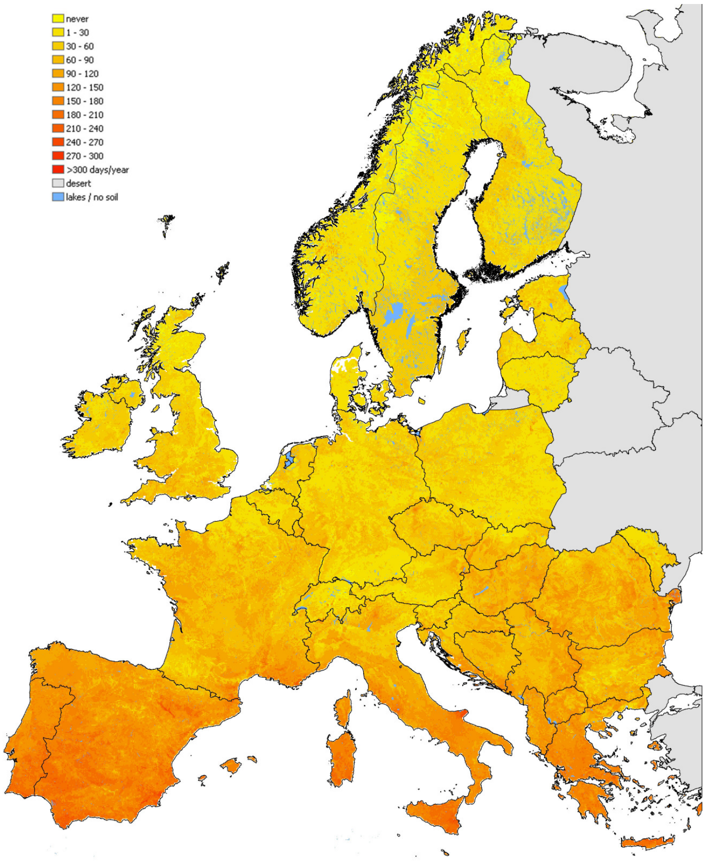

Figure 19 Average annual number of days with soil moisture stress (1990-2010), simulated using the LISFLOOD model. Source: JRC: Bisselink, Burek, DeRoo (2011).

As an additional product, the LISFLOOD model indicates where the daily soil moisture at a certain location is no longer sufficient to meet the water requirements of the vegetation or crop. Figure 19 presents the average number of days in a year when soil moisture amounts are not sufficient to meet the needs of vegetation. The figure shows the on average drier conditions in the Mediterranean. However, the fact that vegetation in the Mediterranean is more drought resistant also needs to be taken into account.

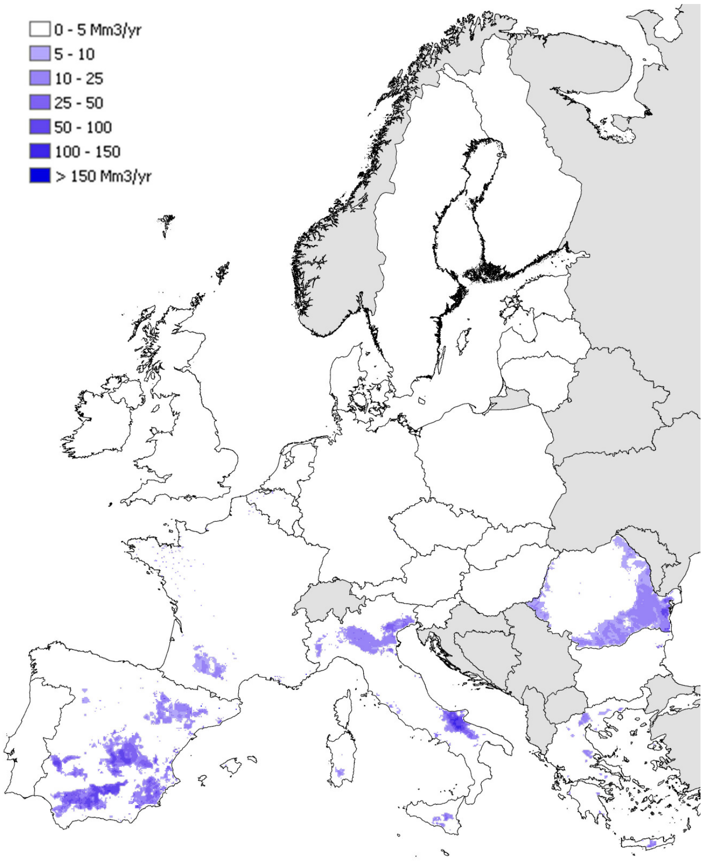

Figure 20 Estimated irrigation water scarcity for Europe (average 1990-2010). Note that this might also be due to single dry years. Source: JRC (2012)

