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A Spatially Distributed Assessment of Water Allocation in EU27 for Year 2000

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Summary

Water management relies not only on data on water availability, but also on data on water abstractions and demands. Hydrological modelling studies often neglect the impact of water abstractions and not all models are designed to handle abstractions. Given the various activities for European scale assessments made at the JRC and other institutions, it is desirable to have quantitative and spatially distributed background information on water abstractions, losses and returns to better judge the potential relevance of human abstractions on water quantity and to have reasonable estimates for modelling purposes.

The work presented in this report aims at evaluating the potential of readily available data from the OECD/EUROSTAT Joint Questionnaire on Inland Waters and relevant EUROSTAT data to support regionalized water balance assessments including human water abstraction and consumption. This report further document the methodological approaches to generate maps on water abstractions, losses and returns across the EU at 10x10km resolution.

Specific tasks documented in this report include:

- Modification and extension of available water abstraction data to generate consistent and complete datasets at national level.
- Spatial disaggregation of national data to regional and local (10x10km cell) level using proxy data and simulation results.
- Estimation of consumptive water losses and returns
- Comparison of water abstractions and losses to water availability and mapping of water resources pressure indicators.

The report describes the data used in this assessment and the approaches to compile the specific data for the Atlas of water use and returns. The work documented in this report relates to other studies, such as the European assessment of irrigation requirements (Wriedt et al., 2008, 2009a, 2009b), a European screening of seawater intrusion risk (Wriedt & Bouraoui, 2009c), and a general water balance modelling (Wriedt & Bouraoui, 2009d).

1 Introduction

The WFD (2000/60/EC) defines a series of environmental objectives to be met, which also focus on groundwater bodies (MGWWG, 2005).

Climatic conditions and physical geographic settings determine the availability of ground- and surface water resources and the supply potential. Technology and institutional framework may increase efficiency of water supply systems. Water demands are defined by the need to maintain drinking water supply, domestic water, industry, food production. They are largely determined by social conditions and individual behaviour, economic factors, technological development and the institutional framework. Water demands can actively be managed by appropriate measures (pricing, information) to reduce pressures on water resources (Figueres et al., 2003). The imbalance of demands and available water resources can cause water scarcity resulting in conflicts between water uses and can damage water resources by overexploitation and related processes (e.g. salinisation). Traditionally water management has been understood as management of water supplies to satisfy the existing water demand. Modern water management aiming at sustainable use of water resources must equally focus on water supply and water demand (Figure 1).

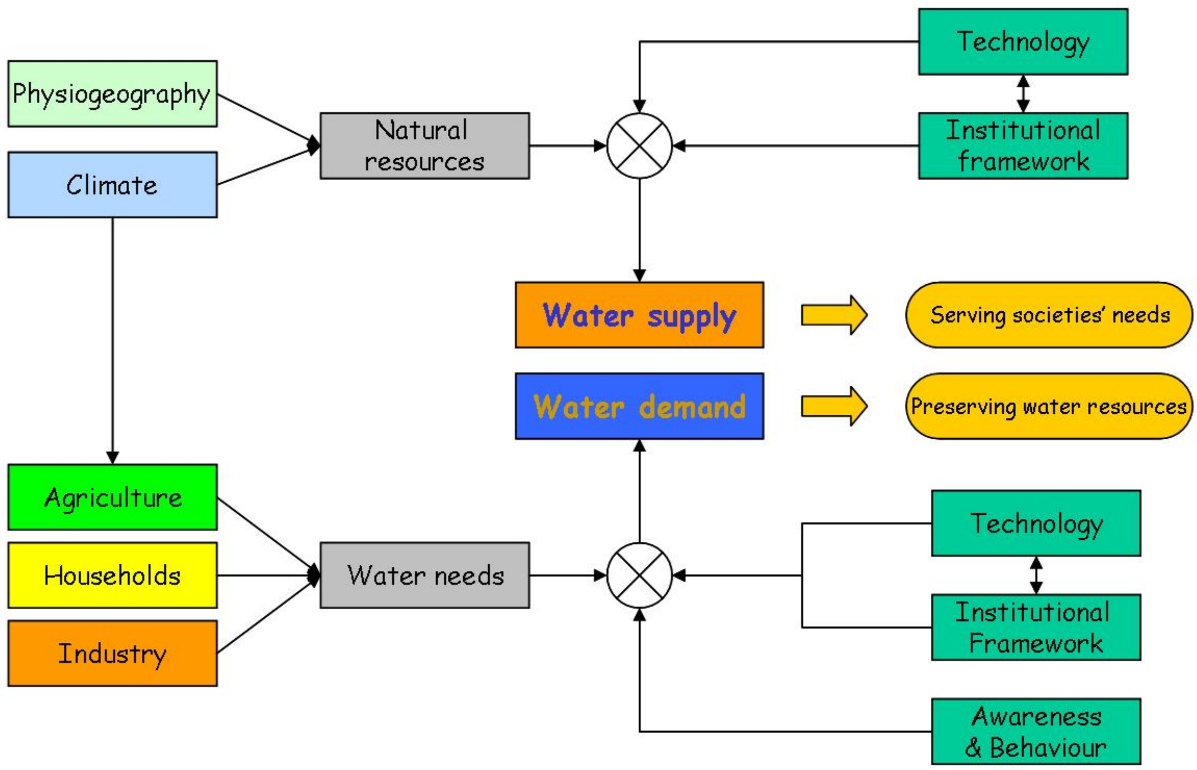

Figure 1: Modern water management combining supply side management and demand side management

To meet societies' water demands, ground- and surface water resources can be exploited. Increased water demands therefore do not necessarily translate to pressures on groundwater or surface water, and groundwater use has to be seen in the context of general water use and availability.

Human water abstractions from ground- and surface waters have considerable impact on the water cycle in catchments and river basins.

- Effective consumption and loss of water by evapotranspiration (agriculture) or export of goods and food, thus decreasing total catchment discharge.
- Alteration of the seasonal patterns of river discharge, for example using reservoirs to store water in the rainy season for slow release in the dry period
- Transfer of water from one water body to another, for example abstracting groundwater and returning the used water into surface waters.

Especially in water scarce regions, the anthropogenic effects can be of significant magnitude, altering water balance and internal flows of catchments and river basins.

Water abstractions can have a double-damaging effect. They decrease water quantity at the place of abstraction, thus affecting groundwater levels, recharge, surface water flow. They also have an impact on the water bodies where the water is returned to, transporting pollutants or adding water to environments with subsequent negative effects (increase of groundwater levels, salinisation problems)

Hydrological models are typically calibrated against discharge data. For local and regional scale water balance modelling, abstractions are often negligible (depending on the study area), or can be accounted for explicitly. For large geographical areas, such as European scale assessments, a large variety of hydro-climatic conditions and human activities come into play. The effects of water abstractions on catchment or river basin discharge must therefore explicitly be accounted for. However, catchment based data collection is no longer feasible and other data sources and approaches are required. Not all hydrological models are actually designed to account for water abstractions, limiting their use to natural catchments or zones with insignificant abstractions and artificial structures.

Given the various activities for European scale assessments made at the JRC and other institutions, it is desirable to quantify the importance of water abstractions and returns more explicit to better judge the potential relevance of abstractions on water flows and to have reasonable estimates for modelling purposes.

The objectives of the work presented in this study were

- to evaluate the potentials and limitations of available water abstraction data to support spatially distributed water balance assessments at European scale,
- to compile spatially distributed data sets on water use for use in subsequent model-based assessments,

- to evaluate the role of different sectors in water consumption and quantitative pressures on water resources in combination with a first estimation of water availability.

Section 2 describes the processing of disaggregation of available European statistics on water abstractions and water use into high-resolution datasets. The documentation includes the main data processing steps and a discussion of conceptual issues related to the human water cycle.

Section 3 is an atlas of water use in Europe, presenting the resulting spatial datasets on water abstractions and deriving maps of spatially distributed water use indicators. Based on the disaggregated datasets on water use various water related indicators compare the abstraction data with preliminary results of a European water balance assessment. A general discussion of approaches and results follows in section 4.

The information derived in this report is a prerequisite for related studies, such as the European screening of seawater intrusion risk, a European groundwater recharge assessment and European scale water balance modelling.

2 Material and Methods

2.1 European scale data

The assessment was based on regional and national data available from EUROSTAT. A collection of regional data from individual countries was beyond the scope and capacity of this assessment. A basic requirement for the use of certain data sources was that information are sufficiently consistent and complete to allow semi-automatic processing and to minimize the need to fill gaps. All water abstraction and water use data collected refer to the year 2000. In case of irrigation sources also data from 2003 have been considered.

2.1.1 Spatial entities

Spatial entities used in this study are historically related to other studies carried out (or currently being carried out) at the JRC-IES' Rural Water and Ecosystem Reseources Unit (RWER). With increasing spatial resolution, the spatial entities used in this study are:

- Countries
- NUTS statistical regions of Europe according to the nomenclature of territorial units for statistics at level 2 (NUTS 2, provinces) and level 3 (NUTS 3, regions).
- A modified NUTS 3 regions layer has been generated by Bouraoui & Aloe (2007) for the development of a Pan-European database for agricultural modelling, which will be referred to as NUTSFATE. The NUTSFATE layer is a mix of NUTS 2, NUTS 3 and aggregated NUTS3 units complying with the data collection for the FATE activities (Mulligan, 2006, Bouraoui & Aloe, 2007; Grizetti et al., 2007).
- A 10x10km raster defines modelling units (grid cells) for the European Agricultural Loss Estimator (EAGLE, Bouraoui & Aloe, 2007). This feature class covers the area of EU-27.
- A European catchment database HydroEurope was developed at IES-RWER Unit, providing catchment and river basin information complying with the ArcHydro database scheme. The database was developed to support water balance and nutrient transport modelling at European scale. The catchments have an approximate size between 100 and 200 km^2. An overlay of grid cells and catchments allows to link and transfer data between from catchments to grid cells and vice versa.

The disaggregation procedure aims at disaggregating water abstractions to the 10x10km grid cells, in compliance with various modelling tools and databases applied at IES-RWER. The catchment database was used for water availability assessment and calculation of the water exploitation index. The 10x10km grid cell layer covers all land areas, while the catchment layer has some gaps along the coastline as a minimum catchment size was required, thus intermediate areas between catchments (draining to the shore line instead to a catchment outlet) were not included.

2.1.2 Water demand data

Data on water abstractions are regularly assessed in the OECD/EUROSTAT Joint Questionnaire on Inland Waters. **Water abstractions** are reported in the following source categories, separated into abstractions from i) groundwater, ii) surface waters and iii) total abstractions from ground- and surface waters:

Table 1: Categories of water abstractions used in OECD/EUROSTAT Joint Questionnaire on Inland Waters

Cat-Nr	Description of abstraction category	Comments
1.	Abstraction by agriculture, forestry, fishing (total)	
1.1.	Abstraction by agriculture, for irrigation purposes	Subcategory to 1
2.	Abstraction by households	
3.	Abstraction by manufacturing industry (total)	
3.1.	Abstraction by manufacturing industry (for cooling purposes)	Subcategory to 3
4.	Abstraction by production of electricity, for cooling purposes	
5.	Abstraction by public water supply	
Total	Total gross abstractions	Sum of 1,2,3,4,5
Returns	Water returned before or without use	
TNet	Net abstraction	Total - Returns

Data on ground- and surface water abstractions are, however, not reported consistently and only reported by some member states. Therefore only the data on total water abstraction are usable.

Water supplies are reported in the following categories, separated into the supply sources i) self supply, ii) public supply and iii) other supply and iv) total supply:

Table 2: Categories of water supply used in OECD/EUROSTAT Joint Questionnaire on Inland Waters

Cat-ID	Description of supply category
1.	Agriculture
1.1.	Irrigation purposes
2.	Domestic
2.1.	Households
2.2.	Other
3.	Industrial (total)
3.1.	Manufacturing Industry, cooling
3.2.	Electricity production, cooling
4.	Total

Third, the Questionnaire reports data on **Wastewater discharge**. These data were not further considered for this assessment.

Processing of the data revealed various inconsistencies and gaps that had to be removed before the data could be applied for further analysis. Such corrections include:

- Gaps were filled by a nearest neighbour interpolation from preceding or subsequent years.
- It was required that subcategories must sum up to their superior categories. This implies that a category can not have a value smaller than the sum of its subcategories. Unfortunately such inconsistencies were frequent.
- Where categories and subcategories are reported and either the category or the subcategory value was missing, the gap was filled projecting the ratio of categories and subcategories rather than the nearest neighbour.

The data reported in the Questionnaire contain frequent gaps and inconsistencies. In general, the data on water abstraction are more complete than on water supply. Partly supplies exceed abstractions. Although water supplies may provide useful information not biased by transport losses, the actual data availability prevents further consideration of supplies in this assessment.

2.1.3 Agricultural water abstractions

Agricultural water abstractions comprise abstractions for irrigation, livestock nutrition, and forestry. Quantitative wise, irrigation is the most important agricultural water use. In countries where irrigation is unimportant and abstractions mainly serve for livestock feeding, reported agricultural abstractions are quantitatively irrelevant compared to public and household abstractions. Therefore only irrigation abstractions were included here. An analysis of irrigation water requirements in Europe was recently completed by Wriedt et al. (2008, 2009a, 2009b), providing estimates of irrigation requirements at a spatial resolution of 10x10 km. The estimation of irrigation requirements was based on the development of a European irrigation map (Wriedt et al., 2008, 2009a) and subsequent modelling of soil water balance, crop growth and irrigation needs (Wriedt, 2009b). Modelling was based on the EAGLE tool (Bouraoui & Aloe, 2007), a pan-European implementation of the EPIC model (Williams, 1995) at a 10x10km resolution. The simulated water requirements typically exceed the reported national agricultural abstractions, especially when accounting for conveyance losses in addition to irrigation requirements. Given the spatial detail of the irrigation assessment and the high inconsistency and uncertainty of reported abstractions (see discussion in Wriedt et al., 2008, 2009b), the model assessment was preferred to the statistical data.

Modelling results constitute irrigation requirements, not the resulting abstractions. Irrigation requirements may be left unsatisfied if water resources are not available (for example Guadalquivir river: Diaz et al., 2007).

2.1.4 Proxy data for spatial disaggregation

EUROSTAT provides regional statistics on selected indicators that were used as proxy-indicators for disaggregation of water abstractions. The statistics used were:

- Total population at NUTS 3 level (base year 2000)
- Gross domestic product at NUTS 3 level (base year 2000)
- Electricity production at NUTS 2 level (values from 1993-2003)

EUROSTAT tourism statistics used to assess the specific impact of tourists on water demands include statistics on

- Nights spent in total (at NUTS 2 level, base year 2005)
- Number of bed places (at NUTS 3 level, base year 2005)

Another data layer was total population by commune (base year 2000). The dataset was taken from the ‘Atlas of Pan-European Data for Investigating the Fate of Agrochemicals in Terrestrial Ecosystems’ (Mulligan et al., 2006) and covers the area of EU-25.

Land use types were based on CORINE Land cover 2000 (ETC, 2005). CORINE land cover is a high resolution data set of land use over Europe at a resolution of 1 ha. The minimum mapping unit is 25 ha and the map scale is 1:100000. CORINE Land Cover maps the spatial distribution of various land use categories. Land use categories were aggregated to more generalized land cover types: water, settlements, pine forest, deciduous forest, mixed forest, arable land, permanent cropland, horticulture & vegetables, bush land, sparse vegetation, sparse bush land, bare rock and ice. The frequency of each land use class was then calculated for each 10x10km grid cell.

2.2 Data processing

2.2.1 Water demand assessment

Water abstractions were available at national level for various use categories. Though some MS report regional data, the information in total is too heterogeneous and incomplete to allow processing of regional data. The following categories of water abstractions were distinguished based on the categories used in EUROSTAT statistics:

- Public water supply
- Household abstractions
- Industrial abstractions
- Agricultural abstractions
- Other abstractions
- (Cooling water abstractions for electricity production)
- Total abstractions as sum of the preceding categories excluding cooling water

Abstractions from Households, Industry, Agriculture and other uses refer to direct abstractions not supplied by public water suppliers (self-supply). Public water suppliers deliver water for various different purposes, including industrial and agricultural activities.

The disaggregation was based on the assumption that water use is coupled to human activities and therefore reflected in the distribution of proxy-data such as population, economic activity (GDP), and land use (settlements and irrigated areas). Specific water uses (per capita, per unit GDP etc.) were considered to be spatially homogeneous within a country, except for irrigation abstractions.

Based on these assumptions, water abstraction data were disaggregated as follows: Water abstractions were disaggregated regionally using proxy-data to derive the fractions of water abstractions (per use category) to be assigned to the smaller spatial units. The abstraction value X_i for each spatial unit *i* was calculated according to:

$$X_i = f_i \cdot X_j \qquad [1.]$$

where f_i is the fraction of X_j assigned to unit *i*. The factor f_i was obtained dividing the proxy-value Y_i for each spatial unit *i* by the proxy-value Y_j for the lower-resolution spatial unit *j*.

$$f_i = \frac{Y_i}{\sum_{i=1}^{n} Y_i} = \frac{Y_i}{Y_j} \qquad [2.]$$

The water abstractions (m3 per unit) were then expressed as m3/km2 and rasterized to a 1km grid. From this 1km grid, the information was summarized to the desired target units. In this study, the target units were the 10x10km grid cells.

Public supply and household abstractions

Abstractions for public water supply and household abstractions were disaggregated to NUTS3 units according to population, as these categories comprise water used for domestic purposes and general social and economic activities. In a second step, water abstractions were disaggregated to communes based on communal population.

Industrial abstractions

To disaggregate industrial abstractions to NUTS3 units, GDP was used as an indicator of economic activities. Further disaggregation to grid cell-level was based on the distribution of settlement area.

Agricultural abstractions

Agricultural abstractions were directly taken from the model based assessment at grid-cell level (Wriedt et al., 2008, 2009b).

Other abstractions

Other abstractions were treated the same way as abstractions for public water supply and household abstractions.

Total abstractions

Total abstractions are calculated as the sum of abstractions from public supply, households, agricultural abstraction, industry and other. Cooling abstractions were excluded.

For some countries (BG, RO, parts of UK), no regional information was given in the statistics and the disaggregation procedure illustrated above could not be applied. In these cases, water abstractions were disaggregated directly from national data to grid cells, using the settlement area within each 10x10km grid cell as a proxy for distribution of human water abstractions (except cooling abstractions).

Though these approaches are rather crude and uncertainties do exist, the spatial distribution is considered to be reasonable for large scale assessments and is an improvement compared with national averages, as the heterogeneous distribution of water-related human activities is accounted for.

The resulting spatial allocation of water abstraction data reflects the locations where water is actually used, rather than where it is abstracted. Strictly speaking, the resulting spatial data sets should therefore be referred to as water use or water demand.

Despite this conceptual difference, the term ‘water abstractions’ is maintained, as the bases for spatial disaggregation are actually the abstraction data. Nevertheless, this distinction is important and would require an additional step of allocating water abstractions in space and to water sources.

2.2.2 Conceptual aspects of water abstraction allocation

The water demands allocated in the preceding section can be abstracted locally (within the same spatial unit) or can be transported over longer distances and even across river-basin boundaries (inter-basin transfer).

The spatial allocation of water abstractions is closely related to the allocation of abstractions to water sources and may depend on various factors, such as

- Presence of exploitable ground- or surface water bodies
- Location of reservoirs for water supply
- Specific water uses may have specific needs or preferences for certain sources (needs for drinking water treatment and seasonal variations of water availability)
- Existing technical infrastructure and level of organisation (centralized or decentralized water supply)
- Economic aspects of exploiting specific water resources

For these reasons, it would be wrong to relate disaggregated water abstractions to the available water resources within the corresponding spatial units. Only at a high level of aggregation (to river basins, regions, or countries) water demands and abstractions are spatially consistent (neglecting inter-basin transfers).

