Hydrogeological processes and geological settings over Europe controlling dissolved geogenic and anthropogenic elements in groundwater of relevance to human health and the status of dependent ecosystem

Deliverable D.7-1

Comparison of internationally commonly applied index methodologies for assessing the vulnerability of the upper aquifer to pollution

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1 PROJEKT OVERVIEW

This deliverable is part of work package (WP) 7 in the overall project HOVER - **H**ydrogeological processes and Geological settings **over** Europe controlling dissolved geogenic and anthropogenic elements in groundwater of relevance to human health and the status of dependent ecosystems. WP7 deals with the harmonized vulnerability to pollution mapping of the upper aquifer, with 16 member states partners (one non-funded).

The HOVER project will address groundwater management issues related to drinking water, human and ecosystem health across Europe in relation to both geogenic elements and anthropogenic pollutants by data sharing, technical and scientific exchange between European Geological Survey Organizations (GSO).

The **WP7 Harmonized vulnerability to pollution mapping of the upper aquifer** will carry out:

1) Investigation, comparison and potential extension of methods for assessment of groundwater vulnerability to pollution in Europe,
2) Harmonization of data referring to pan European, national/cross-border and national scale,
3) Assessments of vulnerability of the upper aquifer to pollution using GIS,
4) Identifying specific areas of high aquifer vulnerability and
5) Deliver data for the GeoERA Information Platform (GIP).

The goal of WP7 is to prepare vulnerability maps at the Pan European (1:1.5 Mio), supra-regional (1:1.5 Mio), national/cross-border (1:250k) and optionally national scale, each referring to the potential vulnerability to pollution of the uppermost aquifer. Parametric system methods for assessing vulnerability will be evaluated and applied according to the aforementioned criteria for establishing these maps.

Groundwater vulnerability maps are widely used, as it is an important tool for groundwater management and protection at drinking water wells/springs. Various methods were developed depending on data availability, scale mapping, hydrogeological characteristics (specific method for karstic areas for example), available technology and scientific traditions.

The main outcome of WP7 are maps that can be used in groundwater management, subsurface spatial planning and environmental decision-making processes, at pan-EU and regional, respectively national/cross-border scale. The project will result in methodological harmonization and the establishment of multi-scale data interoperability. More in detail, the project will contribute to national and EU general activities in fulfilling the objectives of the WFD, and to national and regional authorities in environmental assessment and strategic and regional planning. Moreover, it will support European-level strategic assessment, planning and forecasts and provide coherent, pan-European dataset for testing the impact of policy changes (e.g. intensified agriculture or reduced nutrient application) on groundwater.

The present report (deliverable D.7-1) portrays existing methods assessing the groundwater vulnerability to pollution and proposes a methodology to enable vulnerability maps at the pan-European and regional transboundary scale.

2 DEFINTIONS AND METHOD OVERVIEW

2.1 Definition groundwater vulnerability to pollution

In the literature, numerous definitions of groundwater vulnerability to pollution can be found. In this project, we strictly refer to the intrinsic vulnerability, as defined in Vrba & Zaporozec (1994): „*Vulnerability is an intrinsic property of a groundwater system that depends on the sensitivity of that system to human and/or natural impact*". A similar, but more explicit definition was provided by the COST Action 620 program: "*The intrinsic vulnerability of groundwater to contaminants takes into account the geological, hydrological and hydrogeological characteristics of an area, but is independent of the nature of the contaminants and the contamination scenario*" (Zwahlen, 2003). Hence mapping the degree of groundwater vulnerability to contaminants, as a function of hydro(geo)logical conditions, shows that effective protection provided by the natural environment may vary drastically from one place to another (Gogu & Dassargues, 2000).

2.2 Brief overview of methods for evaluating groundwater vulnerability to pollution

Gogu and Dassargues (2000) categorized the available methods for evaluating groundwater vulnerability to pollution into hydrogeological complex and settings methods and parametric system methods. To the latter belong matrix systems, rating systems and point count system models. Magiera (2000) additionally proposed the groups of mathematical models and statistical approaches. However, these two sets of models are not further taken into account because of their complexity and data expensiveness and hence non-applicability at the pan-EU and transboundary regional scale as required in this project.

Pioneering works in the field of groundwater vulnerability assessments to pollution are the studies published by Margat (1968) and Albinet & Margat (1970). They re-attributed lithological maps in combination with maps on groundwater recharge and overlying strata to obtain groundwater vulnerability maps. With this hydrogeological system analysis relationships evaluated in a more closely studied area or system A was transferred to a system B, by means of conclusion by analogy. As a result, only qualitative statements can be made. This methodology was common in the pre-GIS era and only a limited number of factors influencing groundwater vulnerability could be taken into consideration. Hence this method was mostly used up until the end of the 1970's (Magiera, 2000).

The following description of parametric systems models (i.e., matrix systems, rating systems and point count systems) is retrieved from Gogu & Dassargues (2000):

Matrix Systems (MS) methods are based on a restricted number of carefully chosen parameters. To obtain a quantified degree of vulnerability, these parameters are combined following a number of strategies developed by different research groups. These research applications are site-specific methods developed for local case studies, such *as* the method selected for the Flemish Region of Belgium (Goossens & Van Damme, 1987) and the system used by Severn-Trent Water Authority in some areas of Central England (Carter et al., 1987).

Rating Systems (RS) methods provide a fixed range of values for any parameter considered to be necessary and adequate to assess the vulnerability. This range is properly and subjectively, divided according to the variation interval of each parameter. The sum of rating points gives the required evaluation for any point or area. The final numerical score is divided into intervals expressing a relative vulnerability degree. The rating systems are based upon the assumption of a generic contaminant. Examples are the GOD system (Foster, 1987), the AVI Method (Van Stempvoort et al., 1993), and the ISIS method (Civita & De Regibus, 1995).

Point Count System Models or Parameter Weighting and Rating Methods (PCSM) are also a rating parameters system. Additionally, a multiplier identified as a weight is assigned to each parameter to correctly reflect the relationship between the parameters. Rating parameters for each interval are multiplied accordingly with the weight factor and the results are added to obtain the final score. This score provides a relative measure of vulnerability degree of one area compared to other areas and the higher the score, the greater the sensitivity of the area to groundwater pollution. One of the most difficult aspects of these methods with chosen weighting factors and rating parameters remains distinguishing different classes of vulnerability (high, moderate, low etc.), on basis of the final numerical score. Examples are the DRASTIC method developed by U.S. EPA in

1985 (Aller et al., 1987), SINTACS method (Civita 1994), and the EPIK method used in karst groundwater protection strategy developed by Doerfliger et al. (1999).

Within this project, some 50 methods were identified and are listed below, including the parameters required for the respective vulnerability assessment (Table 1).

Table 1: Overview of identified methods for groundwater vulnerability to pollution assessment (in chronological order)

no.	source / method	soil parameters						parameters of unsaturated zone/cover				aquifer parameters							misc parameters		additional data requirements
		humus/ organic carbon content	soil type	effective field capacity	texture	thickness	hyd. cond.	lithology	thickness	hyd. cond.	residence time	depth to water table	recharge	hyd. cond.	aquifer type	aquifer thickness	surface water/ groundwater connectivity/ interaction	lithology	land use	topo-graphy	
1	Albinet & Margat (1970)							x	x			x			x		x	x			
2	Tkachenko & Rudenko (1973)							x	x	x		x	x								
3	Tkachenko (1978)		x		x	x		x	x	x	x								x		
4	Haertlé & Josopait (1982)							x	x			x									
5	Ministry of Environment Ontario (1982)*							x													
6	Lysianyi (1985)							x	x			x		x	x	x		x	x	x	
7	McCormack, Quebec (1985)*							x												x	potential pumping rates, if available
8	TGL 34334 (1986)								x			x			x			x			
9	Carter et al. (1987)	x			x		x	x	x												
10	Aller et al. (1987) - DRASTIC		x					x				x	x	x	x					x	
11	Foster (1987) - GOD							x	x			x			x			x			
12	Voigt (1987)							x	x			x				x		x			location of faults, if available
13	Gryshchenko (1988)		x			x	x	x	x	x		x	x	x	x	x		x			
14	McRae, Canada (1989)				x			x				x								x	
15	Turner, Manitoba&Saskatchewan (1989)*		x					x											x		
16	Fobe & Goosens (1990) - Flemish method							x	x			x						x			
17	MNR, Manitoba (1990)*							x	x												
18	Roeper (1990)						x	x	x												
19	Barybina (1991)		x		x	x	x	x	x	x											
20	Civita (1991) - SINTACS**		x		x			x				x	x	x	x					x	
21	Carpenter (1992) - SEEPAGE	x			x	x	x	x				x			x			x		x	pH soil
22	Van Stempvoort et al. (1993) - AVI					x	x		x	x											
23	Ray & O'Dell (1993) - DIVERSITY									x			x				x			x	
24	Sokol et al. (1993)	x	x	x									x						x		vegetation periods
25	Seelig (1994)	x					x			x		x									soil adsorption coefficient and pesticide half-life
26	Zelykman E.M. (1994)	x	x		x	x		x	x												pH soil
27	Bencini et al. (1995)							x	x	x											
28	Hölting et al. (1995) - GLA			x				x	x			x	x		x						
29	Civita & De Regibus (1995) - ISIS		x			x		x	x			x	x		x	x			x	x	
30	Meinardi et al. (1995)	x	x						x		x		x					x	x		
31	Lesnychyi (1996)							x	x	x	x	x	x	x	x	x		x	x		
32	Scharp et al. (1997)											x	x	x		x					groundwater quality and usage
33	Maxe & Johansson (1998)										x	x									
34a	Daly & Warren (1998)		x		x	x	x	x	x	x	x	x	x	x	x		x	x			type of polluting source (diffuse, point source)
34b	DELG/EPA/GSI (1999)		x		x	x	x	x	x	x	x	x	x	x	x		x	x			
34c	Fitzsimons, Daly & Deakin (draft 2003)		x		x	x	x	x	x	x	x	x	x	x	x		x	x			
35	Madl-Szonyi & Füle (1998)		x			x		x	x			x	x	x			x			x	hydraulic gradient and tectonic elements (if appl.)
36	Malik et al. (1998)					x								x		x		x		x	geomorphology and velocities
37	Palmer & Lewis (1998)	x			x			x	x					x				x			
38	Rine et al. (1998)	x					x	x	x												
39	Doerfliger et al. (1999) - EPIK					x	x		x	x			x				x		x	x	geomorphology for epikarst identification (if appl.)
40	Goldscheider et al. (2000) - PI			x			x	x	x	x			x		x		x			x	
41	Keimel & Kralik (2001)	x	x	x		x	x	x			x	x	x		x			x		x	variability of slope inclination
42	Heinkele et al. (2002)		x	x				x	x		x	x	x	x				x			
43	Kanopienė, R. (2004)							x	x	x	x	x									
44	Albert (2005)							x	x				x	x	x	x		x	x		
45	Chachadi & Lobo-Ferreira (2005) - GALDIT											x		x	x	x					distance from shore, ratio Cl-/(HCO3-1 + CO32)
46	Witczak (2005)*** - PGI method		x		x	x		x	x		x	x							x	x	
47	Cichocki & Zojer (2006)		x			x		x	x				x		x	x		x		x	karstificat., inf. type, exf. components (stor. cap., res. time, hydrogr.)
48	Mardhel & Gravier (2006) - BRGM method								x											x	geomorphological indicator
49	Vias et al. (2006) - COP				x	x		x	x				x		x		x				
50	Ravbar & Goldscheider (2007)		x		x	x		x	x		x		x	x						x	geomorphology
51	Shestopalov (2007)		x					x	x	x	x	x			x						
52	Kavouri et al. (2011) - PaPRIKa				x	x		x	x	x								x		x	epikarst characterization
53	Koshliakov (2014)											x	x	x	x	x	x	x	x		
54	Wirsing et al. (2015)	x	x	x				x	x	x		x	x		x						effective rooting zone, pH soil
55	Hansen et al. (2016)							x	x		x	x	x	x	x	x	x	x		x	redox conditions in the subsurface

* information retrieved from [22], ** information retrieved from Civita & De Maio (2004), *** information retrieved from Herbich et al. (2015)

2.3 Special case karst aquifers

Because of their particular characteristics, such as thin soils, point recharge in dolines, shafts, and swallow holes, karst aquifers are particularly vulnerable to pollution and will receive particular attention in this project. The COST Action 620 project "Vulnerability and risk mapping for the protection of karst aquifers" attempted to develop a method that allows an integrated intrinsic-specific vulnerability assessment ("European Approach"), consisting of assessing i) the regional resource vulnerability and ii) the source vulnerability. While i) refers to the assessment of the overlying layers down to the groundwater surface (intrinsic vulnerability), ii) refers to the assessment of the well/spring and the karst network and hence the specific vulnerability (Zwahlen, 2003).

