HiHydroSoil: A High Resolution Soil Map of Hydraulic Properties

Version 1.2

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Preface

Soil information is the basis for all environmental studies. Since local soil maps of good quality are often not available, global soil maps with a lower resolution are used. Furthermore soil maps do not include information about soil hydraulic properties, which are of importance, e.g. for hydrological modelling, erosion assessment and crop yield modelling. Therefore the Global Soil Map of Hydraulic Properties was created from soil data of the Harmonized World Soil Database by Droogers (2011).

Since 2011 more soil data has become available and calculation algorithms have been improved, which made it possible to create a global soil map 'SoilGrids1km' with a higher resolution and improved accuracy (Hengl et al., 2014). However, SoilGrids1km does not include soil hydraulic properties (such as pF and Kh relationships) needed for hydrological modeling.

In this report the derivation of soil hydraulic properties from SoilGrids1km to create the HiHydroSoil map is described. The Harmonized World Soil Database (HWSD) is used to fill missing data in the SoilGrids1km. In the meantime the team behind SoilGrids1km is continuously working to further improve their algorithms, so that computer processing times will decrease and more sophisticated statistical models can be used to create global soil maps with increasingly smaller resolutions (up to 100 m). At the very moment a new global soil map will become available, corresponding soil hydraulic properties can be calculated according to the procedures described in this report so that maps are continuously up-to date.

The HiHydroSoil database is freely distributed by FutureWater. Please contact Gijs Simons (g.simons@futurewater.nl) for details on how to obtain the dataset.

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1 SoilGrids1km dataset

1.1 Soil properties

According Hengl et al. (2014) the SoilGrids1km dataset that is produced by ISRIC World Soil Information is “the best possible current, globally-complete, estimate of soil properties and soil classes”. SoilGrids1km is produced in 2014 and has a resolution of 1 km.

Soil properties included in the dataset are:

- soil organic carbon (g/kg)
- soil pH
- sand, silt and clay fractions (%)
- bulk density (kg/m^3)
- cation-exchange capacity (cmol+/kg) of the fine earth fraction
- coarse fragments (%)
- soil organic carbon stock (t/ha)
- depth to bedrock (in cm)
- World Reference Base soil groups
- USDA Soil Taxonomy suborders

More detailed information can be found on http://www.isric.org/content/faq-soilgrids.

1.2 Data access

Data access and download of SoilGrids1km are via http://soilgrids1km.isric.org (Web Mapping Service available at http://wms3.isric.org/geoserver/soilgrids1km/wms), via FTP service or via REST service. To obtain complete grids best use FTP access:
FTP: ftp.soilgrids.org
username: soilgrids
password: soilgrids
The data can be found in the folder Data → Recent (the direct link to that directory is ftp://ftp.soilgrids.org/data/recent/).

1.3 Input variables

The file name starts with the name of the variable. The files of SoilGrids1km that were downloaded were dated 02 April 2014. The input variables that were downloaded are (Table 1):

Table 1. Input variables for deriving soil hydraulic properties

Name	Variable	Unit
BLD	Bulk Density	kg/m^3
CEC	Cation Exchange Capacity	cmol+/kg
CLYPPT	Clay content	%
ORCDR	Organic Carbon (Dry Combustion)	g/kg
PHIHOX	pH x 10 in H_2O	-
SLTPPT	Silt percentage	%
SNDPPT	Sand Percentage	%
BDRICM	Depth to bedrock (within 0-240 cm)	cm

Note the units, especially when using these variable in pedotransfer functions.

Every variable is given for six different (standard) depths (sd1-sd6). The standard depth is also included in the name of the file (Table 2):

Table 2. Standard soil depths

Name	Standard depth	Depth of layer
sd1	0-5 cm	5 cm
sd2	5-15 cm	10 cm
sd3	15-30 cm	15 cm
sd4	30-60 cm	30 cm
sd5	60-100 cm	40 cm
sd6	100-200 cm	100 cm

For example BLD_sd1_M is the mean estimate of bulk density on 2.5 cm depth.
All input variables were downloaded for all depths. Files with the mean estimate (M) and a lower (L) and Upper (U) confidence interval of the variables are available. These are included in the name of the file as M, L and U.
The files with the extension tif.gz were downloaded. These are zipped files that should be unpacked after downloading. Metadata about the files can be found in the files with the extension tif.xml and in Hengl et al. (2014).

For calculation of the Hydrologic Soil Group (USDA, 2009) a simulated groundwater depth map of de Graaf et al. (2015) was used as input.

1.4 Output variables

1.4.1 Overview

The following soil hydraulic properties were calculated (Table 3):

Table 3. Soil hydraulic properties

Name	**Variable**	**Unit**
ORMC	Organic Matter Content	%
STC	Soil Texture Class	O (Organic), VF (Very Fine), F (Fine), MF (Medium Fine), C (Coarse), M (Medium)
ALFA	Alfa parameter for Mualem Van Genuchten Equation	1/cm
N	N parameter for Mualem Van Genuchten Equation	-
WCsat	Saturated Water Content	m^3/m^3
WCres	Residual Water Content	m^3/m^3
Ksat	Saturated Hydraulic Conductivity	cm/d
WCpF2	Water content at pF2 (field capacity)	m^3/m^3
WCpF3	Water content at pF3 (critical point)	m^3/m^3
WCpF4.2	Water content at pF4.2 (permanent wilting point)	m^3/m^3
WCavail	Available water content (between pF2 and pF4.2)	m^3/m^3
SAT-FIELD	Water content between saturation point and field capacity (pF2)	m^3/m^3
FIELD-CRIT	Water content between field capacity (pF2) and critical point (pF3)	m^3/m^3
CRIT-WILT	Water content between critical point (pF3) and permanent wilting point (pF4.2)	m^3/m^3
Hydrologic_Soil_Group	Hydrologic Soil Group	A (low runoff potential), A/D, B (moderately low runoff potential), B/D, C (moderately high runoff potential), C/D, D (high runoff potential)

The soil hydraulic properties were calculated for all six standard depths, except for the Hydrologic Soil Group which is calculated for the soil layers as a whole. The resulting maps were called the 'HiHydroSoil' maps; High-resolution maps of Soil Hydraulic properties.

1.4.2 Averages over different depths

Some modeling applications require only a topsoil layer and a subsoil layer, rather than 6 depth layers. Therefore the soil hydraulic properties were also averaged for the layers that constitute the topsoil (standard depth 1, 2 and 3; 0-30 cm) and for the layers that constitute the subsoil (standard depth 4 and 5; 30-100 cm). Depending on the soil property, a different calculation procedure was used to derive the average.

