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Organic soils in Germany, their distribution and carbon stocks

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ABSTRACT

The knowledge on spatial distribution and status of organic soils are essential for climate reporting and carbon stock calculations. In Germany so far, the official soil map at a scale of 1:1,000,000 is used. With respect to e.g. land use dependent calculations of greenhouse gas emissions, a significantly higher level of detail is required.

The aim of this study was to establish a homogenous and nationwide dataset on the distribution of organic soils and their relevant soil properties for Germany at a sufficient spatial resolution.

For the first time, a detailed and almost complete dataset on organic soils for Germany could be derived based on map legacy data, soil borehole databases and detailed data on topography, hydrology and geology accompanied by additional ground verification.

Based on the new dataset, organic soils are estimated to cover 15,682 km^2 of Germany (4.4% of the total area) and account for an organic carbon pool up to a depth of 2 m of nearly 1.3 Gt.

1. Introduction

Organic soils play an important role in the global climate system and store as much carbon as the terrestrial biomass (Joosten and Couwenberg, 2008). In dependence of e.g. climate change and land use/management practices, they can act as a sink or source of greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4) (Byrne et al., 2004; Joosten and Couwenberg, 2008; Strack, 2008).

In 1994, Germany signed the United Nations framework convention on climate change and therefore is obliged to frequently publish and update its national inventories on greenhouse gas emissions (Federal Environment Agency, 2013). This comprises emissions from agricultural and forestal used sites with organic soils. For a land use specific quantification of greenhouse gas (GHG) emissions for these soils, detailed, spatially accurate and complete data are required.

Up to now, organic soil data for the national GHG inventory are derived from the soil map at a scale of 1:1,000,000 (SM1000) and highly precise data on land use at a scale of 1:10,000 (Federal Environment Agency, 2013). Recent work by Fell et al. (2014) has shown that combining small scaled soil data with detailed land use data may lead to an inaccurate calculation of areal extent and proportional land use. Even the nationwide available soil map (SM200) and the geological map (GM200) at scales of 1:200,000 lead to miscalculations. This applies especially for regions with higher geomorphic heterogeneity. According to Fell et al. (2014), the error may reach up to 60% in comparison to more detailed soil data at scales of 1:25,000.

In the frame of climate reporting for organic soils, more detailed and spatial accurate data are needed. Furthermore these data have to be consistent with the *Intergovernmental Panel on Climate Change* (IPCC, 2006) definitions[1] and suitable for modeling and regionalization purposes. In Germany so far, no single dataset is able to fulfill these requirements.

Different approaches to establish national or regional maps of organic soils have been applied. They vary with respect to data availability, landscape setting and anthropogenic influence (Table 1). Most of them are based on legacy data like traditional soil surveys, remote sensing or field mapping. To synthesize a peatland map of Ireland, a rule based methodology was applied by Connolly et al. (2007) who achieved a raster resolution of 100 m. The classification was mainly based on precipitation and elevation data. Gardi et al. (2010) for example could derive a map of organic soils for Estonia with remote sensing methods. This may be a suitable method for regions where soil and geological data is missing and anthropogenic influence is low.

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[1] According to IPCC, soils are organic if they satisfy the requirements a) and b), or a) and c) below.
a). Thickness of 10 cm or more. A horizon less than 20 cm thick must have 12% or more organic carbon
when mixed to a depth of 20 cm;
b). If the soil is never saturated with water for more than a few days, and contains more than 20% (by
weight) organic carbon (about 35% organic matter);
c). If the soil is subject to water saturation episodes and has either:
(i) at least 12% (by weight) organic carbon (about 20% organic matter) if it has no clay; or (ii) at least 18% (by weight) organic carbon (about 30% organic matter) if it has 60% or more clay; or (iii) an intermediate, proportional amount of organic carbon for intermediate amounts of clay.

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Table 1
Recent research on organic soils and their spatial distribution (SOC = soil organic carbon).