Based on this European Approach, the COP method was established, a parametric system model applicable to different climatic conditions and different types of carbonate aquifers, i.e., diffuse and conduit flow systems (Vias et al., 2006). The intrinsic vulnerability is assessed using a quantification and category system for the parameters concentration of flow (diffuse or concentrated, C factor), overlying layers (soils and unsaturated zone, O factor) and precipitation (P factor). Other methods dedicated to carbonate aquifers are, among others, EPIK (Doerfliger et al., 1999), PI (Goldscheider et al., 2000) and PaPRIKa (Kavouri et al., 2011).

2.4 Overview of vulnerability assessment methods currently applied by WP partners

A brief summary of the groundwater vulnerability to pollution methods applied by the individual WP partners in their respective countries is provided below.

Austria:
National vulnerability assessments have focused on karstic carbonate aquifers in the past. Those contribute to about 50 % of the total drinking water supply in Austria. Several well-known methods like DRASTIC, SINTACS, EPIK or GLA (Hölting et al., 1995) have been considered, but new methods were also developed for Austrian karstic settings. Especially the methods „Time-Input Method" by KEIMEL & KRALIK (2001) and „VURAAS"

(Vulnerabilitäts- und Risikoanalyse in Alpinen Aquifer-Systemen) by CICHOCKI & ZOJER (2006) have to be mentioned. Those were applied at a test site level (local karst massifs), but not tested at a regional scale. Less focus was given to vulnerability assessments of pore aquifers in unconsolidated sediments although modelling concepts like SIMWASER (numeric model of moisture balance by STENITZER, 1988) or STOTRASIM (model of nitrogen dynamics by FEICHTINGER, 1998) have been implemented. Therefore, we would like to apply DRASTIC in a pore aquifer setting.

Brandenburg:
In the federal state of Brandenburg, both qualitative methods (e.g. point count methods after Voigt 1987 and Hölting et al. 1995) and quantitative methods (e.g. index methods after Heinkele et al. 2002) are used to assess vulnerability to pollution in unconsolidated rock aquifers. The three methods will be compared as part of a joint project with the BGR in a test area in Brandenburg and examined with regard to their standardization.

Catalonia:
A shallow aquifer pollution potential index assessment program was conducted at the scale of 1:100 000, applying DRASTIC. However, especially for karst aquifers, the performance of DRASTIC was evaluated poor. At present, suitable methods for the establishment of pollution potential indices are tested in karstic aquifers. Furthermore, it was recognized that there is need for revision and re-calibration of the originally proposed DRASTIC parameter classifications for specific hydrogeological settings. The index-based pollution potential assessments are subjectively evaluated by expert knowledge in collaboration with Catalan water board authorities.

Denmark:
A national groundwater mapping programme has been carried out since 1998 to ensure optimal protection of present and future drinking water resources, and involves approximately the 40 % of the total Danish land area that is classified as particularly valuable for groundwater abstraction. The groundwater mapping has been directly paid by the consumers via an additional 0.09 euros per cubic metre of water. Local groundwater protection plans are carried out in nitrate action zones in order to protect drinking water resources from nitrate pollution. The SCANVA concept is used to assess

the nitrate vulnerability of the aquifers (Hansen et al., 2016). It consists of interpretations of very detailed site-specific hydrogeological measurements based on 3D geophysical investigations (Sky-TEM), boreholes, geological and groundwater modelling that integrates groundwater redox geochemistry. SCANVA is a qualitative dynamic concept adjusted to the specific study area, depending on the hydrogeological and geochemical conditions. SCANVA is directly adaptable to hydrogeological conditions with intensive N loss from agriculture, groundwater-based drinking water supply, nitrate reduction in the ground and glacially dominated landscapes and deposits. Based on this concept, approximately 16 % of the Danish area has been classified as nitrate-vulnerable groundwater abstraction areas in 2017.

Finland:

Current work is focused on groundwater vulnerability to pollution assessments for the ice-marginal and glaciofluviatile aquifers. A case study here is the Hanko shallow aquifer. For this aquifer, speculative index methods to characterize the pollution potential (DRASTIC, SINTACS, AVI and GALDIT) were applied at a certain scale in coastal areas. At present, parameters and their classifications as specified in DRASTIC are adapted and re-calibrated in order to better fit the Finland geology and a modified DRASTIC method is being tested.

France:

The analysis of groundwater vulnerability derives from a so-called multi-criteria analysis. This is a combination of the thickness of the ZNS (unsaturated zone) average per functional unit / or per commune and the IDPR (Development and Persistence of Networks) average per functional unit / or per common (Mardhel & Gravier, 2006). The formula for calculating intrinsic groundwater vulnerability is:

$$\text{Vulnerability} = (\text{IDPR} * \text{Weight [IDPR]}) + (\text{ZNS Weight} * [\text{ZNS}]) *$$

The general principle of the IDPR methodology is a comparison between the existing hydrological network for a given area and a theoretical one, which is being conceptualised on the basis of a number of factors. The theoretical hydrological network is established through the modelling of the presence of talwegs (this is a line drawn to join the lowest points along the entire length of a stream bed or valley in its downward slope, defining its deepest channel) in the landscape from data originating from a digital terrain model (i.e. altitudes). The IDPR index reflects the natural tendency of a given area to let water infiltrate and percolate to groundwater (tendency for infiltration) or to transfer water to an adjacent surface water body (tendency for surface or subsurface runoff).

Germany:

The groundwater vulnerability evaluation is based on a parametric system model assessing the soil and unsaturated zone, hence defining the effectiveness of the protective cover. Parameters required for the assessment include field capacity of the soil, the lithology of the unsaturated zone (unconsolidated or consolidated rock), groundwater recharge, thickness of the cover layers and additionally accounts for perched and artesian aquifers. The parameters are summed, with groundwater recharge serving as weighting factor. The calculated index values relate to transit time of water through the overlying layers (Hölting et al., 1995).

Hungary:

In Hungary the legal base of vulnerability studies concerning groundwater is the Government decree 219/2004 about the protection of subsurface water, which aims to ensure and maintain the good status of subsurface water and the progressive reduction and prevention of pollution and sustainable water use (Albert, 2005). To fulfil these requirements, three vulnerability categories were defined: highly vulnerable, vulnerable and less susceptible areas. To determine areas of the above mentioned categories a GIS based approach was applied considering the spatial distribution of the following parameters:

Highly sensitive areas are the i. declared protection zones of drinking, mineral and medicinal water; ii. karstic areas, where the sediments covering the karst is less than 10 meters thick; iii. 250 meters wide zone around government owned ponds and lakes; and iv. Ramsari, and water habitat areas of Natura 2000 regions.

Sensitive areas are the i. regions, where the recharge from meteoric source is more than 20 mm/year; ii. covered karstic areas, where cover sediments thickness is between 10 to 100 meters; iii. areas where the depth of the main porous aquifer is less than 100 meters; iv. regions from the 250 to 100 meters wide zone around government owned ponds and lakes; v. protected areas, which were not mentioned among the highly sensitive regions. Less sensitive areas considering groundwater are those that are not mentioned above.

The following maps are considered as base maps of groundwater vulnerability to pollution methodology: geology of Hungary for the uppermost 10 meters, depth of the main aquifer surface, protection zone of water supplies, maps of naturally protected areas like national parks and national protected areas, biosphere reserves, national ecological network, Natura 2000 and RAMSARI. The scale of the maps is 1:100 000.

To determine vulnerability, generally DRASTIC based approach has been applied by the different research centres (Mádl-Szőnyi & Füle, 1998).

Ireland:

National groundwater vulnerability maps are based on depth to bedrock, cover layer type and permeability, karst features and are available at the 1:50 000 scale. These maps presently cover all of the Irish territory, with karst estimated as underlying 40-50% of the Republic. The assessment does not consider attenuation properties of the unsaturated zone and assumes that the pollutants are released approximately 1 to 2 metres below the surface. Combined with the type of recharge (point or diffuse) in karstified areas the spatial groundwater vulnerability assessment allows for the delineation of GW protection zones.

Lithuania:

The shallow groundwater vulnerability map of Lithuania at a scale of 1:200 000 was compiled in 2004 (Kanopienė, 2004). The groundwater vulnerability has been evaluated as a permanent property of the geological environment. It depends on the velocity of vertical migration of moisture in the unsaturated zone. The map was compiled for the worst possible conditions – where the depth of the shallow groundwater level is minimal and possible pollutants are conservative. Parameters describing these conditions – minimal predictable depth of shallow groundwater and generalized moisture migration velocity – were calculated at each observation point (dug well or shallow well). Vulnerability of shallow groundwater is characterized by the time of moisture migration to the groundwater level. The shorter is the time the higher is the vulnerability.

The boundary of the North Lithuanian karst region was defined using the data about geological structure and thickness of overlying cover and occurrence of sinkholes. The map of the land groups (4 groups in total) of different ecologic vulnerability was compiled based on quantity of sinkholes over an area of 100 hectares.

Lower Saxony.

The groundwater vulnerability map at the scale of 1:200.000 was published in 1982 (Haertlé & Josopait) and since then has not been updated. Cover layers were characterized petrographically as point data using borehole data. Depth to groundwater was estimated using groundwater contour maps. The final summarized vulnerability was assigned to three classes with the help of geological maps. For areas of hard rock, vulnerability was estimated on the base of conductivity of the near-surface rocks.

Poland:

Groundwater vulnerability assessments are based on the Witczak method (2005) (mean residence time). According to this method, the Groundwater Vulnerability Map for Poland 1:500,000 scale was created. Witczak's method was adopted to maps in 1:50,000 scale by PIG-PIB. Currently, hydrogeological maps at the scale of 1:50 000 provide the basis for groundwater vulnerability assessments. At present, the assessment covers distinct parts of Poland.

Romania:

Currently, no groundwater vulnerability to pollution map at the national 1:200 000 scale is available. Some methods for the vulnerability assessment are adopted on a local scale.

Slovenia:

Several groundwater vulnerability to pollution maps for specific aquifers at scale 1:25.000 and also for entire Slovenian territory at scale 1:1.000.000 on a grid of 1 km x 1 km have been prepared. Vulnerability maps were performed based on the SINTACS approach, while for Karst aquifers a Slovenian approach was used. However, these maps are 10-15 years old and are not updated/evaluated anymore.

Spain:

A modified/simplified DRASTIC approach has been applied to the detrital groundwater bodies of the inter-communities' basins at a national scale. Some of the DRASTIC's parameters/variables are not easily obtained to apply the method at a national scale. On the other hand, some of these parameters/variables are correlated, and therefore, introduce some redundant information. For these reasons a modified/reduced DRASTIC was proposed and applied by the IGME in cooperation with the University of Malaga and the Spanish General Water Directorate. It intends to reduce the number of parameter/variables considered in the assessment. The information was obtained from maps at the scale 1:100.000. The COP method was applied to the karstic aquifers at a national scale in 2009. IGME has also experience with a GALDIT application for the assessment of vulnerability to sea water intrusion in coastal aquifers.