Simple assumptions and rules can be made that potentially allow allocating water abstractions within a river basin in compliance with water availability.

- Preference is given to local abstraction. Only if water demands cannot be met locally, water is taken from more remote sources. The term local refers to the smallest spatial unit distinguished (10x10km grid cell or catchment).
- River basins are structured in sub-basins and catchments, connected by a routing structure. Free water flows from the upstream to the downstream catchments. Also the occurrence of large sedimentary deposits forming relevant exploitable groundwater bodies is more likely in the downstream areas of the river basin.
- As water flows downstream, water demands may be routed upstream, stepwise increasing the transport distance.
- The presence of water sources (groundwater, surface water, reservoirs) has to be taken into account. The problem is therefore closely related to the source apportionment (see following section).
- Water demands may remain unsatisfied. The deficit indicates i) possible overexploitation of water resources or ii) the need for water allocation from other sources outside the river basin

(inter-basin transfers) or iii) water shortage for certain uses (for example irrigation). Uncertainties estimating water abstractions and availability come into play as well.

Such an allocation of water abstractions requires a compliant assessment of water availability, including the generation of surface runoff and the recharge of groundwater bodies. Probably mutual optimisation cycles are necessary to generate a final distribution. This is beyond the scope of this report and the ideas outlined above will be taken into consideration in future research.

2.2.3 Conceptual aspects separating water abstractions into ground- and surface water abstraction

In some cases, EUROSTAT data include water abstractions by abstraction source, including the categories groundwater, surface water and other sources. Only recently the Farm Structure Survey included information on irrigation water sources, which have been made available by EUROSTAT at NUTS2 level. Some MS report agricultural abstractions from ground- and surface waters, also including regional data.

The general problems with national and regional abstraction data are:

- There is no single dataset covering Europe with reasonable accuracy and completeness.
- Abstractions by source are difficult to disaggregate in space, as there are no obvious proxies that can support the disaggregation. As for the spatial allocation, source appointment would require a set of assumptions and rules that can be used to allocate water sources to water demands.

Surface water abstractions may be favoured by:

- presence of exploitable surface water resources
- distance to surface water resources
- presence of surface water distribution networks
- presence of reservoirs in the river basin

Groundwater abstractions are favoured by:

- presence of exploitable aquifers
- sufficient recharge
- low availability of surface water
- lack of organised water distribution network

At European scale, public water supply and households abstract 55% of their total abstractions from groundwater bodies. Industrial water is taken by 75% from surface water sources, while cooling water used for electricity production is almost exclusively taken from surface waters. Agricultural water is abstracted to 75% from surface waters, but there are large regional differences. Groundwater abstractions for agricultural purposes are possibly underestimated due to the high importance of illegal abstractions (all data from EEA, 2009, based on data from EUROSTAT).

Groundwater is a preferred source for public water supply and households but also for agricultural purposes. But limitations are given by the distribution and accessibility of exploitable groundwater resources. Groundwater does not exhibit the seasonal variations of surface water flow, reducing the need for storage capacity (reservoir); the water quality is generally higher, requiring less water treatment; where available, it is an ideal source for decentralized abstractions.

Information on abstraction sources is rarely available in the Joint EUROSTAT/OECD Questionnaire. National sources sometimes provide data for selected sectors and on different administrative level. Even if available, they are bound to national or regional level. This information is not helpful in defining the ratio of water abstractions from ground- and surface water sources at local level, as a disaggregation of regional data to local level can not be based on simple proxy-relations as was done in the case of disaggregating total water abstractions.

Again, a set of assumptions and rules are set up that could help in source allocation:

- Groundwater resources are exploited locally (i.e. within a catchment) and thus directly related to local water demand.
- Though the abstraction rate can affect also the groundwater recharge rate (Bredehoeft, 2002), the recharge rate may indicate an abstraction potential that can be exploited. Specific rules need to be defined how to define the abstraction potential.
- Detailed information on the distribution of exploitable aquifers are not available at European scale. Nevertheless, the substrate distribution indicates the probability of having exploitable aquifers. This information should feed into an estimate of groundwater recharge and abstraction potential.
- Abstractions may be appointed to groundwater first and surface water second. Water demands not satisfied locally have to be routed as described in the preceding section.
- Surface water resources are exploited within the river basin and transported to water users.
- Constraints may be set to meet the ratios of ground- and surface water abstractions for different water use sectors, as suggested by available statistics.

Again, the source apportionment requires a consistent assessment of water availability. The procedure has to be combined with the abstraction allocation. The implementation of these ideas unfortunately must be left to future research.

An important question remains. Should this type of source allocation match the reported statistical data? Given the incompleteness and uncertainties of available statistical data, the general usefulness of this information can be questioned. Abstraction rules may be defined generating spatial allocation patterns and source apportionment. A plausibility control of the results is, however, difficult with the data available. On the other hand, it is technically feasible to include regional data (where available) to set constraints on the spatial allocation and source appointment. The resulting patterns will then comply with the available information.

Table 3: Fraction of reported water abstractions taken from groundwater by water use sector (OECD/EUROSTAT Joint Questionnaire on Inland Waters, averages 2000-2003)

Country	Public water supply	Household abstractions	Industrial abstractions	Cooling water abstractions	Agricultural abstractions	Other abstractions
AT	0.99	1.00	0.26	0.00279	1.00	-
BE	0.67	-	0.11	-	1.00	1.00
BG	0.34	-	0.35	0.0017	0.01	0.79
CH	0.84	-	-	-	-	-
CY	0.64	-	-	-	0.72	-
CZ	0.49	1.00	0.10	0.0019	0.39	0.68
DE	0.74	1.00	0.17	0.0017	0.77	0.45
DK	0.98	1.07	0.87	0.76	1.04	3.81
EE	0.40	-	0.41	0.0000	0.12	0.80
ES	0.25	-	0.22	0.0021	0.14	0.27
FI	0.59	1.00	0.00	-	0.20	-
FR	0.60	-	0.39	0.0012	0.24	-
GR	0.52	-	0.38	0.15	0.41	-
HU	0.56	0.35	0.47	0.0034	0.10	0.69
IE	0.18	-	0.25	-	0.25	-
IS	0.96	1.00	0.93	-	0.99	-
IT	-	-	-	-	-	-
LT	0.98	-	0.19	0.002	0.08	0.62
LU	0.63	-	0.21	-	1.00	0.61
LV	0.99	-	0.35	0.02	0.07	0.57
MT	1.00	-	-	-	-	-
NL	0.63	-	0.10	0.0002	0.76	-
NO	0.09	-	0.06	-	0.01	-
PL	0.65	-	0.27	0.003	-	0.71
PT	0.63	-	0.16	-	0.48	-
RO	0.30	-	0.16	0.003	0.03	0.83
SE	0.49	1.00	0.01	0.01	0.44	0.52
SI	0.22	-	0.30	-	0.11	0.73
SK	0.83	-	0.07	-	0.24	1.00
TR	0.69	-	0.52	-	-	-
UK	0.26	-	-	-	-	-
UK1_9	0.30	0.42	0.24	0.003	0.09	0.57
UKM	0.02	-	-	-	-	-
UKN	0.06	0.08	0.11	-	0.06	0.05

2.2.4 Losses and returns

Abstracted water is not necessarily lost. Large fractions of domestic and industrial water and cooling water are returned to water bodies (purified or unpurified) and are available for re-use downstream. Irrigation water infiltrates the soils and can reach ground- and surface water.

The water is abstracted from a certain water body but often returned to another water body at another location. This could have a double-damaging effect: on the water body where the water is abstracted, having a mainly quantitative impact (subtraction), and on the water body where the water is returned to, having a quantitative (addition) and qualitative (pollution) impact.

True water losses (consumptive losses) occur when water is effectively removed from the blue water cycle by transpiration and evaporation or storage (and export) as goods and products.

Public water supply and household abstractions

Domestic water is almost completely returned, as there are only few consumptive losses. EEA (2009) estimates that 80% of public supply water is returned to the environment and only 20% are actually lost. Water returns may be discharged to surface waters as well as to ground waters. In line with the available EUROSTAT data, it was assumed that household abstractions are returned to groundwater, as they imply on-site abstraction and wastewater treatment.

Industrial abstractions

For industrial abstraction, water may be used for cooling and manufacturing purposes, but it may also be stored in goods and products. Water returns may be discharged to surface waters as well as to ground waters. Regarding the preference for surface waters as abstraction source and requirements for waste water treatment, it was assumed that water is predominantly returned to surface waters.

Agricultural abstractions (Irrigation)

The main loss of irrigation water is crop evapotranspiration. Evapotranspiration values have been calculated by Wriedt et al. (2008, 2009b) and can therefore directly be included. A secondary loss is the water stored in crop biomass, which was neglected in this assessment. Water returns may occur to ground- as well as to surface waters. A more precise assessment has to consider the interaction of surface runoff, soil percolation, and local groundwater flow and groundwater drainage.

Part of water abstractions is lost before use due to leakage in the distribution network. The leakage re-infiltrates to groundwater. The fraction of water leakage can be substantial and ranges between 10% (DK) to 40% (Croatia) (EEA, 2009). Within this assessment, there were no specific data available allowing more precise estimation of leakage rates. Even given availability of national or even regional data, the leakage rates may vary considerable from one location to the other. Water returns from public water supply, household abstractions, and industrial abstractions were estimated using the consumption rates described above. The returns attributed to irrigation were estimated as the difference between irrigation requirement and crop evapotranspiration. For 'other' abstractions, the same values as for public water supply were applied. The water returns to surface water and to groundwater were calculated as follows:

- All returns from public water supply and industry were returned to surface waters by a ratio of 80% and to groundwater by a ratio of 20%. Wastewater treatment plants and direct discharges are typically connected to rivers. However, also wastewater infiltration to groundwater is applied, benefiting from natural purification and recharging groundwater bodies. Abstractions should be equal to the sum of supply and return before use (leakage). Therefore leakage is implicitly included in the abstractions. Lacking reliable country specific data on leakage losses, the 20% return to groundwater substitutes leakage to groundwater and re-infiltration of wastewater.
- Household abstractions were returned to groundwater, assuming that water is abstracted for self-supply and the water is not treated or treated on-site and that surface waters are unlikely to provide water with drinking water quality without treatment.
- Irrigation abstractions were assigned to surface water and ground water based on the ratio of surface runoff and groundwater discharge (baseflow index) as a surrogate measure for surface and groundwater availability. The calculation of this baseflow index is described in Wriedt et al. (2009d).
- Other abstractions were returned to surface waters.
- All water returns were spatially allocated to the entities where the water is used.

2.3 Specific aspects

2.3.1 Cooling water abstractions for electricity production

Cooling water abstractions were not included in total abstractions and treated separately. Cooling water is almost exclusively abstracted from surface water bodies (EEA, 2009) and returned immediately after use with minor losses. 'Once-through' systems return water directly after the cooling process with negligible consumptive losses (0.36%) but with considerably elevated temperature. Modern 'cooling tower' or 'recirculation systems' do not discharge heated water, but evaporation losses are higher (EEA, 2009). General rules-of-thumb can not be given.

In contrast to other sectors, cooling water abstractions are highly localized and should be related to the location of dams and power plants. There are no obvious proxy-data that can be used for further disaggregation below regional level. Assuming uniform distribution within a NUTS region or using inappropriate proxy-data introduces high uncertainty without adding value. Therefore data on cooling water abstractions were disaggregated to NUTS2 level only. Energy production was used as a proxy-indicator. Nevertheless, cooling water abstractions can make up a considerable part of total water abstractions having qualitative impacts on water bodies (increasing water temperature).

For the context of this research, focusing on general water balance assessment and groundwater pressures, cooling water abstractions are of minor relevance.

2.3.2 Tourist pressure on water resources

Tourism puts considerable pressure on water resources. First, tourism concentrates large number of people in holiday regions in addition to resident population. Approximately 200 million travellers visit the southern European region each year, their numbers are expected to triple until 2005 (De Stefano, 2004). Water consumption of tourists can be significantly higher than that of local population. For example, UNEP (2007) (in EEA, 2009) report that the average tourist staying in a Mediterranean hotel uses between 33% and 100% more water than the average local resident, whilst a luxury tourist can use up to 600% more. The additional water demand is often concentrated to a short period of the year, i.e. summer holidays.

Tourism water demand is implicitly contained in the data for public water supply and households. The specific effect of tourism can theoretically be accounted for during disaggregation. EUROSTAT statistics on ‘Nights spent by tourists’ provide a starting point, as they reflect the touristic pressure integrating number of tourists and duration of stay. A breakdown to NUTS3 level was made using the ‘number of bedplaces’ as a proxy-measure. The ‘nights spent by tourists’ where converted into a population equivalent as ‘nights spent / 365’ times a tourism water use factor of 3, assuming that the overall tourist water use is 300% of resident water use. The population equivalent of tourism water use was further expressed as a tourism pressure calculated as ratio of population equivalent to resident population.

The mass tourism putting water resources under pressure concentrates in small areas, i.e. along the seaside, in winter sport regions, and so on. Within NUTS3 regions, the spatial patterns are unlikely to correspond to the distribution of resident population. There are no straightforward proxies that can be used in further disaggregation, nor more specific statistics. At NUTS3 level, the specific impact of tourism is generally a small fraction of NUTS3 population and therefore too unspecific to include tourism effects explicitly at NUTS3 level. Therefore the specific tourism impact was not considered in the disaggregation of water demands. Nevertheless, the local impact can be considerable and future research should develop a reasonable approach for explicit consideration.

2.4 Available water resources

Water available for runoff can potentially be exploited to satisfy water demands. This amount of water can be estimated from water balances as hydrological excess water (HXS) that remains from rainfall after accounting for evapotranspiration and that is available for surface and subsurface runoff. Practically, only a fraction of HXS can be used in a sustainable way, considering for ecological flows necessary to maintain ecosystem functioning. Also part of the water may be stored and discharged in water bodies which are difficult to exploit.

HXS was calculated using a monthly water balance model. A detailed documentation of the model is given in Wriedt et al. (2009d). The model includes a simple correction of precipitation for snow storage and a soil water balance model based on Pistocchi et al. (2008) calculating actual evapotranspiration, surface runoff and infiltration. HXS was calculated as sum of surface runoff and infiltration (representing subsurface flow components). The actual implementation was set up for catchments across Europe using JRC’s HydroEurope Database (Bouraoui & Aloe, 2008), using climatic data from the MARS database (Micale & Genovese, 2004), soil data from the European Soil Database (ESDB 2.0) and land use information derived from CORINE landcover (ETC, 2005). The base flow index was calculated externally accounting for impact of slope, soil permeability and hydrogeological substrate properties. HXS can be used to calculate spatialized water exploitation indices at catchment or river basin level as the ratio of total water abstractions to HXS. To transfer water abstraction data to catchments, water fluxes per 10x10km grid cell were assigned to catchments according to the areal fraction of the grid cell attributable to a certain catchment.

Two indicators were applied to evaluate quantitative pressure on water resources at catchment and river basin level. The water exploitation index (WEI) is the ratio of abstractions and excess water available for runoff and groundwater recharge (HXS):

$$WEI = \frac{Abstraction}{HXS} \qquad [3.]$$

The water loss index WLI is defined as the ratio of losses and excess water (HXS). In contrast to the WEI, the WLI accounts for potential re-use of abstracted water after return.

$$WLI = \frac{Loss}{HXS} \qquad [4.]$$

Interpreting these indices requires considering that for sustainable water management the hydrological excess water available for groundwater recharge and runoff can not fully be exploited. A certain amount of water must be left to guarantee ecological functioning of ecosystems, and to support other human related services of water bodies such as transport, power generation. In addition, part of the water may not be available for human consumption, as topographical and geological conditions limit accessibility for exploitation. This would require rewriting the above equations into:

$$WEI = \frac{Abstraction}{HXS - MinFlow - NonExploitableWater}, \qquad [5.]$$

and *WLI* re-defined analogously

The minimum flow and non exploitable water are difficult to determine in a straightforward way and local conditions must be considered. Therefore this extended concept was not applied in this assessment.

This implies that the threshold for both indices indicating where water resources must be considered under pressure is far below one. The catchment based indices give information on the imbalance of local water demand and supply. They do not account for satisfying water demands from surpluses in some distance (other catchments and river basins). In contrast, the indices at river basin level at least partly take this into account, aggregating surpluses and demands to the river basin level.

3 Atlas of water abstractions and water use in Europe

This section presents the statistical information and the compiled datasets and indicators as an atlas of water abstraction and water use data and pressure indicators. A presentation of the main results and discussion follow in Section 3. The maps are organised in the following order:

- Spatial units used for the assessment
- Disaggregated water abstraction data by sector as volume
- Disaggregated water abstraction data by sector as share in total abstractions
- Cooling water abstractions
- Abstraction sources for different sectors
- Assessment of water losses and returns
- Indicator of tourism related pressure on water resources
- Assessment of hydrological excess water available for runoff
- Indicators of water pressures at catchment and river basin scale – water exploitation index and water loss index

3.1 Spatial concepts

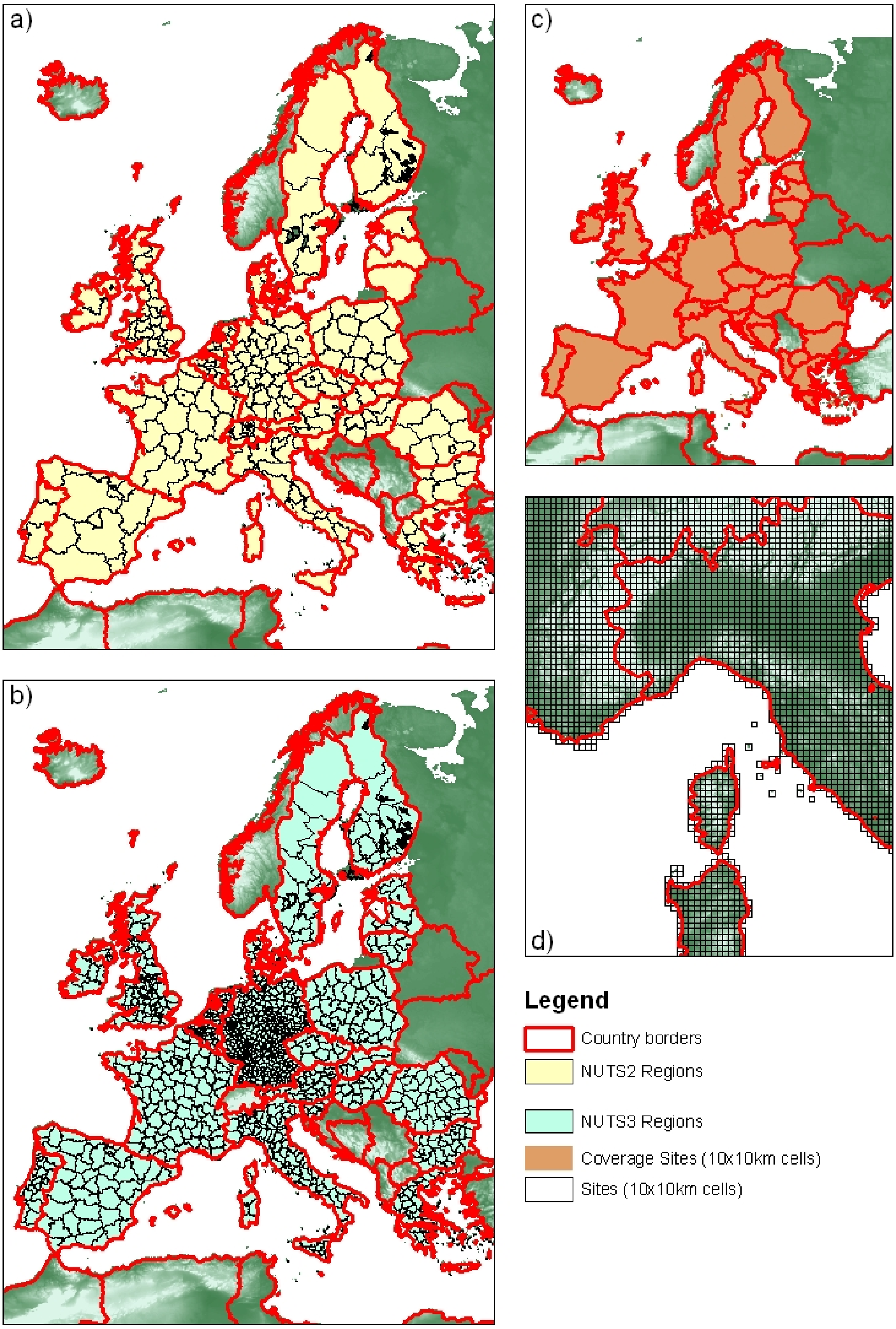

Figure 2: Spatial units: a) Countries, NUTS2 regions (Provinces), b) NUTS3 regions (Regions), c) geographical coverage of 10x10km grid), d) detail of 10x10km grid.

