



Food and Agriculture
Organization of the
United Nations

GLOBAL SOIL NUTRIENT AND NUTRIENT BUDGET MAPS (GSNMAP)

10th Meeting of the
International Network
of Soil Information
Institutions (INSII)

15-16-17 January 2025

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GSP - Land & Water Division - FAO





GSNmap

Global Soil Nutrient and Nutrient Budget Maps



GSNmap



Historically **high input prices** have been driven by the current global challenges



Data-driven management solutions are needed to boost **farmer resilience**



The **GSNmap** will provide **soil nutrient as well as soil nutrient budget maps** to optimize the sustainable management of soil nutrients

GSNmap – Two phase approach:

Phase I

Development of soil macronutrient
and soil property maps

Generation of
Soil Nutrient Budget maps for
NPK

Phase II

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GSP Members
request for
GSNmap

Global, Country-driven – *Of the countries, by the countries, for the countries*

**GSNmap
Products**

Methodology

Definition of a methodology
through the support of the
GSP's technical networks,
Working groups and the ITPS

✓ published

Technical specifications and country guidelines

Publication and divulgation to
define a standardized approach

✓ done

Capacity Building Program

Online Technical Manual
Online regional training &
follow-up one to one
technical sessions with
National Experts

National Submission

Quality assessment and
quality check of the
submitted maps

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GSNmap



Methodology



Extent



Process

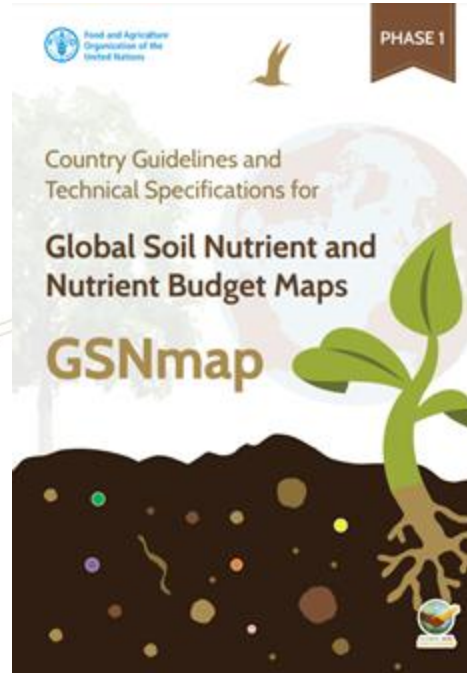
- **Phase I: Digital Soil Mapping** based on a machine learning algorithm (Quantile Regression Forest)
- **Phase II: N, P, K nutrient budgets**
 - Scale: **National (Croplands)**
 - Depth: **0-30 cm**
 - Resolution: **250 x 250 m**
- **Country-driven** (global map based on national submissions)
- Updated following a **Versioning system**

Join the country-driven mapping exercise



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Country guidelines & technical specifications

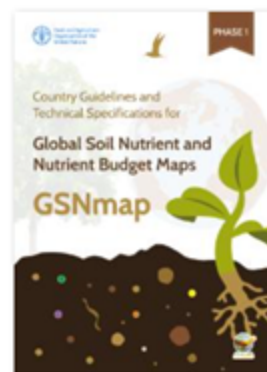
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Document

Country guidelines and technical specifications for global soil nutrient and nutrient budget maps

GSNmap: Phase 1



Download: 

Year of publication: 2022

Place of publication: Rome, Italy

Pages: #34 p.

ISBN: 978-92-5-136795-7

Author: FAO

Publisher: FAO

Agrovoc: farmland; soil fertility; soil properties; nutrient availability (soil); soil maps; digital technology; modelling; guidelines

Abstract:

The "Country Guidelines provides guidance and technical specifications for the first phase of the GSNmap initiative which aims to generate national maps of soil nutrients and associated soil properties at 250 m resolution for agricultural lands based on a country-driven approach. On the one hand, soil nutrient maps will provide a baseline for identifying areas where their levels are critical for crop growth and will thus serve as an important decision-making tool. On the other hand, associated soil parameters such as organic carbon, pH, soil texture, bulk density, and cation exchange capacity will be mapped, which can highlight the key limits to nutrient availability. In order to obtain consistent results and to allow comparisons between countries and regions, we propose a standard methodology based on digital soil mapping techniques. General modelling procedures, data requirements and data sources are described. The final product specifications and data submission formats are also provided. The final product will be relevant to identify the level of nutrients and associated soil properties per regions, environments and agricultural systems, and to establish priorities for the implementation of global and national public and private policies.

Cite this content as:

FAO. 2022. *Country guidelines and technical specifications for global soil nutrient and nutrient budget maps – GSNmap: Phase 1*. Rome.

<https://doi.org/10.4060/cc1717en>

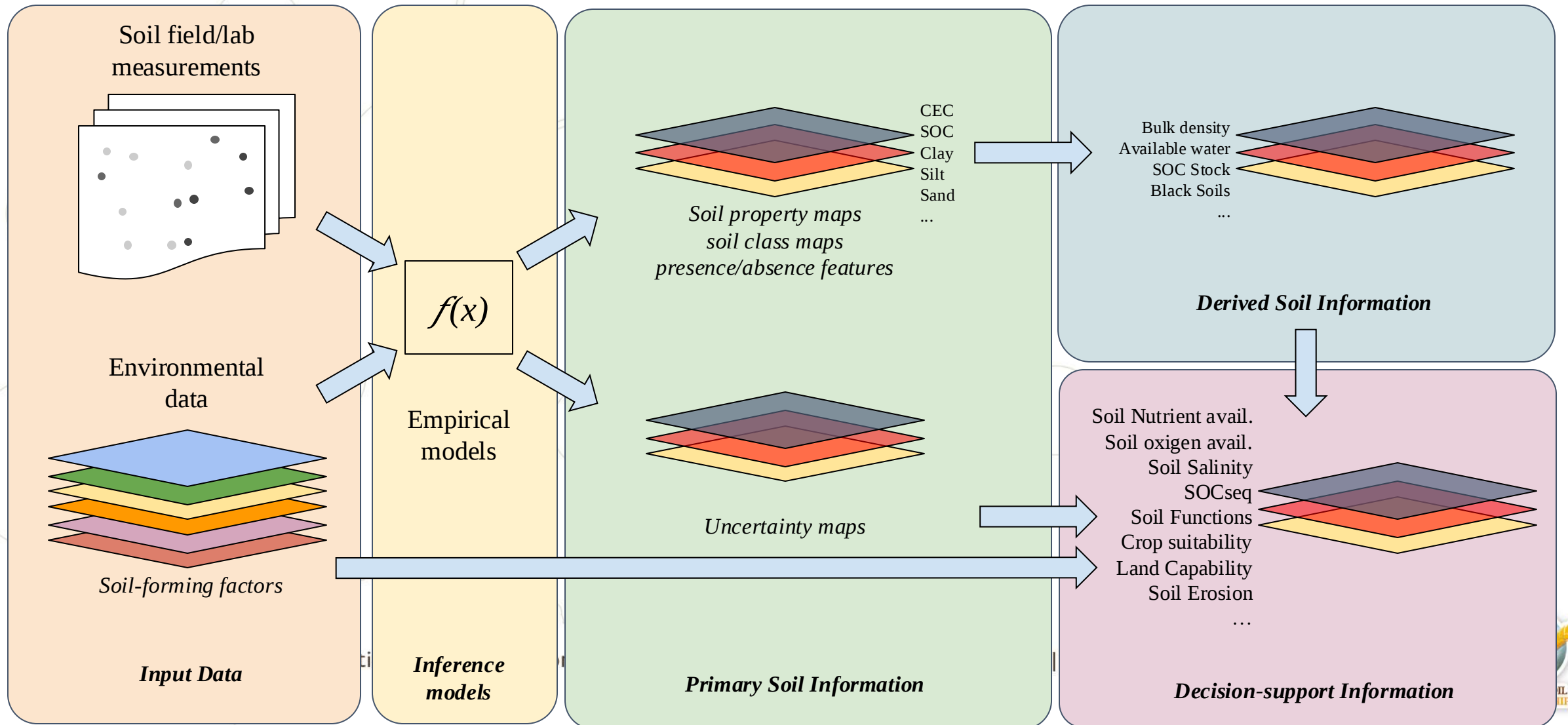
<https://www.fao.org/documents/card/en/c/cc1717en>