The first procedure to average topsoil and subsoil for a variable was by taking the weighted average of the variable e.g.:

$$ORMC\_Topsoil = (D_1 * ORMC\_sd1) + (D_2 * ORMC\_sd2) + (D_3 * ORMC\_sd3) / (D_1 + D_2 + D_3)$$

in which D_1, D_2, D_3 are the depths of layers sd1, sd2 and sd3 respectively and ORMC_sd1, ORMC_sd2, ORMC_sd3 are the Organic Matter Content at sd1, sd2 and sd3 respectively.

This calculation procedure was used for the following variables:

- Clay content
- Sand content
- Silt content
- Bulk density
- Organic carbon content
- Cation exchange capacity
- Organic matter content
- Saturated water content
- Volumetric water content at pF2, pF3, pF4.2
- Available water content
- Saturated water content minus field capacity
- Field capacity minus critical point
- Critical point minus wilting point

Another procedure to average topsoil and subsoil for a variable was by taking the weighted average of variables (calculated with the first procedure) as input for the pedotransfer function, e.g.:

$$WCres\_Topsoil = (0.041 * (SNDPPT\_Topsoil \geq 2)) + (0.179 * (SNDPPT\_Topsoil < 2)).$$

This calculation procedure was used for the following variables:

- Soil Texture Class
- Residual water content
- Alfa
- N

For output variable K_{sat} the average for topsoil and subsoil was calculated as follows:

$$K_{sat}Topsoil = (D_1 + D_2 + D_3) / ((D_1/K_{sat}\_sd1) + (D_2/K_{sat}\_sd2) + (D_3/K_{sat}\_sd2)).$$

1.4.3 *Organic Matter Content*

The Organic Matter Content is related to the Organic Carbon Content. Organic Matter Content was calculated by multiplying Organic Carbon Content by 1.72 (Pluske et al.).

1.4.4 *Soil Texture Class*

Soil Texture Classes were calculated according a simplification of the FAO-method (Moeys, 2011).

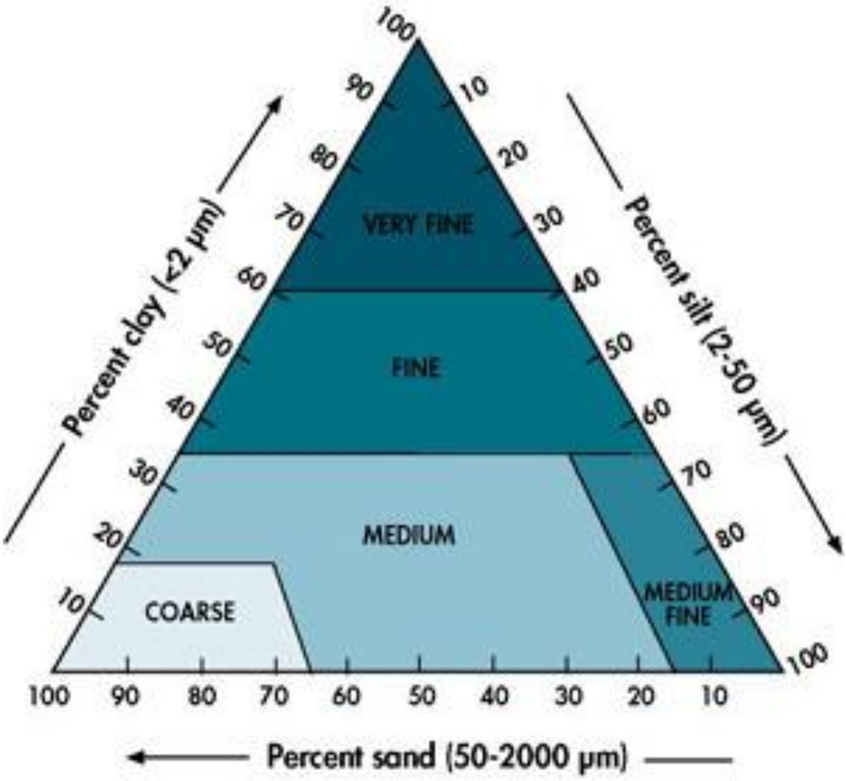

Figure 1. Simplified FAO Soil Texture Classification triangle[1]

Six soil textural classes were distinguished based on the organic matter content, percentage clay and percentage sand (Table 4).

Table 4.Soil Texture Classes

Code on map	Abbreviation	Description
1	O	Organic
2	VF	Very Fine
3	F	Fine
4	MF	Medium Fine
5	C	Coarse
6	M	Medium

[1] Source: http://www.ess.co.at/MANUALS/WATERWARE/soilclassification.html.

The soil texture classification tree first distinguishes between organic and mineral soils:

ORGANIC SOILS:

1. Organic Matter > 20%

Mineral soils are classified according the classification triangle in Figure 1:

MINERAL SOILS

Organic Matter ≤ 20% and:

2. If Clay content > 60%: VF

3. If Clay content ≤ 60% and > 35%: F

4. If Clay content ≤ 35% and Sand content < 15%: MF

5. If Clay content is < 18% and Sand content > 65%: C

6. If Clay content ≥ 18% and ≤ 35% and Sand content ≥ :M
   Or if Clay content < 18% and Sand content ≤ 65% and ≥ 15%: M

1.4.5 Hydrologic Soil Group

Along with land use, land management practices and soil hydrologic conditions the Hydrologic Soil Group (HSG) determines the Runoff Curve Number which is often used in hydrological modelling to estimate the direct runoff from rainfall. Four hydrologic soil groups and three dual hydrologic soil groups are described by the USDA (2009) as follows:

- Group A: Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil.
- Group B: Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded.
- Group C: Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted.
- Group D: Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted.
- *Dual hydrologic soil groups*: Soils having a water table within 60 centimeters of the surface are placed in group D even though the saturated hydraulic conductivity may be favorable for water transmission. If these soils can be adequately drained, then they are assigned to dual hydrologic soil groups (A/D, B/D, and C/D) based on their saturated hydraulic conductivity and the water table depth when drained. The first letter applies to the drained condition and the second to the undrained condition. For the purpose of hydrologic soil group, adequately drained means that the seasonal high water table is kept at least 60 centimeters below the surface in a soil where it would be higher in a natural state.

The HSG classification criteria given by the USDA (2009) are given in Table 5.