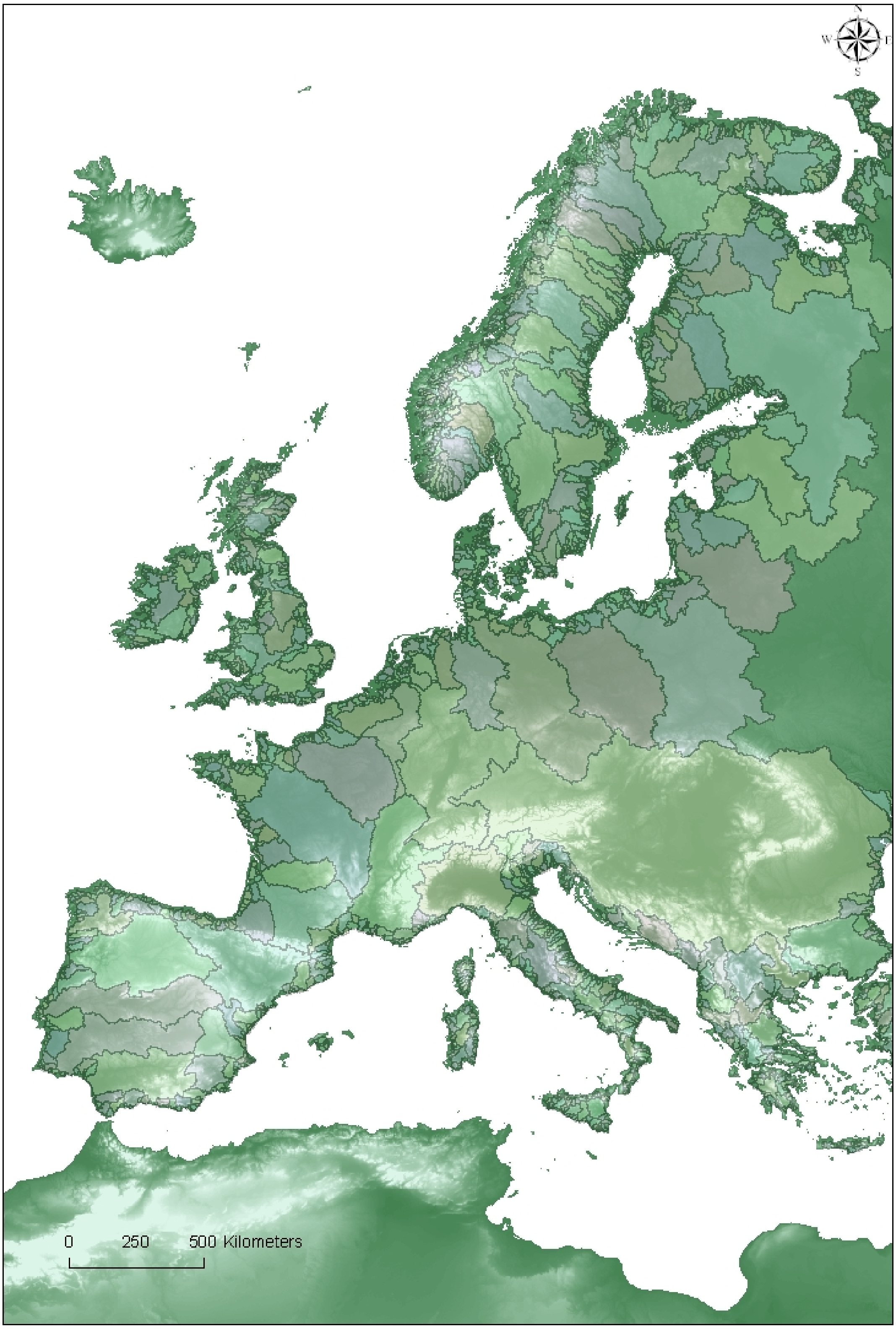

Figure 3: HydroEurope database - River basins

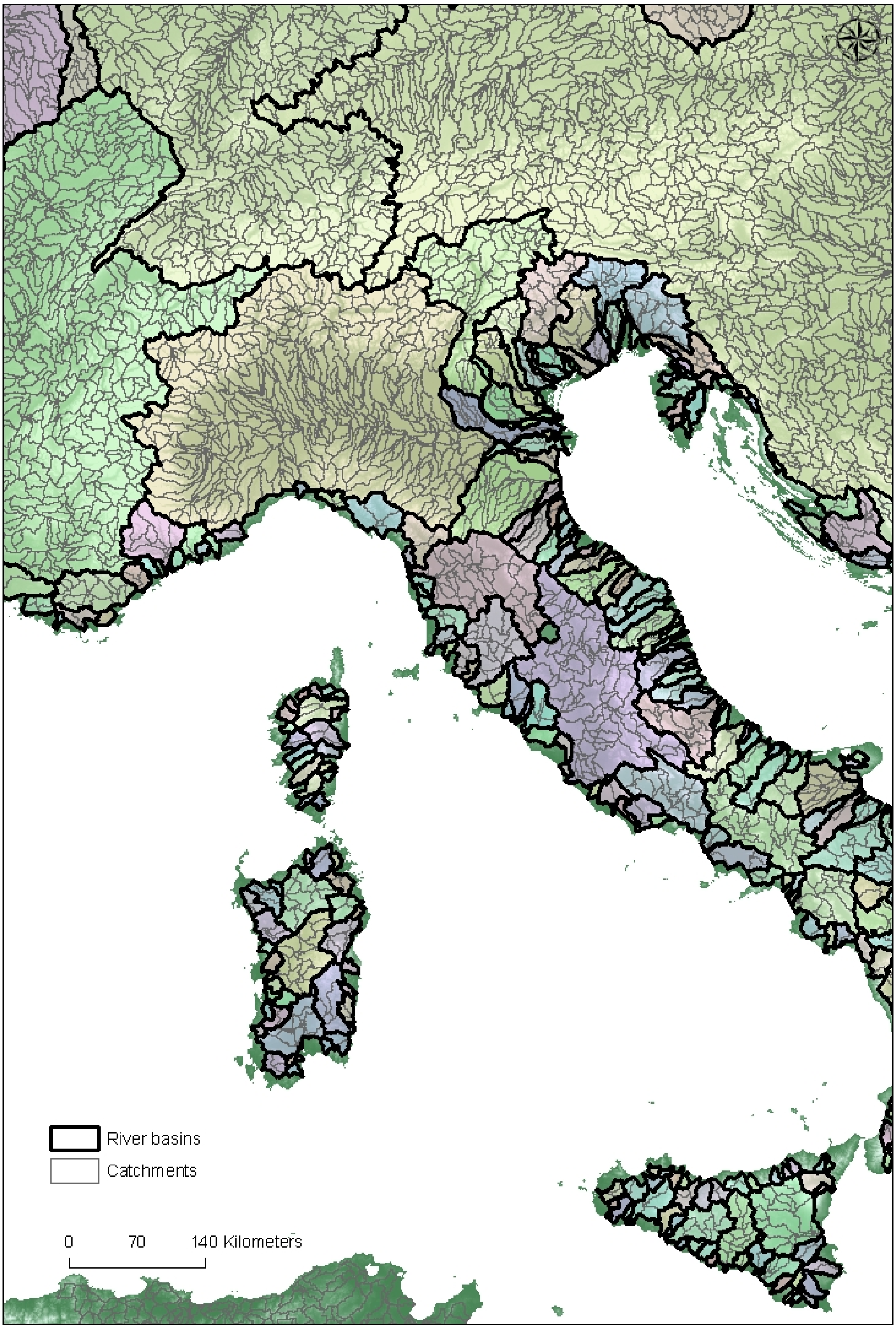

Figure 4: HydroEurope database - Catchments (Detail)

3.2 Water abstractions

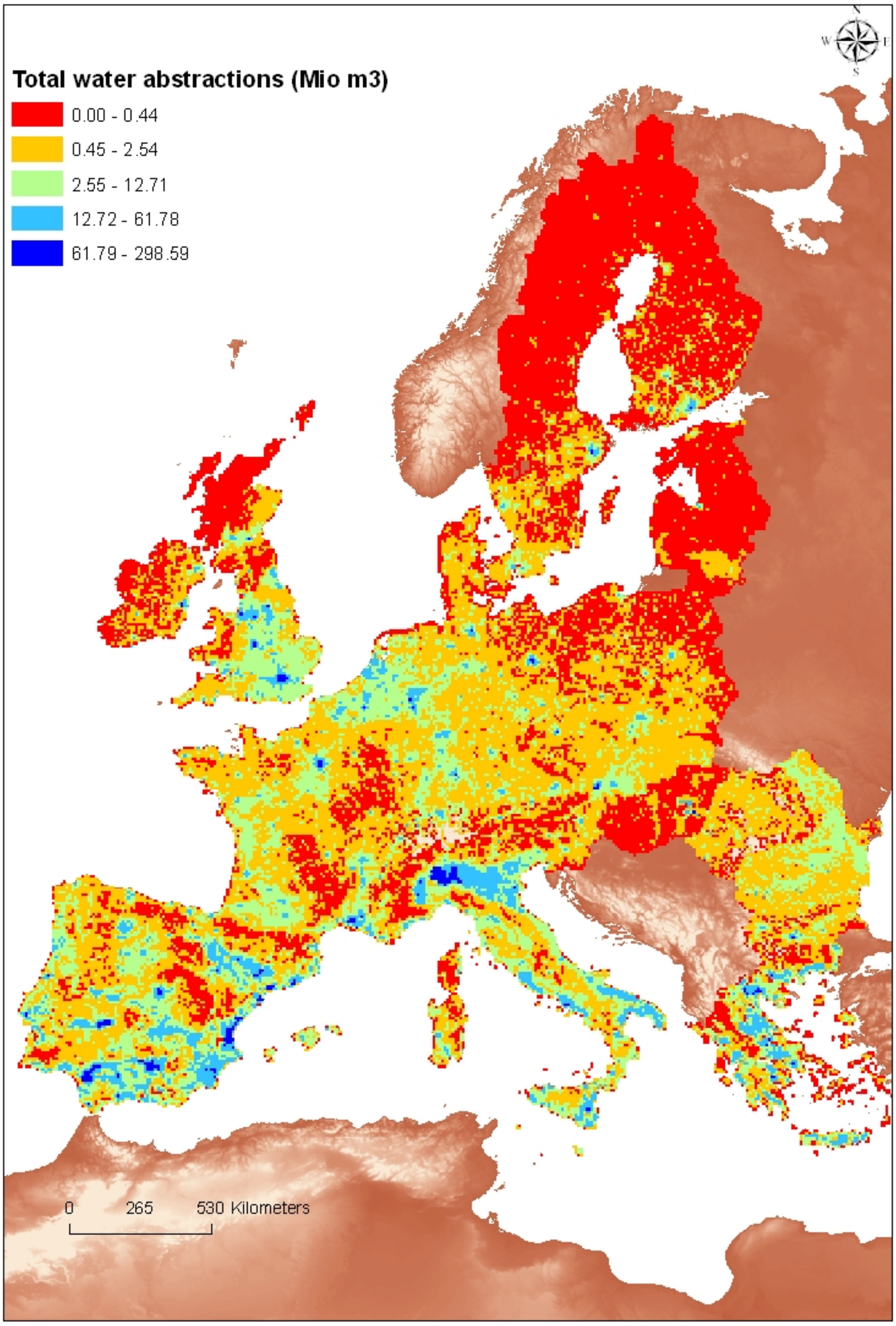

Figure 5: Total water abstractions* per 10x10km cell (Mio m3), without abstractions for electricity cooling. OECD/EUROSTAT Joint Questionnaire on Inland waters. (* excluding cooling water for electricity production)

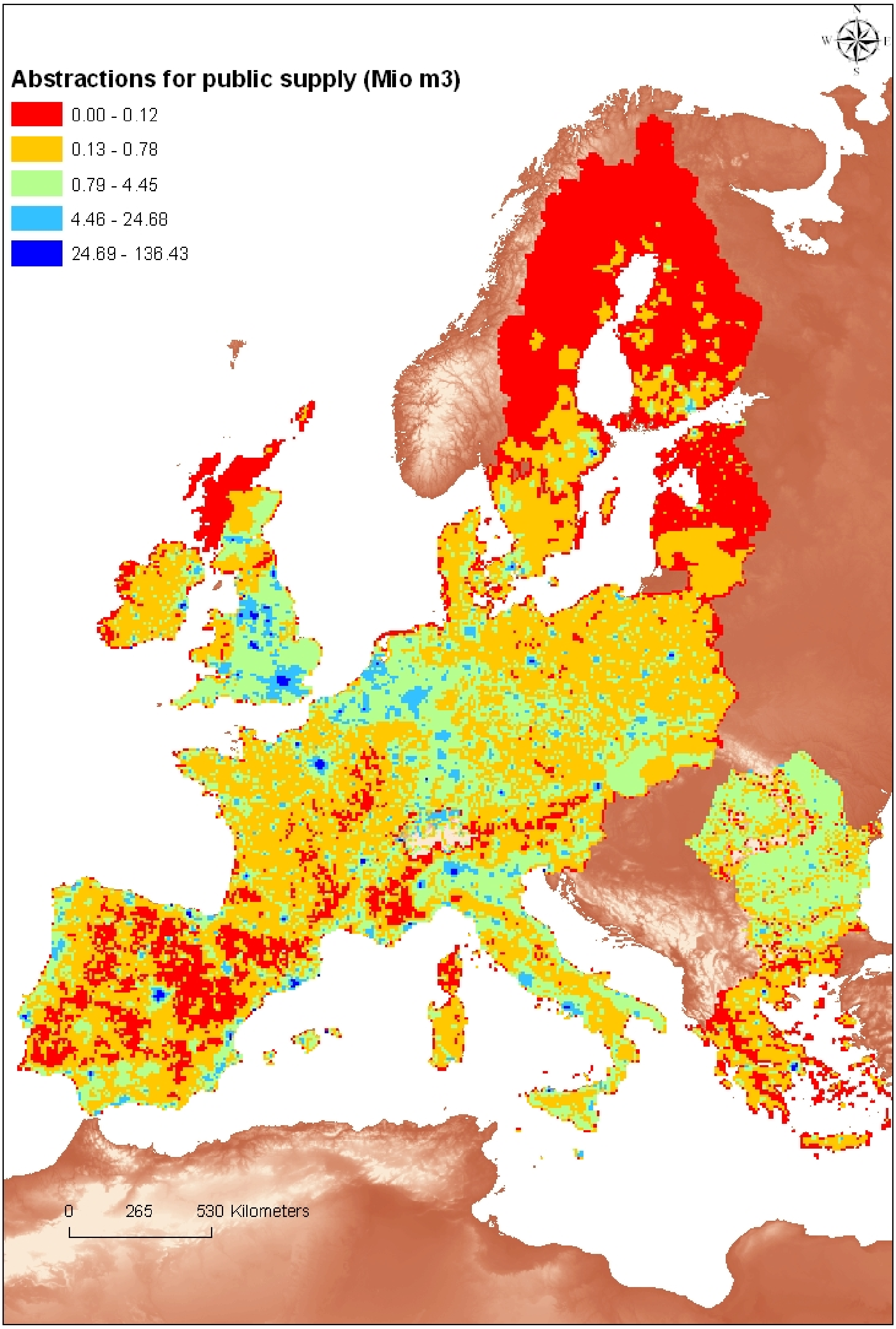

Figure 6: Abstractions for public water supply per 10x10 km cell (Mio m3). OECD/EUROSTAT Joint Questionnaire on Inland waters.

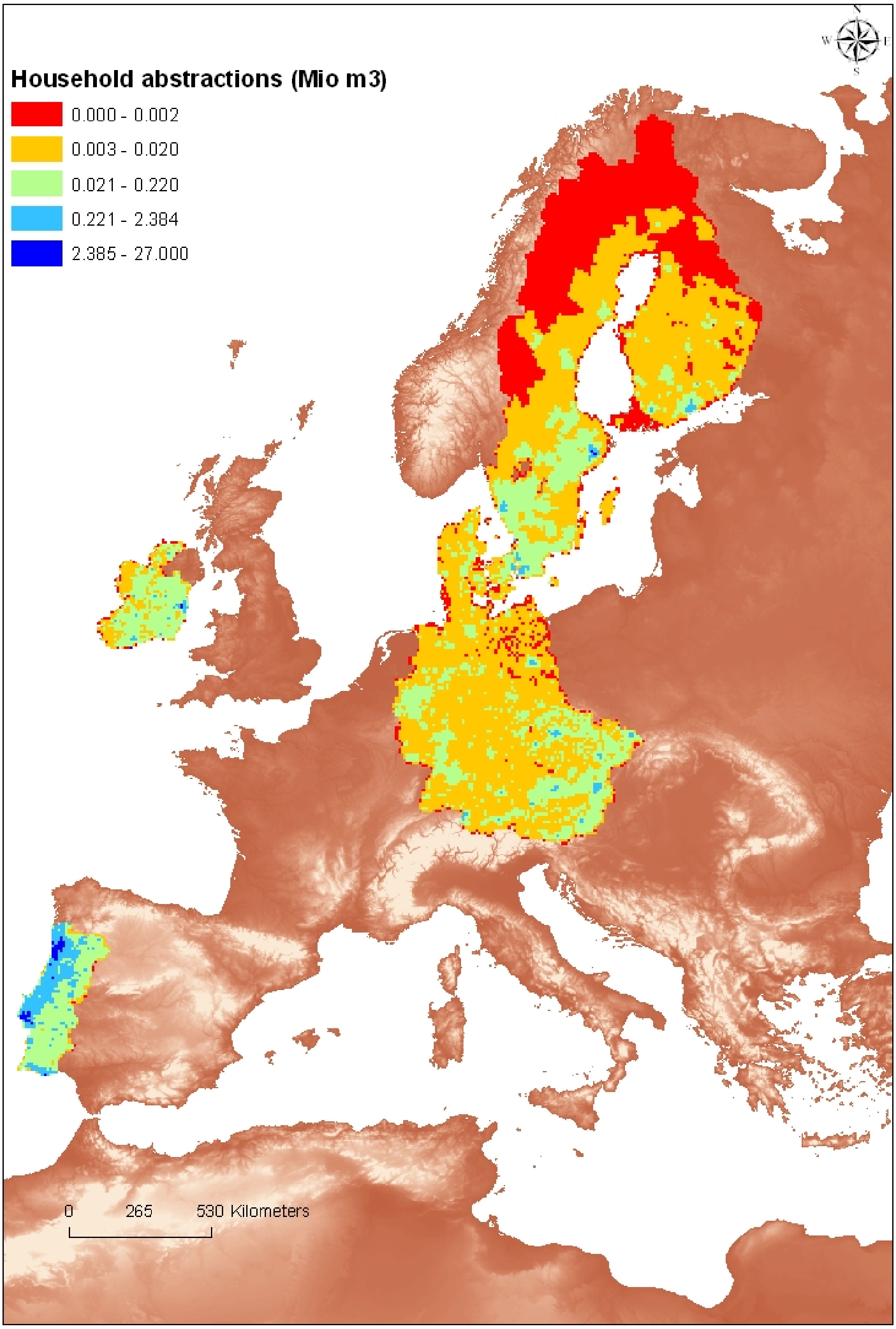

Figure 7: Household water abstractions per 10x10km cell (Mio m3). OECD/EUROSTAT Joint Questionnaire on Inland waters.