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Digital Soil Mapping

$$S = f(s, c, o, r, p, a, n) + \varepsilon$$



Target nutrients and soil properties

Table 3: Overview of the laboratory methods that are used to measure the soil properties mapped in the GSNmap

Soil attribute	Unit	Laboratory method
Total Nitrogen	ppm	Dumas dry combustion method (FAO, 2021a) or Kjeldahl method (FAO, 2021b)
Available Phosphorus	ppm	Bray I and II, Mehlich I, Olsen (FAO, 2021c; FAO, 2021d; FAO, 2021e)
Available Potassium	ppm	Mehlich III (Mehlich, 1984)
Cation exchange capacity	cmol _c /kg	Ammonium acetate (Schollenberger and Simon, 1945)
pH	-	Soil pH in H₂O, KCl, CaCO₂ (FAO, 2021f)
Soil fractions (clay, silt, sand)	g/100g	Hydrometer (e.g. Bouyoucos, 1962)
SOC	%	Dumas dry combustion, Walkley-Black, Tyurin spectrophotometric (FAO, 2019a; FAO, 2019b; FAO, 2021g)
Bulk density	g/cm ³	Overview of methods provided by Blake (1965)
Nutrients (Ca, S, Mg, Fe, B, Cl, Mn, Zn, Cu, Mo, Ni, Si)	ppm	DTPA extraction method (FAO, 2022), Mehlich III (Mehlich, 1984), aqua regia extraction (Berrow and Stein, 1983)



Technical Manual

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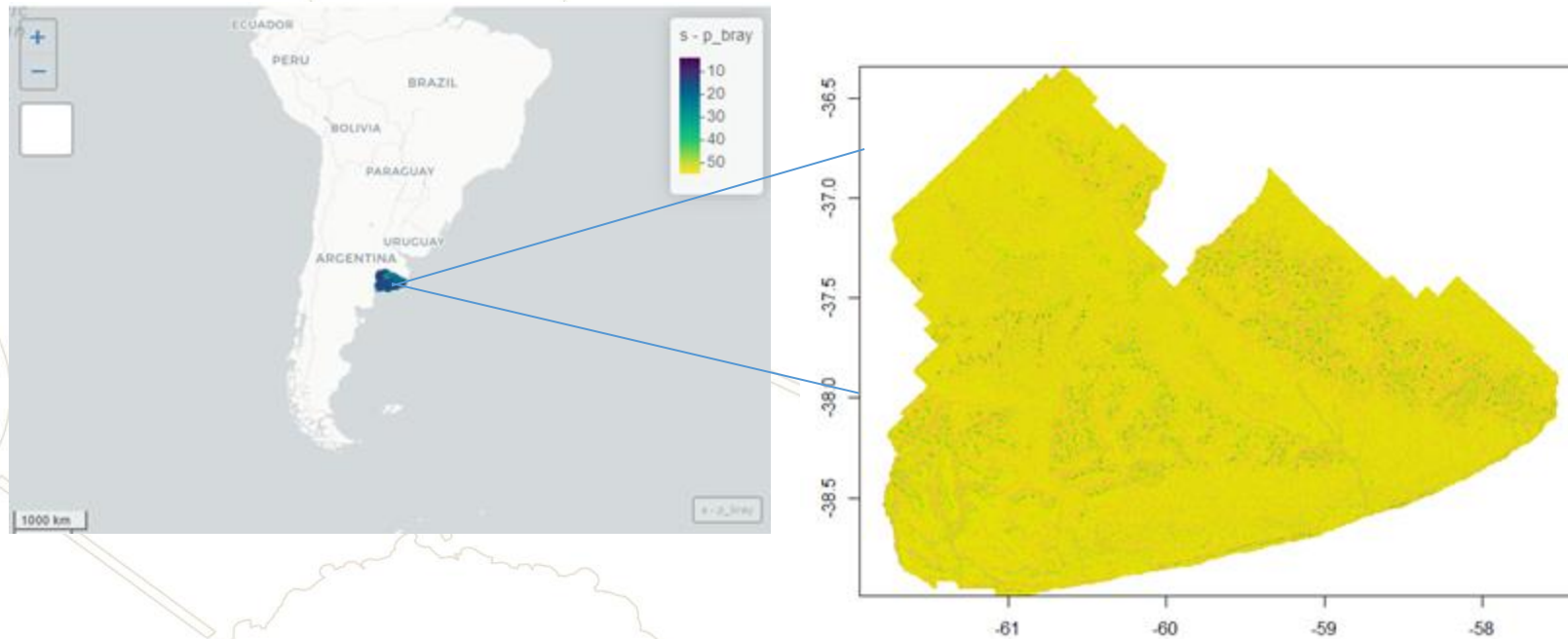
Technical Manual at a glance

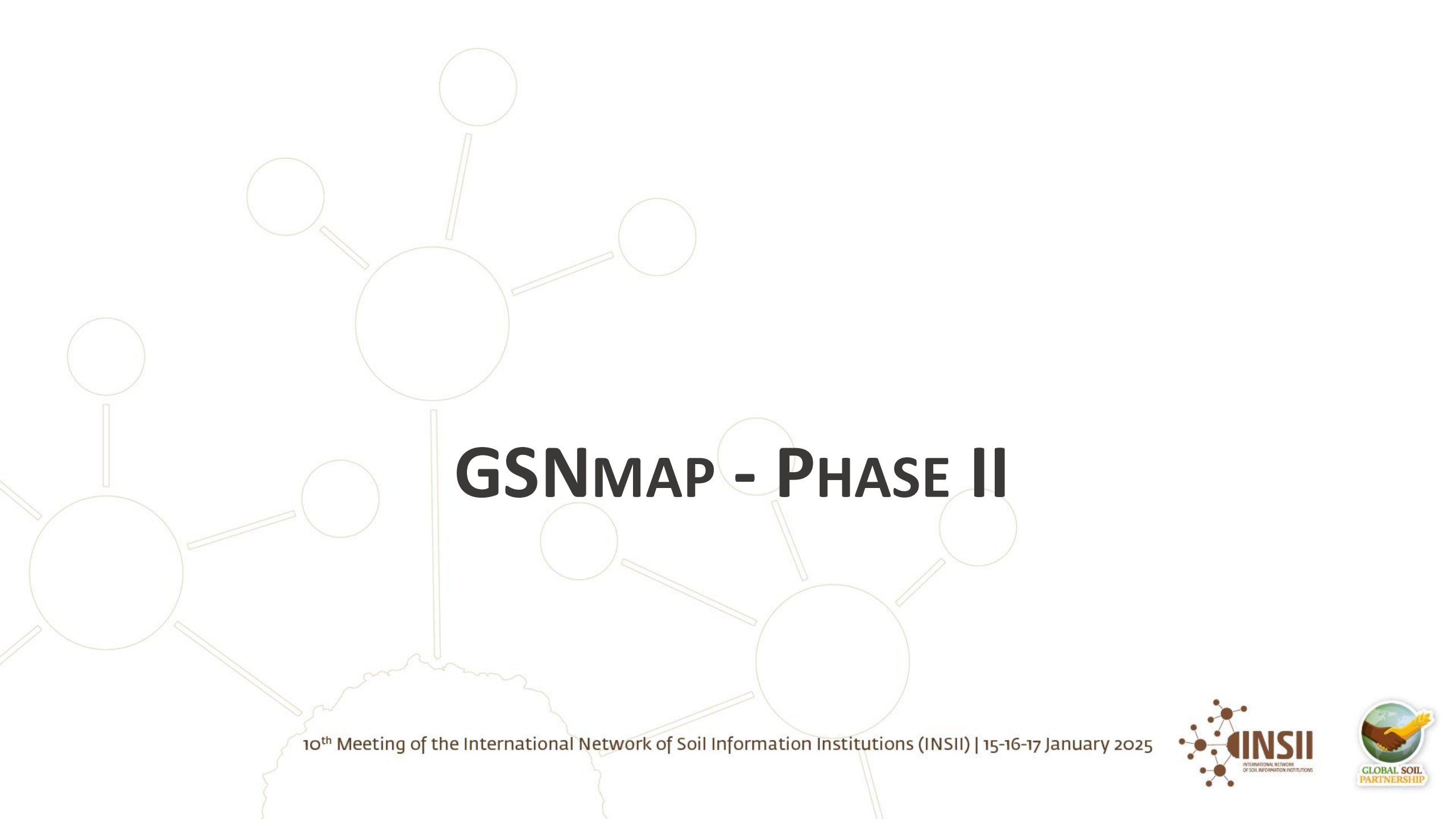
Advanced version: <https://fao-sid.github.io/GSNmap-TM/>