Table 5. Hydrologic Soil Group classification criteria

Depth to water impermeable layer[1]	Depth to high water table[2]	K_{sat} of least transmissive layer in depth range (cm/d)	K_{sat} depth range (cm)	HSG[3]
< 50 cm	-	-	-	D
≥ 50 cm ≤ 100 cm	< 60 cm	> 345.6	0- 60	A/D
		> 86.4 ≤ 345.6	0- 60	B/D
		> 8.64 ≤ 86.4	0- 60	C/D
		≤ 8.64	0- 60	D
	≥ 60 cm	> 345.6	0- 50[4]	A
		> 86.4 ≤ 345.6	0- 50[5]	B
		> 8.64 ≤ 86.4	0- 50[5]	C
		≤ 8.64	0- 50[5]	D
> **100 cm**	< 60 cm	> 86.4	0- 100	A/D
		> 34.56 ≤ 86.4	0- 100	B/D
		> 3.456 ≤ 34.56	0- 100	C/D
		≤ 3.456	0- 100	D
	≥ 60 cm ≤ 100 cm	> 345.6	0- 50[5]	A
		> 86.4 ≤ 345.6	0- 50[5]	B
		> 8.64 ≤ 86.4	0- 50[5]	C
		≤ 8.64	0- 50[5]	D
	> 100 cm	> 86.4	0- 100	A
		> 34.56 ≤ 86.4	0- 100	B
		> 3.456 ≤ 34.56	0- 100	C
		≤ 3.456	0- 100	D

As can be seen from Table 5 an impermeable layer can consist of bedrock, but it can also be a soil layer with a K_{sat} lower than 0.0864 cm/d. However, the minimum K_{sat} of sd1-sd5 was nowhere lower than 0.154 cm/d. Therefore only the depth to bedrock was used in the analysis.

Since values for the complete land mask were required, missing data was replaced by data from the Harmonized World Soil Database (HWSD). The Hydrologic Soil Group had to be calculated for the HWSD as consistent as possible with the way the HSG was calculated for SoilGrids1km. Since information on depth to impermeable layer and water table depth were not available for the HWSD, only K_{sat} was used a classification criteria. For the HWSD a distinction was made only between topsoil (T) and subsoil (S). Topsoil was defined as 0-30 cm and subsoil as 30-100 cm (FAO, 2008). From the HiHydroSoil maps it was noted that the least transmissive layer was almost always sd4. Therefore it was decided to use the minimum K_{sat} of the topsoil

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[1] An impermeable layer has a K_{sat} less than 0.0864 cm/d or a component restriction of fragipan; duripan; petrocalcic; orstein; petrogypsic; cemented horizon; densic material; placic; bedrock, paralithic; bedrock, lithic; bedrock, densic; or permafrost.

[2] High water table during any month during the year.

[3] Dual HSG classes are applied only for wet soils (water table less than 60 cm. If these soils can be drained, a less restrictive HSG can be assigned, depending on the Ksat.

[4] Since no distinction between a depth range of 0-60 cm and a depth range of 0-50 cm could be made (sd1-sd3 = 0-30cm, sd1-sd4 = 0-60 cm), the minimum K_{sat} was always determined for a depth range of 0-60 cm.

and subsoil layer for further classification. Since data on depth to impermeable layer and water table depth were not available, dual hydrologic soil groups could not be calculated for the HWSD. Furthermore, only the criterion for K_{sat} that corresponds to a Ksat depth range of 0-50 or 0-60 cm was used.

2 Mualem Van Genuchten Model

2.1 Soil Moisture Retention curve

To calculate water content at a certain pressure head the moisture retention curve derived by Van Genuchten was used (Khaleel et al., 1995):

$$\theta(\psi) = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + (\alpha|\psi|)^n\right]^{1-1/n}}$$

where
θ is volumetric moisture content (m^3/m^3);
θ_s is saturated moisture content (m^3/m^3);
θ_r is residual moisture content (m^3/m^3);
α is a van Genuchten curve-fitting parameter(1/cm);
ψ is matric potential or pressure head (-cm);
n is a van Genuchten curve-fitting parameter (-);
m is 1 - 1/n.

2.2 Water Content Values

For calculation of the water content at pF2 with the van Genuchten equation as pressure head of -100 cm was used, for pF3 a pressure head of -1,000 cm was taken and for pF 4.2 a pressure head of -16,000 cm was assumed.

2.3 Hydraulic conductivity curve

For calculating unsaturated hydraulic conductivity for a certain pressure head the original van Genuchten equation with Mualem substitution (Equation 1 in Figure 2) was used, the value of L was assumed to be 0.5 and K_0 was equal to the K_{sat} that was derived with a pedotransfer function (see Chapter 3). This results in Equation 2 in Figure 2 (Rucker et al., 2005):

$$\frac{\theta - \theta_r}{\theta_s - \theta_r} = [1 + (\alpha_{VG} h)^n]^{-m}, \tag{1}$$

$$K = K_s \frac{[1 - (\alpha_{VG} h)^{n-1}[1 + (\alpha_{VG} h)^n]^{-m}]^2}{[1 + (\alpha_{VG} h)^n]^{-m/2}}, \tag{2}$$

$$m = 1 - \frac{1}{n}, \tag{3}$$

where θ [–] is the volumetric water content at a pressure head of h [L], θ_r is the residual water content, θ_s is the saturated water content, n [–] and m [–] are empirical parameters relating to the pore size distribution, K_s [L T^{-1}] is the saturated hydraulic conductivity, K [L T^{-1}] is the unsaturated hydraulic conductivity as a function of pressure head, and α_{VG} [L^{-1}] is a constant.

Figure 2. van Genuchten model equations (Rucker et al., 2005).

3 Pedotransfer functions

In order to convert the soil properties into soil hydraulic functions as described by the Mualem Van Genuchten (MVG) model, so-called pedotransfer functions can be used. The pedotransfer functions that were used here were described by Tóth et al. (2014), who derived pedotransfer functions for a wide range of European soils. The soil hydraulic parameters that were derived with pedotransfer functions were the parameters of the Soil Moisture Retention curve (θr, θs, α and N) and Ksat.

3.1 Residual water content (θr)

A regression tree was used to determine the residual water content (θ_r in m^3/m^3).

Rule 1:
IF Sand content (%) >= 2.00 $\theta_r = 0.041$

Rule 2:
IF Sand content (%) < 2.00 $\theta_r = 0.179$

3.2 Saturated water content (θ_s)

Linear regression was used to determine saturated water content (θ_s in m^3/m^3) with the following equation:

$$\theta_s = 0.83080 - 0.28217 * BD + 0.0002728 * Cl + 0.000187 * Si$$

in which BD is bulk density (in g/cm^3), Cl is clay content (%) and Si is silt content (%).

3.3 Mualem van Genuchten parameter Alfa

For deriving the Alfa parameter (1/cm) used in the Mualem-Van Genuchten equations the following equation was used:

$$\log_{10}(\alpha) = -0.43348 - 0.41729 * BD - 0.04762 * OC + 0.21810 * T/S - 0.01581 * Cl - 0.01207 * Si$$

in which BD is bulk density (in g/cm^3), OC is Organic Carbon Content (%), T/S is the topsoil and subsoil distinction, Cl is clay content (%)and Si is silt content (%). In the Global Soil Map of Hydraulic Properties a distinction was made only between topsoil (T) and subsoil (S). Topsoil was defined as 0-30 cm and subsoil as 30-100 cm (FAO, 2008). When soil depth is within the definition of topsoil, the value for T/S in the equations is 1, otherwise it is 0.