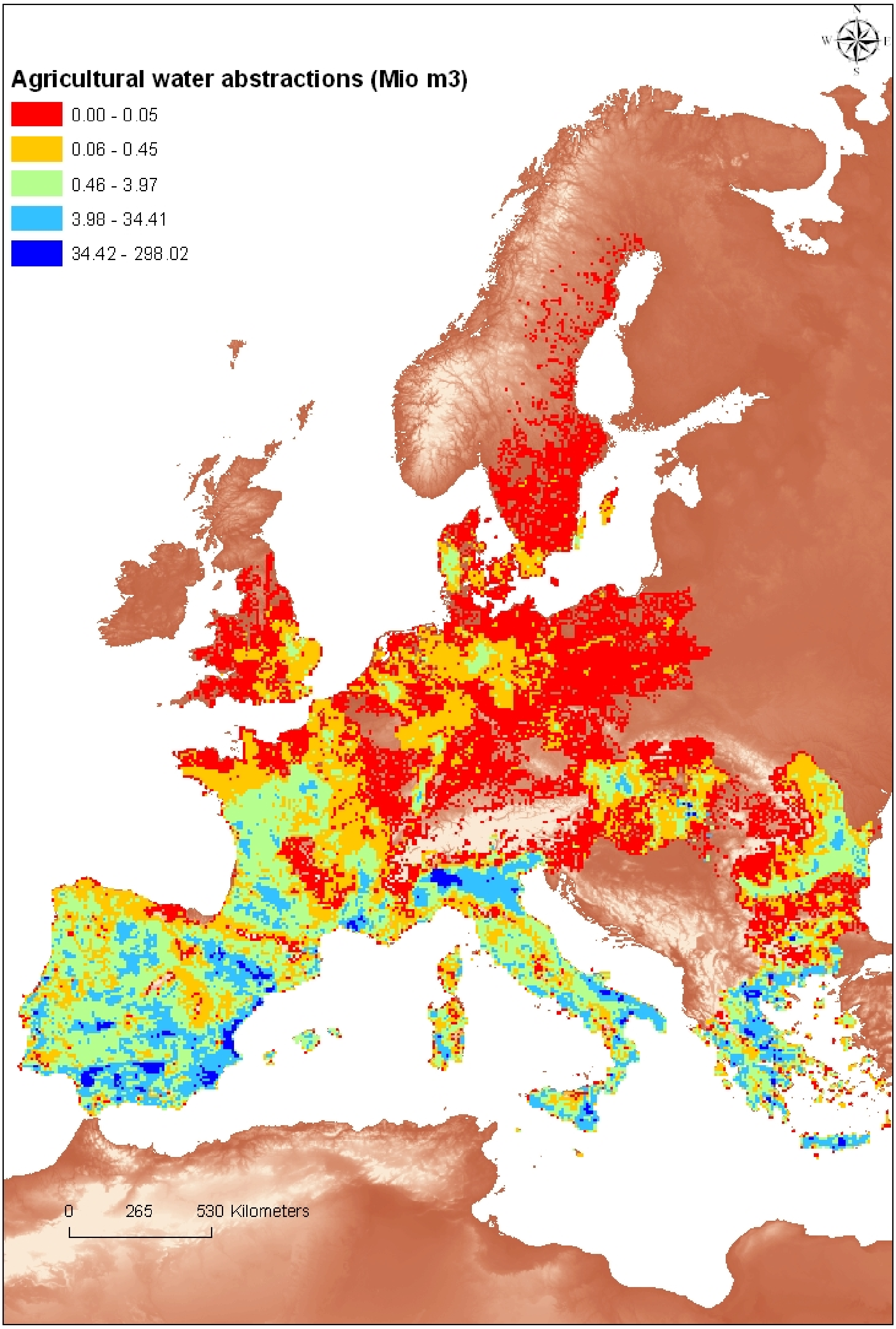

Figure 8: Agricultural water abstractions per 10x10km cell (Mio m3) (Wriedt et al. 2008, 2009b).

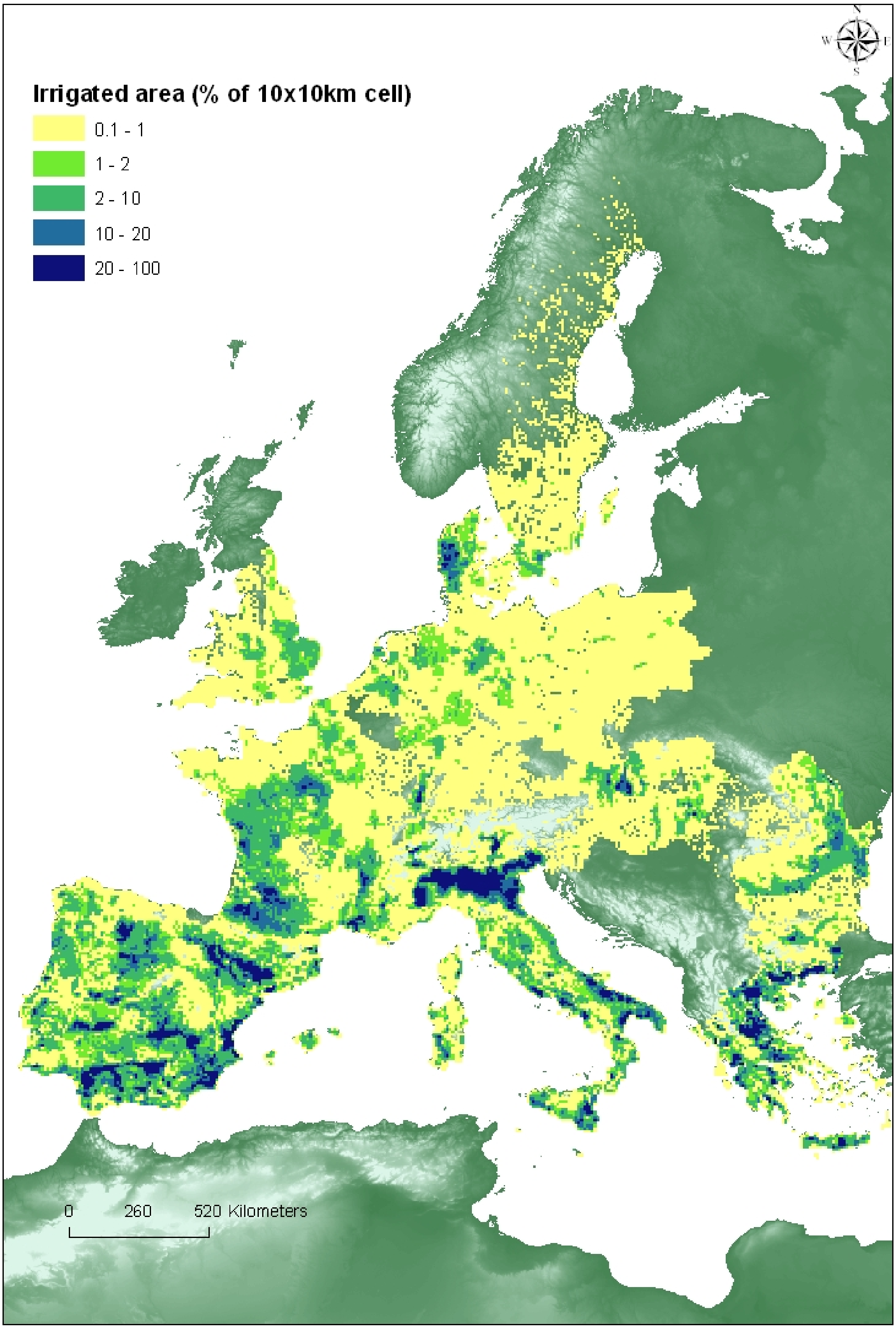

Figure 9: Distribution of irrigated agricultural areas as % of total area per 10x10km grid cell (Wriedt et al. 2009a).

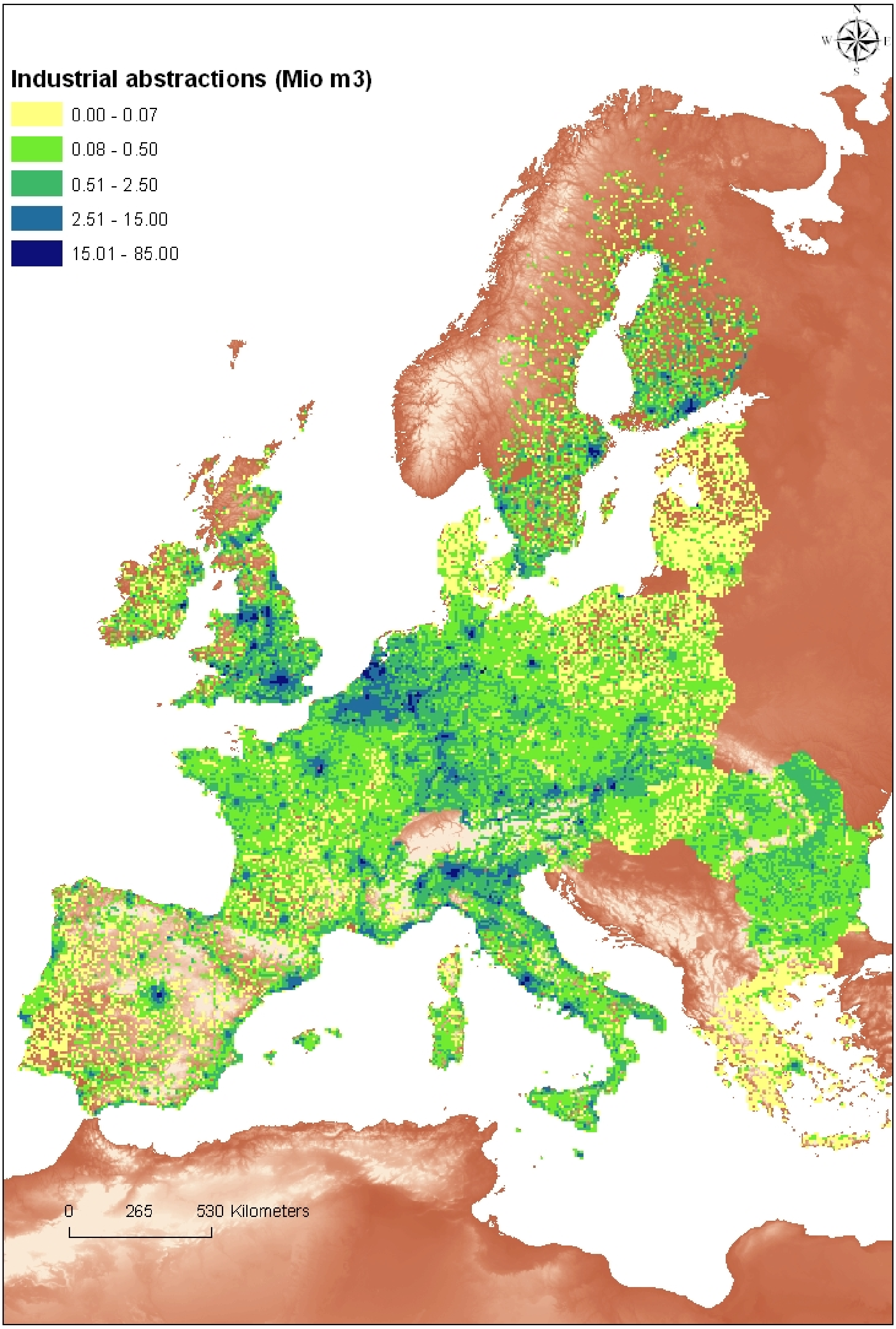

Figure 10: Industrial water abstractions per 10x10km cell (Mio m3). OECD/EUROSTAT Joint Questionnaire on Inland waters.

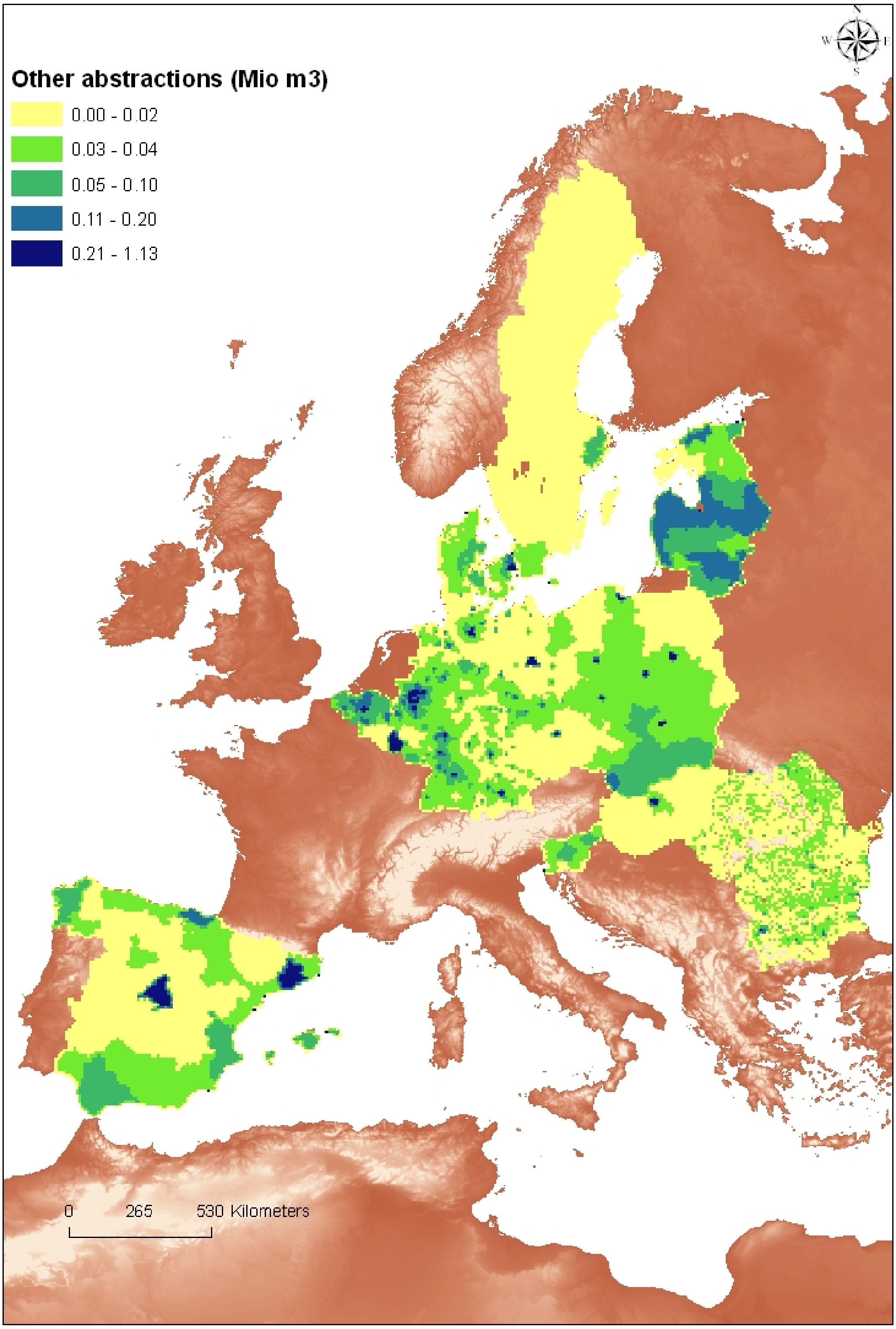

Figure 11: Other water abstractions per 10x10km cell (Mio m3). OECD/EUROSTAT Joint Questionnaire on Inland waters.

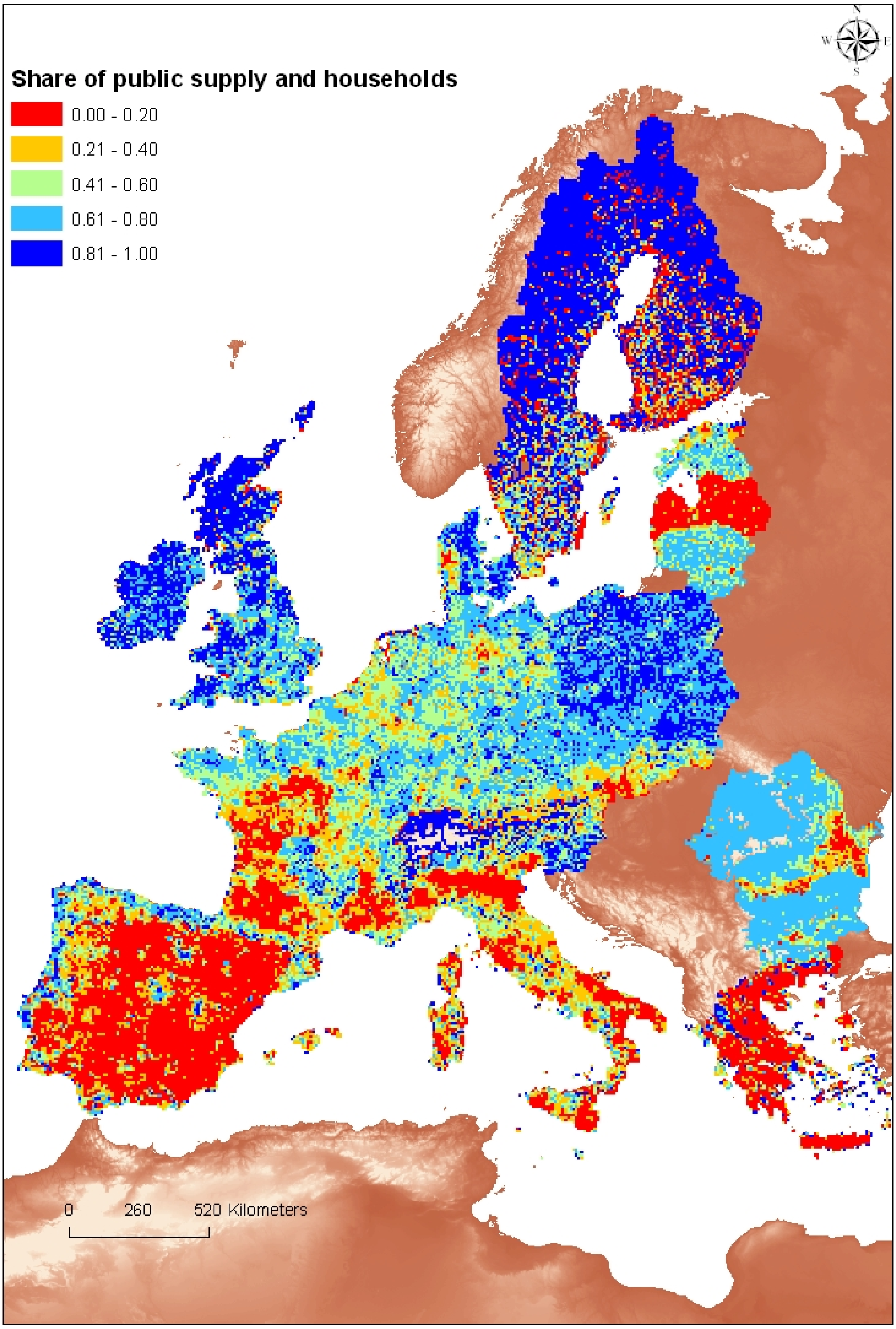

Figure 12: Share of combined abstractions for public water supply in total water abstractions per 10x10km cell.