Figure 20 shows the areas where local and regional water supply might not be sufficient – at least during some parts of the year – to meet the irrigation water requirements. Indicative amounts of water scarcity are also given. This water scarcity could well be the result of single dry years, or an accumulation of more permanent water scarcity. It should be noted, however, that since inter-basin water transfers are not taken into account, the scarcity may be overestimated for areas that 'import' water and underestimated for areas that 'export' water.

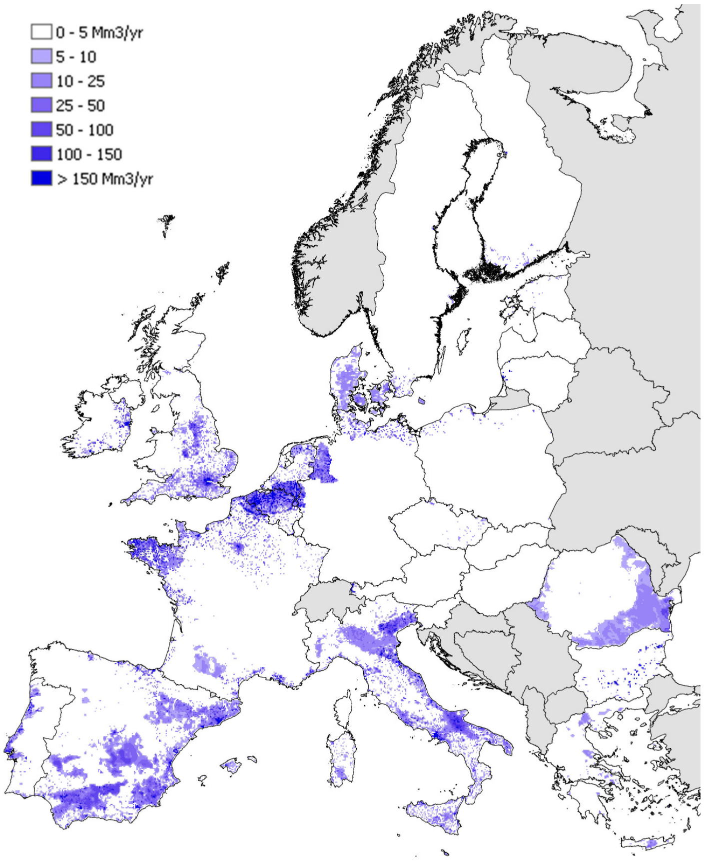

Figure 21 Estimated water scarcity with respect to the combined water needs from all sectors (average 1990-2010). Note that this might also be due to single dry years. Source: JRC (2012).

Figure 21 shows the areas where the local and regional water supply might not be sufficient – at least during some parts of the year – to meet all the water requirements (irrigation, livestock, industry, energy, households). Indicative amounts of water scarcity are also given. Again, since large inter-basin water transfers and the use of fossil groundwater are not considered (because of a lack of information), the scarcity values might be overestimated in some regions that receive external water, and underestimated in regions that 'export' water.

Available water resources in Africa

For the African continent, the calibration and validation of the hydrological model is hindered by the limited availability of river flow data, especially at the sub-basin level. Also, observed precipitation data are scarce, so satellite meteorological data need to be used. As is shown by Thiemig et al. (2012, submitted), various available satellite precipitation data exhibit substantial bias, and corrections are needed before using them in water resource modelling. Such corrections have been carried out on the ERA-interim precipitation data (ERA = ECMWF ReAnalysis), made available by the European Centre for Medium-Range Weather Forecasts (ECMWF).