3.4 Mualem van Genuchten parameter N

For deriving the N (-) parameter used in the Mualem-Van Genuchten equations the following equation was used:

$\log10(n-1) = 0.22236 - 0.30189 * BD -0.05558 * T/S - 0.005306 * Cl - 0.003084 * Si - 0.01072 * OC$

in which BD is bulk density (in g/cm^3), T/S is the topsoil and subsoil distinction, Cl is clay content (%), Si is silt content (%) and OC is Organic Carbon Content (%).

3.5 Saturated hydraulic conductivity

The saturated hydraulic conductivity (K_{sat} in cm/d) was derived using the following equation:

$\log_{10}K_S = 0.40220 + 0.26122 * pH + 0.44565 * T/S - 0.02329 * Cl - 0.01265 * Si - 0.01038 * CEC$

in which pH is pH in water, T/S is the topsoil and subsoil distinction, Cl is clay content (%), Si is silt content (%) and CEC is cation exchange capacity (meq/100g).

3.6 Units

Note that for SoilGrids1km some variables have different units than in the pedotransfer functions described above. Bulk Density is expressed in kg/m^3, Organic Carbon Content in permilles (‰), pH in pH*10 and CEC in cmolc/kg (which is equal to meq/100g).

4 Results

4.1 Raster characteristics

The pixel size of all output rasters is 0.00833333 * 0.00833333 degree, which is about 0.9 km (at the equator). The XY-resolution is 43200 by 21600.
The No Data Value is -99999 for the non-gap-filled HiHydroSoil maps and -3.40282e+38 for the gap-filled maps. The data type is Float32.

4.2 Missing Data

In contrast to the HWSD the SoilGrids1km maps contained missing data. The explanation of the map composers in Hengl et al. (2014) is as follows:
"We have also purposely excluded all areas that show no evidence of historical vegetative cover. Our predictions are hence not globally complete. This is a definite drawback for use in global modelling and we acknowledge a need to use either expert judgment or data from other mapping sources to provide alternative predictions for areas with missing values. Again, for deserts and bare rock areas it is perfectly valid to assume a 0 value for soil organic carbon, but it is not as straightforward to estimate soil pH for shifting sand areas for example. For the present, we argue that it is inappropriate to try to make predictions for areas that completely lack vegetative cover e.g. shifting sands of Sahara. These areas have very few to zero point profile observations which can be used to calibrate statistical prediction models. In addition, even if they did have a sufficient number of point profile measurements, the environments of extreme climatic conditions are so different from vegetated ones so that any prediction model is likely to be very different from ones we develop for vegetated areas. We recommend that SoilGrids1km users who require values for the complete land mask fill in the gaps by using expert knowledge or best regional estimates as available from conventional soil mapping (e.g. HWSD, ISRIC-WISE)."

Since values for the complete land mask were required, missing data was replaced by the values from the Global Soil Map of Hydraulic Properties (Droogers, 2011) that was based on the HWSD map. In the Global Soil Map of Hydraulic Properties a distinction was made only between topsoil (T) and subsoil (S). Topsoil was defined as 0-30 cm and subsoil as 30-100 cm (FAO, 2008). Data gaps in the HiHydroSoil maps that were averaged for the topsoil layers (0-30 cm) were filled with the topsoil layer of the Global Soil Map of Hydraulic Properties that has the same depth range. Data gaps in the HiHydroSoil maps that were averaged for the subsoil layers (30-100 cm) were filled with the subsoil layer of the Global Soil Map of Hydraulic Properties that has the same depth range.

4.3 Comparing HiHydroSoil with Global Soil Map of Hydraulic Properties

4.3.1 Soil Texture Class for the Netherlands

The Soil Texture Classes differed considerably for the Global Soil Map of Hydraulic Properties and HiHydroSoil. For HiHydroSoil soil texture class ‘Very Fine’ (VF) is not present anymore, anywhere in the world for any depth. For the Netherlands class ‘Fine’ (F) and class ‘Medium Fine’ (MF) are neither present anymore (Figure 3 and Figure 4). Also the extent of class ‘Coarse’ (C) has decreased. Instead the presence of class ‘Medium’ (M) has increased. This is caused by a decrease of the clay content and a decrease in variation in sand content for SoilGrids1km (Figure 5, Figure 6, Figure 7 and Figure 8).

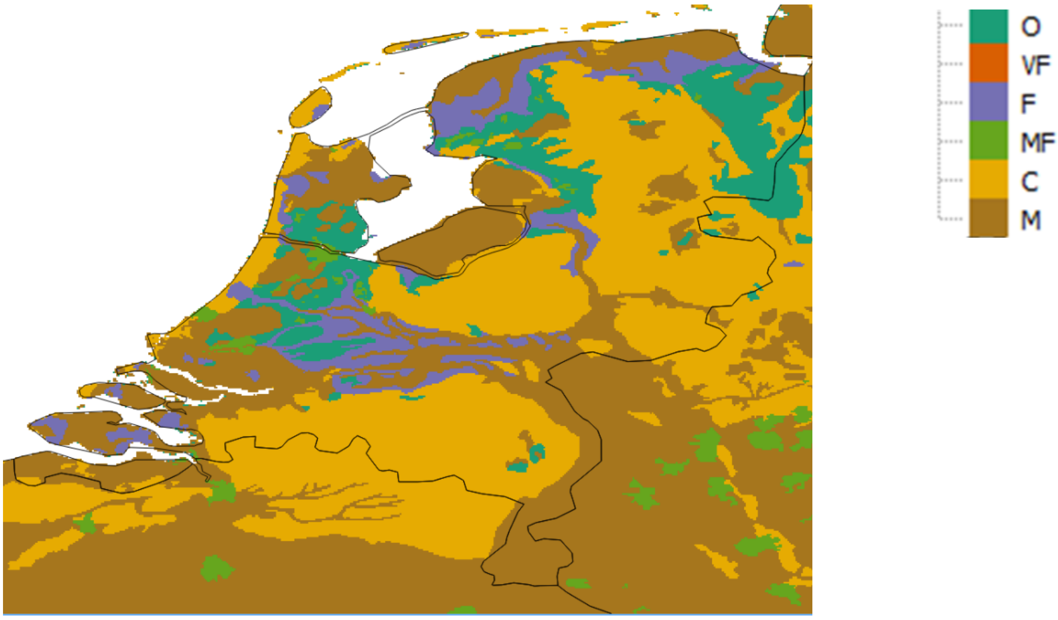

Figure 3. Soil Texture Class of the topsoil of the Netherlands for Global Soil Map of Hydraulic Properties.