Ukraine:

Groundwater vulnerability assessments are conducted in two stages: qualitative and quantitative (Gryshchenko et al., 1988). The vulnerability definition is commonly used as reverse function to the term “a level of aquifer protection”. Thus, the procedure of vulnerability estimation in Ukraine (qualitative assessment) consists in overlapping of estimated and scored factors (factor weighted analysis methodology). These factors are naturally depth to groundwater table, aquitard thickness and lithological composition of the unsaturated zone. A national map of aquifer natural protection is presented at the scale of 1:500 000. The quantitative assessment includes geochemical data and information on the composition of the critical zone for pollution characterization/monitoring in critical areas identified by the qualitative assessment

3 SELECTED METHOD FOR APPLICATION AT PAN-EU AND TRANSBOUNDARY REGIONAL SCALE

Given the application of DRASTIC by a number of WP partners, at the WP7 kickoff meeting on October 17 and 18 2018, the DRASTIC method was selected for assessing groundwater vulnerability to pollution in non-karst areas at the pan-EU and transboundary regional scale in selected pilot areas. The DRASTIC method, published by Aller et al. (1985) and based on Dee et al. (1973), is an index based methodology used to determine the potential of groundwater contamination by surface pollutants based on seven natural characteristics:

D = depth to groundwater
R = net recharge
A = aquifer media
S = soil media
T = topography
I = impact of the vadose zone
C = hydraulic conductivity of the aquifer

The parameters are rated and weighted due to their relative importance to contamination. Depending on the respective influence on the protection potential, each parameter receives a weighting of 1-5. The most important factors are assigned a weighting of 5, while the less significant ones are assigned a weighting of 1. The rating ranges are defined from 1 to 10 (see Annex 1 for details). The weights are multiplied with each parameter rating for each interval and then the products are summed to calculate the DRASTIC index:

$$Drastic\ Index = DrD_w + RrRw + ArA_w + SrS_w + TrTw + IrIw + C_rCw \qquad (1)$$

r = rating
w = weighting

This index indicates the relative degree of groundwater vulnerability of an area. The higher the pollution potential, the higher the sensitivity to contamination or the lower the protective function of the groundwater cover.

However, based on numerous experiences made by the WP partners testing DRASTIC in karst environments, DRASTIC may not the most appropriate method to be applied. It hence was decided to establish a sub-working group to identify the most reasonable methodology to be applied for the vulnerability assessment. For coastal areas, a specific method as for instance GALDIT (Chachardi & Lobo-Ferreira, 2005) will be taken into account.

4 PRELIMINARY APPLICATION OF DRASTIC AT PAN-EU SCALE

In a preliminary assessment, DRASTIC was applied with a partially pan-EU dataset readily available. For the assessment, the following data were used (using the weights (w) as in the legend, Figure 1):

A) “Depth to water” derived from contour line information provided by “European Groundwater Resources Map 1 : 500k” (https://esdac.jrc.ec.europa.eu/content/groundwater-resources-maps-europe) and selected IHME1500 map sheets,

B) “Recharge” calculated with Worldclim 1.0 (http://www.worldclim.org/version1) data for the climatologic normal period 1960 – 1991 on an average monthly basis using a simplified WaterGap approach,

C) “Aquifer Media” classified from IHME1500 information,

D) “Soil Media” derived from European Soil Database derived raster product (https://esdac.jrc.ec.europa.eu/content/european-soil-database-derived-data),

E) “Topography” from GTOPO30 data (http://www.temis.nl/data/gtopo30.html),

F) “Impact of vadose zone” derived from “European Soil Regions Map 1 : 5Mil” soil parent material information (https://www.bgr.bund.de/EN/Themen/Boden/Projekte/Informationsgrundlagen_abgeschlossen/EUSR5000/EUSR5000_en.html) ,

G) “Hydraulic Conductivity” derived from IHME1500 information

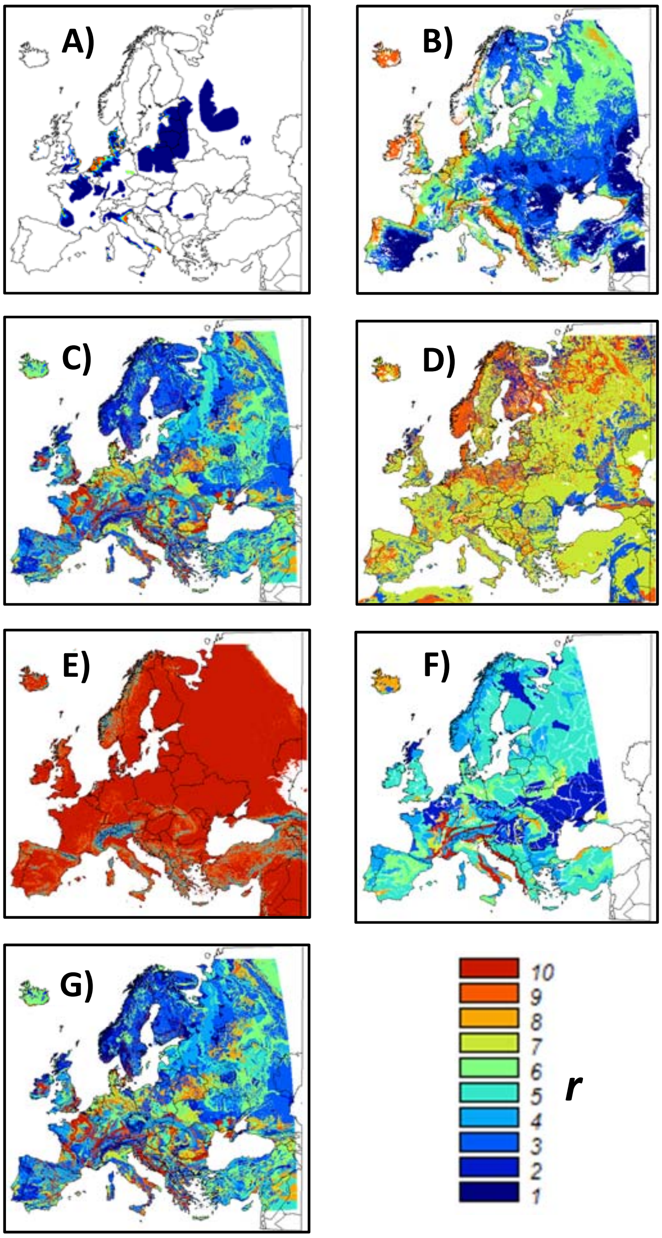

Figure 1: Data used for preliminary DRASTIC application and respective ratings (r)

Limiting parameter in this preliminary study is the depth to water table, as this parameter is not yet available for all the European continent. Results are depicted in Figure 2.

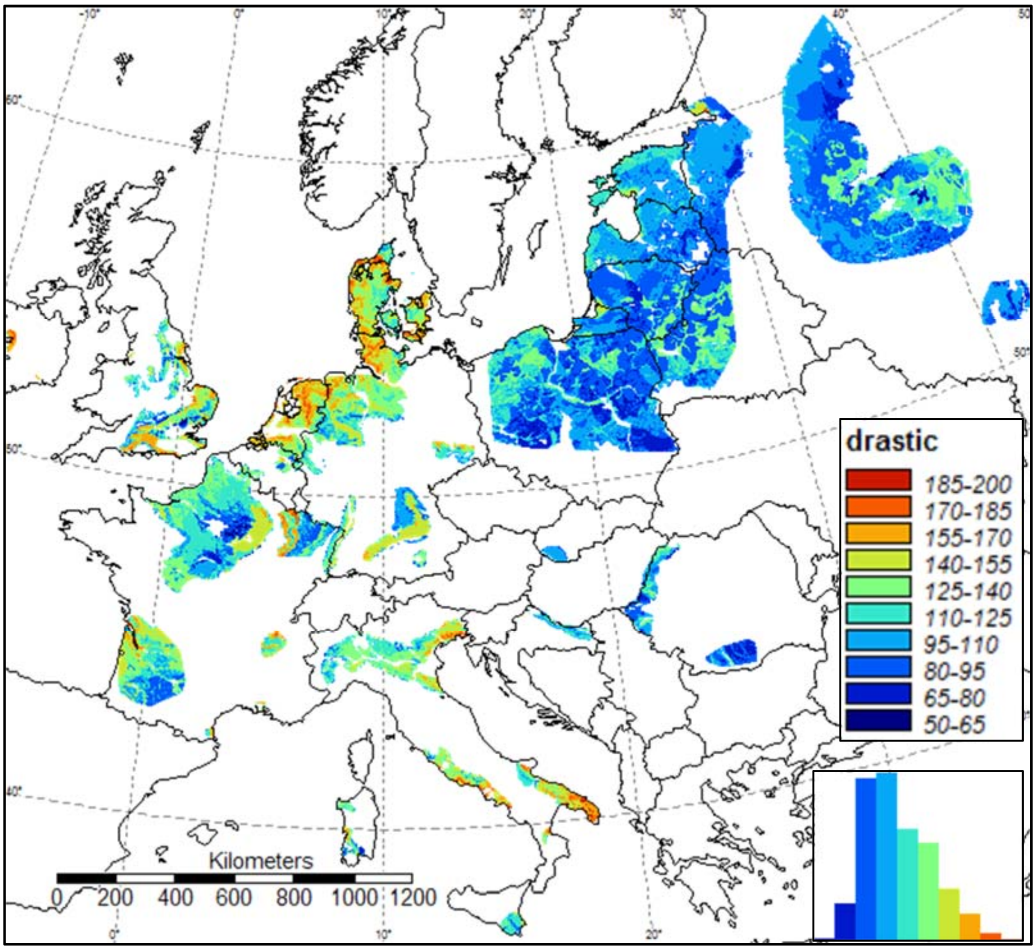

Figure 2: Preliminary DRASTIC application with readily available data at pan-EU scale

5 OUTLOOK

This report summarizes available methodologies for the assessment of the intrinsic aquifer vulnerability to pollution and outlines the application of the selected DRASTIC model at the pan-EU and transboundary regional scale.

The preliminary, so far only conceptual pan-EU assessment needs to be calibrated in such that the categorical pan-European data used (i.e., information on aquifer properties, soil material and impact of the vadose zone) should be aggregated and weighted to grossly resemble DRASTIC evaluations in the pilot areas. In this respect, it may be necessary to subdivide the continental European terrain into distinct model regions where different aggregations and weightings of the pan-European data used can be applied for DRASTIC. A crucial question here is whether karstic aquifers should be excluded from a pan-European DRASTIC evaluation and assessed using a different methodology. When successfully calibrated, the pan European DRASTIC assessment can be validated in terms of data basis and soundness with respective national or regional level vulnerability assessments, through quantitative map comparisons, bearing in mind the aquifer conceptualization in the IHME1500. For this, the currently constraining parameter depth to groundwater table should be updated to allow for a DRASTIC vulnerability assessment covering the national territories of the WP partners.

At the regional (partially transboundary) pilot scale, the DRASTIC model will be applied in the following regions (Figure 3):

-Austria (Groundwater body of the Traun-Enns Platte)
-Denmark (The Tønder area, South-western Jutland)
-Irleand (The Curragh regionally important gravel aquifer)
-Poland/Germany (Groundwater catchment of the lower Oder River)
-Romania (Cobadin-Mangalia Basin)
-Slovenia (entire country)
-Spain (entire country, Catalonia, Upper Guadiana Basin)
-Ukraine (Starokostyantyniv)

Factsheets describing the individual pilot areas and the respective data available can be found in Annex 2.

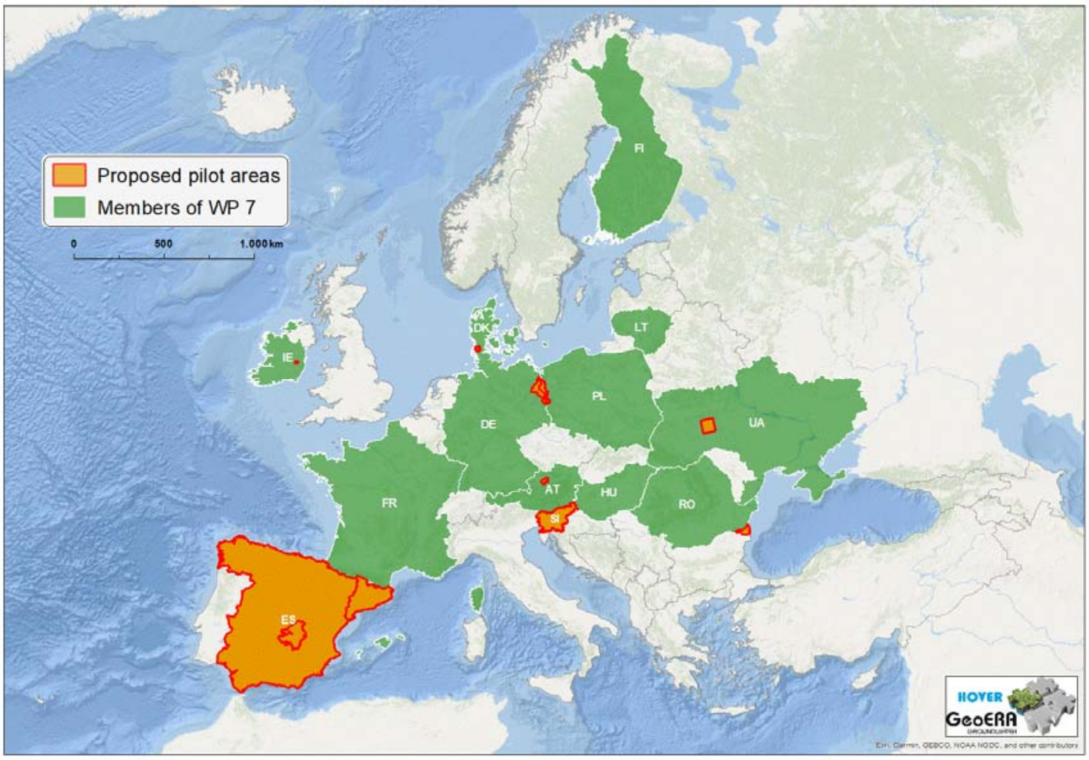

Figure 3: Participating member states in WP7 and pilot areas

DRASTIC parameter classifications will be revised and re-calibration procedures adopted, where necessary. As DRASTIC performs poor in karstic environments, a to be defined karst specific method (COP, for instance) will be applied in the respective regions.