- Step-by-step instructions for mapping
- Topics covered:
 - i. Preprocessing
 - ii. Soil data preparation
 - iii. Download of environmental covariates
 - iv. Covariate selection and model calibration
 - v. Prediction of soil properties
 - vi. Uncertainty assessment
 - vii. Export of layers
 - viii. Steps for quality assurance and quality control
- Published on GitHub with interactive features

Case study - Argentinian district

Dummy data modified for educational purposes originally derived from the *National Institute of Agriculture Technology* and *National University of Mar del Plata* (Unidad Integrada INTA-FCA) (Sainz Rozas et al., 2019)



A faint, light green background graphic consisting of several interconnected circles of varying sizes, representing a network or map. The circles are connected by thin lines, and some are larger than others, creating a hierarchical or interconnected structure.

GSNMAP - PHASE II

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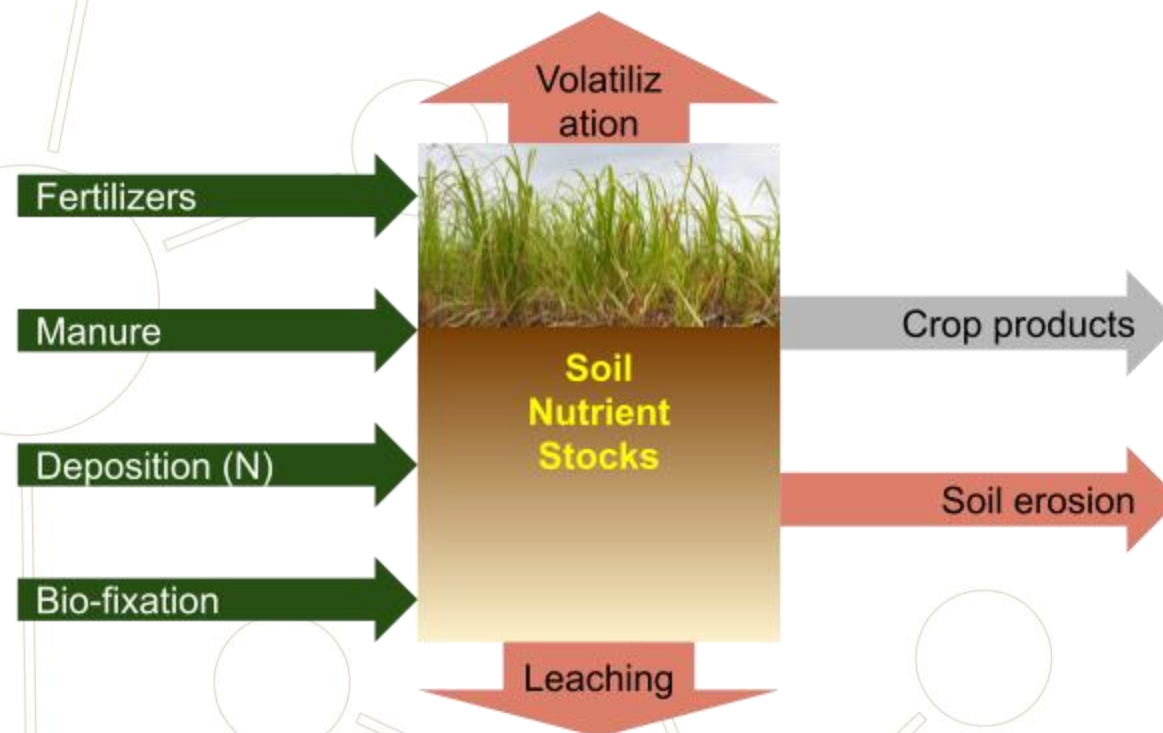


Introduction

- FAOSTAT, IFA and IFRI have been the leading providers of nutrient dynamics at global levels by delivering information on a national and yearly basis
- In the last years, some studies have already addressed mapping the global soil nutrient budget (West et al., 2014 and Zhang et al., 2021), as well as estimations of input and output factors
- GSNmap - Phase II aims to enhance global-scale soil nutrient budgets by considering the soil nutrient stocks and losses from erosion and leaching factors under a country-driven approach
- Initial soil nutrient stocks provide a reference baseline for assessing the impact of nutrient budget maps and determining soil degradation
- Country-driven approach, combining local expertise and global data on fertilizer use and crop data
- Phase II of the GSNmap presents a Tier approach that allows for the incorporation of nationally available information

Nutrient budget framework

- Zhang et al., 2021
- FAOSTAT, 2022
- Lesschen et al., 2007

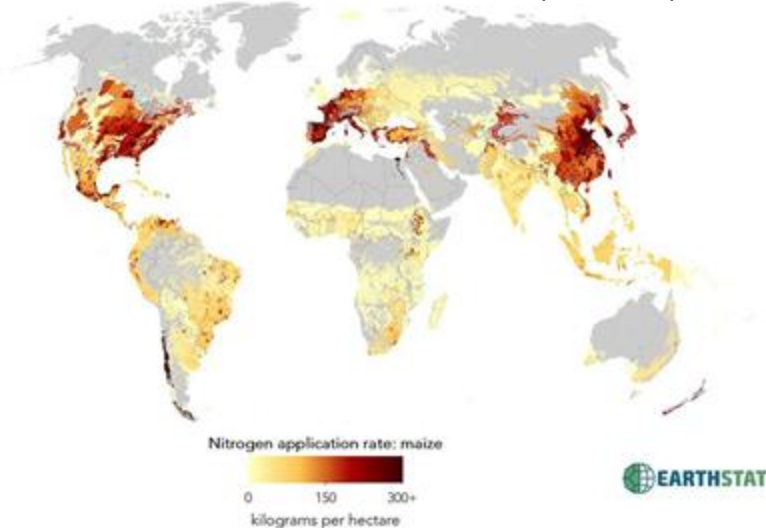


$$SNB_y = \sum_{i=1}^n (SF_{i,y} + MAS_{i,y} + ND_{i,y} + BF_{i,y}) - \sum_{i=1}^n (CR_{i,y} + NL_{i,y} + NLO_{i,y} + ER_{i,y}) \quad (Eq. 1)$$

INPUT: Synthetic Fertilizers (crop type)