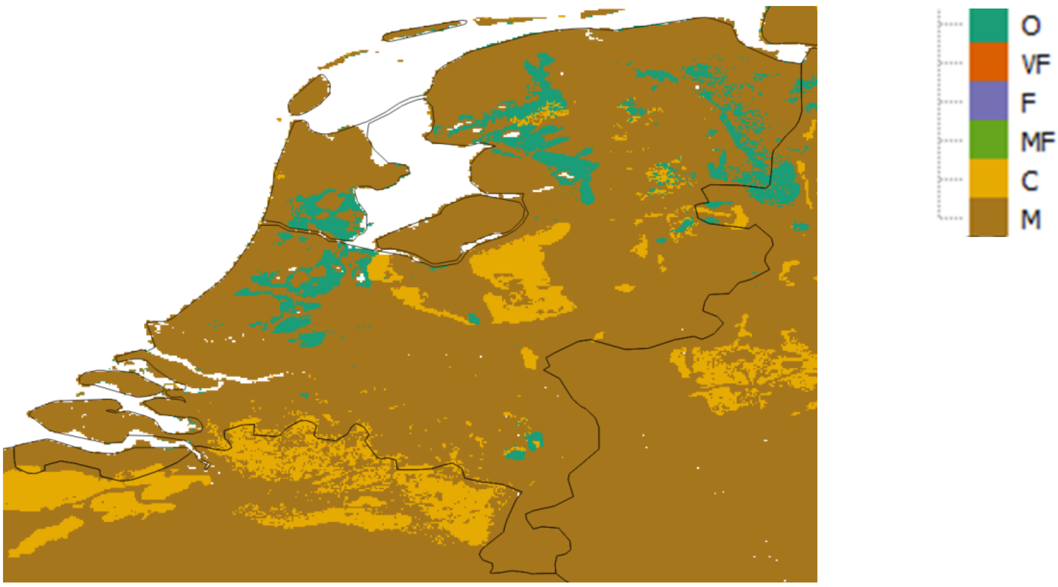

Figure 4. Soil Texture Class of the topsoil of the Netherlands for HiHydroSoil.

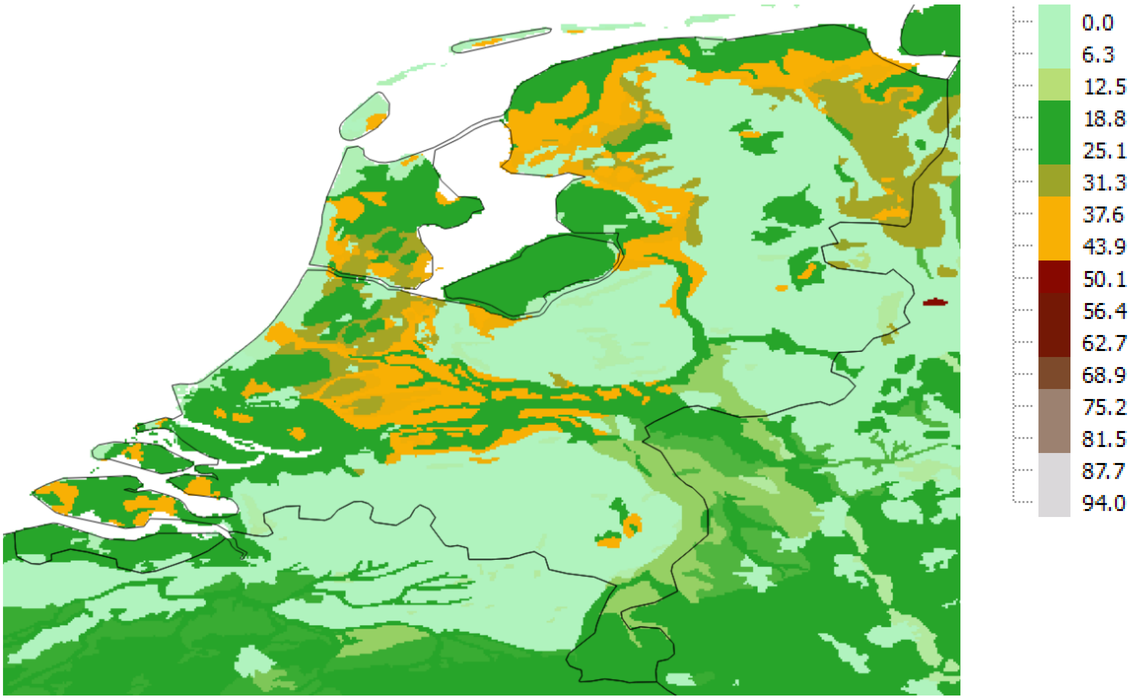

Figure 5. Clay content (%) of the topsoil of the Netherlands for HWSD.

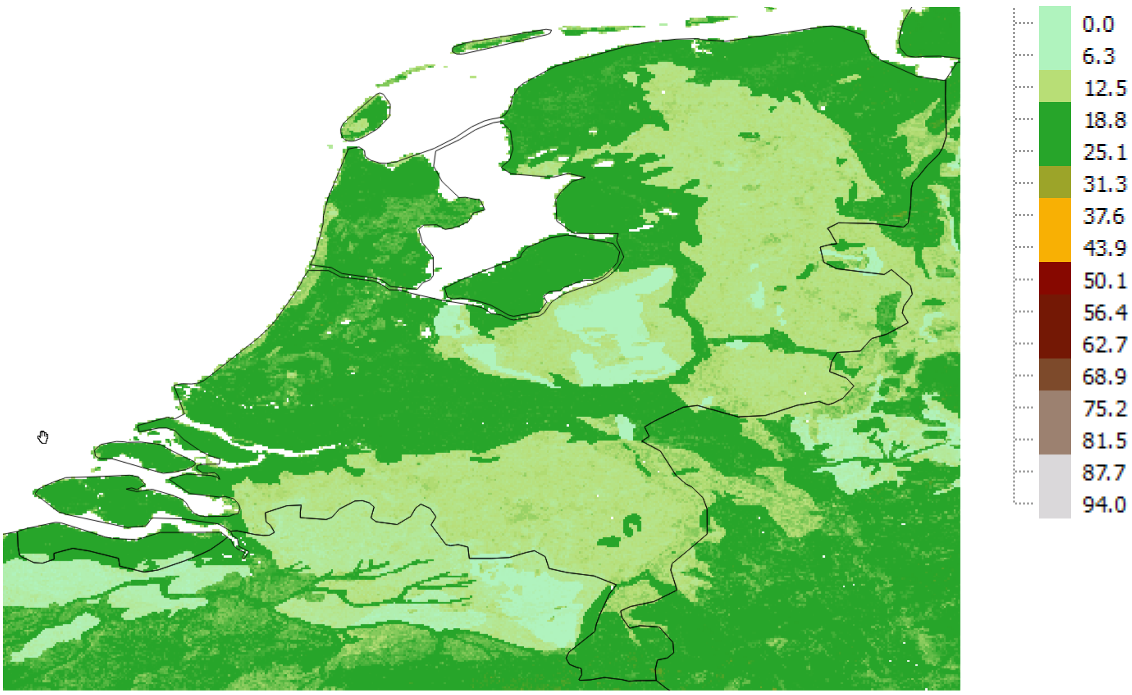

Figure 6. Clay content (%) of the topsoil of the Netherlands for SoilGrids1km.