A crucial element is the validation of the groundwater vulnerability maps. In this regard it will be necessary to gather available spatial information on contaminated areas and point information with pollutants beyond their respective threshold. As all listed methods in Table 1 suffer from their fundamental concept of excluding the nature of groundwater flow, assuming vertical infiltration and no horizontal transport. Hence, the validation procedure should include exemplary a methodology to delineate recharge areas and combining them with the hydraulic gradient in the respective region.
Additionally, quantitative approaches like the estimation of the transit time of contaminants analyzing breakthrough curves obtained by artificial tracer test, could be

used combined with information on land use and the pollution load applied to the ground, ultimately combining intrinsic vulnerability with hazards maps (and developing risk maps). The aforementioned COST Action 620 proposed a common framework for vulnerability, hazard and risk mapping, and although it was thought for karst aquifers it could be used for other environments and hence represents a possible validation approach.

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ANNEX 1 – DRASTIC WEIGHTING AND RATING SCHEME

Drastic weighting scheme

Parameter	Weighting
Depth to water	5
Net recharge	4
Aquifer media	3
Soil media	2
Topography	1
Impact of the vadose zone media	5
Hydraulic conductivity of the aquifer	3

Ranges and ratings of parameters applied

Depth to water [m]	Rating
0-1,5	10
1,5-4,6	9
4,6-9,1	7
9,1-15,2	5
15,2-22,9	3
22,9-30,5	2
30,5+	1

Net recharge [mm/a]	Rating
0-51	1
51-102	3
102-178	6
178-254	8
254+	9

Topography/slope [%]	Rating
0-2	10
2-6	9
6-12	5
12-18	3
18+	1

Aquifer media	Rating	Typical rating
Massive shale	1-3	2
Metamorphic/igneous	2-5	3
Weathered metamorphic/igneous	3-5	4
Glacial till	4-6	5
Bedded sandstone, limestone and shale sequences	5-9	6
Massive sandstone	4-9	6
Massive limestone	4-9	6
Sand and gravel	4-9	8
Basalt	2-10	9
Karst limestone	9-10	10

Soil media	Rating
Thin or absent	10
Gravel	10
Sand	9
Peat	8
Shrinking and/or aggregated clay	7
Sandy loam	6
Loam	5
Silty loam	4
Clay loam	3
Muck	2
Non-shrinking and non-aggregated clay	1

Impact of vadose zone media	Rating	Typical rating
Confining layer	1	1
Silt/clay	2-6	3
Shale	2-5	3
Limestone	2-7	6
Sandstone	4-8	6
Bedded limestone, sandstone, shale	4-8	6
Sand and gravel with significant silt and clay	4-8	6
Metamorphic/igneous	2-8	4
Sand and gravel	6-9	8
Basalt	2-10	9
Karst limestone	8-10	10

Hydraulic conductivity [m/s]	Rating
$5*10^{-7}$ – $5*10^{-5}$	1
$5*10^{-5}$ – $1*10^{-4}$	2
$1*10^{-4}$ – $3*10^{-4}$	4
$3*10^{-4}$ – $5*10^{-4}$	6
$2*10^{-4}$- $1*10^{-3}$	8
$1*10^{-3}$ +	10

ANNEX 2 – FACTSHEETS OF PILOT AREAS

Name of pilot area:	**Traun-Enns-Platte (Austria)**
Item	**Description**
1. Pilot area	
1.1 Location, area (km²)	Molasse Basin, Upper Austria, approx. 400 km²
1.2 Observation scale / mapping unit DRASTIC	1:50,000 / grid cell 50 m × 50 m
2. Environmental setting of pilot area	
2.1 Climate	Humid continental climate/temperate transitional climate
2.2 Geomorphology	Forland basin north of the Alps
2.3 Geology	Mainly glacial deposits (e.g. terrasse gravels, moraines, loess)
2.4 Hydrology	Terrasse gravels above marl act as the aquifer. Those are covered by loess and partially moraines.
2.5 Hydrogeology	Pore aquifer, groundwater in unconsolidated gravels (mostly "Deckenschotter")
3. Spatial information for DRASTIC	
3.1 Depth to water	
3.1.1 Areal coverage in pilot (%)	100 %
3.1.2 Data used	Interpolated groundwater tables from published isolines and single water tables, GBA project: "Prozesse der Grundwasserneubildung in der Traun-Enns-Platte"
3.1.3 Type of water table information	Piezometric water table of unconfined aquifer
3.1.4 Method to construct water table(s)	Interpolated groundwater tables from published isolines and single water tables, GBA project: "Prozesse der Grundwasserneubildung in der Traun-Enns-Platte"
3.1.5 Temporal dimension of WT information	Monthly measurements of the groundwater table between 1980 and 2009
3.1.6 Scale and grid cell size	1:50,000, 50 m × 50 m (geological model and hydrological balance)
3.2 Net recharge	
3.2.1 Areal coverage in pilot (%)	100 %
3.2.2 Data used	Results from hydrological balance, GBA project: "Prozesse der Grundwasserneubildung in der Traun-Enns-Platte"
3.2.3 Observation method	Results from hydrological balance based on temperature, precipitation and elevation, GBA project: "Prozesse der Grundwasserneubildung in der Traun-Enns-Platte"
3.2.4 Regionalization method	Results from hydrological balance, GBA project: "Prozesse der Grundwasserneubildung in der Traun-Enns-Platte"

3.2.5 Temporal dimension/resolution of data	Monthly measurements between 1980 and 2009
3.2.6 Scale and grid cell size	
3.3 Aquifer media	
3.3.1 Areal coverage in pilot (%)	100 %
3.3.2 Thematic data used	Results from 3D geological model, GBA project: "Prozesse der Grundwasserneubildung in der Traun-Enns-Platte"
3.3.3 Type of data	Raster data
3.3.4 Classification	6 classes in geological 3D model ("Alluvium", "Terras-senschotter", "Deckenschotter", "Moräne", "Lösslehm über Schlier", "Schlier"); can be simplifed for DRASTIC
3.3.5 Scale and resolution	1:50,000
3.4. Soil media	
3.4.1 Areal coverage in pilot (%)	100 %
3.4.2 Thematic data used	eBOD2 (soil map)
3.4.3 Type of data	Raster data
3.4.4 Classification	
3.4.5 Scale and resolution	1:50,000
3.5 Topography (slope)	
3.5.1 Areal coverage in pilot (%)	100 %
3.5.2 Raw data for DEM	DEM product (10 m)
3.5.3 Method to construct DEM	Not needed
3.5.4 Correction of DEM	Not needed
3.5.5 Method used to derive slope	DEM model
3.5.6 Scale and grid resolution	10 m
3.6. Impact of vadose zone	
3.6.1 Areal coverage in pilot (%)	100 %
3.6.2 Thematic data used	Results from 3D geological model, GBA project: "Prozesse der Grundwasserneubildung in der Traun-Enns-Platte"
3.6.3 Type of data	Vector data
3.6.4 Classification	6 classes in geological 3D model ("Alluvium", "Terras-senschotter", "Deckenschotter", "Moräne", "Lösslehm über Schlier", "Schlier"); can be simplifed for DRASTIC
3.6.5 Scale and resolution	1:50,000
3.7. Hydraulic conductivity of aquifer	
3.7.1 Areal coverage in pilot (%)	100 %
3.7.2 Data used	Mean values for different types of aquifer and geological 3D model, GBA project: "Prozesse der Grundwasserneubildung in der Traun-Enns-Platte"
3.7.3 Regionalization	Only available for test site
3.7.4 Scale and resolution	1:50,000
3.8 Auxiliary datasets	

4. Evaluation of DRASTIC

4.1 Data used	No vulnerability maps available
4.2 Qualitative evaluation	No vulnerability maps available
4.3 Quantitative evaluation	No vulnerability maps available

Name of pilot area:	Tønder (Denmark)
Item	**Description**
1. Pilot area	
1.1 Location, area (km²)	293 km²
1.2 Observation scale / mapping unit DRASTIC	100 m × 100 m
2. Environmental setting of pilot area	
2.1 Climate	Coastal temperate climate
2.2 Geomorphology	Flat near-coastal area composed of the remaining heights (up to 62 m above sea level) of a Saalian glacially formed landscape surrounded by outwash plans and Holocene marshland
2.3 Geology	Quaternary glaciotectonic layers with a number of burried valleys, and below, sandy Miocene layers
2.4 Hydrology	Average precipitation is 1,000 mm/a, and the groundwater recharge 394 mm/a for the period 1991-2010 (Rasmussen & Sonnenborg, 2015)
2.5 Hydrogeology	Aquifers are found in sandy Quaternary and Miocene layers used for drinking water production
3. Spatial information for DRASTIC	
3.1 Depth to water	
3.1.1 Areal coverage in pilot (%)	100 %
3.1.2 Data used	Information from wells in the Jupiter database: https://eng.geus.dk/products-services-facilities/data-and-maps/national-well-database-jupiter/, (Rasmussen & Sonnenborg, 2015)
3.1.3 Type of water table information	Piezometric water table of confined/unconfined aquifers
3.1.4 Method to construct water table(s)	Direct measurements from 604 wells
3.1.5 Temporal dimension of WT information	1990-2013
3.1.6 Scale and grid cell size	Well density: 2 wells per km^2
3.2 Net recharge	
3.2.1 Areal coverage in pilot (%)	100 %
3.2.2 Data used	National water resources model for Denmark: http://dk.vandmodel.dk/in-english/
3.2.3 Observation method	Mechanistically, transient and spatially distributed groundwater-surface water model
3.2.4 Regionalization method	
3.2.5 Temporal dimension/resolution of data	1991-2010
3.2.6 Scale and grid cell size	500 m × 500 m

3.3 Aquifer media	
3.3.1 Areal coverage in pilot (%)	100 %
3.3.2 Thematic data used	Electromagnetic SkyTEM data, seismic data and lithological borehole information are used to build a 3D geologic model by use of three different modelling methodologies: clay fraction stochastic, and cognitive layer modelling (Jørgensen et al., 2015)
3.3.3 Type of data	Vector data
3.3.4 Classification	Quaternary or Tertiary sandy layers: Glaciotectonic complex, Sandur, Buried Valley and Miocene layers
3.3.5 Scale and resolution	168 layers with voxels of 100 m × 100 m × 5 m
3.4. Soil media	
3.4.1 Areal coverage in pilot (%)	100 %
3.4.2 Thematic data used	Surface Geology Map of Denmark: https://frisbee.geus.dk/geuswebshop/index.xhtml
3.4.3 Type of data	Vector data
3.4.4 Classification	57 typologies
3.4.5 Scale and resolution	1:25,000
3.5 Topography (slope)	
3.5.1 Areal coverage in pilot (%)	100 %
3.5.2 Raw data for DEM	LiDAR (Light Detection And Range): https://download.kortforsyningen.dk/content/dhmterræn-04-m-grid
3.5.3 Method to construct DEM	
3.5.4 Correction of DEM	
3.5.5 Method used to derive slope	
3.5.6 Scale and grid resolution	0.4 m × 0.4 m
3.6. Impact of vadose zone	
3.6.1 Areal coverage in pilot (%)	100 %
3.6.2 Thematic data used	Thickness of protecting clay layer above aquifer
3.6.3 Type of data	Modelling result from the 3D geologic model: Figur 8d , vector data (Hansen et al., 2016)
3.6.4 Classification	5 classes: 0-5 m, 5-10 m, 10-15 m, 15-30 m and > 30 m
3.6.5 Scale and resolution	100 m × 100 m
3.7. Hydraulic conductivity of aquifer	
3.7.1 Areal coverage in pilot (%)	100 %
3.7.2 Data used	Modelling result from a local 3D steady state groundwater flow model based on MODFLOW

	2000 (Rasmussen & Sonnenborg, 2015; Hansen et al., 2016)
3.7.3 Regionalization	
3.7.4 Scale and resolution	100 m × 100 m
3.8 Auxiliary datasets	

4. Evaluation of DRASTIC

4.1 Data used

4.2 Qualitative evaluation

4.3 Quantitative evaluation

References

Jørgensen, F., Høyer, A.-S., Sandersen, P.B.E, He, X., and Foged, N. 2015: *Combining 3D geological modelling techniques to address variations in geology, data type and density – an example from southern Denmark.* Computers & Geosciences 81, 53–63. DOI: 10.1016/j.cageo.2015.04.010

Hansen, B., Sonnenborg, T.O., Møller, I., Bernth, J.D., Høyer, A.-S., Rasmussen, P., Sandersen, P.B.E. & Jørgensen, F., 2016. *Nitrate vulnerability assessment of aquifers*. Environ. Earth Sci., 75, 999. Doi: 10.007/s12665-016-5767-2.