Input/Output	Tier One (Default Datasets)	Tier Two (National Datasets)
Synthetic Fertilisers (SF)	Mueller et al., 2012. Nutrient Application for Major Crops (EarthSTAT) Lu et al. 2017. Global nitrogen and phosphorus fertilizer use in agriculture.	- Fertilisers by Nutrient (FAOSTAT https://www.fao.org/faostat/en/#data/RFN) at subnational level

mineral fertilizers, manure, and atmospheric deposition



<http://www.earthstat.org/nutrient-application-major-crops/>

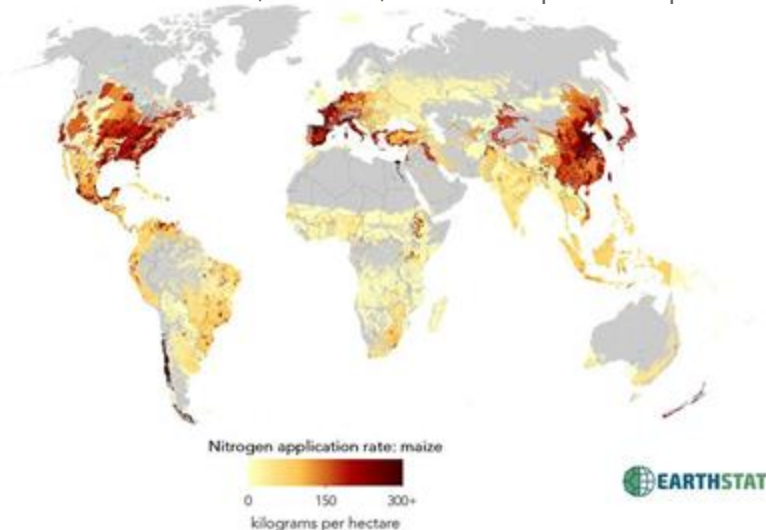
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INPUT: Manure applied to soils

Input/Output	Tier One (Default Datasets)	Tier Two (National Datasets)
Manure Applied to Soils (MAS)	West, et al., 2014. Nutrient Application for Major Crops (EarthSTAT) Zhang, B et al. 2017. Global manure nitrogen production and application in cropland	- Livestock Manure (FAOSTAT https://www.fao.org/faostat/en/#data/EMN) at subnational level

mineral fertilizers, manure, and atmospheric deposition



<http://www.earthstat.org/nutrient-application-major-crops/>

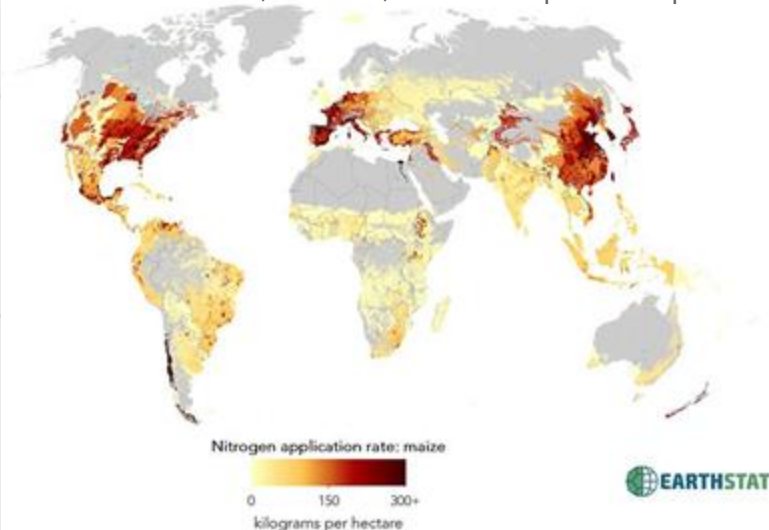
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INPUT: Nitrogen deposition

Input/Output	Tier One (Default Datasets)	Tier Two (National Datasets)
Nitrogen Deposition (ND)	West, et al., 2014. Nutrient Application for Major Crops (EarthSTAT)	- Cropland Nutrient Budget (FAOSTAT https://www.fao.org/faostat/en/#data/ESB) at subnational level

mineral fertilizers, manure, and atmospheric deposition



<http://www.earthstat.org/nutrient-application-major-crops/>

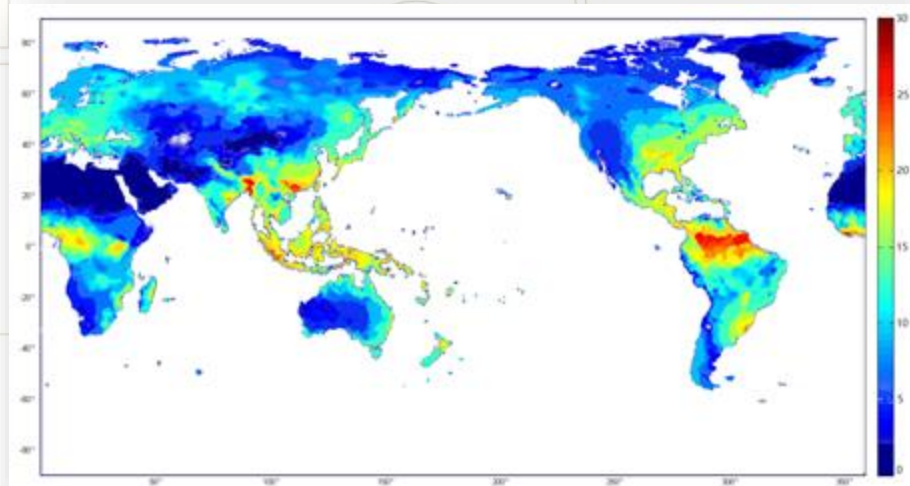
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INPUT: Biological fixation

Input/Output	Tier One (Default Datasets)	Tier Two (National Datasets)
Biological Fixation (BNF)	Yu, T. and Zhuang, Q. 2020. Modelling biological nitrogen fixation in global natural terrestrial ecosystems.	- Cropland Nutrient Budget (FAOSTAT https://www.fao.org/faostat/en/#data/ESB) at subnational level

Simulated spatial distribution of BNF rates ($\text{kg N}_2 \text{ ha}^{-1} \text{ yr}^{-1}$)



<https://bg.copernicus.org/articles/17/3643/2020/>

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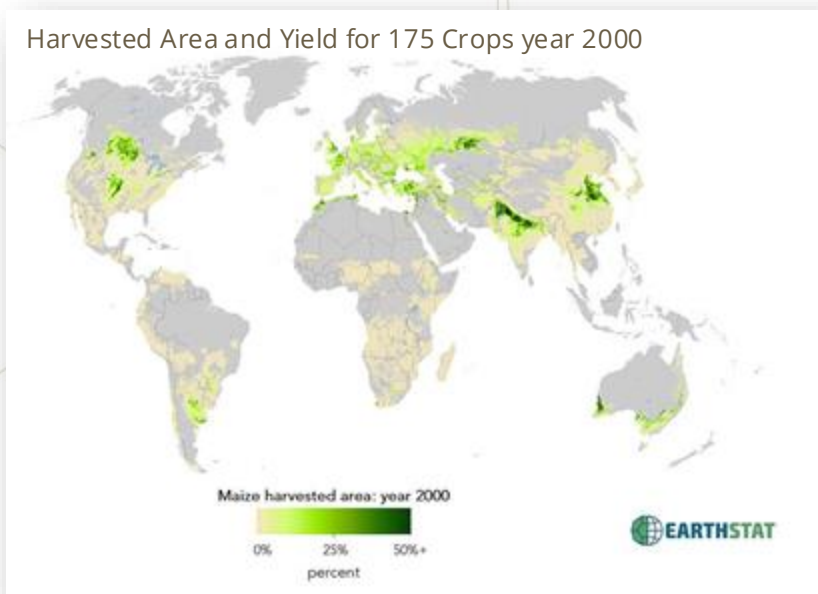