Reference	Coverage	Application	Intention	Source data, method
Bellamy et al. (2005)	England and Wales	Soils with ca. SOC > 15%	Description of SOC losses	Field work
Byrne et al. (2004)	Europe	Peat soils	Carbon stocks	Legacy data and literature review
Chapman et al. (2013)	Scotland	Peat soils	Carbon stocks	Legacy data
Connolly et al. (2007)	Ireland	Peat soils	Peatland map	Legacy data
Eswaran et al. (1993)	World	All soils	SOC stored in soils	Legacy data
Farmer et al. (2014)	Sumatra, Indonesia	Tropical peat soils	Comparison of methods for SOC quantifications in tropical peat soils	Analytical data of bulk density and loss on ignition, literature review
Fell et al. (2014)	Germany	Organic soils	Impact of the spatial resolution of soils data on climate reporting for organic soils	Legacy data
Gardi et al. (2010)	Estonia	Peat soils	Peatland map	Remote sensing
Hammond (1981)	Ireland	Peat soils	Peatland map	Legacy data, aerial photographs
Holden and Connolly (2011)	Ireland	Peat soils	Carbon stocks	Legacy data, field work
Kasimir-Klemedtsson et al. (1997)	Finland, Sweden, The Netherlands	Organic soils	Greenhouse gas emissions	Literature review
Kuikman et al. (2003)	The Netherlands	Agricultural soils	SOC stored in soils	Legacy data
Montanarella et al. (2006)	Europe	Peat soils	Peatland map Europe	Legacy data
Van den Akker et al. (2008)	The Netherlands	Peat soils	Estimation of emission of CO_2 from agricultural peat soils	Legacy data
Zauft et al. (2010)	Mecklenburg-Western Pomerania, Germany	Peat soils	Carbon stocks	Legacy data

In Germany, the situation is as follows: due to intense and long lasting agricultural and forestal land use, accompanied by drainage and hydraulic engineering, sites with organic soils are heavily disturbed. The formerly wetland specific vegetation and the hydromorphic character on which remote sensing relies are absent. Even though remote sensing data is available nationwide in high quality, mapping based on remote sensing will not lead to sufficient soil data quality. Best quality data would be achieved with field mapping methods. In Germany, due to limited resources and political constraints, this is not possible on a national scale.

Hence only methods based on legacy data remain. A multitude of different data sources on organic soils are available in Germany at smaller scales (more than 1:50,000). This comprises soil and geoscientific maps as well as borehole datasets. Due to the federal structure of Germany, these data sources are distributed over a multitude of institutions and differ in classification, actuality and conformity with the IPCC-definitions. Not the lack of available data per se, but their fragmentation, heterogeneity and age is the problem for Germany.

Four main tasks could be identified with the goal to derive more detailed and homogenous data on organic soil distribution and properties:

I. To systematically assess and compile digitally available organic soil data (maps and borehole databases)
II. To establish a homogeneous pedological characterization of the data compiled under step I
III. To qualify the compiled data by ground verification
IV. To provide nationwide spatial and statistical data on organic soils for Germany

2. Methods

2.1. Data acquisition and data preprocessing

Standard soil maps, mire inventories and additional geological, forestal and agricultural data sources were used to derive an almost complete, nationwide, high resolution map of organic soils. Prerequisite for each data source was its conformity to the IPCC-definitions. According to those, organic soils are characterized by at least 12–18% C_{org} per dry mass and a thickness of ≥10 cm for the upper organic horizon (IPCC, 2006). To cover the whole of Germany, more than 25 different digitally available data sources had to be acquired. The resulting data collection is rather inhomogeneous in terms of the underlying classification, actuality, data structures and formats (see Table 2). For the north-west, north-east, east and south of Germany extensive data were available in contrary to the center and west, for which data at smaller scales had to be taken into account. Nationwide data on land use was derived based on the ATKIS Basis DLM (AdV, 2005). A complete and detailed list of all input data can be found in Appendix A and Appendix B.

2.2. Assessment and compilation of spatial data on organic soils (map of organic soils)

To assure a comparable data quality, primarily those data sources were integrated where mapping was done in the field rather than in a GIS mapping process. Another prerequisite was a minimum scale of 1:50,000. Only for those regions where detailed data is completely missing, soil maps and geological maps at a scale of 1:200,000 were used as substitutes. Even though input data is partly old, age was not a criterion for data selection at this stage, but it will be considered during a quality assessment step later. After homogenization of coordinate systems and basic soil information, data sources were compiled hierarchically with respect to their field mapping scale, soil related data quality and mapping standard. In case multiple datasets were available for a single site, only those with the highest quality were chosen. Further data sources were added site specific, avoiding errors due to overlapping or spatial fuzziness. Only in a few cases, where large areas of organic soils were not sufficiently described by available digital data, additional digitizing based on soil raster maps was done.

The resulting dataset, further on referenced to as *map of organic soils*, is a topologically correct and almost complete compilation of organic soils based on data with the site specific highest spatial accuracy. But, due to its diverse data sources and classification schemes, it is heterogeneous concerning level of detail and data age.

Table 2
Input data (see Appendix A and Appendix B for further details).

Data origin	Scale	Age
Peatland inventories	1:5000	1950–today
Agricultural data	1:5000–1:10,000	1930–1950
Soil data	1:25,000–1:50,000	Not defined
Geological data	1:25,000	1888–1940
Silvicultural data	1:10,000	Not defined
Soil data	1:100,000–1:200,000	Not defined
Geological data	1:100,000, 1:200,000	1960–today