Rasmussen & Sonnenborg, 2015. Grundvandsmodel for kortlægningsområdet Tønder - Løgumkloster. GEUS report. http://jupiter.geus.dk/Rapportdb/Grundvandsrapport.seam?grundvandsrapportRapportid=91458

Name of pilot area:	The Curragh (Ireland)
Item	**Description**
1. Pilot area	
1.1 Location, area (km²)	110 km²
1.2 Observation scale / mapping unit DRASTIC	1:50,000
2. Environmental setting of pilot area	
2.1 Climate	Temperate maritime/oceanic
2.2 Geomorphology	Meltwater channels, esker ridge, hummocky sand and gravel (deglacial landforms). Drumlins to northern and western boundary.
2.3 Geology	Gravels derived from limestones
2.4 Hydrology	For determining vulnerability to pollution using the DRASTIC method, a Regionally Important Sand & Gravel aquifer was selected. The aquifer is a feeder for the Grand Canal and provides baseflow for the major river catchments in Kildare, namely the Liffey, the Barrow and the Boyne. Pollardstown Fen, an important Natural Heritage Site, also derives its water from the aquifer.
2.5 Hydrogeology	A Regionally Important Aquifer and public water supply source.
3. Spatial information for DRASTIC	
3.1 Depth to water	Well point data. Do not have nationwide depth to water table. The aquifer is considered to be unconfined. Groundwater levels fluctuate 1-3 m annually, and the water table generally lies between 15 and 19 m below ground in the vicinity of the supply boreholes
3.1.1 Areal coverage in pilot (%)	~5 %
3.1.2 Data used	National well database - Groundwater Well, Borehole and Spring locations Ireland, GSI in-house records and EPA HYDRONET Water level database.
3.1.3 Type of water table information	Point information
3.1.4 Method to construct water table(s)	Populate conceptual models / cross sections with water level data
3.1.5 Temporal dimension of WT information	Irregular, one-off measurements
3.1.6 Scale and grid cell size	Groundwater Well, Borehole and Spring locations Ireland layer = 1:50,000
3.2 Net recharge	
3.2.1 Areal coverage in pilot (%)	100 %

3.2.2 Data used	Methodology set out in *Hunter Williams et al 2013*. National recharge map. The main hydrogeological controls on groundwater recharge include: subsoil permeability, subsoil thickness, saturated soils, and the ability of the underlying aquifer to accept percolating waters. Combinations of these factors are assessed, and a 'recharge coefficient' established for 26 different hydrogeological settings Recharge co-efficient datasets: Teagasc soils (1:25,000), GSI Quaternary Sediments, GW vulnerability datasets (subsoil permeability (1:50,000) & thickness layer, depth to bedrock), national aquifer. Recharge co-efficient ´ effective rainfall= recharge map. Effective rainfall: Ireland's Meteorological Service (Met Éireann's) 1971-2000 rainfall dataset (Rainfall data are interpolated on a 5 km × 5 km grid) is used, in tandem with an adapted Potential Evapotranspiration dataset.
3.2.3 Observation method	Calculated data
3.2.4 Regionalization method	Derived from already regionalized hydrological/ climatological data
3.2.5 Temporal dimension/resolution of data	The recharge map presented uses 30 year average climatic data (1971-2000).
3.2.6 Scale and grid cell size	1:50,000
3.3 Aquifer media	
3.3.1 Areal coverage in pilot (%)	100 %
3.3.2 Thematic data used	GSI 1:100,000 Bedrock Aquifer map; GSI 1:50,000 Sand and Gravel Aquifer map, Quaternary Sediments map
3.3.3 Type of data	Vector data
3.3.4 Classification	Original: 11 classes / DRASTIC: Sand and Gravel, Glacial Till
3.3.5 Scale and resolution	1:50,000
3.4. Soil media	
3.4.1 Areal coverage in pilot (%)	100 %
3.4.2 Thematic data used	Teagasc Soils Data - Surface Soils Classification and Description, GSI's Quaternary Geomorphology 2016 - Sediment Datasets with Topographic Detail
3.4.3 Type of data	Vector data
3.4.4 Classification	Original: 25 classes / DRASTIC: Peat, Sand and Gravel
3.4.5 Scale and resolution	1:40,000
3.5 Topography (slope)	GSI use base maps and hillshade (raster) supplied by Ordnance Survey Ireland (OSi) and Environment Protection Agency (EPA)
3.5.1 Areal coverage in pilot (%)	100 %

3.5.2 Raw data for DEM	DTM_EPA_HILLSHADE_20M_IG, GSISPATIAL.DTM_ROI_NI_5m_ITM, EPA 20m Contour Tile Layer (Details of EPA 20m Contour layer here: secure.dccae.gov.ie/arcgis/rest/services/THIRD_PARTY/EPAContours20m/MapServer/0)
3.5.3 Method to construct DEM	
3.5.4 Correction of DEM	
3.5.5 Method used to derive slope	
3.5.6 Scale and grid resolution	
3.6. Impact of vadose zone	**Not considered in Irish methodology. Soil Media data applies to same**
3.6.1 Areal coverage in pilot (%)	
3.6.2 Thematic data used	
3.6.3 Type of data	
3.6.4 Classification	
3.6.5 Scale and resolution	
3.7. Hydraulic conductivity of aquifer	
3.7.1 Areal coverage in pilot (%)	
3.7.2 Data used	
3.7.3 Regionalization	
3.7.4 Scale and resolution	
3.8 Auxiliary datasets	
4. Evaluation of DRASTIC	
4.1 Data used	
4.2 Qualitative evaluation	
4.3 Quantitative evaluation	

Name of pilot area:	Groundwater catchment of the lower Oder/Odra river Polish part
Item	**Description**
1. Pilot area	
1.1 Location, area (km²)	Central Europe, ~ 7,400 km² (total area)
1.2 Observation scale / mapping unit DRASTIC	1:50,000 / grid cell: 200 × 200 m
2. Environmental setting of pilot area	
2.1 Climate	Humid continental climate/temperate transitional climate
2.2 Geomorphology	Lowland of the river Oder/Odra
2.3 Geology	Sand and gravel (glacial or fluviatile)
2.4 Hydrology	For the determination of vulnerability to pollution according to the DRASTIC method, a first-order river basin with a total area of about 7,400 km² was selected. This catchment area of the Oder river is located in the North German and Northwest Polish lowlands. The investigation area will provide an initial assessment of how the DRASTIC methodology is applicable to areas of unconsolidated rock cover and what modifications are needed in assessing vulnerability to pollution.
2.5 Hydrogeology	Groundwater catchment of the river Oder/Odra, porous aquifer
3. Spatial information for DRASTIC	**Poland:**
3.1 Depth to water	
3.1.1 Areal coverage in pilot (%)	100 %
3.1.2 Data used	**Mapa Hydrogeologiczna Polski 1:50,000** - measurement of groundwater table in wells for MHP needs complemented with data from PIG-PIB database: **Centralna Baza Danych Hydrogeologicznych-BANK HYDRO, Monitoring Wód Podziemnych** (well point information, groundwater table monitoring point)
3.1.3 Type of water table information	Piezometric water table of confined/unconfined aquifers
3.1.4 Method to construct water table(s)	Interpolation method
3.1.5 Temporal dimension of WT information	Average measurement of groundwater table depends on available data from monitoring points (e.g. from last 10 years or 5 years)
3.1.6 Scale and grid cell size	1:50,000
3.2 Net recharge	
3.2.1 Areal coverage in pilot (%)	100 %
3.2.2 Data used	Precipitation and temperature from **Instytut Meterologii i Gospodarki wodnej (IMiGW), Mapa hydrograficzna 1:50,000,** literature values (river flows, water gauge level)
3.2.3 Observation method	Measured data

3.2.4 Regionalization method	Depends on available data from IMiGW , derivation from hydrological and climatological data
3.2.5 Temporal dimension/resolution of data	Depends on available data from IMiGW (1971-2010), but there is no data for all the area
3.2.6 Scale and grid cell size	1:50,000?
3.3 Aquifer media	
3.3.1 Areal coverage in pilot (%)	100 %
3.3.2 Thematic data used	**Mapa Hydrogeologiczna Polski 1:50,000** [hydrogeological map of Poland - coverage: 100 %]
3.3.3 Type of data	Vector data
3.3.4 Classification	DRASTIC: 2 - 3 classes (Sand and gravel, Glacial till)
3.3.5 Scale and resolution	1:50,000
3.4. Soil media	
3.4.1 Areal coverage in pilot (%)	100 %
3.4.2 Thematic data used	**Mapa Glebowa 1:500,000** (soil map of Poland)
3.4.3 Type of data	Vector data
3.4.4 Classification	Original classes still needs to be clarified
3.4.5 Scale and resolution	1:500,000
3.5 Topography (slope)	
3.5.1 Areal coverage in pilot (%)	100 %
3.5.2 Raw data for DEM	Laser scan, commercial DEM product (DGM 25)
3.5.3 Method to construct DEM	
3.5.4 Correction of DEM	Unknown
3.5.5 Method used to derive slope	
3.5.6 Scale and grid resolution	100 m
3.6. Impact of vadose zone	
3.6.1 Areal coverage in pilot (%)	100 %
3.6.2 Thematic data used	**Szczegółowa Mapa Geologiczna Polski 1:50,000 (**geological map of Poland, geological cross sections 1:50,000), **Mapa Hydrogeologiczna Polski 1:50,000** (hydrogeological map of Poland, cross sections, symbol of hydrogeological units) **Centralna Baza Danych Hydrogeologicznych - Bank Hydro** (well point data)
3.6.3 Type of data	Vector data
3.6.4 Classification	DRASTIC: 2 - 3 classes (Sand and gravel, Glacial till)
3.6.5 Scale and resolution	1:50,000
3.7. Hydraulic conductivity of aquifer	
3.7.1 Areal coverage in pilot (%)	100 %
3.7.2 Data used	**Mapa hydrogeologiczna Polski 1:50,000** (hydrogeological map of Poland, coverage:100

	%), observations from grain size information, literature values
3.7.3 Regionalization	Attribution of hydrogeological maps
3.7.4 Scale and resolution	1:50,000
3.8 Auxilliary datasets	

4. Evaluation of DRASTIC

4.1 Data used	Information from different vulnerability maps of the pilot area
4.2 Qualitative evaluation	Visual map comparison
4.3 Quantitative evaluation	Regression analysis for hydrographs (planned)