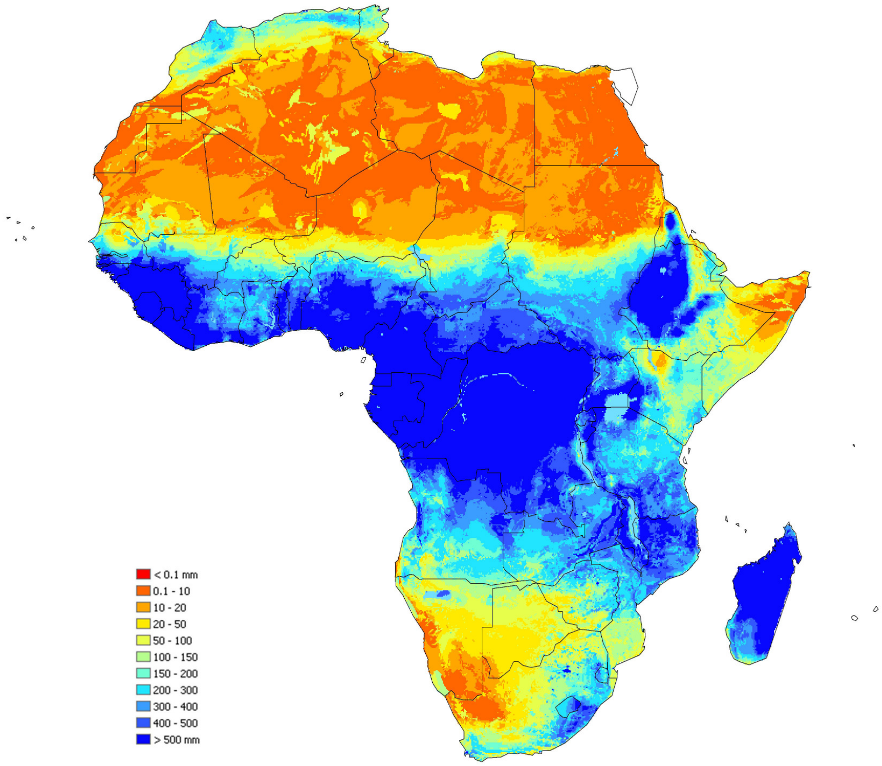

Figure 22 Average annual average net runoff (1989-2010), simulated with LISFLOOD. Source: JRC / Bisselink, DeRoo (2012).

The water resources assessment for the African continent reveals large areas with less than 200 mm of freshwater generation per year. Areas with freshwater generation greater than 200 mm are situated in Marocco, equatorial Africa, Southwest Ethiopia, Eastern South-Africa and Madagascar (Figure 22).

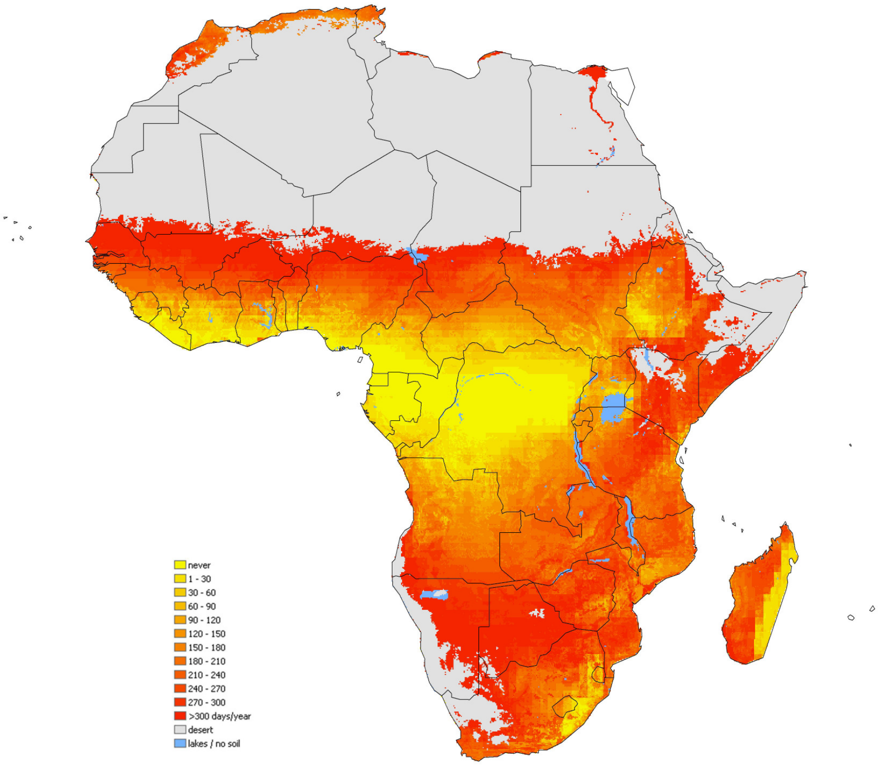

Figure 23 Average annual number of days with soil moisture stress. Source: JRC / Bisselink, DeRoo (2012).