OUTPUT: Crop removal

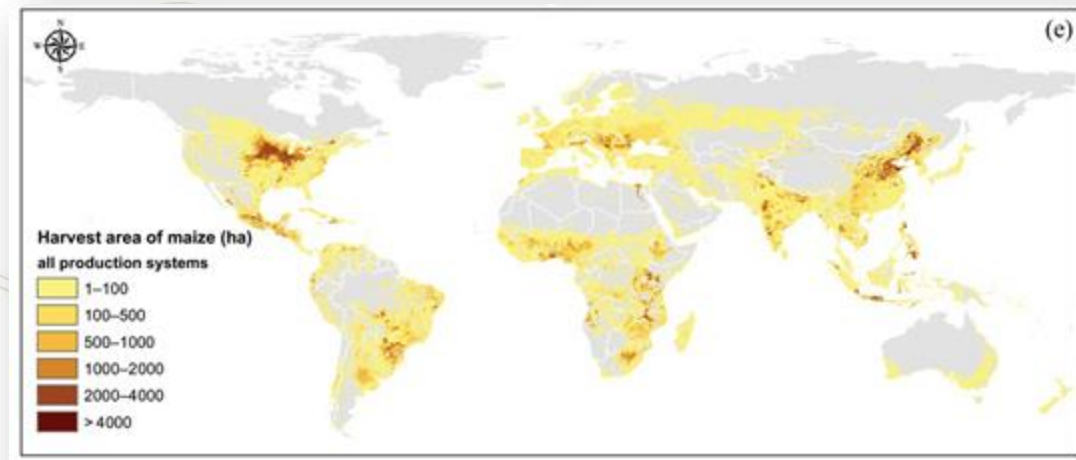


Input/Output	Tier One (Default Datasets)	Tier Two (National Datasets)
Crop Removal (CR)	Monfreda et al. 2008. Harvested Area and Yield for 175 Crops (EarthSTAT) SMAP IFPRI V4 (Yu et al., 2020)	Subnational information

Harvested-area maps for maize in all farming systems (Yu et al., 2020)



<http://www.earthstat.org/harvested-area-yield-175-crops/>



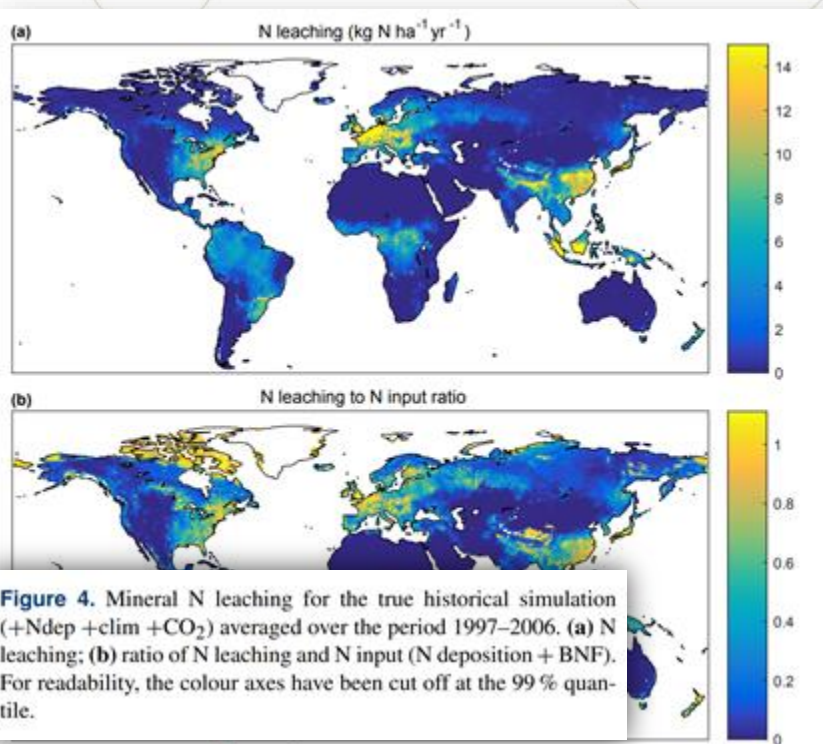
<https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/PRFF8V>

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OUTPUT: Nitrogen leaching

Input/Output	Tier One (Default Datasets)	Tier Two (National Datasets)
Nitrogen Leaching (NL)	Braakhekke et al., 2017. Nitrogen leaching from natural ecosystems under global change	Lesschen et al., 2007



$$L_N \text{ (kg N/ha/year)} = 0.0463 + 0.0037 * (P / (C - L)) * (FN + D - NOM - U)$$

$$L_K \text{ (kg K/ha/year)} = 6.87 + 0.0117 * P + 0.173 * FK - 0.265 * CEC$$

where:

- L_N and L_K = N leaching and K leaching, respectively
- P = precipitation (mm/year)
- C = clay (%)
- L = layer thickness (m) [rooting depth]
- FN = mineral and organic fertilizer nitrogen (kg N/ha/year)
- D = decomposition rate of organic matter (1.6% per year)
- NOM = amount of nitrogen in soil organic matter (kg N/ha)
- U = uptake by crop (kg N/ha/year)
- FK = mineral and organic fertilizer potassium (kg K/ha/year)
- CEC = cation exchange capacity (cmol/kg)

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<https://esd.copernicus.org/articles/8/1121/2017/esd-8-1121-2017.pdf>

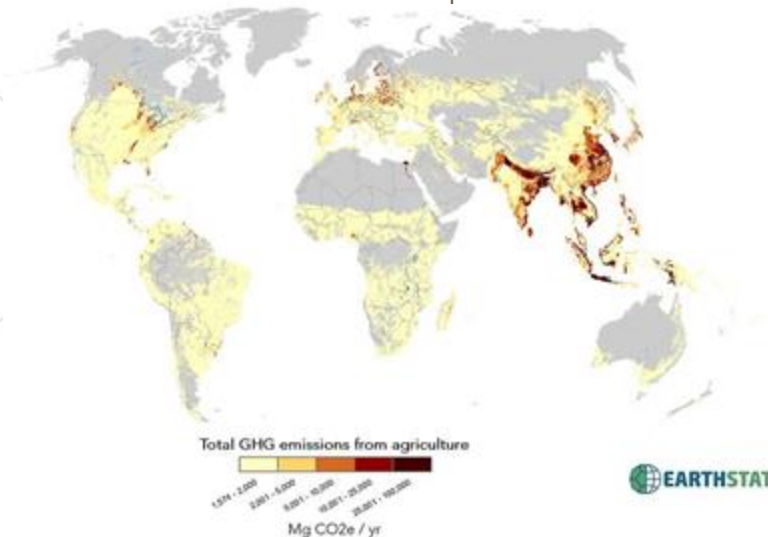
<https://easy.dans.knaw.nl/ui/datasets/id/easy-dataset:75687>



OUTPUT: Nitrogen loss

Input/Output	Tier One (Default Datasets)	Tier Two (National Datasets)
Nitrogen Loss (denitrification + volatilization) (NLO)	Carlson et al. 2016. Greenhouse gas emissions intensity of global croplands (EarthSTAT)	$NLO \text{ (Kg N ha yr}^{-1}\text{)} = 0.025 + 0.000855 \text{ P (mm)} + 0.13 \text{ F (inputs mineral + organic kg N ha yr)} + 0.117 \text{ SOC (\%)} \text{ (Lesschen et al., 2007)}$