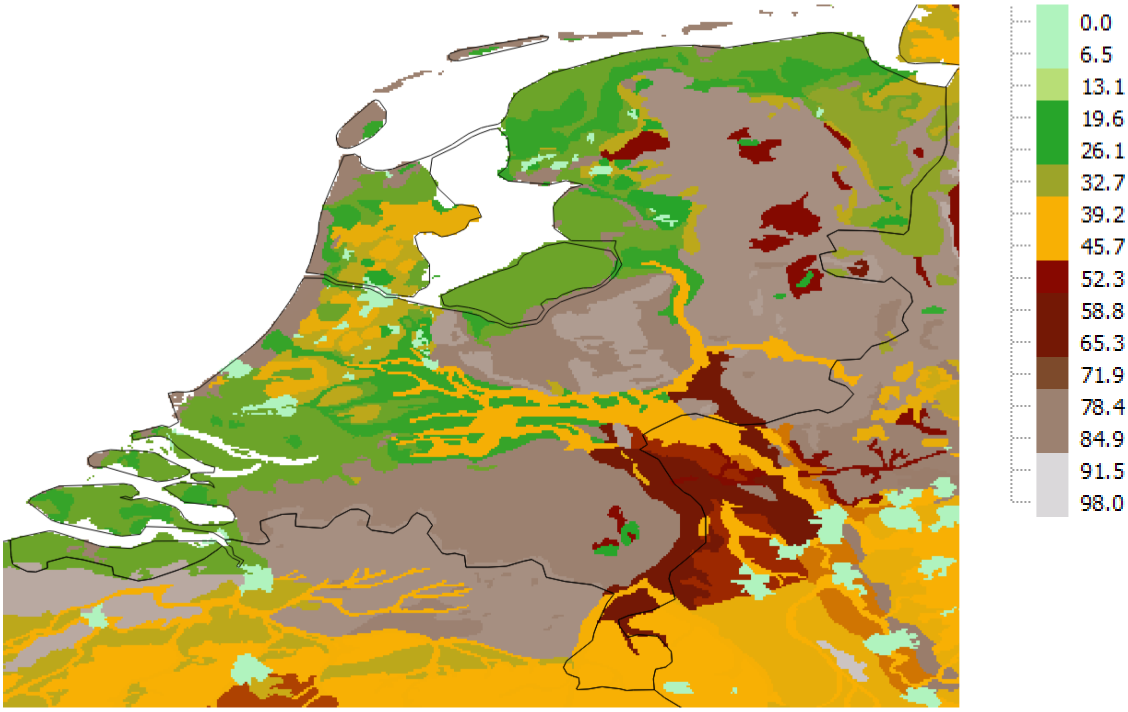

Figure 7. Sand content (%) of the topsoil of the Netherlands for HWSD.

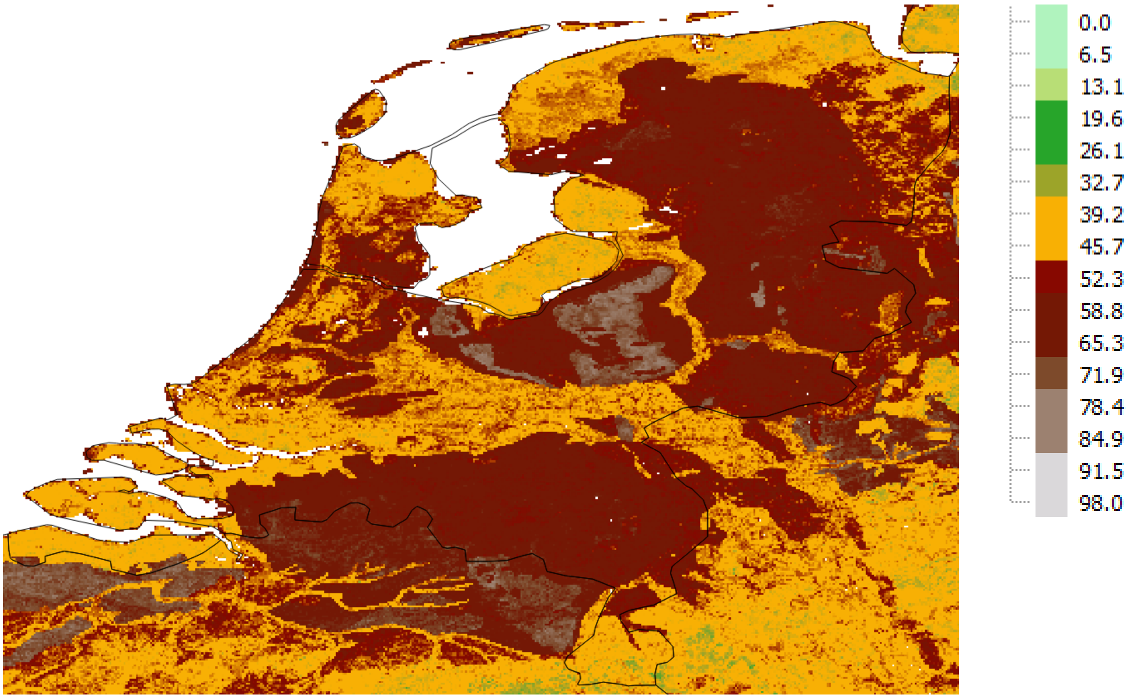

Figure 8. Sand content (%) of the topsoil of the Netherlands for SoilGrids1km.

4.3.2 Sand content northern Vietnam

From the Sand content maps of northern Vietnam it can be seen that detail has increased much for SoilGrids1km compared to the HWSD (Figure 9 and Figure 10).