Name of pilot area:	**Groundwater catchment of the lower Oder/Odra river** **German Part**
Item	**Description**
1. Pilot area	
1.1 Location, area (km²)	Central Europe (German part ~ 4,500 km²)
1.2 Observation scale / mapping unit DRASTIC	1:50,000 / grid cell: 200 × 200 m
2. Environmental setting of pilot area	
2.1 Climate	Humid continental climate/temperate transitional climate
2.2 Geomorphology	Lowland of the river Oder/Odra
2.3 Geology	Sand and gravel (glacial or fluviatile)
2.4 Hydrology	For the determination of vulnerability to pollution according to the DRASTIC method, a first-order river basin with a total area of about 7,400 km² was selected. This catchment area of the lower Oder river is located in the North German and Northwest Polish lowlands. The investigation area will provide an initial assessment of how the DRASTIC methodology is applicable to areas of unconsolidated rock cover and what modifications are needed in assessing vulnerability to pollution.
2.5 Hydrogeology	Groundwater catchment of the lower Oder/Odra river, porous aquifer
3. Spatial information for DRASTIC	
3.1 Depth to water	
3.1.1 Areal coverage in pilot (%)	100 %
3.1.2 Data used	Grundwasserflurabstand fuer den oberen genutzten Grundwasserleiter des Landes Brandenburg [depth to groundwater for the upper used aquifer]; grid of groundwater table (from annual measurement of the groundwater table by Landesamt fuer Umwelt Brandenburg (LfU))
3.1.3 Type of water table information	Piezometric water table of confined/unconfined aquifers
3.1.4 Method to construct water table(s)	Interpolation method: Kriging
3.1.5 Temporal dimension of WT information	Annual measurement of the groundwater table
3.1.6 Scale and grid cell size	10 × 10 m
3.2 Net recharge	
3.2.1 Areal coverage in pilot (%)	100 %
3.2.2 Data used	**Niederschlags-Abfluss-Modell ArcEGMO** [Precipitation-outflow model ArcEGMO]; precipitation, temperature (original data from German Meteorological Service (Deutscher Wetterdienst, DWD); outflow rate measurements

	from State Office of Environment (Landesamt fuer Umwelt Brandenburg, LfU)
3.2.3 Observation method	Modelled data
3.2.4 Regionalization method	Derivation from already regionalized hydrological/climatological data / regression analysis of baseflow rates
3.2.5 Temporal dimension/resolution of data	Long-term mean annual net recharge (1991-2010)
3.2.6 Scale and grid cell size	1:50,000
3.3 Aquifer media	
3.3.1 Areal coverage in pilot (%)	100 %
3.3.2 Thematic data used	**Hydrogeologische Karte Brandenburg 1:50,000 (HYK50)** [Hydrogeological map of Brandenburg 1:50,000] (coverage: 50 %, source: LBGR) **Geologische Uebersichtskarte 1:100,000 (GUEK100)** [Geological map of Brandenburg 1:100,000] (coverage: 100 %, source: LBGR) **Geologische Uebersichtskarte der Bundesrepublik Deutschland 1:200,000 (GUEK200)** [General Geological Map of the Federal Republic of Germany 1:200,000] (coverage: 100 %, source: BGR) **Hydrogeologische Uebersichtskarte 1:200,000 von Deutschland (HUEK200)**, **Oberer Grundwasserleiter** [Hydrogeological Map of Germany at the scale of 1:200,000 (HUEK200), uppermost aquifer] (coverage: 100 %, source: BGR)
3.3.3 Type of data	Vector data
3.3.4 Classification	Original: 14 classes / DRASTIC: 2 - 3 classes (Sand and gravel, Glacial till)
3.3.5 Scale and resolution	1:50,000 - 1:100,000
3.4. Soil media	
3.4.1 Areal coverage in pilot (%)	100 %
3.4.2 Thematic data used	**Bodenuebersichtskarte des Landes Brandenburg 1:300,000** [soil map of the federal state of Brandenburg 1:300,000] (coverage 100 %) **Bodenuebersichtskarte der Bundesrepublik Deutschland 1:200,000 (BUEK200)** [Soil map of Germany 1:200,000 (BUEK200)] (coverage: 100 %, source: BGR)
3.4.3 Type of data	Vector data
3.4.4 Classification	Original: 23 classes / DRASTIC: 10 classes
3.4.5 Scale and resolution	1:300,000
3.5 Topography (slope)	
3.5.1 Areal coverage in pilot (%)	100 %
3.5.2 Raw data for DEM	Laser scan, commercial DEM product (DGM 25)

3.5.3 Method to construct DEM	
3.5.4 Correction of DEM	Unknown
3.5.5 Method used to derive slope	**Bodenkundliche Kartieranleitung. KA5** [Manual of soil mapping. 5th Ed. (KA5)] (source: BGR) **Bodenuebersichtskarte des Landes Brandenburg 1:300,000** [soil map of the federal state of Brandenburg 1:300,000] (coverage 100 %, source: LBGR), calculation of slope after BAUER et al. (1985)
3.5.6 Scale and grid resolution	100 m
3.6. Impact of vadose zone	
3.6.1 Areal coverage in pilot (%)	100 %
3.6.2 Thematic data used	**Geologische Uebersichtskarte 1:100,000 (GUEK100)** [Geological overview map 1:100,000] (coverage: 100 %, source: LBGR) **Geologische und Hydrogeologische Profilschnitte 1:50,000 (HYK50 und Lithfazieskarte Quartaer)** [Geological and hydrogeological cross sections 1:50,000] (coverage: 100 %, source: LBGR) **Geologische Uebersichtskarte der Bundesrepublik Deutschland 1:200,000 (GUEK200)** [General Geological Map of the Federal Republic of Germany 1:200,000] (coverage: 100 %, source: BGR) **Hydrogeologische Uebersichtskarte 1:200,000 von Deutschland (HUEK200), Oberer Grundwasserleiter** [Hydrogeological Map of Germany at the scale of 1:200,000 (HUEK200), uppermost aquifer] (coverage: 100 %, source: BGR)
3.6.3 Type of data	Vector data
3.6.4 Classification	Original: 14 classes / DRASTIC: 2 - 3 classes (Sand and gravel, Glacial till)
3.6.5 Scale and resolution	1:50,000 - 1:200,000
3.7. Hydraulic conductivity of aquifer	
3.7.1 Areal coverage in pilot (%)	50 - 100 %
3.7.2 Data used	**Hydrogeologische Karte Brandenburg 1:50,000 (HYK50)** [Hydrogeological map of Brandenburg 1:50,000] (coverage: 50 %, source: LBGR) **Hydrogeologische Uebersichtskarte 1:200,000 von Deutschland (HUEK200), Oberer Grundwasserleiter** [Hydrogeological Map of Germany at the scale of 1:200,000 (HUEK200), uppermost aquifer] (coverage: 100 %, source: BGR) additional observations from grain size information, literature values

3.7.3 Regionalization	**Hydrogeologisches Kartenwerk der DDR 1:50,000 (HK50)** Hydrogeological map of the GDR 1:50,000 (HK50); (coverage: 100 %, but not digitized and not up to date)
3.7.4 Scale and resolution	1:50,000 - 1:200,000
3.8 Auxilliary datasets	

4. Evaluation of DRASTIC

4.1 Data used	Information from different vulnerability maps of the pilot area: e.g. **Hydrogeologisches Kartenwerk der DDR 1:50,000 (HK50)** [Hydrogeological map of the GDR 1:50,000 (HK50)]
4.2 Qualitative evaluation	Visual map comparison
4.3 Quantitative evaluation	Regression analysis of hydrographs (planned)

Name of pilot area:	Catalonia
Item	**Description**
1. Pilot area	
1.1 Location, area (km²)	32,112 km²
non-karstic aquifers (DRASTIC method)	24,680 km² (76.86 %)
Limestone karstic aquifers (Other: e.g. COP, etc.)	7,432 km² (23.14 %)
1.2 Observation scale / mapping unit DRASTIC	1:100,000 / 1:100,000
2. Environmental setting of pilot area	
2.1 Climate	Regional scale with variable types of climates: Temperate in coastal areas / High mountain climate / continental climate
2.2 Geomorphology	Regional scale with variable type of geomorphology areas: Mountainous, hilly and flat regions and coastal regions
2.3 Geology	Regional scale: detrital deposits in neogenic basins, current and subactual deposits in fluvial valleys, karstic materials and Palaeozoic mountain massifs of granitodes, metamorphic materials and Palaeozoic detrital.
2.4 Hydrology	Regional scale: Alluvial valleys, detrital plains, delta plains, open waters, sinkholes areas and others,
2.5 Hydrogeology	Regional scale, with 6 large groups of types of aquifers: alluvial, detrital not alluvial, carbonate, igneous, metamorphic and volcanic-alluvial / Porous / Karstic / fissured aquifers
3. Spatial information for DRASTIC	
3.1 Depth to water	62 % territory with enough data: Dataset: Raster of water table depth; piezometric lines, GWL well data (hydrogeological Map database of Catalonia); 38 % territory covered with little data: GWL well data, plus indirect information (springs discharge level, regional river level, etc.); areas without data covered with indirect information.
3.1.1 Areal coverage in pilot (%)	
3.1.2 Data used	GWL depth data in well points; contour line information. Indirect information: River levels, coast line, knowledge of the areas with superficial NP information.
3.1.3 Type of water table information	Depth to the top of the aquifer in confined aquifer, free water tables for unconfined aquifers.
3.1.4 Method to construct water table(s)	Interpolation / range values grouped by each aquifer.
3.1.5 Temporal dimension of WT information	–
3.1.6 Scale and grid cell size	1:100,000

3.2 Net recharge	
3.2.1 Areal coverage in pilot (%)	100 %
3.2.2 Data used	Precipitation and temperature data from 1940 to 2002.
3.2.3 Observation method	Measured data
3.2.4 Regionalization method	Recharge calculated in 506 aggregated hydrological basins (by means of a Semi-Distributed Hydrologic Model using the Sacramento Soil Moisture Accounting modelo – SSMA – in the whole Catalan territory)
3.2.5 Temporal dimension/resolution of data	Monthly discretization
3.2.6 Scale and grid cell size	1:250,000
3.3 Aquifer media	
3.3.1 Areal coverage in pilot (%)	100 %
3.3.2 Thematic data used	Official Catalan Aquifer delimitation database, at 1:50,000 scale. Geologic Map Database of Catalonia, at 1:50,000 scale (BGC50M)
3.3.3 Type of data	Vector data (.shp)
3.3.4 Classification	6 type of aquifer; original classification
3.3.5 Scale and resolution	1:50,000
3.4. Soil media	The Soil Map of Catalonia at 250,000 scale
3.4.1 Areal coverage in pilot (%)	100 %
3.4.2 Thematic data used	Soil map with 3,000 points across the territory with soil information
3.4.3 Type of data	Vector data (.shp) and raster
3.4.4 Classification	Soil map based on USDA soil taxonomy and WRB soil classification systems, and other data included (lithology, soil texture, parent material, etc...)
3.4.5 Scale and resolution	1:250,000
3.5 Topography (slope)	
3.5.1 Areal coverage in pilot (%)	100 %
3.5.2 Raw data for DEM	LIDAR data
3.5.3 Method to construct DEM	Unknown
3.5.4 Correction of DEM	Unknown
3.5.5 Method used to derive slope	With geospatial GIS applications
3.5.6 Scale and grid resolution	Different scales available (e.g. 5x5, 15x15, etc.)
3.6. Impact of vadose zone	
3.6.1 Areal coverage in pilot (%)	100 %
3.6.2 Thematic data used	Shallow geological map / geological map
3.6.3 Type of data	Vector data (.shp) / raster

3.6.4 Classification	Original classification
3.6.5 Scale and resolution	1:50,000
3.7. Hydraulic conductivity of aquifer	
3.7.1 Areal coverage in pilot (%)	100 %
3.7.2 Data used	Literature values, sample data, indirect observations (aquifer lithology, grain size, fracture, karst)
3.7.3 Regionalization	Range of hydraulic conductivity for each of the 199 aquifers defined in Catalonia
3.7.4 Scale and resolution	1:50,000
3.8 Auxilliary datasets	
4. Evaluation of DRASTIC	
4.1 Data used	Nitrate concentration expressed as NO3= (or also Sulfate or Chloride concentration expressed as $SO_4^=$ and Cl), as the most common indicator of anthropogenic pollution. (Data not homogeneously distributed)
4.2 Qualitative evaluation	The DVI – **D**RASTIC **V**ulnerability **I**ndex map for non-karstic aquifers (or others like: COP for karstic aquifers) will be tested using hydrogeochemical data, and by considering a 'Risk map' or **I**ndex of **P**ollution **R**isk Map (**IPR**) combining a reclassified land-use map (hazard map) with the vulnerability map. The evaluation will be done by means of a qualitative analysis comparing the pollution data with the Risk maps (Vulnerability x Hazard). Hazard Map will be generated rating and weighting the land uses form land-use maps like Corine Land cover / The Land Cover Map of Catalonia (MCSC). Nitrate data from the Hydrogeological Map Database of Catalonia.
4.3 Quantitative evaluation	