Greenhouse Gas Emissions on Croplands



<http://www.earthstat.org/greenhouse-gas-emissions-croplands/>

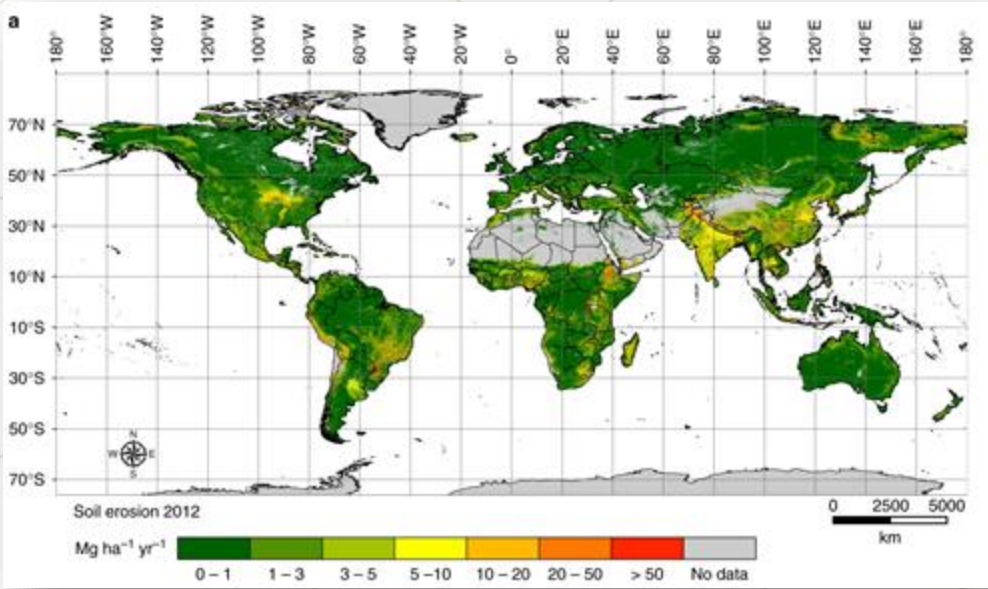
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OUTPUT: Erosion

Input/Output	Tier One (Default Datasets)	Tier Two (National Datasets)
Erosion (ER)	Borrelli et al 2017. JSR Global Soil Erosion	National Soil Erosion Map