An additional LISFLOOD product indicates when the daily soil moisture at a certain location is no longer sufficient to meet the water requirements of the vegetation or crop. Figure 23 presents the average number of days in a year when soil moisture amounts are not sufficient to meet the needs of vegetation. It basically shows that equatorial Africa has fewer deficiencies than other areas. The desert areas are indicated separately, since they do not include any significant vegetation.

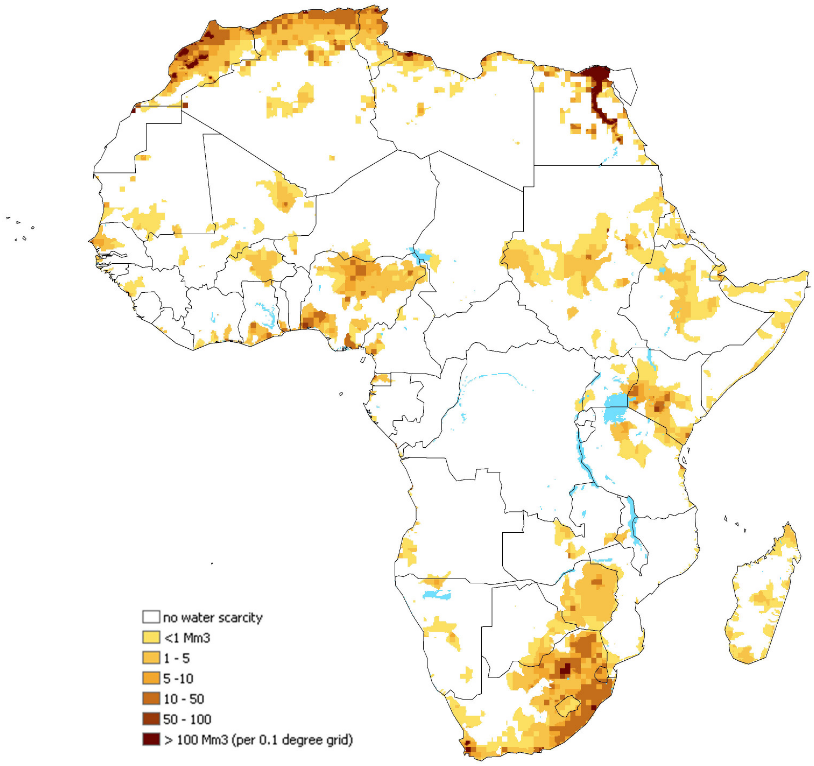

Figure 24 An estimation of water scarcity in Africa (based on simulations from 1989-2010). Note that this scarcity may be present during parts of a year only, or as a consequence of a single dry year. Source: JRC (2012).

Estimating water scarcity is again a challenging exercise. First of all, the most recent pan-African data on water abstractions (Van Beek et al., 2011, Wada et al., 2011) date from the year 2000, so this needs to be updated. Next, as in Europe, information on large inter-riverbasin water transfers is not available. Figure 24 shows a first approximation of water scarcity in Africa. The water scarcity in Egypt may be overestimated. The Aswan High Dam and Lake Nasser are included in the model setup, but the single pan-African approach chosen in the model for upstream water use for downstream areas is likely to be insufficient for the situation in Egypt. A separate approach will be developed for this.

The water scarcity in the Southern-African Limpopo basin is confirmed also in other assessments (Hoekstra and Mekonnen, 2011).

In addition, water scarcity in various areas in Nigeria has recently been acknowledged by the national authorities (http://digitaljournal.com/article/301656).

Conclusions and outlook

The growing availability of high resolution global datasets, growing computer capacity and advanced model capabilities allows for more detailed assessments of water resources and water scarcity than ever before.