Name of pilot area:	Cobadin-Mangalia (Romania)
	It is also RODL04 Groundwater body
Item	**Description**
1. Pilot area	
1.1 Location, area (km²)	The aquifer is located within South Dobrogea structural Unit, in the Eastern part of Romania, near the Black Sea and has a surface of 2,192 km². It is represented by Sarmatioan limestones deposits.
1.2 Observation scale / mapping unit DRASTIC	Primary data based on which DRASTIC method will be applied are at 1:200,000 scale.
2. Environmental setting of pilot area	
2.1 Climate	The South Dobrogea Plateau has a temperate continental climate with mostly semiarid continental influences. Due to its low altitudes of 70 - 250 m, Southern Dobrogea has climatic characteristics of a plain.
2.2 Geomorphology	The character of the platform is evidenced by poorly curved, almost flat deposits, which have undergone epirogenic tipping movements. On the regional level, the relief is represented by a plateau with broadly wavy and flat interfluves, with average heights between 50 - 100 m, ending by a steep to the Black Sea. The shore of the sea is tall with cliffs in the Sarmatian and Quaternary deposits. The height of the cliff varies between 15 and 30 m.
2.3 Geology	Mainly in Southern Dobrogea there are two structural levels: • the crystalline foundation (the lower structural floor), consisting of metamorphic crystalline rocks of archaic and proterozoic age; • sedimentary cover (upper structural layer), consisting of paleozoic, mesozoic and neozoic sedimentary formations. The peculiarities of geotectonic evolution of the South Dobrogean Platform have a great influence on the hydrogeological conditions due to the presence of fissure systems up to the karst in the mass of carbonate deposits, generated by the tectonic movements.
2.4 Hydrology	In the Southern Dobrogean Plateau, under the influence of semiarid climatic conditions and a tabular relief, fragmented by meandered valleys, there are a series of typical rivers through their drainage regime and some limestones of fluvial or maritime nature. The rivers are made up of a divergent network, tributary to the Danube (72 %), the Black Sea (23 %) and semi-senate areas (5 %). The lakes are located on the right bank of the Danube and on the Black Sea coast, between Cape Midia and the state border with Bulgaria.

2.5 Hydrogeology	From a hydrogeological point of view, in South Dobrogea there are accumulations of water in different age formations, such as Quaternary, Pliocene, Eocene and Senonian, but these have only minor extensions and local importance. The most important aquifers, both as an extension and as an economic potential, are linked to Barremian-Jurassic and Sarmatian limestone deposits. The **Barremian-Jurassic aquifer**, also called the lower aquifer, is developed in the calcarous and dolomitic deposits, sometimes fractured and carstified, which extend in almost all of South Dobrudja, forming a unitary complex. The thickness of this complex gradually decreases from southwest to east and northeast, from over 1,000 m to approx. 400 m. **The Sarmatian aquifer, also referred to as the upper aquifer, is hydrogeologically significant in the south-eastern part of the region, where the thickness of the Sarmatian limestone deposits exceeds 10 m. Figure 3. This aquifer was delineated as RODL04 GWB, and named Cobadin-Mangalia. It is proposed as a test site for this project.** The **quaternary aquifer**, also called the phreatic aquifer, is developed in alluvial deposits of meadows, seaside lakes, and loessoid deposits. Sarmatian aquifer is the subject of our analysis process.
3. Spatial information for DRASTIC	
3.1 Depth to water	
3.1.1 Areal coverage in pilot (%)	100 %
3.1.2 Data used	Hydrogeological map, scale 1:100,000, 40 well points information, other wells information from IGR's studies
3.1.3 Type of water table information	Well point information, contour line information
3.1.4 Method to construct water table(s)	Interpolation method
3.1.5 Temporal dimension of WT information	Piezometric water tables for confined aquifers, free water tables for unconfined aquifers, multiple water tables for stratified aquifers,annual, decadal water table information
3.1.6 Scale and grid cell size	Hydrogeological map, scale 1:100,000
3.2 Net recharge	
3.2.1 Areal coverage in pilot (%)	100 %
3.2.2 Data used	Multiannual values of temperature, precipitation from www.worldclim.org
3.2.3 Observation method	Measured data, calculated data
3.2.4 Regionalization method	Derivation from already regionalized environmental/climatological data
3.2.5 Temporal dimension/resolution of data	Precipitation, temperature / interpolation
3.2.6 Scale and grid cell size	Cell is 1 km²

3.3 Aquifer media	
3.3.1 Areal coverage in pilot (%)	100 %
3.3.2 Thematic data used	Hydrogeological map, geological map, geological cross sections
3.3.3 Type of data	Vector and raster data, cross sections
3.3.4 Classification	Original classification; 2 classes
3.3.5 Scale and resolution	Hydrogeological maps scale 1:100,000; geological maps scale 1:200,000, geological cross sections
3.4. Soil media	
3.4.1 Areal coverage in pilot (%)	100 %
3.4.2 Thematic data used	Soil map, scale 1:200,000, soil cross sections, observations
3.4.3 Type of data	Vector and raster data
3.4.4 Classification	Original classification; 9 classes
3.4.5 Scale and resolution	Soil map, scale 1:200,000
3.5 Topography (slope)	
3.5.1 Areal coverage in pilot (%)	100 %
3.5.2 Raw data for DEM	The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) is concurrently distributed from the Ministry of Economy, Trade, and Industry (METI) Earth Remote Sensing Data Analysis Center (ERSDAC) in Japan and the National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) Data Information System (EOSDIS) Land Processes (LP) Distributed Active Archive Center (DAAC) in the United States. Tile Size – 3,601 × 3,601 (1 × 1); Pixel Size – 1 arc-second Geographic Coordinate System Geographic latitude and longitude DEM Output Format GeoTIFF, signed 16-bit, in units of vertical meters Referenced to the WGS84/EGM96 geoid Special DN Values -9999 for void pixels, and 0 for sea water body Coverage - North 83 to South 83, 22,702 tiles
3.5.3 Method to construct DEM	
3.5.4 Correction of DEM	
3.5.5 Method used to derive slope	Sink fill
3.5.6 Scale and grid resolution	Grid 30 × 30
3.6. Impact of vadose zone	
3.6.1 Areal coverage in pilot (%)	100 %
3.6.2 Thematic data used	Soil map, shallow geological map, geological map,
3.6.3 Type of data	Vector and raster data

3.6.4 Classification	Original classification; 3 classes
3.6.5 Scale and resolution	Soil map and geological maps, both scale 1:200,000, cross sections
3.7. Hydraulic conductivity of aquifer	
3.7.1 Areal coverage in pilot (%)	
3.7.2 Data used	Indirect observations from grain size/fracture information, literature values, expert-assigned values, etc.
3.7.3 Regionalization	Attribution of geological/hydrogeological map
3.7.4 Scale and resolution	–
3.8 Auxilliary datasets	Hopefully we can convince the waterboard to provide some data.
4. Evaluation of DRASTIC	
4.1 Data used	IGR's hydrogeological map, scale 1:100,000, IGR's geological and soil maps, scale 1:200,000, geological cross sections, soil cross sections, IGR's studies, Romanian hydrogeological literature, world literature, etc.
4.2 Qualitative evaluation	Our institute did not make a vulnerability study by now. Still, we give a rough estimation of the scores, based on the data we have (see sheet scores Romania). This estimation may be subject of changes during the vulnerability study elaboration.
4.3 Quantitative evaluation	–

Name of pilot area:	Slovenia (entire territory)
Item	**Description**
1. Pilot area	
1.1 Location, area (km²)	The pilot area is entire territory of Slovenia, covering around 20,273 km².
1.2 Observation scale / mapping unit DRASTIC	The scale is 1:250,000 and the mapping unit will be 1 km × 1 km
2. Environmental setting of pilot area	
2.1 Climate	Several climate types: continental climate - majority of the area, Alpine climate - high mountains in NW part of the area, coastal sub-Mediterranean climate - SW part of the country
2.2 Geomorphology	Altitude changes from the sea level (0 m a.s.l.) in the SW part of the area and up to the 2,864 m a.s.l. in the NW part of the area.
2.3 Geology	Complex geological territory: from Paleozoic to Holocene - sedimentary (93 %), metamorphic and igneous rocks (7 %). Carbonate rocks (karst) are present in S and NW part, carboniferous clastic sediments (shale, quartz sandstone and conglomerate) are present in central part and flysch in SW part of the territory. Quaternary clastic sediments cover river basins in central and NE part. Igneous and metamorphic rocks are present in the NE and N part of the territory.
2.4 Hydrology	All types of surface water are present. Density of river network is 1.33 km/km². Most surface waters are short; more than 100 km long are only Sava, Drava, Kolpa and Savinja rivers. Most rivers drain to the Black Sea, the rest belongs to the Adriatic water catchment area. The largest lake is a disappearing karst Cerknica Lake, lakes of glacial origin are Bohinj and Bled lake and also many small mountain lakes. Slovenia lies on the N coast of the Adriatic sea, occupying one third of the Gulf of Trieste.
2.5 Hydrogeology	In the Slovenian territory there are several types of aquifers present. Almost 20 % of territory is covered with the aquifers with intergranular porosity, 14 % with aquifers with fissured porosity and 33 % of aquifers with karstic porosity. The rest of the country present areas without important quantities of groundwater in less permeable areas (flysch rocks, sandstones, marls, metamorphic rocks).
3. Spatial information for DRASTIC	
3.1 Depth to water	From 2 m in the alluvial aquifers to 200 m in the karst area

3.1.1 Areal coverage in pilot (%)	For 20 % of the territory we have contour line information, other part well point information are available
3.1.2 Data used	Well point information
3.1.3 Type of water table information	Contour line information, well point information
3.1.4 Method to construct water table(s)	Interpolation method: Kriging for contour line information in the alluvial aquifers
3.1.5 Temporal dimension of WT information	On specific date information
3.1.6 Scale and grid cell size	–
3.2 Net recharge	
3.2.1 Areal coverage in pilot (%)	100 %
3.2.2 Data used	Data on climate (average annual amount of precipitation from 1971-2000, average year temperature from 1971-2000), interpolation map - shapefile with 1-2 km resolution. Data are available from the Environmental Agency of Slovenia.
3.2.3 Observation method	
3.2.4 Regionalization method	Interpolation of point observations
3.2.5 Temporal dimension/resolution of data	Average point data from 1971-2000 has been interpolated; shapefile with 1-2 km resolution
3.2.6 Scale and grid cell size	–
3.3 Aquifer media	
3.3.1 Areal coverage in pilot (%)	100 %
3.3.2 Thematic data used	Hydrogeological map
3.3.3 Type of data	Vector data
3.3.4 Classification	Original classification of IAH map
3.3.5 Scale and resolution	1:250,000
3.4. Soil media	
3.4.1 Areal coverage in pilot (%)	100 %
3.4.2 Thematic data used	Pedological map
3.4.3 Type of data	Vector data
3.4.4 Classification	Original pedological classification; 39 original classes will be aggregated for applying DRASTIC
3.4.5 Scale and resolution	1:25,000
3.5 Topography (slope)	
3.5.1 Areal coverage in pilot (%)	100 %
3.5.2 Raw data for DEM	ASCI format (YXZ); The model includes more than 25 types of altitude data collected from 1947 to 2005, such as digital models of relief with a resolution of 10 to 600 m, digitized layers, layers of roads and the railways of various criteria, geodetic points, building cadastre, etc.
3.5.3 Method to construct DEM	ASCI to raster
3.5.4 Correction of DEM	The DEM is homogeneous and does not include big errors. The estimated accuracy of the model is 3.2 m.
3.5.5 Method used to derive slope	ArcMap