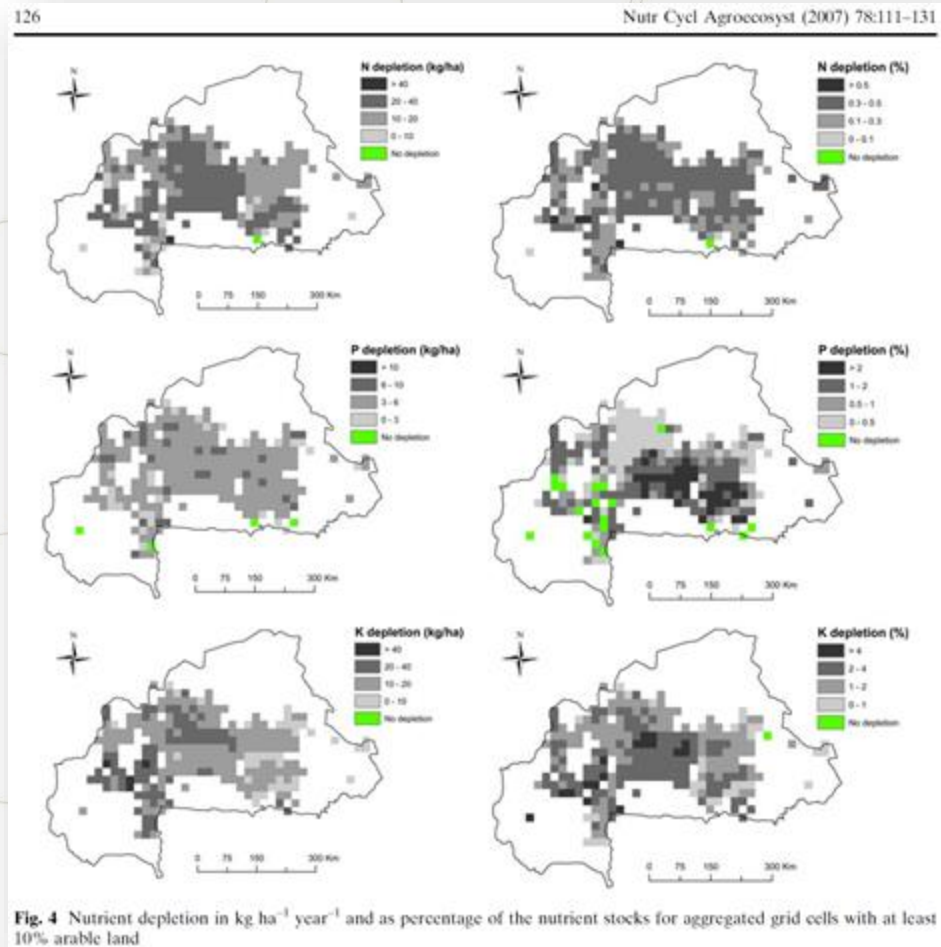
Global soil (water) erosion



+

Soil nutrient
stock
from Phase I

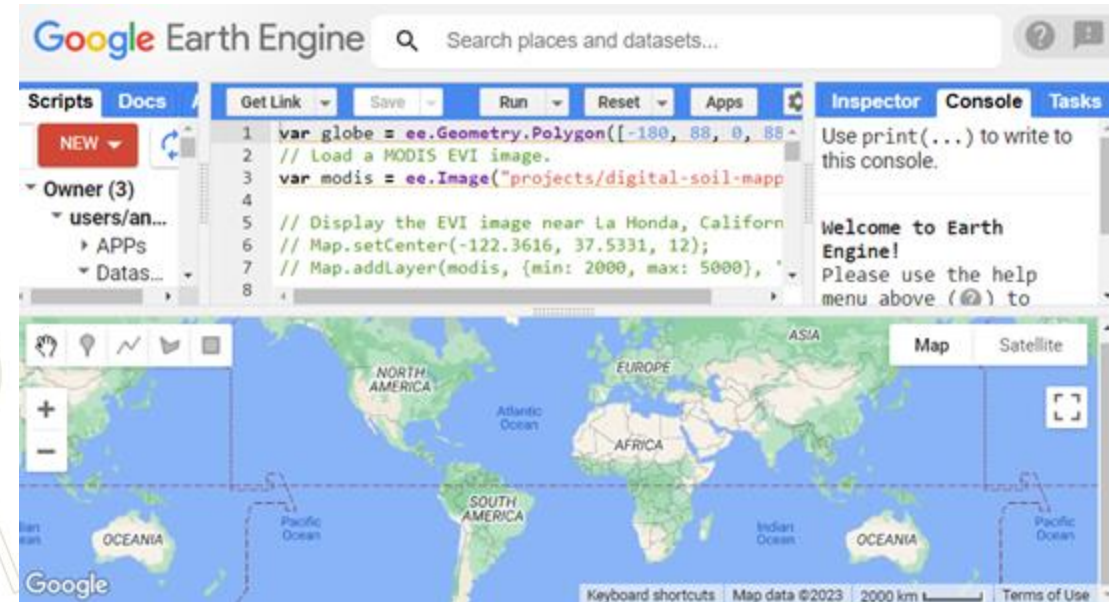
Expected results

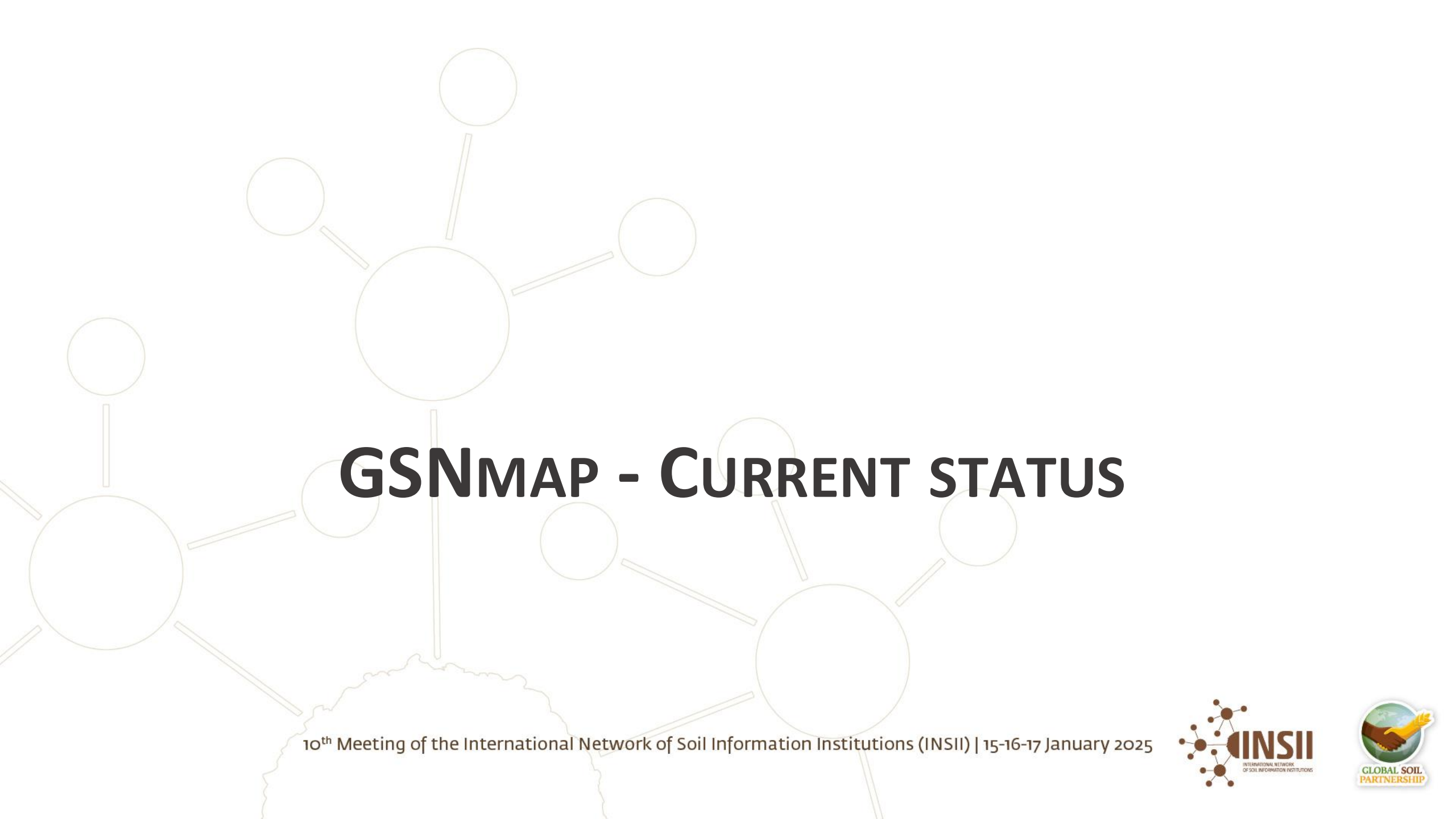


- Nutrient stocks estimated during Phase I might be included as an input factor to estimate nutrient loss by soil erosion, and to the ratio between nutrient depletion with regard to nutrient stock
- While this will only be a (static) picture, not on a yearly basis, it can be taken as a baseline to measure the risk of soil degradation

Implementation plan

- GEE script with global defaults and GSNmap layers from Phase I
- Countries can upload assets (layers) for the other global parameters if available at national level
- A country could request to be blank in the final map, to submit all standard layers (Tier 1), or to improve the estimation of any of the input layers (Tier 2).