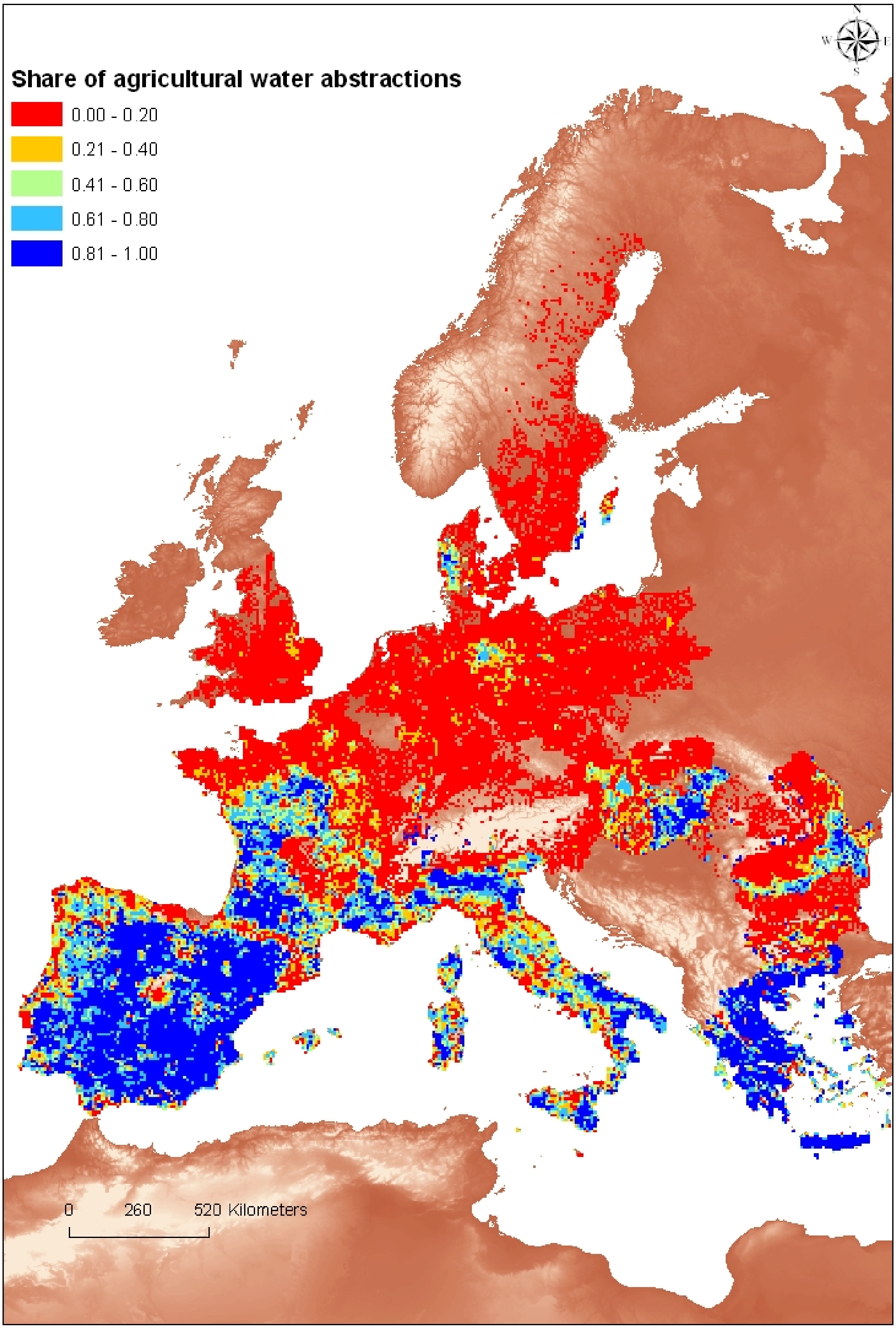

Figure 13: Share of agricultural water abstractions in total water abstractions per 10x10km cell.

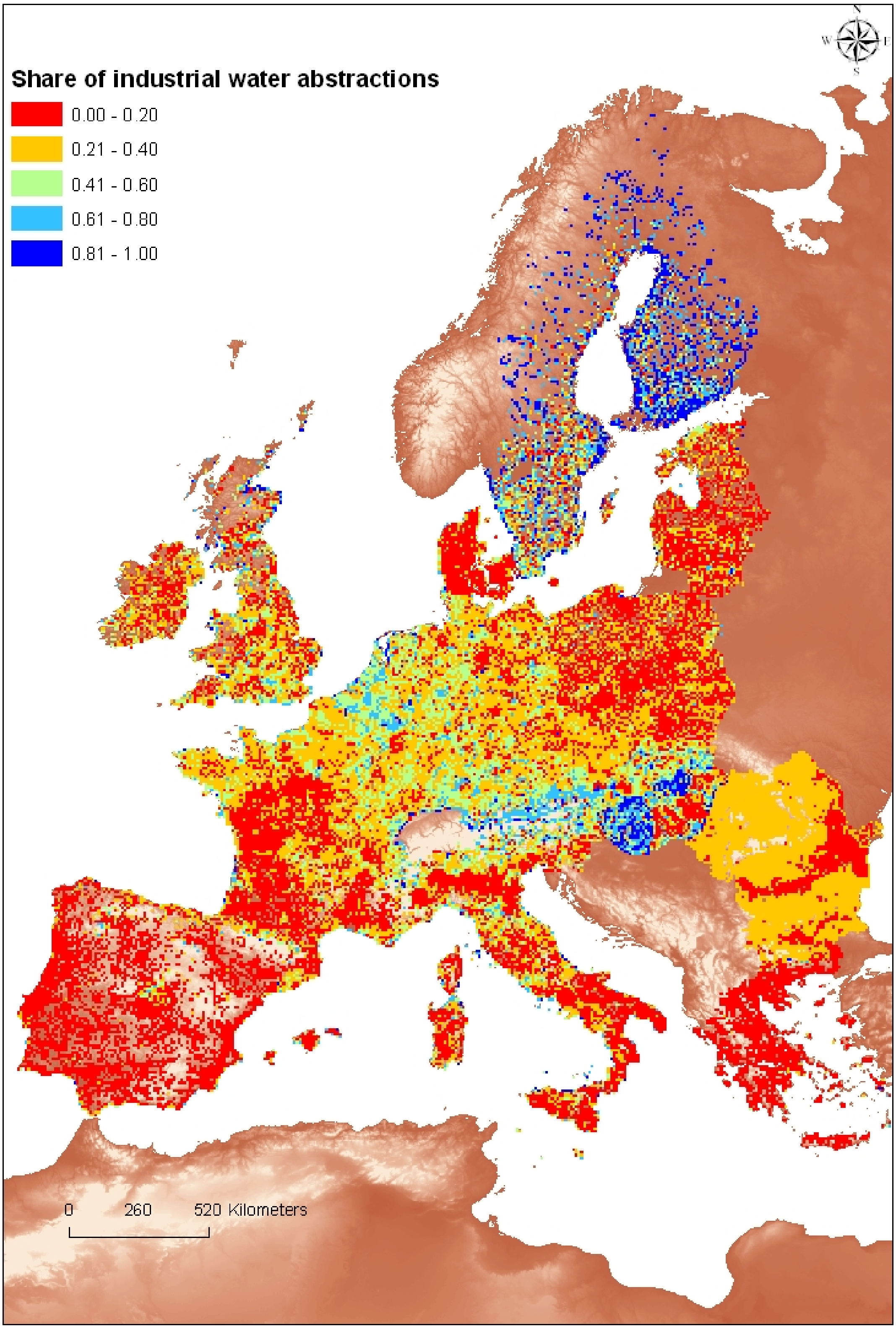

Figure 14: Share of industrial abstractions in total water abstractions per 10x10km cell.

3.3 Cooling water abstractions

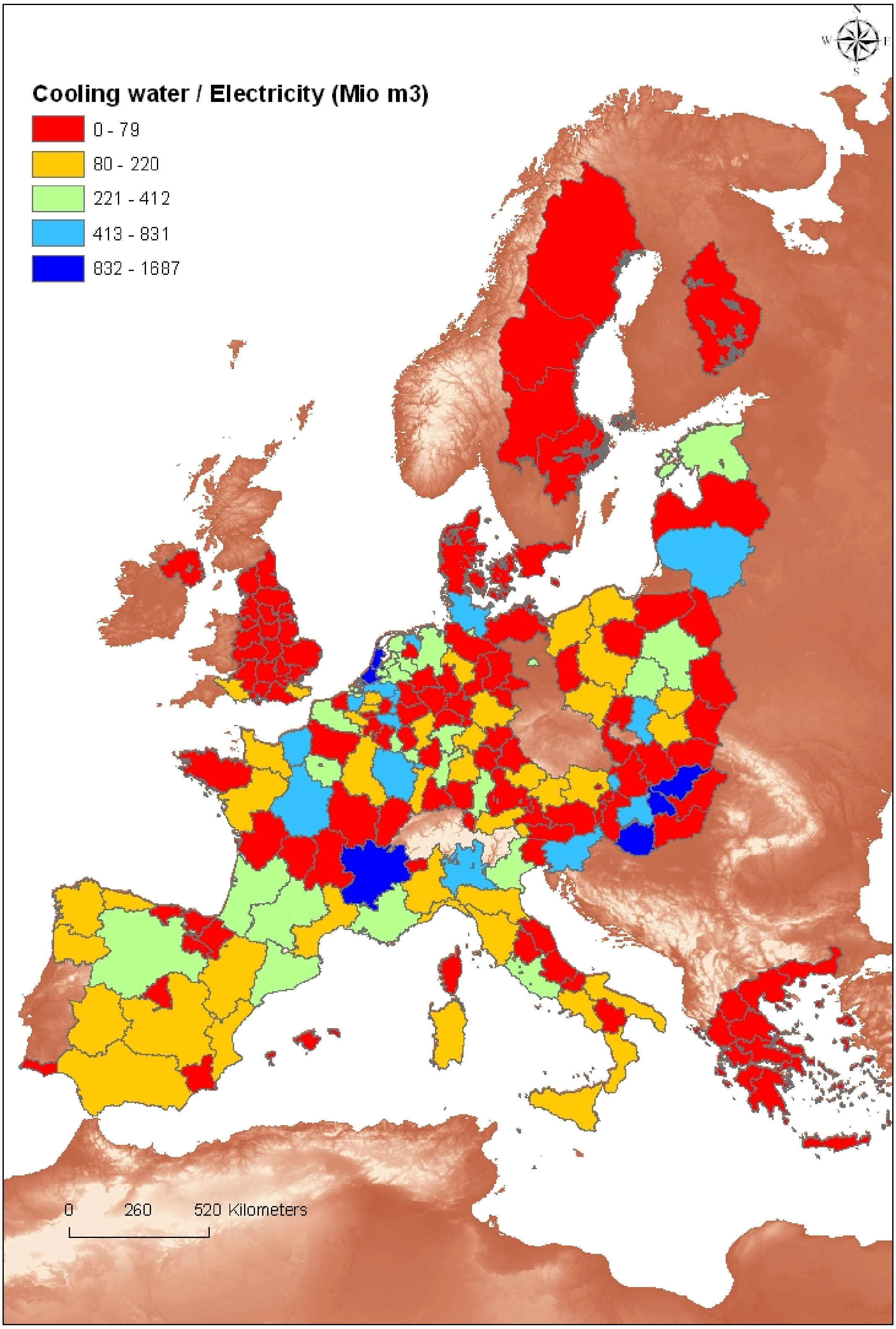

Figure 15: Cooling water abstractions for electricity production, disaggregated to NUTS2 regions

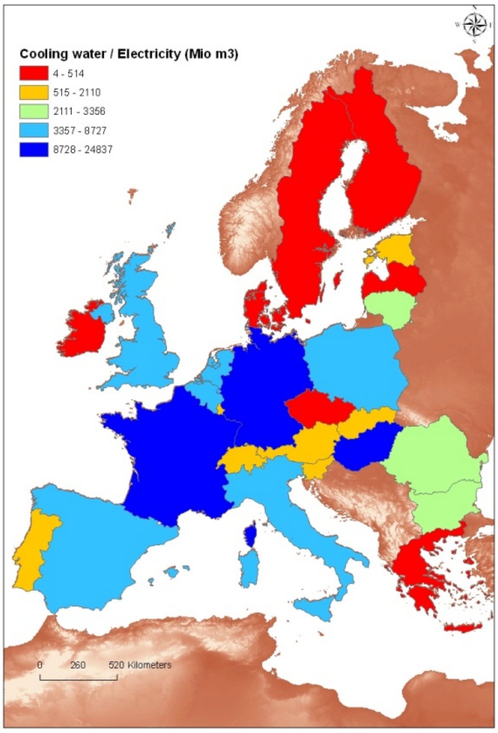

Figure 16: Cooling water abstractions for electricity production, national values

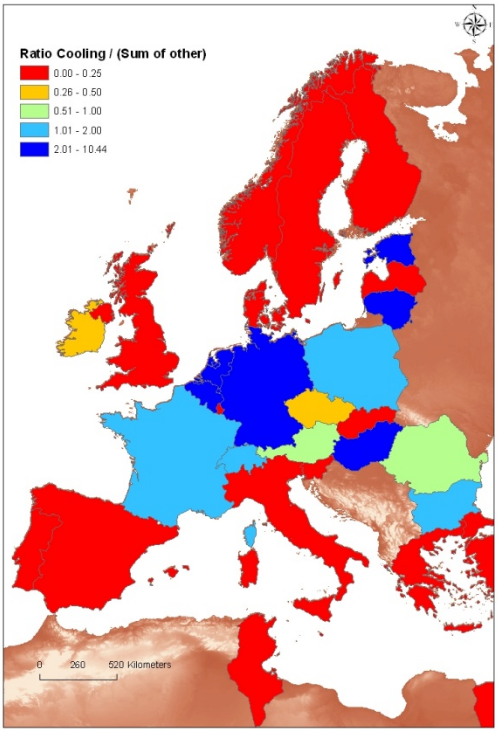

Figure 17: Ratio of cooling water abstractions to sum of other abstractions (=Total abstractions without cooling)