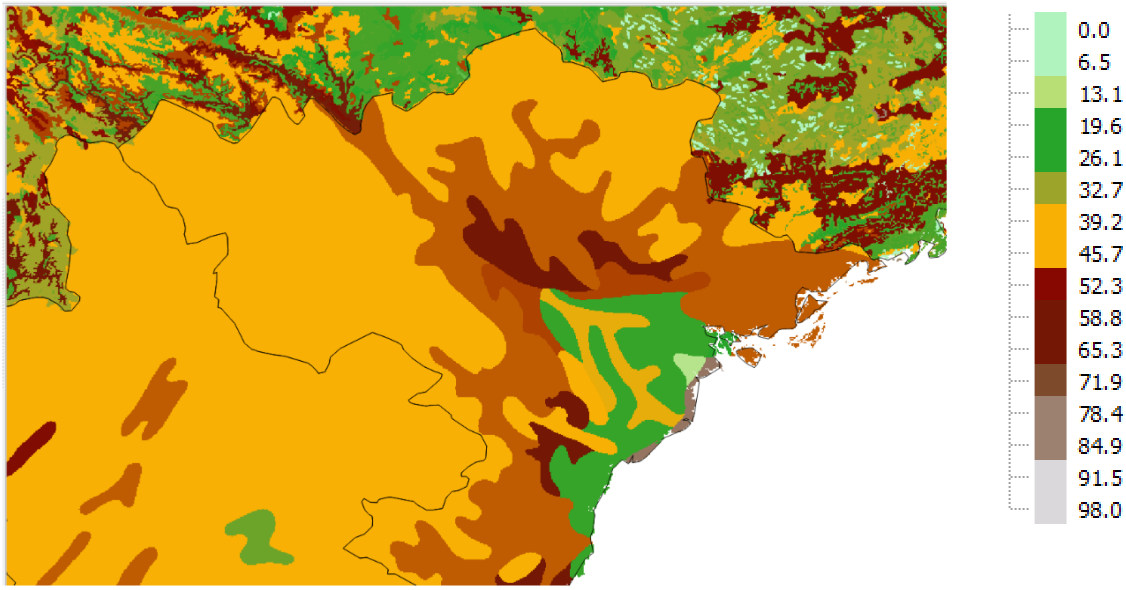

Figure 9. Sand content (%) of the topsoil of Vietnam for HWSD.

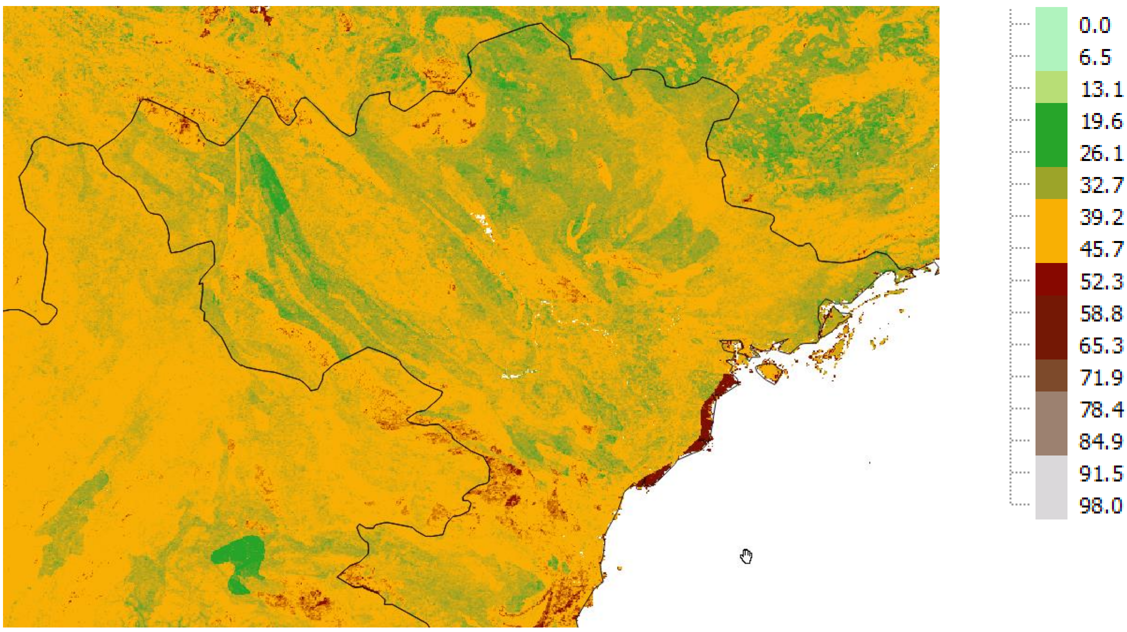

Figure 10. Sand content (%) of the topsoil of Vietnam for SoilGrids1km.

4.3.3 *Clay content and Soil Texture Class for southern Mozambique*

The clay percentages along the borders with South-Africa and Zimbabwe are clearly higher for the HWSD (Figure 11, upper left) than for SoilGrids1km (Figure 11, upper right). To the contrary, in the inlands and along the coastline the clay percentages are lower for HWSD than for SoilGrids1km. Along with a change in sand content, the decrease of variation in clay content leads to a more uniform Soil Texture Classification (Figure 11, lower panels).