3.5.6 Scale and grid resolution	12.5 × 12.5 m
3.6. Impact of vadose zone	
3.6.1 Areal coverage in pilot (%)	100 %
3.6.2 Thematic data used	Soil and geological map
3.6.3 Type of data	Vector data
3.6.4 Classification	Original classification; soil 39 classes; geological map 117 classes - for DRASTIC will be aggregated
3.6.5 Scale and resolution	Soil map: 1:25,000; geological map: 1:100,000
3.7. Hydraulic conductivity of aquifer	
3.7.1 Areal coverage in pilot (%)	100 %
3.7.2 Data used	Measured values, expert-assigned values
3.7.3 Regionalization	Attribution of geological/hydrogeological map
3.7.4 Scale and resolution	1:250,000
3.8 Auxilliary datasets	
4. Evaluation of DRASTIC	will be used
4.1 Data used	Borehole and spring information
4.2 Qualitative evaluation	Borehole information
4.3 Quantitative evaluation	Borehole information

Name of Pilot Area:	Spain (continental)
Item	**Description**
1. Pilot area	
1.1 Location, area (km²)	Spain, 493,519 km²
1.2 Observation scale / mapping unit DRASTIC	10 × 10 km
2. Environmental setting of pilot area	
2.1 Climate	Mainly Mediterranean + continental and semiarid
2.2 Geomorphology	Mountainous and flat region
2.3 Geology	Varied geology (The most important aquifers lie in Plio-Quaternary sedimentary formations, and Triassic to Tertiary carbonate massifs)
2.4 Hydrology	All the country; frequent droughts
2.5 Hydrogeology	Porous, fissured, karstic
3. Spatial information for DRASTIC	
3.1 Depth to water	
3.1.1 Areal coverage in pilot (%)	100 %
3.1.2 Data used	Depth to groundwater table for the upper used aquifer. DEM and hydraulic head measurements
3.1.3 Type of water table information	Piezometric water table of confined/unconfined aquifers
3.1.4 Method to construct water table(s)	Interpolation method
3.1.5 Temporal dimension of WT information	Annual measurement of the groundwater table
3.1.6 Scale and grid cell size	10 × 10 km
3.2 Net recharge	
3.2.1 Areal coverage in pilot (%)	100 %
3.2.2 Data used	Distributed empirical precipitation-recharge model
3.2.3 Observation method	Modelled data
3.2.4 Regionalization method	Derivation from already regionalized hydrological/climatological data
3.2.5 Temporal dimension/resolution of data	Long-term mean and standard deviation of annual net recharge (1976-2005)
3.2.6 Scale and grid cell size	10 × 10 km
3.3 Aquifer media	
3.3.1 Areal coverage in pilot (%)	100 %
3.3.2 Thematic data used	Geological/hydrogeological map from IGME
3.3.3 Type of data	Vector data
3.3.4 Classification	Original/DRASTIC
3.3.5 Scale and resolution	1:200,000 - 1:1,000,000
3.4. Soil media	
3.4.1 Areal coverage in pilot (%)	100 %
3.4.2 Thematic data used	Soil map from IGN
3.4.3 Type of data	Vector data

3.4.4 Classification	Original/DRASTIC
3.4.5 Scale and resolution	1:1,000,000
3.5 Topography (slope)	
3.5.1 Areal coverage in pilot (%)	100 %
3.5.2 Raw data for DEM	DEM
3.5.3 Method to construct DEM	
3.5.4 Correction of DEM	Unknown
3.5.5 Method used to derive slope	Surface tools from GIS
3.5.6 Scale and grid resolution	> 100 m
3.6. Impact of vadose zone	
3.6.1 Areal coverage in pilot (%)	100 %
3.6.2 Thematic data used	Lithostratigraphic map from IGME
3.6.3 Type of data	Vector data
3.6.4 Classification	Original
3.6.5 Scale and resolution	1:200,000
3.7. Hydraulic conductivity of aquifer	
3.7.1 Areal coverage in pilot (%)	50-100 %
3.7.2 Data used	Literature values
3.7.3 Regionalization	
3.7.4 Scale and resolution	1 value/pilot area
3.8 Auxilliary datasets	
4. Evaluation of DRASTIC	
4.1 Data used	Generated and previous maps
4.2 Qualitative evaluation	
4.3 Quantitative evaluation	Validation? Risk assessment + contamination loads

Name of pilot area:	Starokostyantyniv (Ukraine)
Item	**Description**
1. Pilot area	
1.1 Location, area (km²)	The territory of pilot area is located in Shepetivskiy, Starokostyantynivskiy, Khmelnytskiy, Starosynavskiy, and Letychivskiy areas of Khmelnytska Oblast, Lyubarskiy area of Zhytomyrska Oblast, Khmilnytskiy and Litynskiy areas of Vinnytska Oblast. It is limited by coordinates 27˚ and 28˚ E longitude, and 49˚20'- 50˚00' N latitude. The pilot area is 5,352 km².
1.2 Observation scale / mapping unit DRASTIC	Primary data based on which DRASTIC method will be applied are at 1:200,000 scale, 1:100,000 scale. Predictable grid cell size is 2-5 km².
2. Environmental setting of pilot area	
2.1 Climate	The territory is situated in the forest-steppe zone. The area climate is moderate-continental with month-average temperature in January -5.3…-5.5°C (minimum temperature -30…-35°C), in July +18.4…+20.0°C (maximum +38.5°C). Annual average amount of precipitation is 540-610 mm.
2.2 Geomorphology	In the orographic respect most part of the territory is situated within Volyno-Podilska height and comprises hilly plain cut by the river and gully valleys especially in the western and southern parts. The surface altitudes are 250.0-400.0 m. Hill tops are mainly flat and their slope angles – 4-10°. To the north-east from the line Khmilnyk-Starokostyantyniv the cutting degree decreases and the surface becomes wavy. The river and gully valleys are broad, swamped, with flat (up to 5°) slopes.
2.3 Geology	The studied area is located in the western part of Ukrainian Shield and its western slope, mainly within Dnistersko-Buzkiy mega-block (according to zonation accepted in the "Chrono-stratigraphic scheme of Early Precambrian in Ukrainian Shield", Kyiv, 2004), which in the far southern and south-western map sheet parts adjoins Volynskiy mega-block. By geology the area is classified to be closed three-fold one. The territory includes Quaternary and pre-Quaternary (including Vendian rocks in the western part of map sheet) cover complexes and the folded complex of the basement.

2.4 Hydrology

The hydrographic network is branched enough. The major rivers in the area include South Boug and Sluch. Their river course width is 12-40 m, depth – 0.9-2.0 m, flow speed – 0.1-0.4 m/sec. The courses are often dammed with accompanied big pond formation. The South Boug river basin includes the right branches Vovk and Fosa, and the left ones: Zinchytsya, Buzhok, Ikva. The Sluch river basin includes the right branches: Mshanetska Ruda, Popivka, Taranka, Verbka, and the left ones: Ikopot, Korytnytsya, Stavyska, Derevychka.

2.5 Hydrogeology

According to the scheme of zonation of Ukraine with regard to the groundwater development, the western part pilot is located in Volyno-Podilskiy artesian basin whereas remaining territory is confined to the western part of Ukrainian basin of fractured waters. The groundwater recharge and store conditions in the area are favorable enough because of climatic factors and aquifers lithology. General cutting of the modern surface and spatial discontinuity of impermeable rocks facilitate the surface and ground water flow providing extensive water exchange in the draining influence zone of the local river network.
According to the geological structure and hydrogeological conditions, the following aquifers and complexes are distinguished in the pilot area:
1)an aquifer in Holocene alluvial sediments of river flood-lands and gully bottoms (aH);
2) an aquifer in Upper Neo-Pleistocene aeolian-deluvial and eluvial sediments (vd,ePIII);
3) an aquifer in Middle-Upper Neo-Pleistocene alluvial sediments of the first-sixth over-flood terraces (a1-6PII-III);
4) an aquifer in Middle Neo-Pleistocene alluvial-fluvio-glacial sediments (afPII);
5) an aquifer in Middle Neo-Pleistocene water-glacial and lake-glacial sediments (f,lgPII);
6) an aquifer complex in Miocene Sarmatian sediments (N1s);
7) an aquifer in Miocene Novopetrivska Suite (N1np);
8) an aquifer in Miocene Podilska Suite (N1pd);
9) an aquifer in Eocene Obukhivska Suite (P2ob);
10) an aquifer in Eocene Buchatska Suite (P2bč);
11) a complex of aquifers in Upper Cretaceous Pylypchanska and Ozarynetska suites (K2pl+oz);
12) a complex of aquifers in Upper Vendian Mogyliv-Podilska Series (V2mp);
13) a complex of aquifers in Lower Vendian

	Volynska Series (V1vl); 14) a complex of aquifers in fracturing zone of Precambrian crystalline rocks and their gruss weathering crust (AR-PR1). The subject of investigations within WP7 and DRASTIC method applying are upper aquifers in Quaternary and Miocene (mostly Sarmatians) sediments (unconfined aquifers).
3. Spatial information for DRASTIC	
3.1 Depth to water	
3.1.1 Areal coverage in pilot (%)	60 %
3.1.2 Data used	Hydrogeological map, scale 1:200,000, observation wells points information, maps of groundwater heads contour
3.1.3 Type of water table information	Well point information, contour line information
3.1.4 Method to construct water table(s)	Interpolation method
3.1.5 Temporal dimension of WT information	Annual groundwater level information
3.1.6 Scale and grid cell size	1:100,000,1:200,000; predictable grid cell size is 2-5 km²
3.2 Net recharge	
3.2.1 Areal coverage in pilot (%)	60 %
3.2.2 Data used	Multiannual values of temperature, precipitation from Annual Report "Groundwater resources condition on the territory of Ukraine" (SRDE "Geoinform of Ukraine"), National Atlas
3.2.3 Observation method	Measured data
3.2.4 Regionalization method	Regional climate data
3.2.5 Temporal dimension/resolution of data	Monthly and average annual data on precipitation
3.2.6 Scale and grid cell size	Predictable grid cell size is 2-5 km²
3.3 Aquifer media	
3.3.1 Areal coverage in pilot (%)	80 %
3.3.2 Thematic data used	Hydrogeological map, geological map, geological cross-sections, data from wells
3.3.3 Type of data	Paper maps, vector, raster and attributive data
3.3.4 Classification	Haven't been defined yet
3.3.5 Scale and resolution	Hydrogeological maps scale 1:100,000 and 1:200,000; geological maps scale 1:200,000, geological cross-sections in a 1:50,000 scale
3.4. Soil media	
3.4.1 Areal coverage in pilot (%)	100 %
3.4.2 Thematic data used	Soil map (but as a subject to refine)
3.4.3 Type of data	Need to be refined to raster
3.4.4 Classification	Haven't been defined yet
3.4.5 Scale and resolution	1:200,000
3.5 Topography (slope)	

3.5.1 Areal coverage in pilot (%)	100 %
3.5.2 Raw data for DEM	A total DEM for Ukraine, spatial resolution 90 m. Model is built on the topographic base with 1:100,000 scale. Referenced to the WGS84. Geographic Coordinate System. Will try to adopt more detailed DEM with pixel size – 1 arc-second.
3.5.3 Method to construct DEM	Interpolation (if necessary)
3.5.4 Correction of DEM	
3.5.5 Method used to derive slope	Tool Slope (from ArcGIS)
3.5.6 Scale and grid resolution	Haven't been defined yet
3.6. Impact of vadose zone	
3.6.1 Areal coverage in pilot (%)	50 %
3.6.2 Thematic data used	Soil map, shallow geological map, geological map,
3.6.3 Type of data	Need to be refined to raster
3.6.4 Classification	Haven't been defined yet
3.6.5 Scale and resolution	Soil map and geological maps, cross-sections, predictable scale 1:200,000
3.7. Hydraulic conductivity of aquifer	
3.7.1 Areal coverage in pilot (%)	50 %
3.7.2 Data used	Data from wells, literature values
3.7.3 Regionalization	Interpolation, attribution of geological/hydrogeological map
3.7.4 Scale and resolution	1:200,000
3.8 Auxilliary datasets	
4. Evaluation of DRASTIC	
4.1 Data used	Only data from maps that display the level of aquifer protection from pollution (built with weightes factor analysis method considering thickness of vadose zone, lithology of vadose zone, depth of groundwater table, thickness of aquitards)
4.2 Qualitative evaluation	Geoinform and Ukrainian hydrogeologists have never applied DRASTIC in its original appearance, though our methods of groundwater vulnerability estimation are very close to it. However we will try to test DRASTIC on our pilot within project and to find out some methodological aspects in order to ensure the applicability of DRASTIC for Ukrainian hydrogeological setting and technical potential.
4.3 Quantitative evaluation	