3.4 Abstraction sources

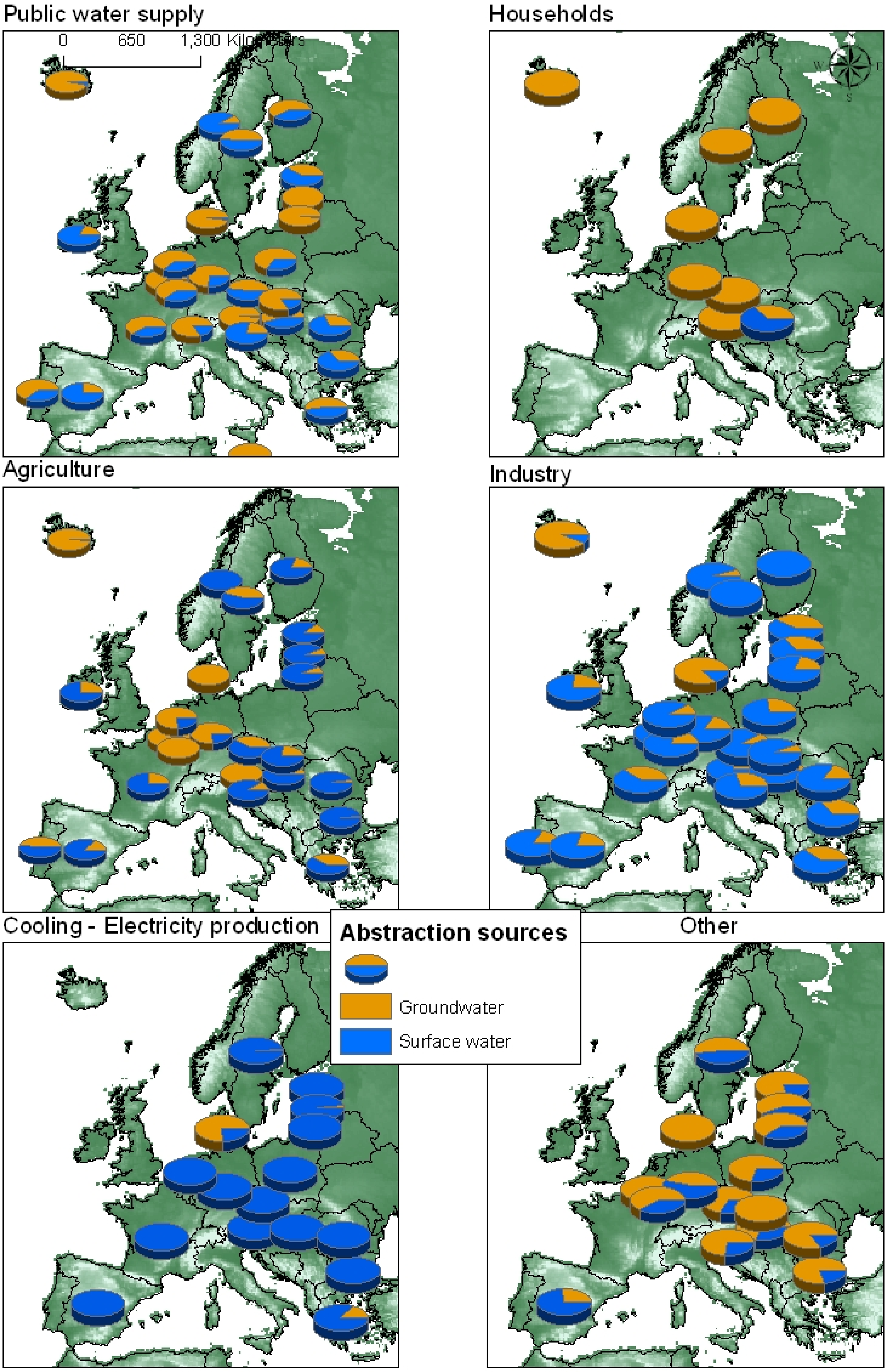

Figure 18: Water sources by abstraction sector

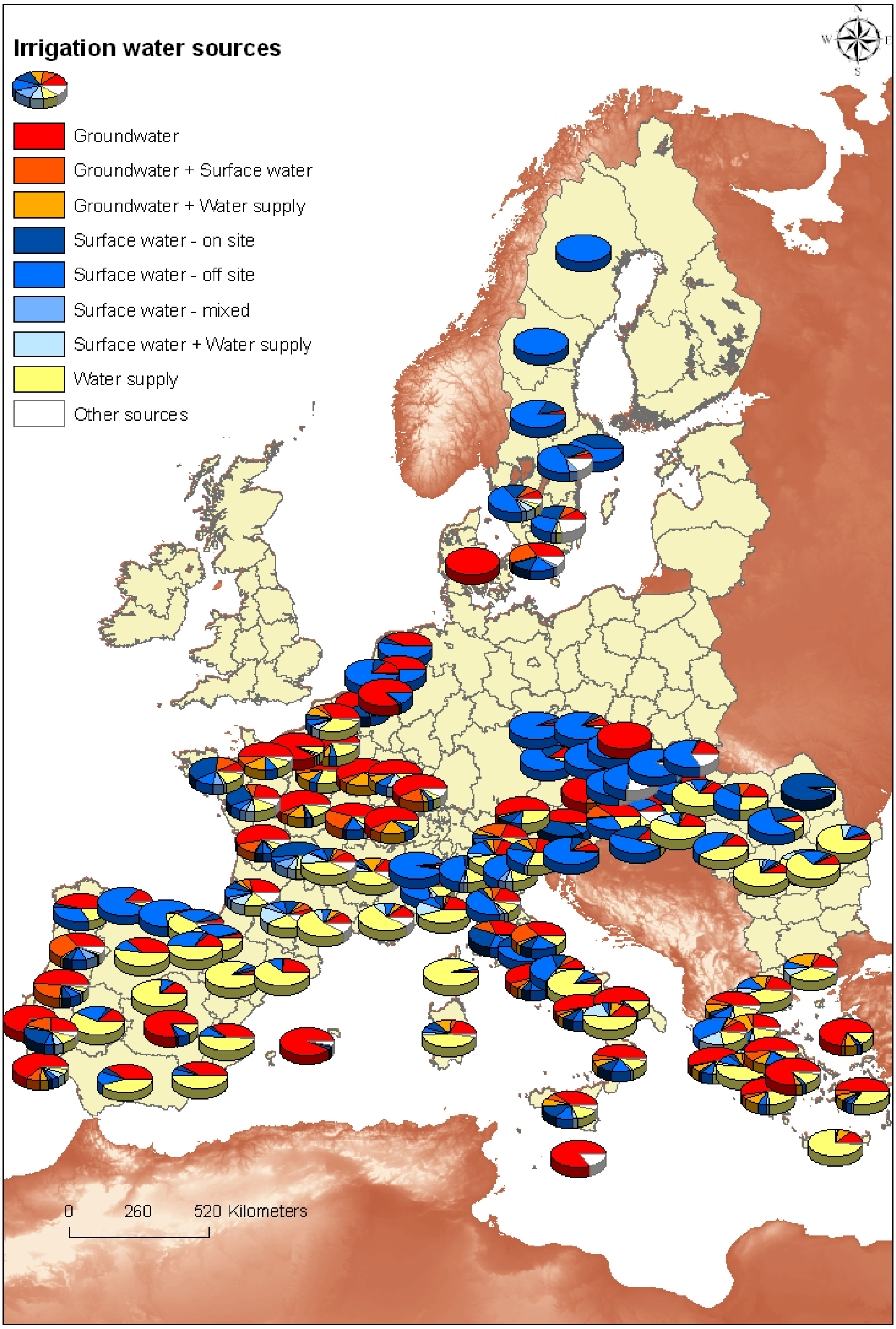

Figure 19: Sources for irrigation water. Red: groundwater dominated self supply, blue: surface water dominated self supply, yellow: supply through public suppliers. EUROSTAT, Farm Structure Survey 2003

3.5 Losses and returns

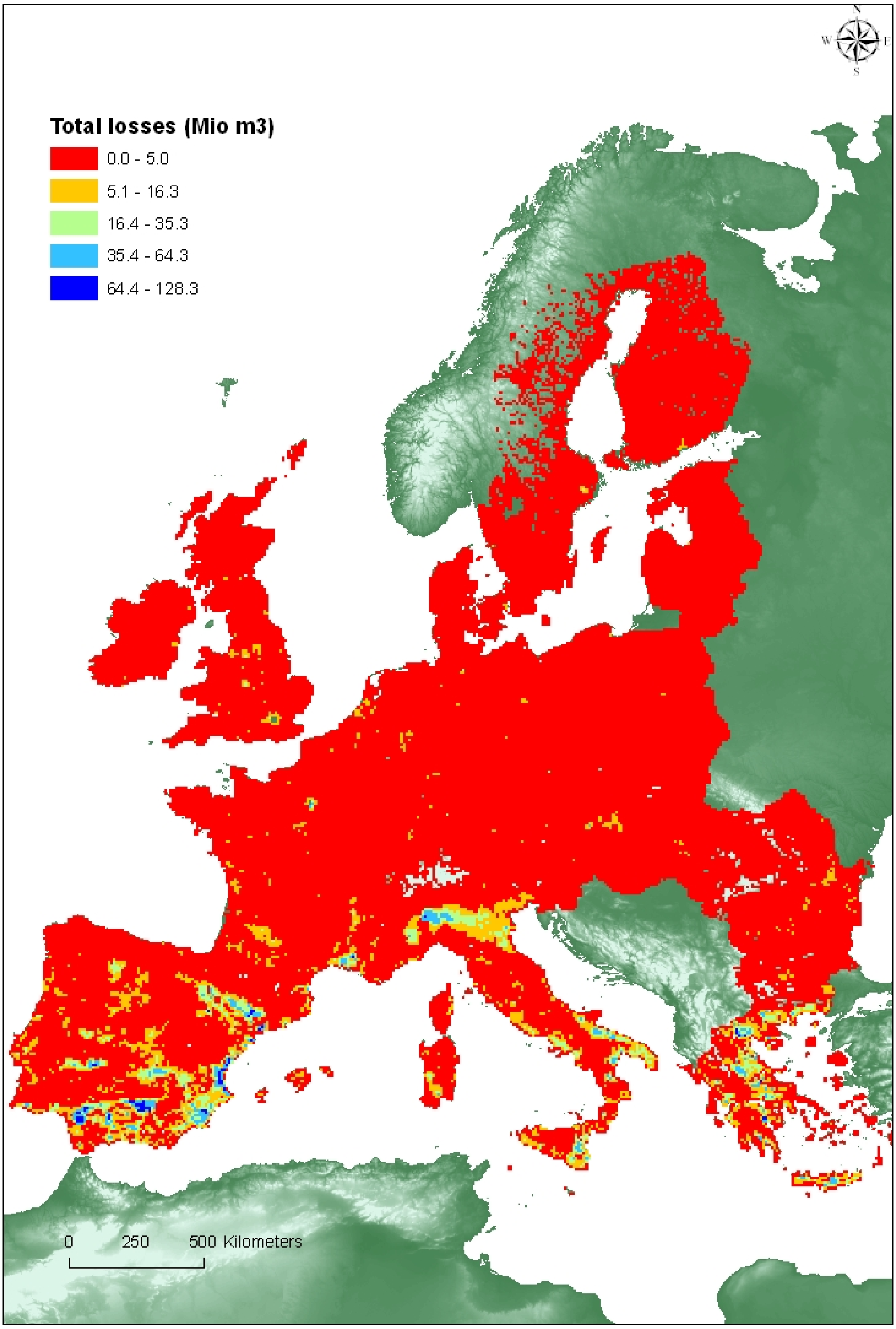

Figure 20: Estimated total water losses (Mio m3) per 10x10km cell.

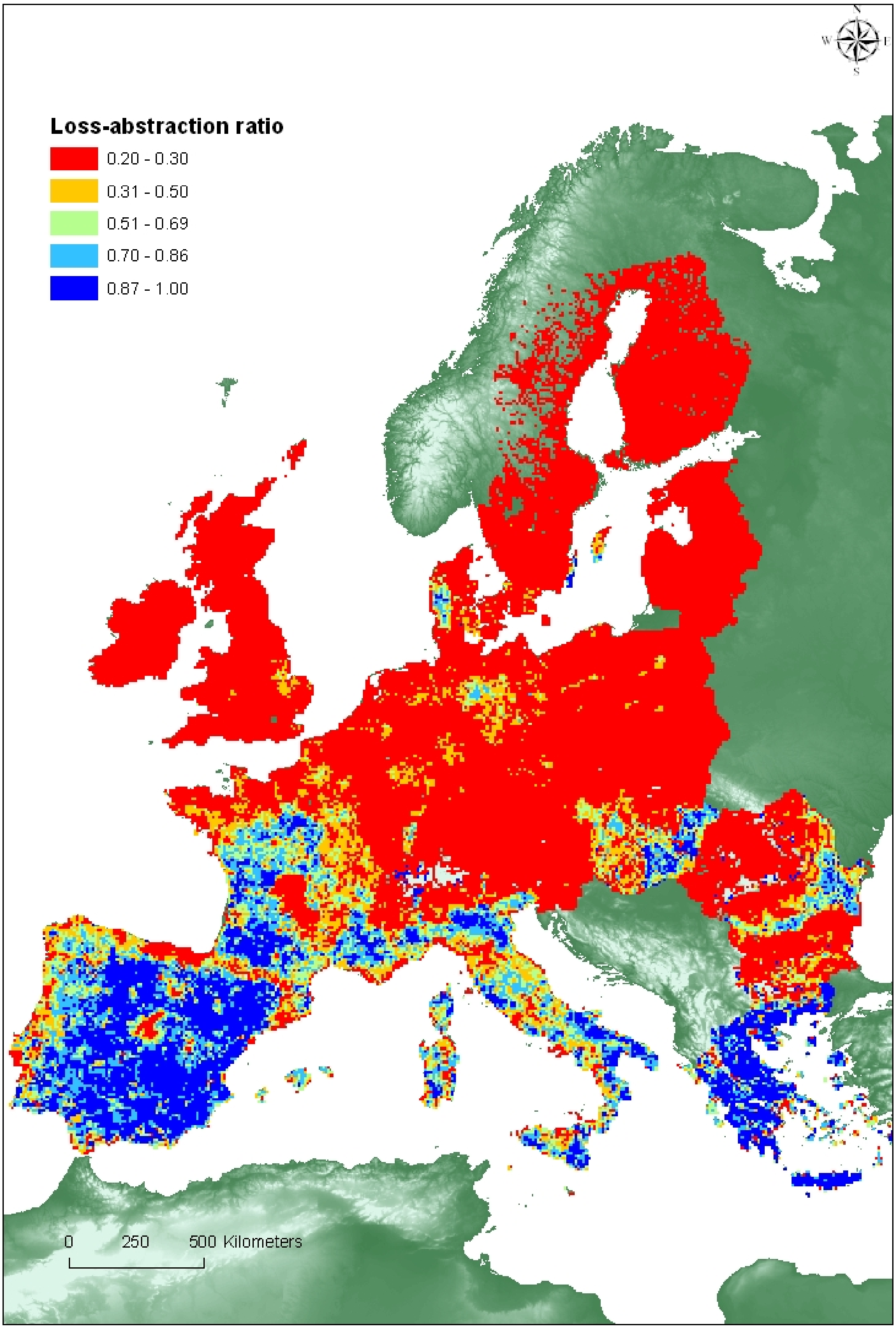

Figure 21: Ratio of water losses to total water abstractions* per 10x10km cell.

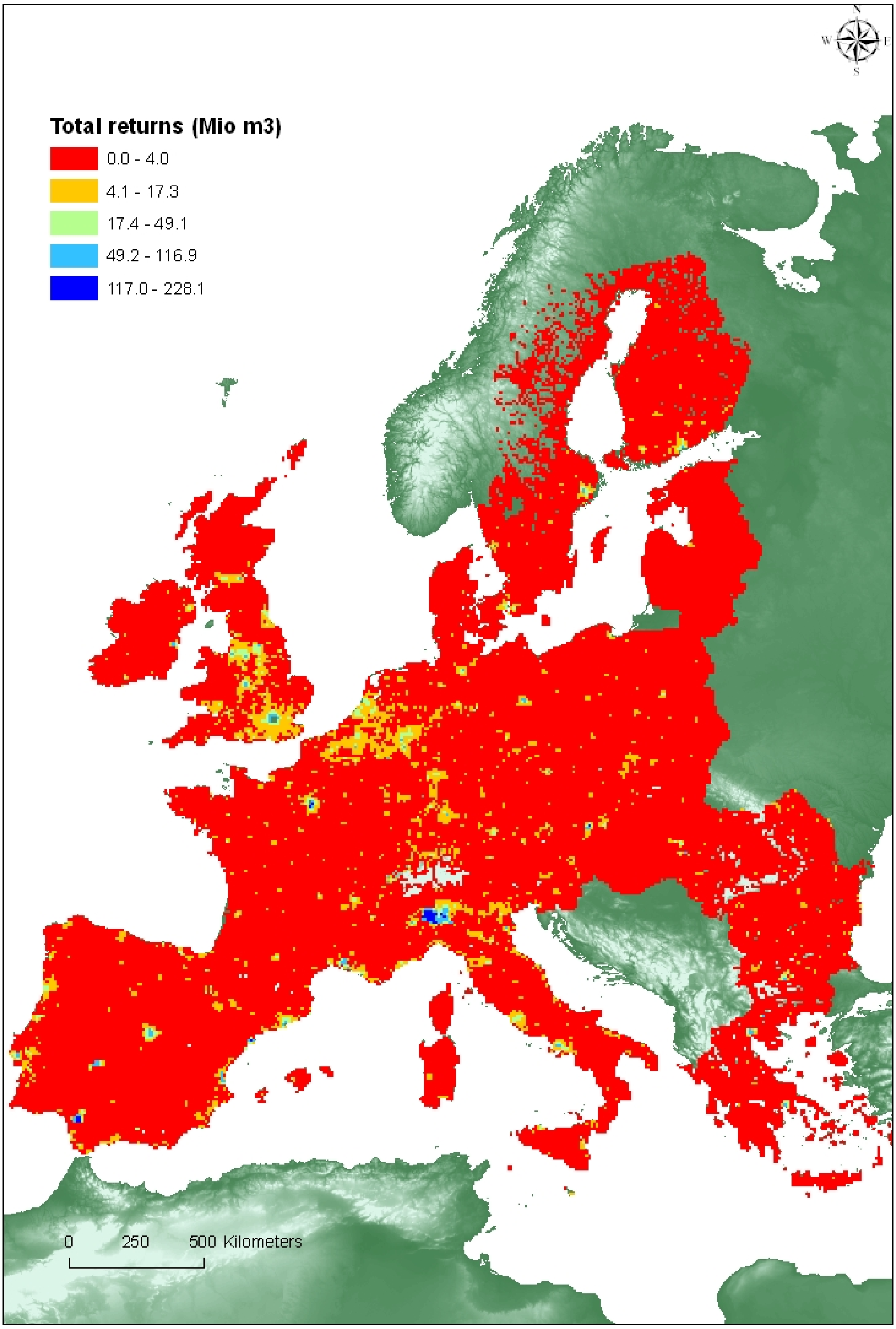

Figure 22: Estimated total water returns (Mio m3) per 10x10km cell.

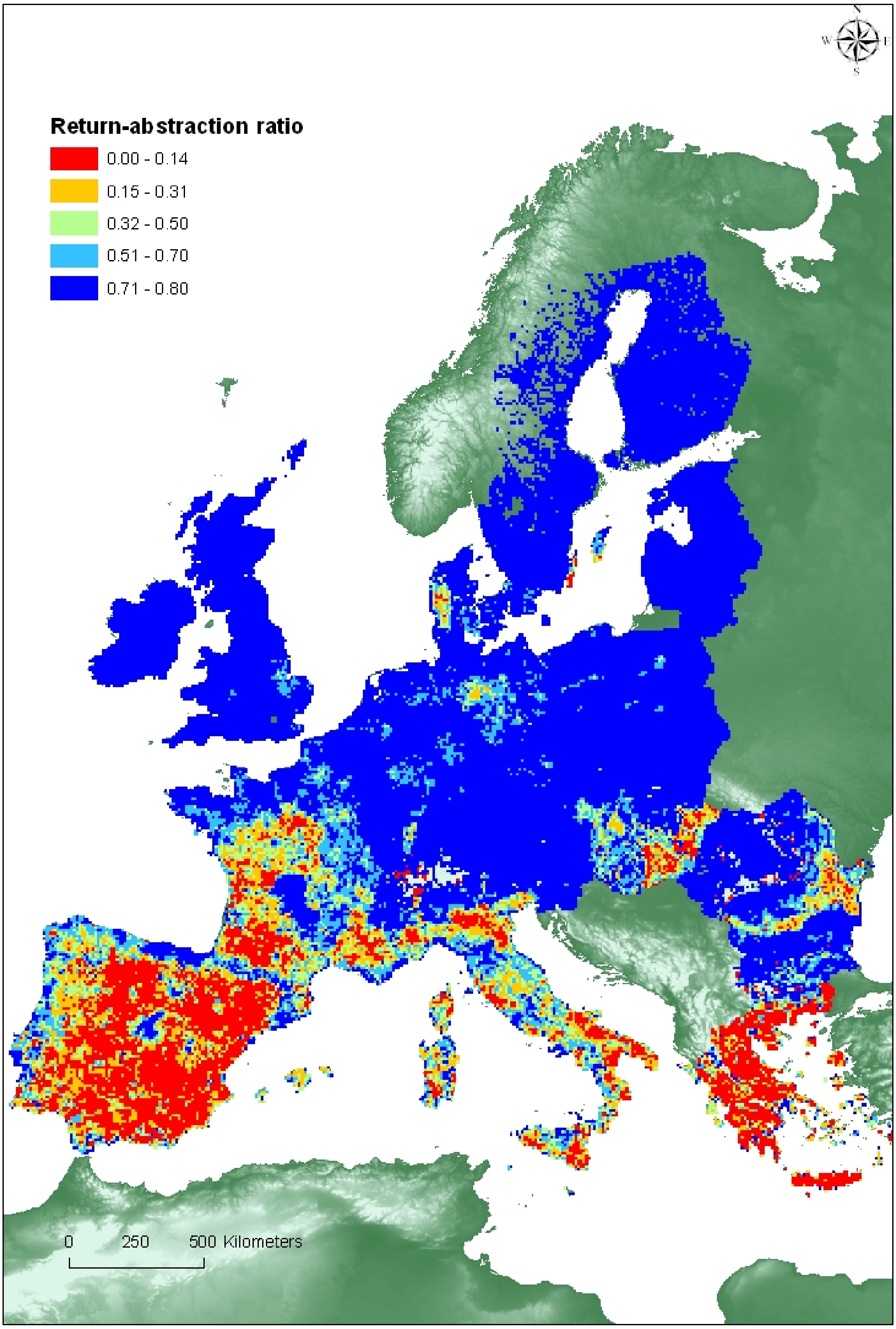

Figure 23: Ratio of water returns to total water abstractions per 10x10km cell.