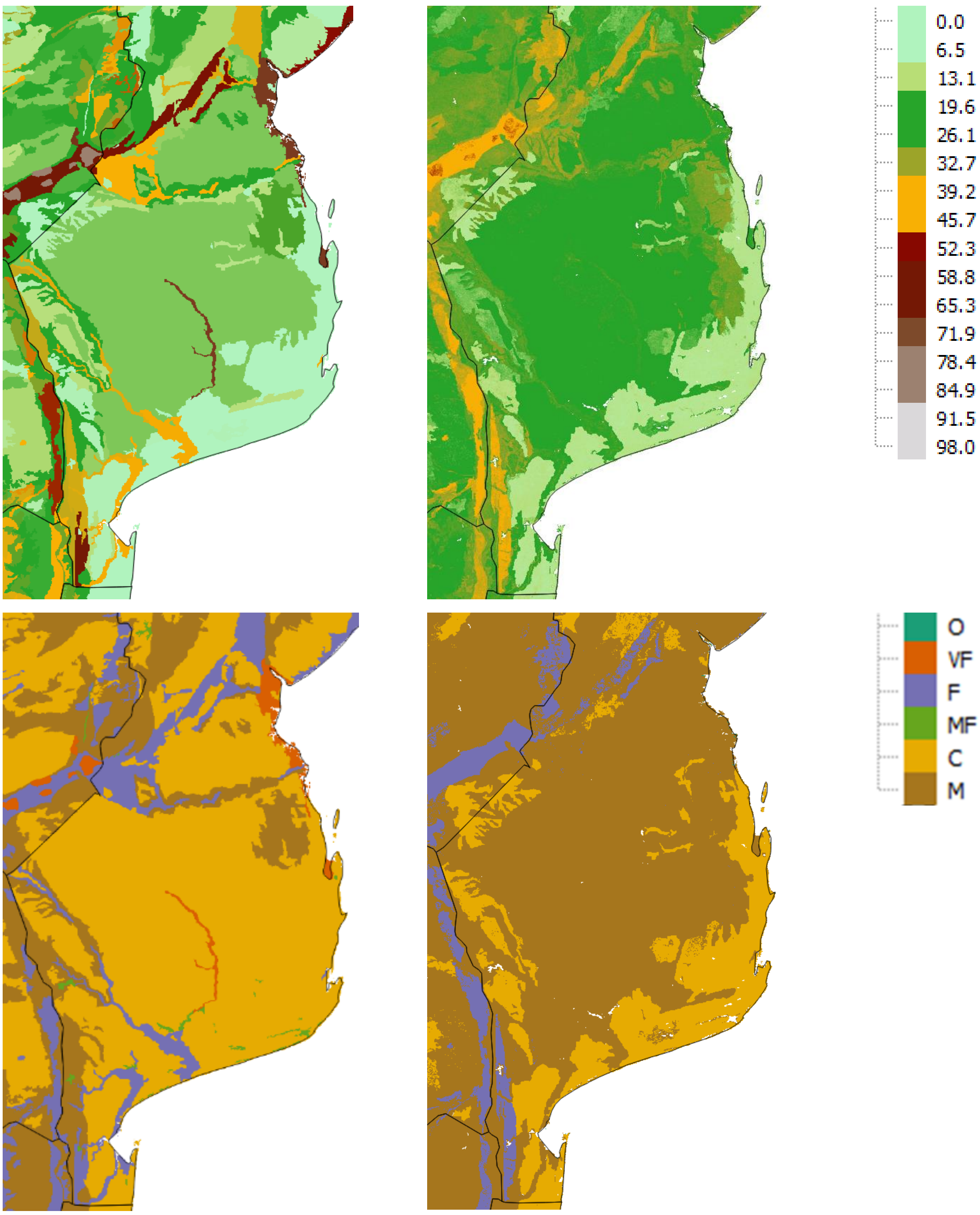

Figure 11. Clay content (%) of the topsoil of Mozambique for the HWSD (upper left) and SoilGrids1km (upper right). Soil Texture Class for the topsoil of Mozambique for the Global Soil Map of Hydraulic Properties (lower left) and HiHydroSoil (lower right).

4.3.4 *Saturated Hydraulic Conductivity for Romania*

In general K_{sat} has decreased for HiHydroSoil compared to the Global Soil Map of Hydraulic Properties. However, in some areas (upper left corner in Figure 12) where K_{sat} was relatively high, K_{sat} has increased for HiHydroSoil. So for this particular area variation in K_{sat} has increased. Also the detail has increased largely for HiHydroSoil (Figure 13).

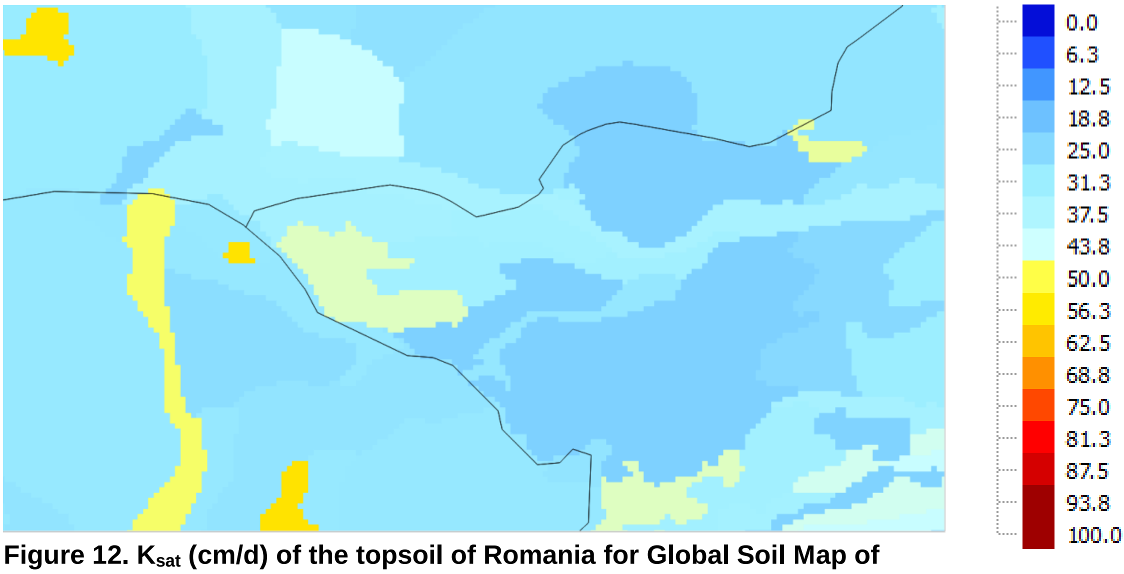

Figure 12. K_{sat} (cm/d) of the topsoil of Romania for Global Soil Map of Hydraulic Properties.

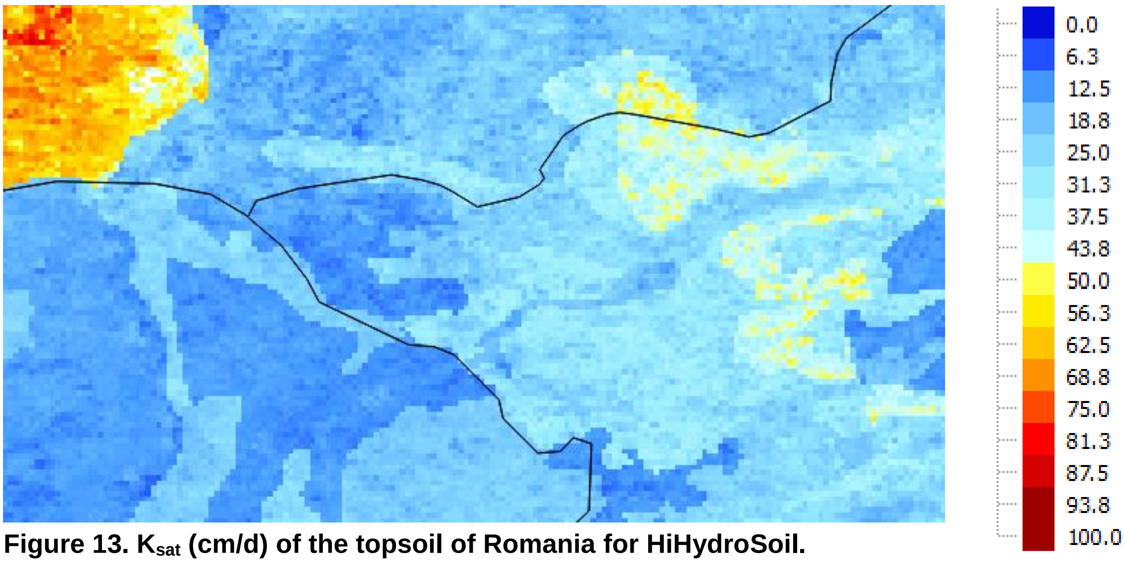

Figure 13. K_{sat} (cm/d) of the topsoil of Romania for HiHydroSoil.

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