Especially with respect to the assessment of climate change effects on water resources, it is crucial to have an accurate overview of current water resources and scarcity. Freshwater availability will change as a consequence of climate change, and water demands will also further change. This study presents ongoing research at the JRC on water resources in Europe and Africa, using several water models operating at a daily timestep.

An assessment for Europe on available water resources and a comparison with water demands from various economic sectors shows that freshwater availability varies significantly in the European continent. Large areas in Spain and Eastern Europe have, on average, less than 200 mm generated freshwater per year. At the same time, in some parts of those areas, annual water demand from the various sectors is equal to or even greater than the freshwater generation amounts. However, estimating water scarcity is not a straightforward exercise, since important parts of the 'puzzle' are missing, such as inter-riverbasin water transfers, detailed information on various water storages in lakes and reservoirs, as well as the availability and use of deep/fossil groundwater. Therefore, estimating water scarcity still includes many uncertainties, and the estimation made in this report needs further improvement.

In addition, although data needed for water resources assessment do exist in Europe, access to these data for the purposes of making a pan-European overview could still be improved; in particular, the public availability of observed river flows is still a concern. The availability of meteorological observations has already greatly improved, together with the increased availability of satellite observations.

An assessment of the African continent reveals large areas with less than 200 mm freshwater generation per year. Areas with freshwater generation larger than 200 mm are situated in Morocco, equatorial Africa, Southwest Ethiopia, Eastern South-Africa and Madagascar. Estimating water scarcity is a challenging exercise. The most recent pan-African data on water abstractions date from the year 2000, so this information needs to be updated. Also, information on large inter-riverbasin water transfers is not available.

There are many future research challenges, knowledge gaps, and data gaps in the area of water resources estimation. For example, the lack of availability of observed river flow data for Africa presents a major bottleneck in calibrating and verifying hydrological models for the continent. Satellite data provide improved meteorological data for Africa, but data on water abstractions need to be updated more frequently. In general, information on long-distance water transfers - intra riverbasin, inter-riverbasin, or cross-border water transfers - is largely unavailable at the continental and global level.

Within the framework of the envisaged EU Blueprint to Safeguard Europe's Waters, research is being carried out on optimising water supply and demand for Europe. Assessing emerging trade-offs at the intersection of energy and water is a challenge that the JRC will address through the development of an optimisation model that will facilitate the selection of the best combination of measures affecting water availability and water demand. Based on economic and environmental constraints, the optimisation module will allocate available water to all end users while ensuring the best trade-off in the interests of economic and environmental sustainability. Results on this will be made available later in 2012.

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Abstract

An assessment for Europe on available water resources and a comparison with water demands from various economic sectors shows that freshwater availability over the European continent varies significantly. Large areas in Spain and Eastern Europe have on average less than 200 mm generated freshwater per year. At the same time, in parts of those areas annual water demand from the various sectors is equal or even larger than the freshwater generation. However, estimating water scarcity is not a straightforward exercise, since important parts of the 'puzzle' are missing, such as inter-riverbasin water transfers, detailed information on various storages in lakes and reservoirs, as well as the use of deep/fossil groundwater. Therefore, estimating water scarcity still includes many uncertainties, and the estimation made here needs further improvement.

In addition, although data needed for water resources assessment do exist in Europe, the access to these data to make a pan-European overview could still be improved - the public availability of observed river flows is still a particular concern. The availability of meteorological observations, together with increased availability of satellite observations, has greatly improved already.

An assessment of the African continent reveals large areas with less than 200 mm freshwater generation per year. Areas with freshwater generation larger than 200 mm are situated in Morocco, equatorial Africa, Southwest Ethiopia, Eastern South-Africa and Madagascar. Estimating water scarcity is again a challenging exercise. First of all, the most recent pan-African data on water abstractions date from the year 2000, which needs improvement. Next, as in Europe, information on large inter-riverbasin water transfers is not available.

There are many future research challenges, knowledge gaps, and data gaps in the field of water resources estimation. The lack of available observed river flow data for Africa, for example, creates a major bottleneck in calibrating and verifying hydrological models for this continent. Satellite data provide improved meteorological data for Africa, but data on water abstractions need to be updated more frequently. In general, information on long-distance water transfers - intra riverbasin, inter-riverbasin, or cross-border - is largely unavailable at continental and global level.

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