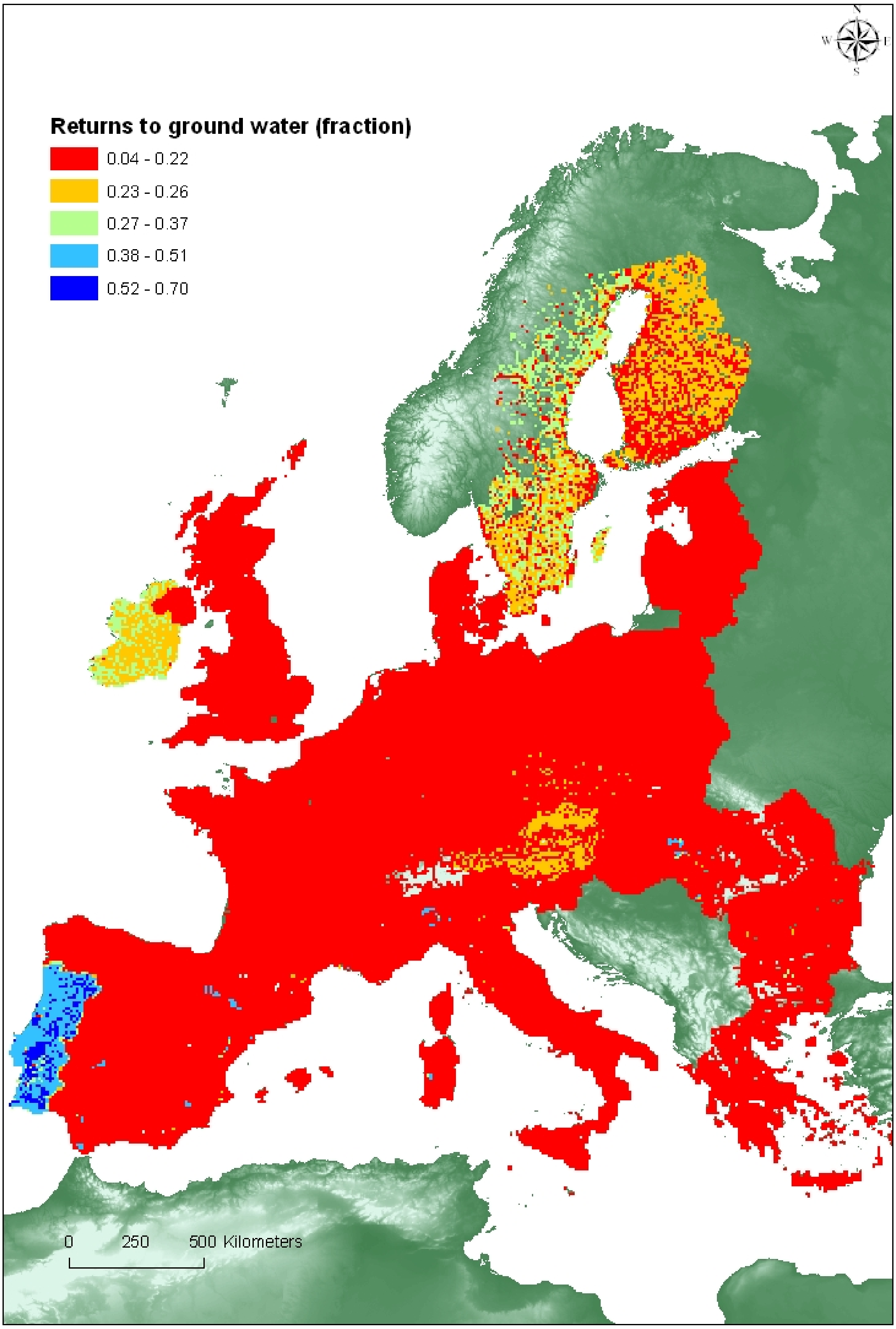

Figure 24: Estimated fraction of total returns that was returned to groundwater

3.6 *Tourism water pressure*

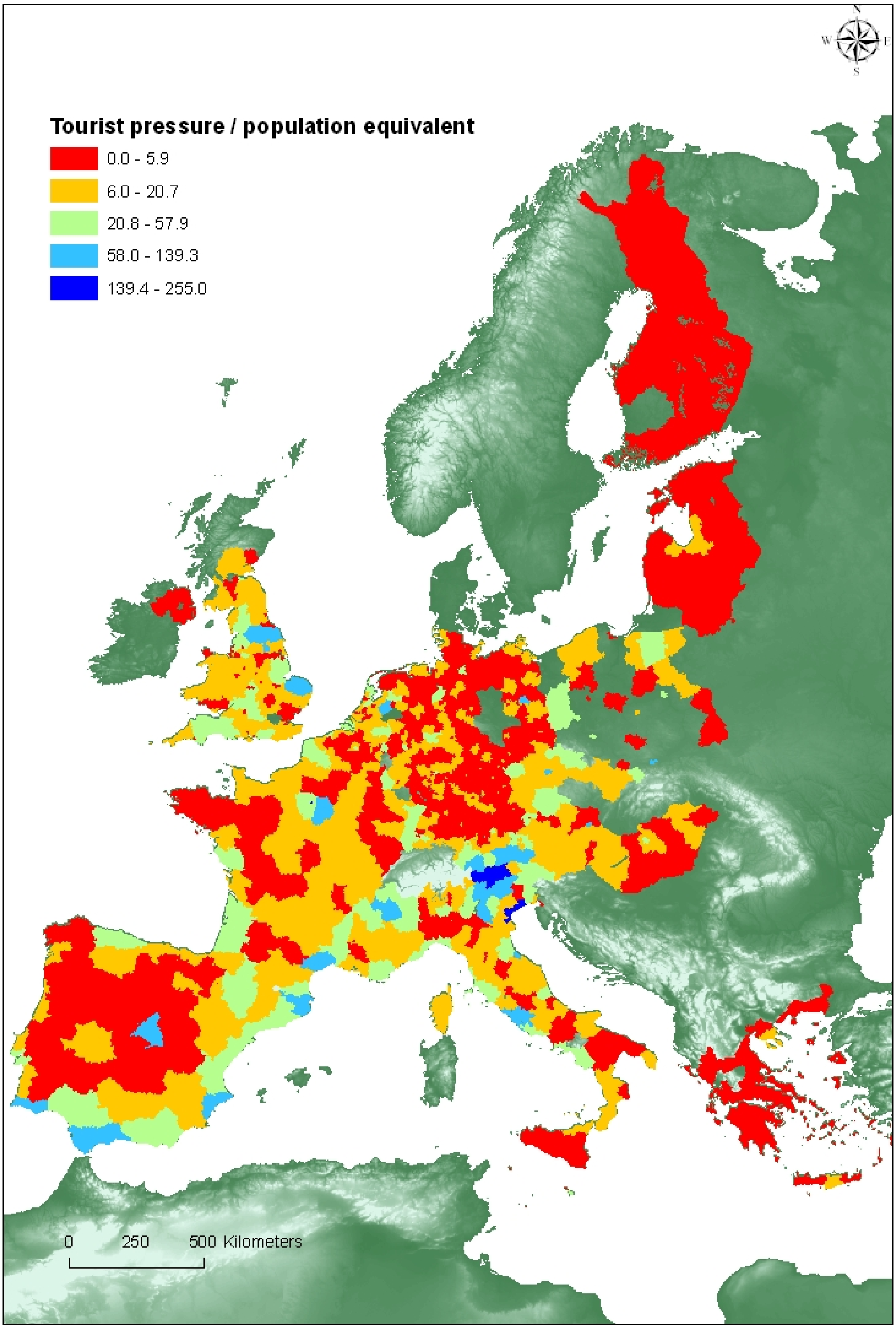

Figure 25: Tourism pressure on water, expressed as tourism population equivalent (1000 inhabitants) per NUTS3 region.

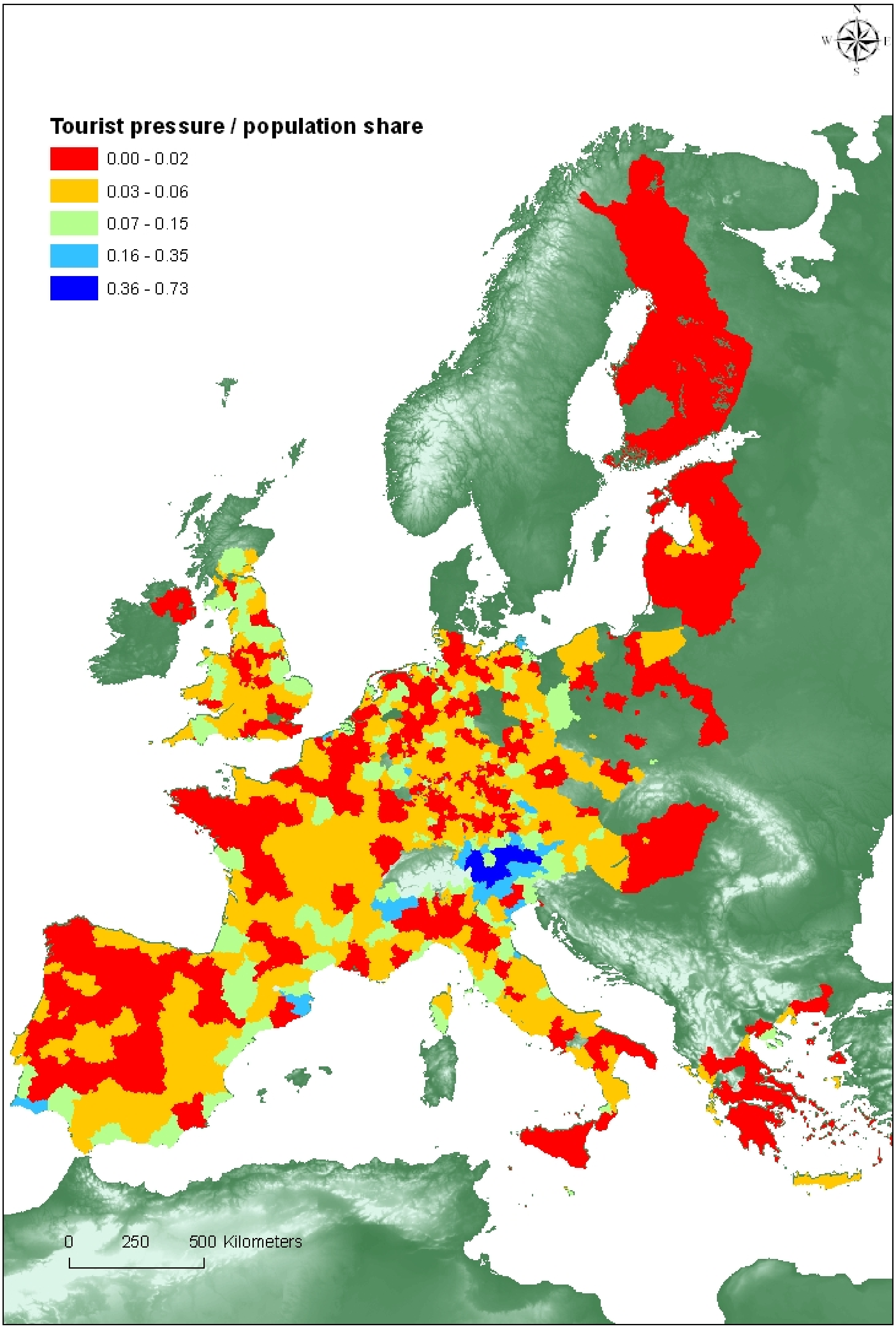

Figure 26: Tourism pressure on water, expressed as ratio of population equivalent to NUTS3 population.

3.7 Water exploitation at catchment and river basin scale

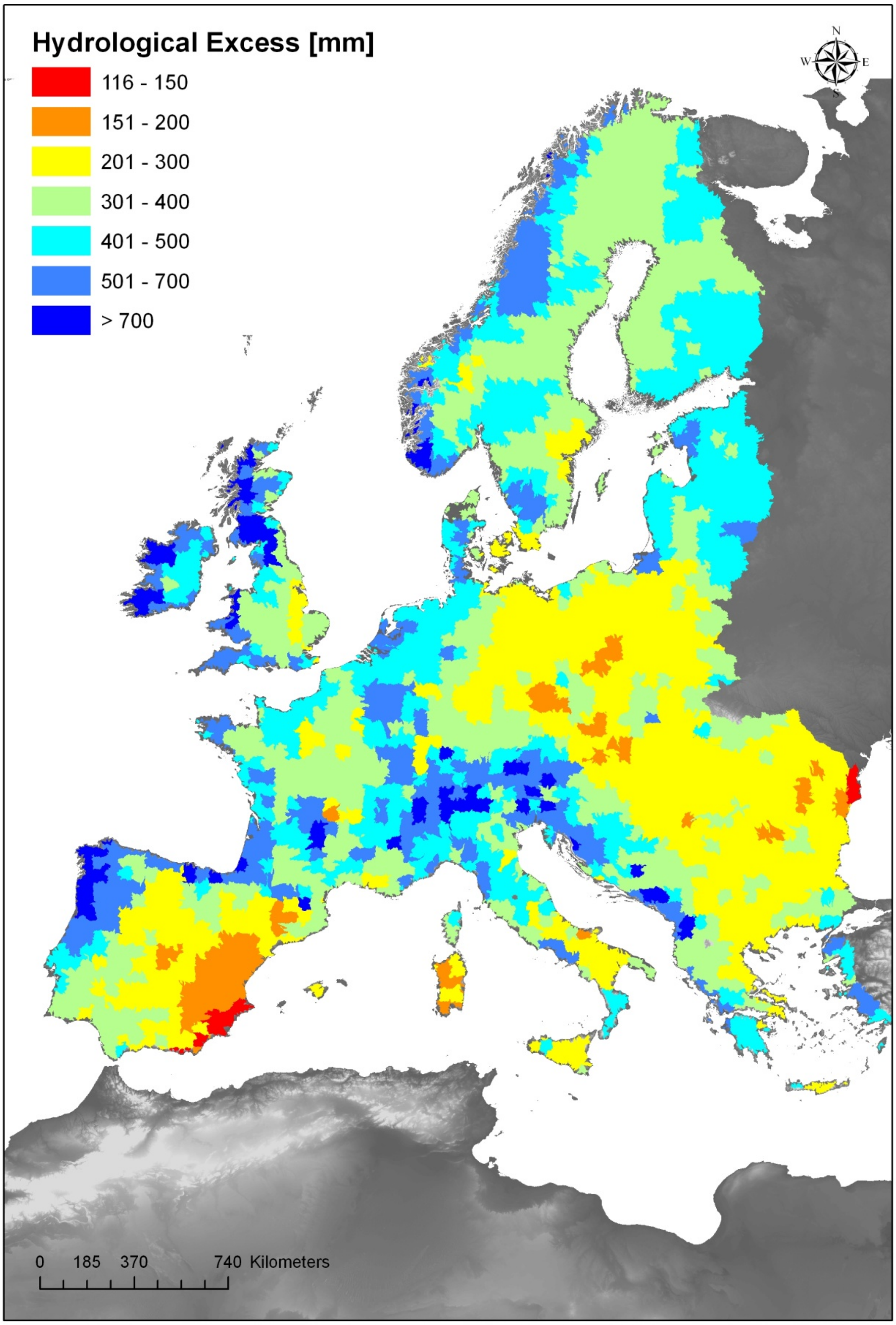

Figure 27: Hydrological Excess water (mm)

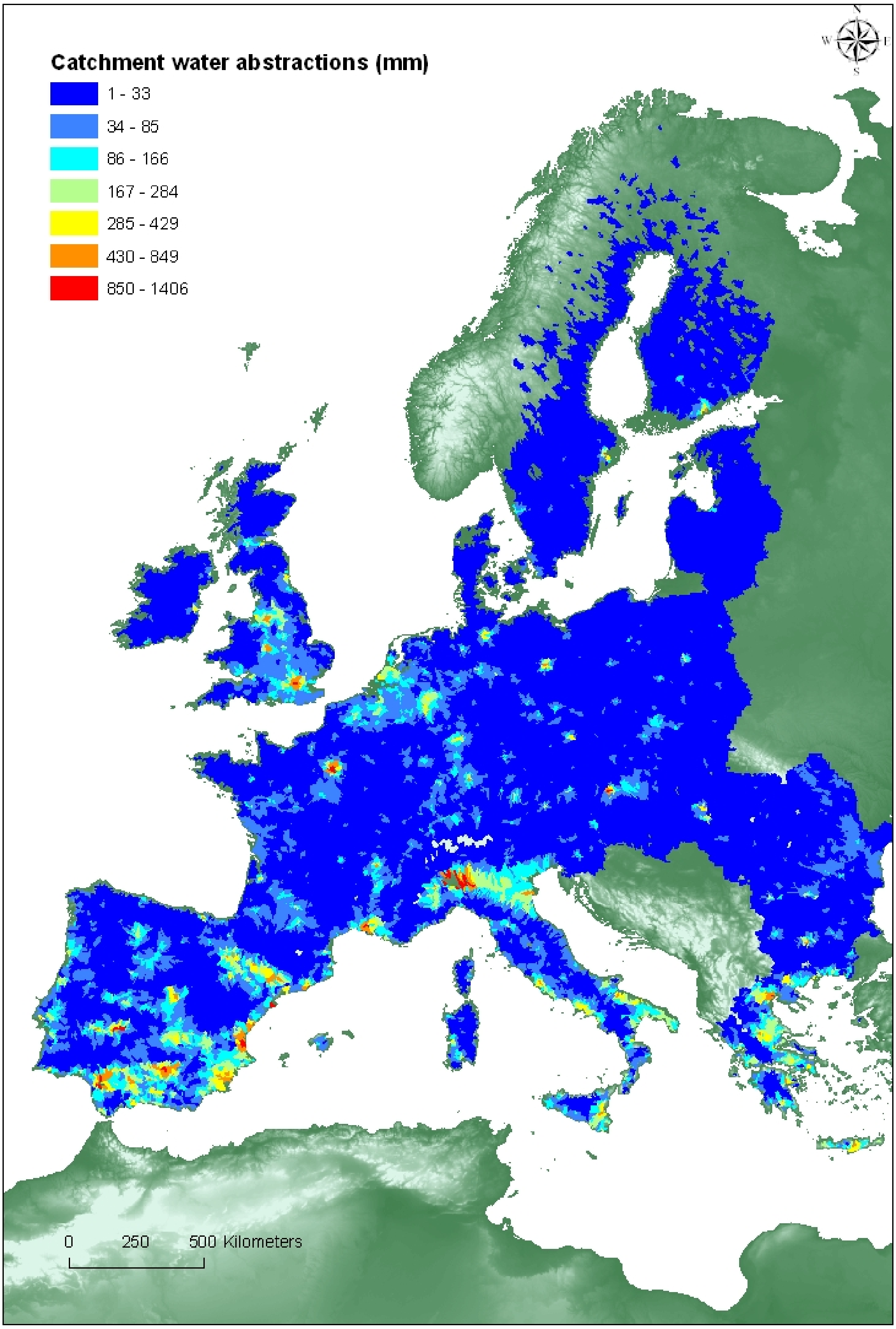

Figure 28: Total water abstractions (mm) (excluding cooling water)