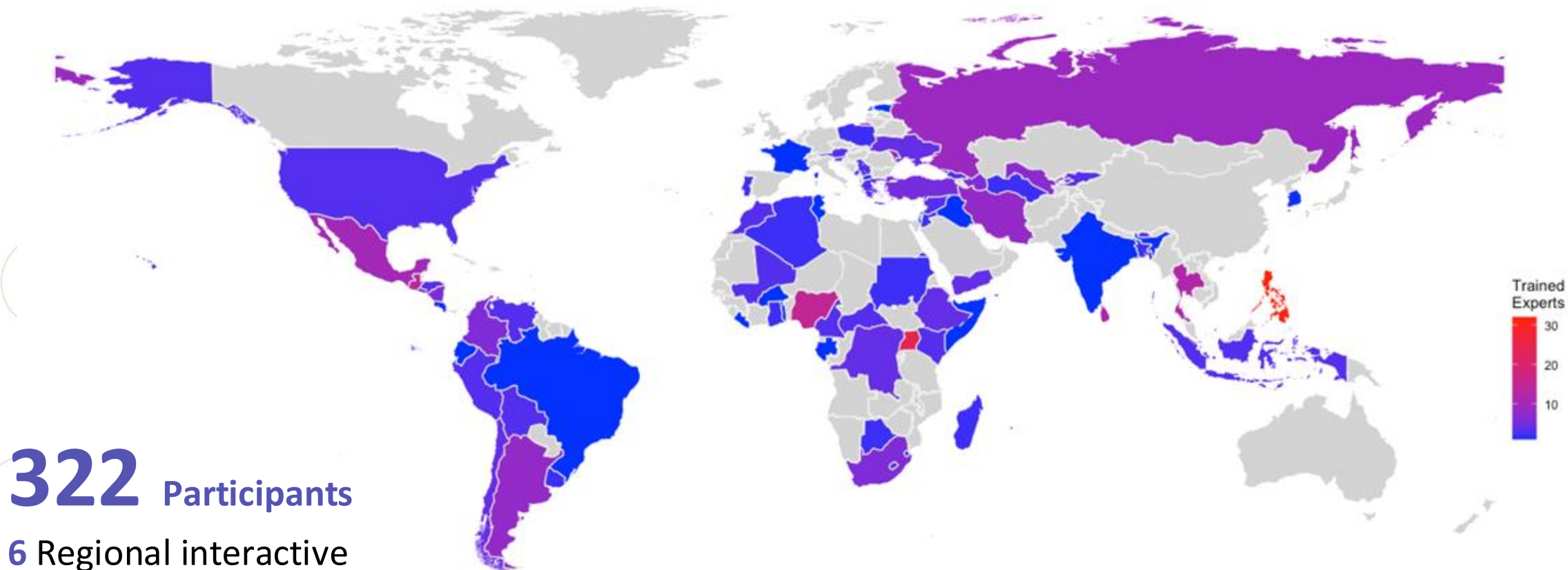




GSNMAP - CURRENT STATUS

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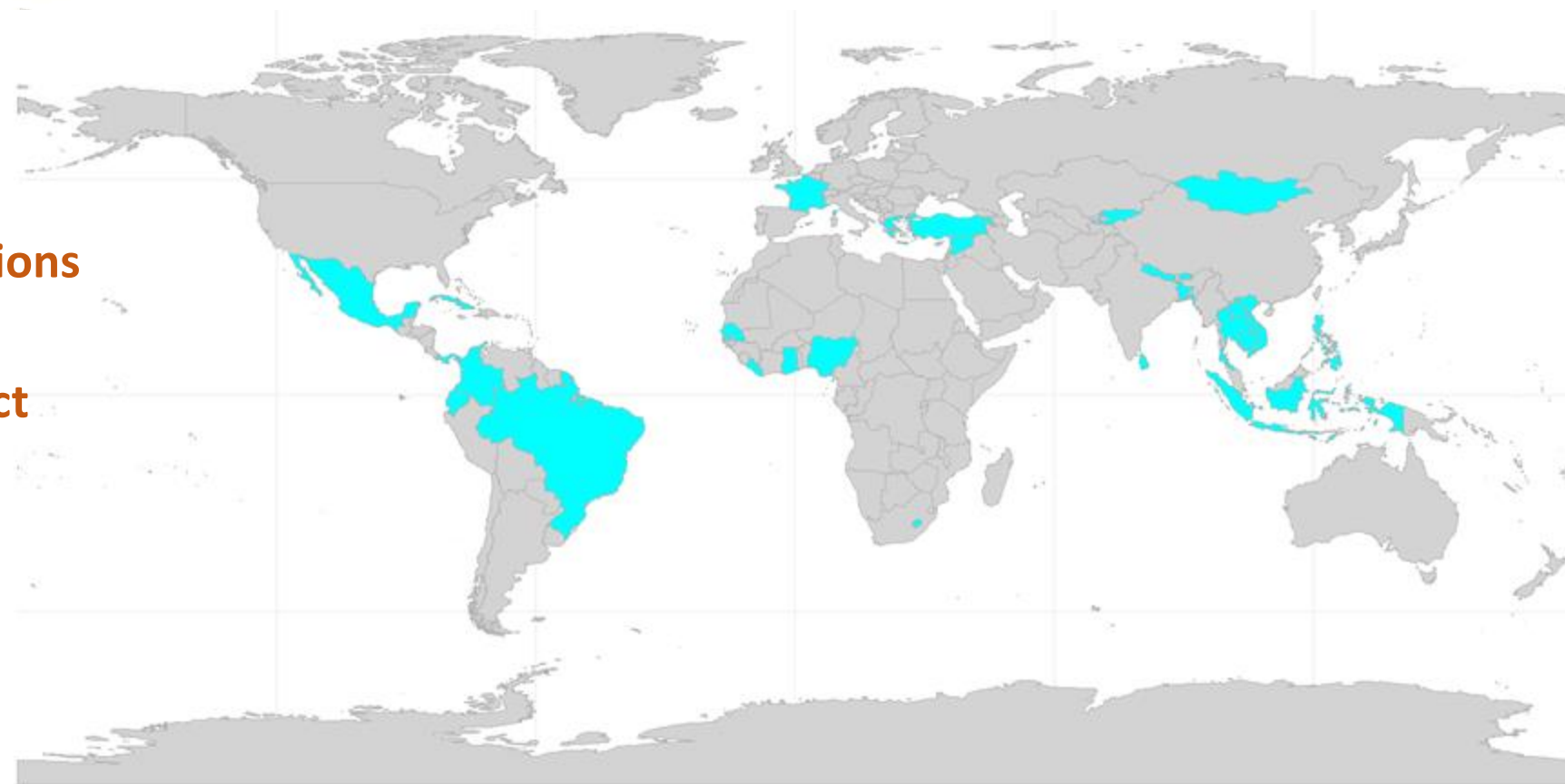
322 Participants

6 Regional interactive
online trainings based on
real soil data.

Source: United Nations Geospatial. 2020. Map geodata [shapefiles]. New York, USA, United Nations, modified by the authors.
Notes: Dotted lines represent approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan.
The final status of Jammu and Kashmir has not yet been agreed upon by parties.



16 GSNmap submissions
+ 12 AFACI Soil+ project
04 SOILCARE project
32 Countries

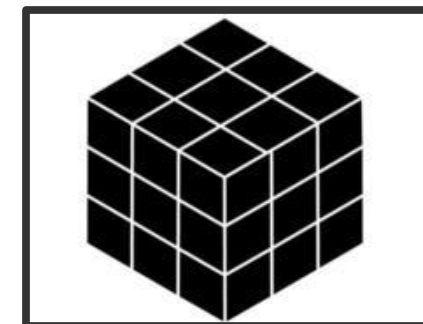
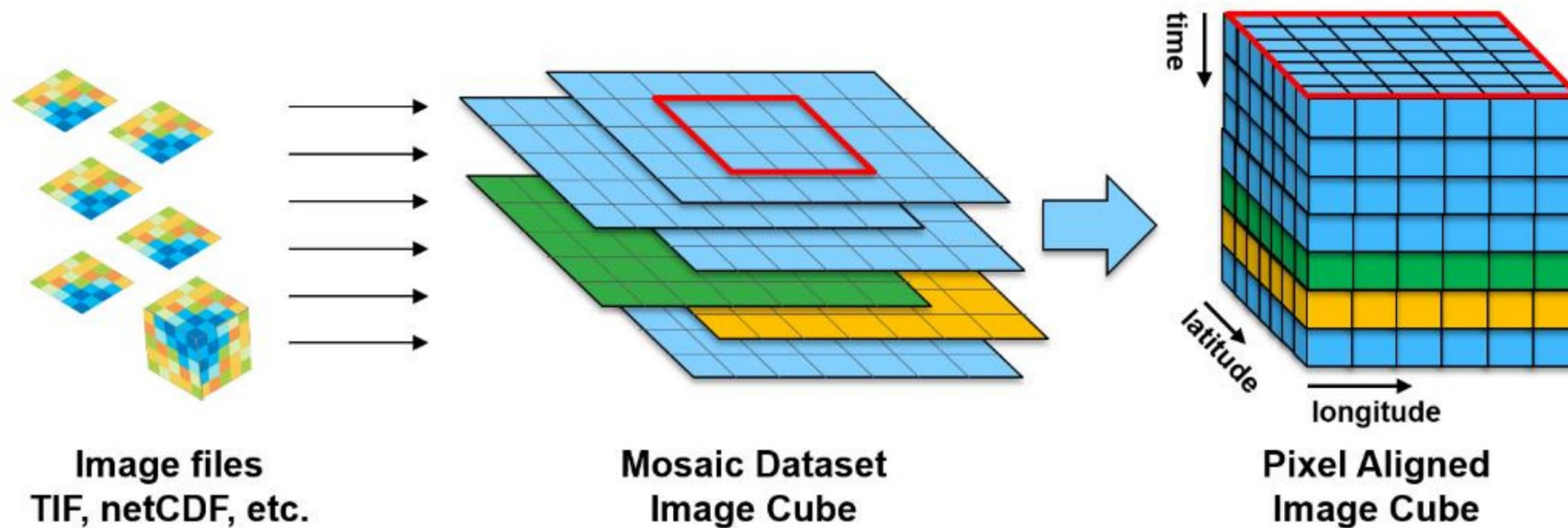


Source: United Nations Geospatial. 2020. Map geodata [shapefiles]. New York, USA, United Nations, modified by the authors.
Notes: Dotted lines represent approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan.
The final status of Jammu and Kashmir has not yet been agreed upon by parties.



GSNmap

National map publication process



COG

1. Datacube

2. Metadata

3. Publish

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GLOSIS
Global Soil Information System

Search for locations

Explore Data

Map

UN Country Boundaries of the World

Soil Organic Carbon Salinisation **Soil Nutrient Imbalance** Soil Erosion

Harmonized World Soil Database Boundaries and Backgrounds My Data

Done

Search the catalogue

Soil Nutrient Imbalance

[Share](#)

Description

FAO's Global Soil Partnership kicks start a country-driven process to map soil nutrients and soil nutrient budgets at all scales

Rapidly increasing fertilizer prices as well as growing food insecurity driven by the global COVID-19 pandemic, current conflicts as well as intensifying climatic patterns have exacerbated the need for informed decision-making based on digital soil mapping and monitoring. Soil maps capture the spatial variability of our soil resources to identify intervention hotspots and guide localized management decisions.

Continuing with its country-driven approach to map our global soils, the FAO's Global Soil Partnership (GSP) and its members are working on the Global Soil Nutrient and Nutrient Budget Maps (GSNmap) to understand the global spatial distribution of soil nutrients and soil nutrient budgets. Soil nutrient budgets are an important indicator of nutrient flows that can signal an excess or insufficiency in the soil.

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Lat: 38.57707°N Lon: 21.73788°W Elev: 1000 km

Conclusions and next steps

- ↗ GSNmaps methodologies are robust after revisions from international experts
- ↗ Several countries have been trained to produce these maps
- ↘ Updated Soil Nutrient maps are a hot topic after the fertilizer crisis, but lack of data and data accessibility are the most common barriers to provide these maps
- ↘ Budget maps are even more challenging than soil property maps
- ↗ Synergies with expert INSOILFER could boost engagement and data accessibility

Conclusions and next steps

- ↗ Involving GLOSOLAN in this product could boost GSNmap.
- Do we stop producing global maps, but we continue providing trainings?
- Is it valuable for INSII members to publish these national products in GloSIS?
- Would you consider successful the initiative although we don't get Global Maps?



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Thank you for your attention

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