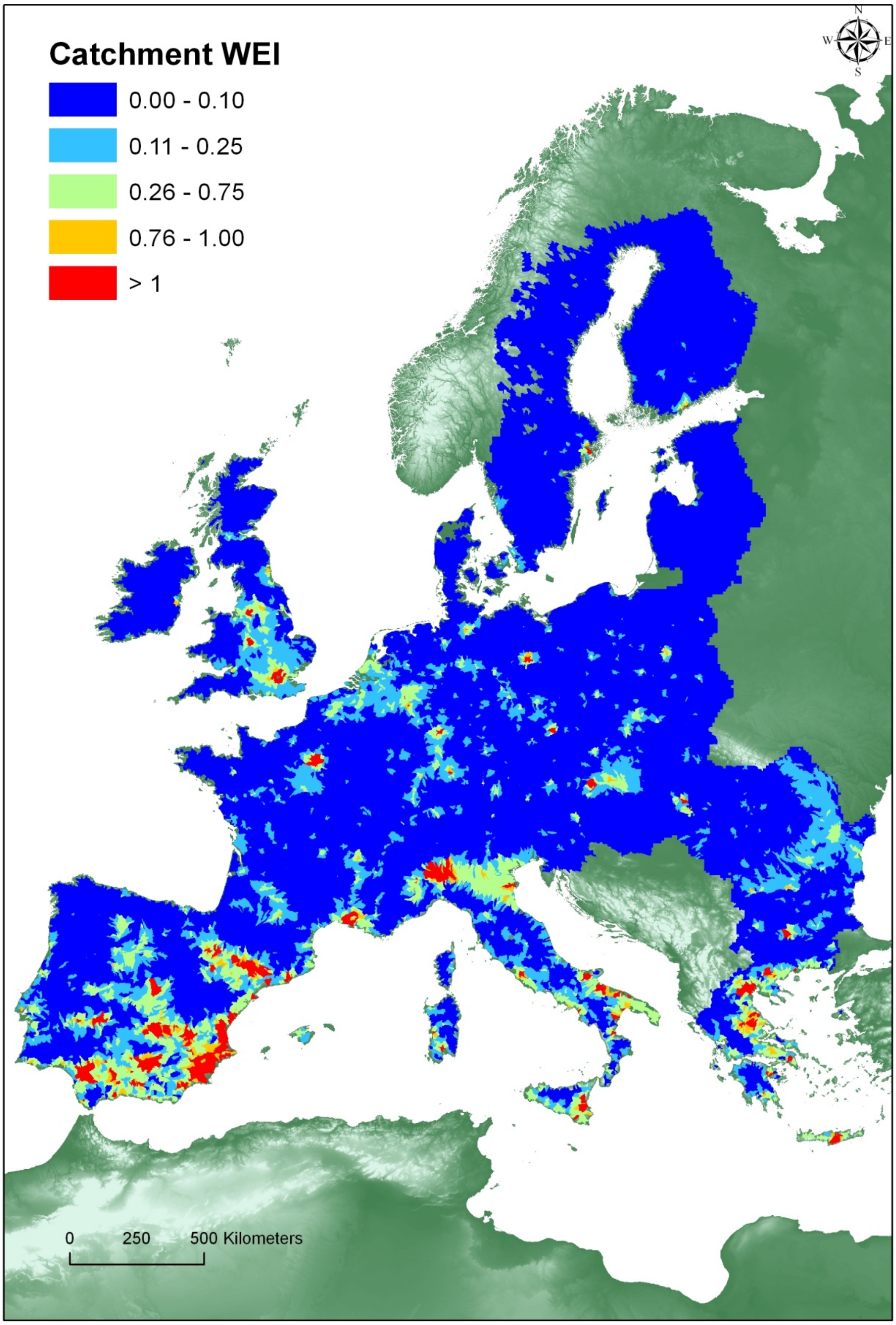

Figure 29: Catchment water exploitation index (abstractions excluding cooling abstractions)

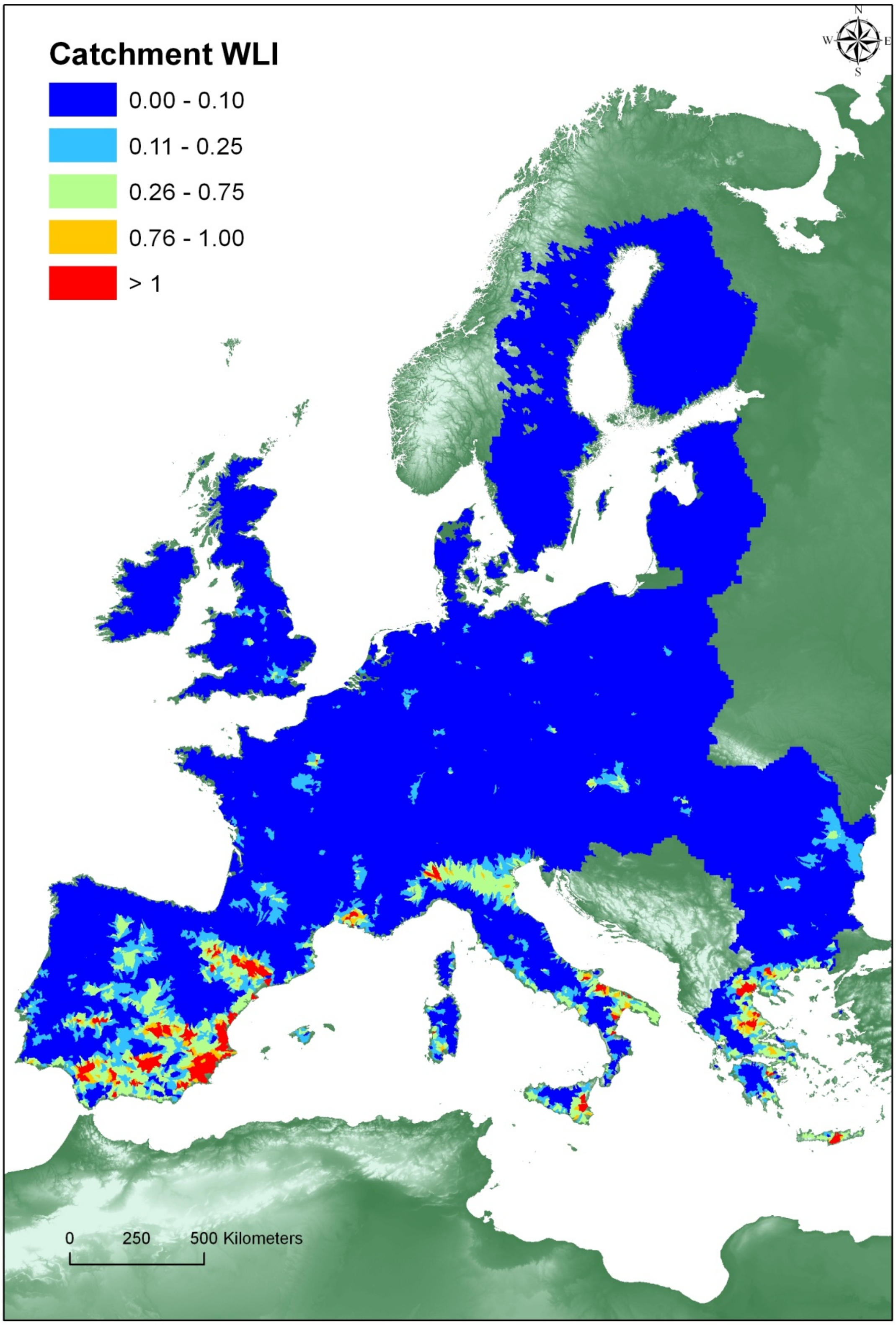

Figure 30: Catchment water loss index (WLI)

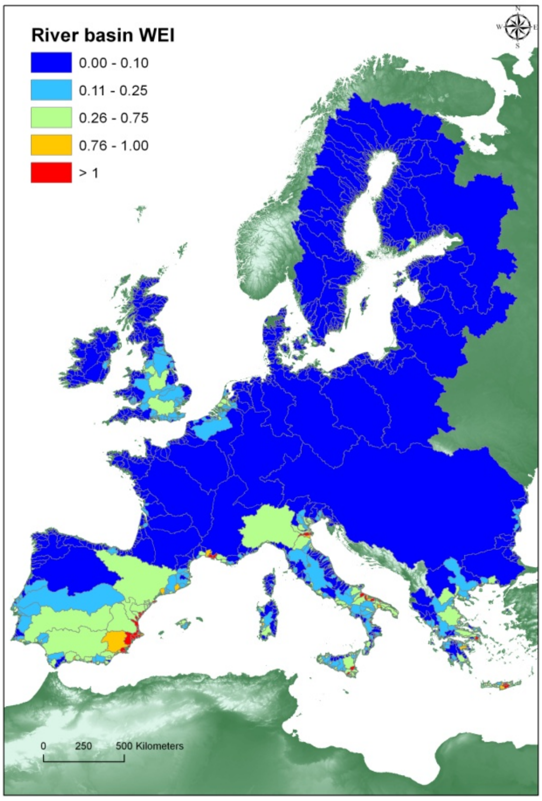

Figure 31: River basin water exploitation index WEI (abstractions excluding cooling abstractions)

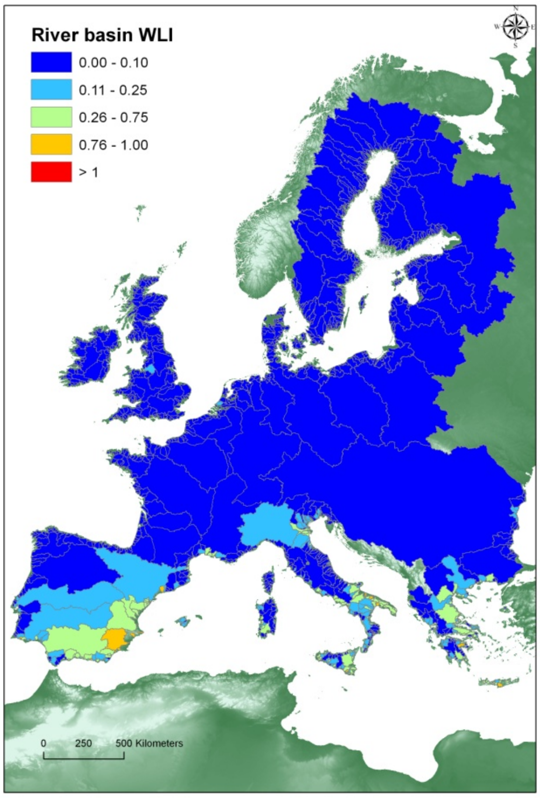

Figure 32: River basin water loss index (WLI)

4 Summary of main results and discussion

The Atlas presented in this report collects and presents water use data in a consistent way and compiles large-scale datasets at high spatial resolution. The assessment can provide background information on pressures on water quantity that is relevant for large scale distributed water resource modelling.

Main results

Obvious is the separation of Europe into regions where water use is dominated by public supply, households and industry (Central, Northern and Eastern Europe), and regions where water use is dominated by irrigation (Southern Europe).

The contrast between irrigation-dominated regions and other regions is also reflected in water returns and water losses, as irrigation serves to maintain crop evapotranspiration (implying a considerable water loss), while other uses (drinking, cleaning, manufacturing) return most of the water to the environment sooner or later and consumptive losses can be considered to be low.

Water use for public water supplies and industrial purposes mainly follow the population distribution. Analysis of abstraction sources shows that public water supplies use both, ground- and surface water resources, depending on availability and accessibility of water resources, with a higher share of groundwater sources in central Europe and higher surface water use in Southern and Northern Europe. Household abstractions have a strong preference for groundwater sources. This is logical, given that private abstractions typically require a certain water quality that can not be secured by surface waters and abstractions are made on site without transportation. Quantitatively, household abstractions play only a marginal role, as the majority of households are connected to public supply networks. Industrial water abstractions (provided that water is not used for food production), have a preference for surface waters, allowing short circuits of abstraction and returns. Agricultural abstractions exploit both surface and groundwater sources. There are, however, general regional differences at European scale, with groundwater dominated abstractions in Central Europe and surface water dominated abstractions in Southern Europe and Northern Europe. Preference of surface water sources (partially in combination with public supply) in Southern Europe is strongly related to the important role of irrigated agriculture, requiring centralised irrigation infrastructure, such as reservoirs, transportation infrastructure (channels and pipes) and water distribution network in irrigation districts. In the dominantly rain-fed regions, farmers meet irrigation requirements on an individual basis, abstracting water on-site from groundwater or using public supplies. In Northern Europe, there are only few exploitable groundwater resources, as geology is dominated by solid and fractured rocks (Baltic shield), again requiring exploitation of surface waters.

Cooling water abstractions can be by far the highest water abstraction sector according to the reported data. They are almost exclusively drawn from and returned to surface waters. The quantitative pressure exerted by abstractions for cooling purposes can be considered to be negligible. Therefore it is justified to treat them separately and not to include them in an assessment of pressures on water quantity. It must not be forgotten, however, that cooling water abstractions do have significant ecological impacts, for example changing the temperature regime of surface water bodies.

Explicitly splitting the water abstractions into returns and losses is important, as only the quantitative losses ‘remove’ water from the environment, while returns are available for other and subsequent uses. Nevertheless, abstractions and returns go along with an internal redistribution of water among different water bodies, having environmental impacts on its own. The calculation of returns was based on heuristic considerations due to the lack of precise data. Also the allocation of returns to water sources is indicative based on heuristic considerations. The spatial patterns of the loss-abstraction ratio clearly correspond to the distribution of irrigated areas, as evapotranspiration losses are in the order of abstractions while losses for other uses where estimated to be in the order of 20%. Consequently, the return-abstraction ratio provides the opposite patterns.

Tourism is an import pressure on water resources in many coastal regions. The approach converting nights spent by tourists into a population equivalent that can be combined with a tourist specific consumption is promising to indicate the share of tourism in water use. However, the spatial aggregation at NUTS3 level averages out the highly localized problems (concentrating along the coastlines). An assessment at communal level would be required to develop a meaningful indicator for tourism related water pressures.

The water exploitation index (WEI) reflects the pressure on water resources at a catchment and river basin level indicating how far water demands can be met by water available within the catchment or river basin. The WEI does not account for water returns and re-use of water. This is justified considering that all abstractions are a pressure exerted on the specific water body from which water is abstracted. In contrast, the water loss index as the ratio of water losses to available water (WLI) does account for water returns and re-use as it is based on the consumptive loss. The indices do not account for long-distance transport to meet water requirements. They describe how local resources (within the catchment or river basin) meet local water requirements. A high imbalance at catchment level can therefore level out at regional or river-basin level. In general, both indicators reflect the distribution of regions with strong impact of irrigated agriculture and/or agglomerations of population and industry in combination with natural water scarcity. Care has to be taken defining the threshold at which a catchment or river basin is set under pressure. Part of the available water must be left to secure functioning of the hydrological system and protecting dependent ecosystems (ecological flow). There are other issues like transport and power generation that require minimum flows in rivers. Sufficient groundwater recharge must be maintained to secure water supply also in dry periods and to prevent ground subsidence. A threshold can not be quantified straightforward, especially not at a European scale. It must be taken into account, however, that the threshold for the water loss index is in any case far below one, as an index of one implies that all water that is available during a year is lost by human consumption and crop evapotranspiration.

For the WEI a higher threshold may apply, but a value of one implies that all available water has been abstracted once. Given that returns are not directed to the same water bodies where the water was abstracted, this already implies a severe pressure.

Data issues and methodological limitations

Water abstraction and water use data reported by Member States contain considerable gaps and inconsistencies that have impact on the assessment requiring gap filling, substitution and adjustment. EUROSTAT has launched various activities improving and extending the data collection and reporting. National data sources could be used to fill gaps and potentially also to collect better regional information. However, an additional data collection initiative including all EU Member States and neighbouring countries was beyond the scope of this assessment.

In general, data on water abstractions from public suppliers, households and industry can be considered sufficiently reliable for application in this assessment, as they can generally based on data available from water suppliers. Reported agricultural and irrigation water abstractions are not available in many countries or uncertain, as they are often based on indirect methods rather than direct measurements and methods vary between countries (Wriedt et al., 2008, 2009b). In Mediterranean countries, reported irrigation abstractions are likely to underestimate true abstractions by far due to insufficient data collection and also due to a considerable role of illegal water abstractions (WWF, 2003; WWF/Adena, 2006). Also the model based assessment has limitations, as legal, economic, infrastructural and water availability limitations were not accounted for. However, it is independent of reported abstractions and reflects reported land use and climate data (Wriedt et al., 2008, 2009b).

The proxy data (population and GDP) reflect the focal points of human activities and are therefore suitable to provide a reasonable disaggregation for a European screening assessment. However, various issues can be addressed that can improve the disaggregation: Generally, it would be desirable to start with abstraction data at a regional level (NUTS2 or NUTS3). Regional data may already account for structural differences between regions that may be relevant but are not captured in such simple indicators such as population and GDP. Other proxies may be used or included. For example, in addition to population (per capita use), domestic water consumption also depends on household size and structure (EEA, 2009). This information can help in refining domestic water use and filling data gaps. GDP is a very coarse indicator of general economic activity. As such, it contains no information on the water demand of economic activities. Different economic sectors have different water demands, and depending on the type of economic activity, also the related losses may differ considerably. For a European scale screening this approach may be acceptable, but in the long term should be replaced by more specific information on the distribution of water consumptive industries. Settlement areas derived from a land use classification do not contain information on the density or type of settlement (rural-urban, city or suburb, industrial-housing). This results in considerable uncertainty at communal and local level, while the uncertainties level out at regional scale.

Two unsolved challenges remain for the assessment: The spatial disaggregation of water abstraction data strictly speaking reflects the distribution of water use rather than abstraction. Self-supply for households, industry and agriculture can be related to local abstractions. However, the water supply for cities and also for irrigated agriculture in water scarce regions can be linked to transportation distances ranging from local to regional level, including inter-basin transfers. A strategy of spatial allocation based on water availability and suitable allocation rules was proposed. Also the apportionment of water abstractions to ground- and surface water is not straightforward and relies on information on water availability, location and recharge of ground water resources, surface water runoff and a set of allocation rules. Potentially, additional information needs to be included and allocation rules may include an optimization process. These problems have to be left to future work, as the development and implementation of suitable algorithms could not be completed within the scope if this work.

Future perspectives

As the assessment was data-based, it can not project trends and future estimates. This is not necessary in the context of this study, focussing on the generation of reasonable background information. However, in the long run, a general water demand model will be useful to i) evaluate future changes and scenarios in relation to land use change, demography and climate change and to ii) provide water use data in a form that can be linked to or integrated in general water resource models.

Final Conclusion

The work presented in this report does not stand alone, but relates to other work, either providing input for this assessment or using the assessment results in more problem-oriented water balance analysis. It adds value to the national statistics providing spatially disaggregated information on the anthropogenic water cycle for a large geographical area, i.e. EU 27 and Switzerland, that can be used in large-scale assessment and modelling. Limitations of the assessment are given by i) the completeness of input data, ii) the spatial level of reporting input data (national data!) requiring the need for disaggregation based on more or less available indicators, and iii) the yet unsolved problem of allocating water abstractions in space and to ground- and surface water resources. Further comparison with data on water availability, such as precipitation, surface runoff, groundwater recharge, and evapotranspiration, is required to exploit the information collected in the atlas. The information shall be used in related applications focussing on the assessment of quantitative and qualitative pressures on water resources across Europe.

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Abstract
Water management relies not only on data on water availability, but also on data on water abstractions and demands. Hydrological modelling studies often neglect the impact of water abstractions and not all models are designed to handle abstractions. Given the various activities for European scale assessments made at the JRC and other institutions, it is desirable to have quantitative and spatially distributed background information on water abstractions, losses and returns to better judge the potential relevance of human abstractions on water quantity and to have reasonable estimates for modelling purposes.
The work presented in this report aims at evaluating the potential of readily available data from the OECD/EUROSTAT Joint Questionnaire on Inland Waters and relevant EUROSTAT data to support regionalized water balance assessments including human water abstraction and consumption. This report further document the methodological approaches to generate maps on water abstractions, losses and returns across the EU at 10x10km resolution.
Specific tasks documented in this report include:

- Modification and extension of available water abstraction data to generate consistent and complete datasets at national level.
- Spatial disaggregation of national data to regional and local (10x10km cell) level using proxy data and simulation results.
- Estimation of consumptive water losses and returns
- Comparison of water abstractions and losses to water availability and mapping of water resources pressure indicators.

The report is organized in three parts. Section 2 describes the data used in this assessment and the approaches to compile the specific data for the Atlas of water use and returns. Section 3 is an Atlas documenting and presenting the datasets. Section 4 is a general discussion of the approaches and results.

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