THE ROLE OF DIGITAL SOIL MAPPING IN SOIL SURVEY AND AGRICULTURAL PLANNING

Comment [DHN1]: Is the manuscript a review???

This is vague, please indicate that in the title

Abstract:

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The reason for conducting the study, the goal, the date, the brief method of work and the place

Digital Soil Mapping (DSM) is an essential tool for soil survey and agricultural planning. It involves creating and populating spatial soil information using field and laboratory observations, often referred to as "predictive soil mapping" or "pedometric mapping." DSM provides detailed information on various soil properties, including soil pH, soil moisture content, soil organic carbon, electrical conductivity (EC), cation exchange capacity (CEC), and nutrient concentrations such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), and other micronutrients. It also measures gypsum concentration, base saturation percentage, heavy metal concentrations, and parent material characteristics. DSM utilizes digital elevation models, geostatistical modeling, and spatial interpolation of collected soil samples from a specific area. Instruments like the Portable X-ray Fluorescence Spectrometer (PXRF), combined with polynomial algorithms and various 'R' software packages, are integral to DSM. Geostatistical modeling tools such as kriging, splines, simulation options, covariance functions, semivariance functions, and variograms are employed for spatial interpolation of collected data to generate digital soil maps. \

Keywords: Digital soil mapping, SCORPAN model, PXRF, R packages for DSM, Digital elevation models, Geo statistical modeling, Portable X-ray fluorescence spectrometer

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1. Introduction

Digital Soil Mapping (DSM) constitutes a vital facet of soil science, focusing on the computerized generation of digital soil maps encompassing soil types and properties. It is alternatively referred to as 'predictive soil mapping' or 'pedometric mapping'. Typically, the process of soil mapping entails the creation and dissemination of spatial soil data through the integration of field and laboratory observational methods with spatial and non-spatial soil inference systems (Sonka, 2021). As noted by Carré et al. (2007), DSM serves multiple purposes including the creation of initial soil survey maps, refinement or updating of existing soil surveys, and the generation of specific soil interpretations. According to the International Working Group on Digital Soil Mapping (WG-DSM), Digital Soil Mapping encompasses "The establishment and population of geo referenced soil databases produced at a specified resolution, achieved through the integration of field and laboratory observation techniques alongside environmental data via quantitative correlations." The National Soil Survey Center-Geospatial Research Unit (NCSS-GRU) within the United States Department of Agriculture (USDA) has recognized Digital Soil Mapping (DSM) as a pivotal area of emphasis to bolster soil survey endeavors. Employing a range of techniques such as numerical classification, spatial and temporal interpolation, statistical analysis, sampling design, uncertainty assessment, and integration of auxiliary data (including proximal and remotely sensed imagery alongside soil-terrain modeling), the NCSS-GRU endeavors to craft predictive maps delineating soil classes and properties [10-14]. The framework of digital soil mapping integrates disciplines such as soil science, geographic information science, quantitative methods (including statistics and geostatistics), and cartography. Typically, this framework encompasses technological components such as Global Positioning System (GPS) receivers, remote sensing devices, field scanners, among others, alongside computational tools like Geographic Information Systems (GIS), Digital Elevation Models (DEMs), geostatistical interpolation methods, inference algorithms, and data mining techniques (Rossiter *et al.*, 2018).

DSM utilizes digital elevation models, geostatistical modeling, and spatial interpolation of collected soil samples from a specific area. Instruments like the Portable X-ray Fluorescence Spectrometer (PXRF), along with polynomial algorithms and various 'R' software packages, are crucial to DSM. Geostatistical modeling tools such as kriging, splines, simulation options, covariance functions, semivariance functions, and variograms are employed to spatially interpolate collected data, thereby generating digital soil maps (Biswajit Lenka and Divya R. -2020). In DSM, semi-automated methodologies and technologies are used to gather, process, and visualize soil information alongside auxiliary data, aiming to achieve higher accuracy at reduced costs [15,16]. The outcome of DSM efforts manifests as digital soil maps, constituted as raster-based maps comprising two-dimensional cells known as pixels, systematically arranged within a grid wherein each pixel corresponds to a specific geographical location and encapsulates distinct soil data. These digital soil maps portray the spatial distribution of soil classes or properties while also accounting for the uncertainty inherent in soil predictions within surveys [17-20]. A notable distinction between DSM and traditional soil mapping lies in the former's utilization of quantitative inference models to forecast soil classes or properties within a geographically referenced raster database. Leveraging models rooted in data mining, statistical analysis, and machine learning, DSM transforms extensive geospatial data output into coherent clusters, facilitating the recognition of spatial patterns (Filippi *et al.*, 2020).

2. Theoretical models for digital soil mapping

The Jenny's CLORPT model of soil formation (1941) encompasses various processes such as laterization, podsolization, calcification, salinization, gleization, decomposition, humification, acidification, and pedoturbation. These processes are intricately influenced by factors including climate, soil flora, soil fauna, relief, and the nature of parent material within a given geographical context. At its core, the scientific framework for soil mapping rests upon Jenny's conceptual model of soil formation, wherein five key factors—climate (cl), organisms (o), relief (r), nature of parent material (p), and time (t)—are recognized as primary influencers:

$$S=f(cl,o,r,p,t)$$

Jenny's model finds predominant use in traditional soil mapping systems. However, due to limitations in quantitative data representation and spatial data interpolation, it has restricted applicability in digital soil mapping. Recognizing this gap, McBratney et al. (2003) introduced the SCORPAN model of soil formation. This model is designed to integrate soil and related environmental factors into spatial-based interpolation processes, offering quantitative expressions for enhanced usability within digital soil mapping contexts. In digital soil mapping, the SCORPAN model leverages five environmental covariates: soil properties (s), climate (c), organisms (o), relief (r), and parent material (p). The SCORPAN model functions as a spatial inference model, aiming to provide comprehensive representations of soil formation processes across landscapes. Its formulation can be expressed as:

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Comment [DHN5]: DSM utilises digital elevation models, geostatistical modelling, and spatial interpolation of collected soil samples from a specific area. Instruments like the Portable X-ray Fluorescence Spectrometer (PXRF), along with polynomial algorithms and various 'R' software packages, are crucial to DSM. Geostatistical modelling tools such as kriging, splines, simulation options, covariance functions, semivariance functions, and variograms are employed to spatially interpolate collected data, thereby generating digital soil maps (Biswajit Lenka and Divya R., 020). In DSM, semi-automated methodologies and technologies are used to gather, process, and visualise soil information alongside auxiliary data, aiming to achieve higher accuracy at reduced costs [15, 16]. The outcome of DSM efforts manifests as digital soil maps, constituted as raster-based maps comprising two-dimensional cells known as pixels, systematically arranged within a grid wherein each pixel corresponds to a specific geographical location and encapsulates distinct soil data. These digital soil maps portray the spatial distribution of soil classes or properties while also accounting for the uncertainty inherent in soil predictions within surveys [17–20]. A notable distinction between DSM and traditional soil mapping lies in the former's utilisation of quantitative inference models to forecast soil classes or properties within a geographically referenced raster database. Leveraging models rooted in data mining, statistical analysis, and machine learning, DSM transforms extensive geospatial data output into coherent clusters, facilitating the recognition of spatial patterns (Filippi *et al.*, 2020).

$$Sc,a=f(s,c,o,r,p,a,n)+\epsilon$$

Where, Sc, a =Soil (either soil classes, Sc or soil attributes, Sa) at a point in space and time is an empirical quantitative function of the seven environmental covariates

s: Soil data obtained from Jenny's model

c: Climate conditions at the location

o: Organisms present in the area

r: Relief characteristics of the terrain

p: Nature of the parent material

a: Age of the soil

n: Spatial location defined by (x, y) coordinates

Additionally, the term ϵ represents the standard error resulting from spatial and geographical variability.

Soil

Soil data for a specific location is generated through Jenny's CLORPT model. Soil, being the upper layer of the Earth's surface, comprises a blend of organic matter, minerals, gases, and liquids, vital for sustaining life. It forms from the breakdown of rocks and the accumulation of humus. Representing soil involves utilizing covariates derived from geo-referenced point data, remotely sensed spectral data, and existing soil maps. In the realm of digital soil mapping, soil data is gathered through soil sensing technology and by collating legacy soil data sourced from soil maps and soil profile information.

Climate

Soil data for a specific location is derived from Jenny's CLORPT model, which considers climate, organisms, relief, parent material, and time. Soil, constituting the uppermost layer of the Earth's surface, encompasses a mixture of organic matter, minerals, gases, and liquids essential for sustaining life. It arises from the weathering of rocks and the accumulation of humus. To represent soil, various covariates are utilized, including data from geo-referenced points, remotely sensed spectral information, and pre-existing soil maps. In digital soil mapping, soil data is acquired through soil sensing technologies and by compiling historical soil data obtained from soil maps and soil profile records.

Organism

Soil harbors a diverse array of flora and fauna, encompassing microorganisms such as fungi, bacteria, and actinomycetes, as well as macroorganisms like earthworms and lichens. The particular composition of organisms within each soil type plays a pivotal role in mineral transformations, which are integral to soil formation processes. These soil organisms wield significant influence over critical factors like the rate of atmospheric nitrogen fixation and the levels of soil. In Digital Soil Mapping (DSM), data concerning soil organisms is gathered through remote sensing techniques focused on vegetation and land use areas, along with utilizing datasets such as the Normalized Difference Vegetation Index (NDVI).

Relief

Relief, also known as "terrain," refers to the topographical representation of the highest and lowest elevations across a given area of land. The recurring patterns of topography give rise to sequences of soils known as "soil catenas." Relief plays a crucial role in determining soil properties due to gravitational forces and slopes. In low-lying areas, soils often exhibit deeper colors and are rich in organic matter and minerals, as they accumulate substances washed down from higher elevations. Conversely, soils in higher elevations tend to have a paler color due to surface runoff and the loss of nutrient-rich organic matter. Relief data for Digital Soil Mapping (DSM) is typically collected through outputs from digital terrain models.

Nature of the parent material

The parent material is the underlying geological material upon which soil horizons develop. It significantly shapes soil properties, including texture, colour, pH, and mineral composition. It is usually the unconsolidated and unchanged rock material which undergoes natural processes of soil formation to give rise to true soil. Data regarding the nature of the parent material for Digital Soil Mapping (DSM) is collected through the utilization of digitalized geological maps.

Age of the soil

The age of soil represents an advanced aspect of the time factor influencing the process of pedogenesis. It is the passive factor as well as the most important factor of soil formation. Soil formation is a continuous process. recently deposited soils exhibit minimal signs of development activities and consist mainly of primary minerals and are lighter in colour. The more matured soils on the other hand consist of secondary and tertiary minerals and are darker in colour as they are rich in soil organic matter. According to researchers, it takes approximately 200 to 400 years for the formation of 1 cm of soil, depending on the latitude of the geographical area. Soil formation processes more rapidly in wet tropical regions compared to temperate areas. The data on age of the soil for DSM is collected by utilizing statistical techniques and spatial inference models.

Spatial

The spatial location is typically defined by using (x, y) coordinates, which represent the geographical positioning of any given area. In Digital Soil Mapping (DSM), data regarding the spatial location of soil is gathered through the application of statistical techniques and spatial inference models (Mosleh, *et al*., 2016).

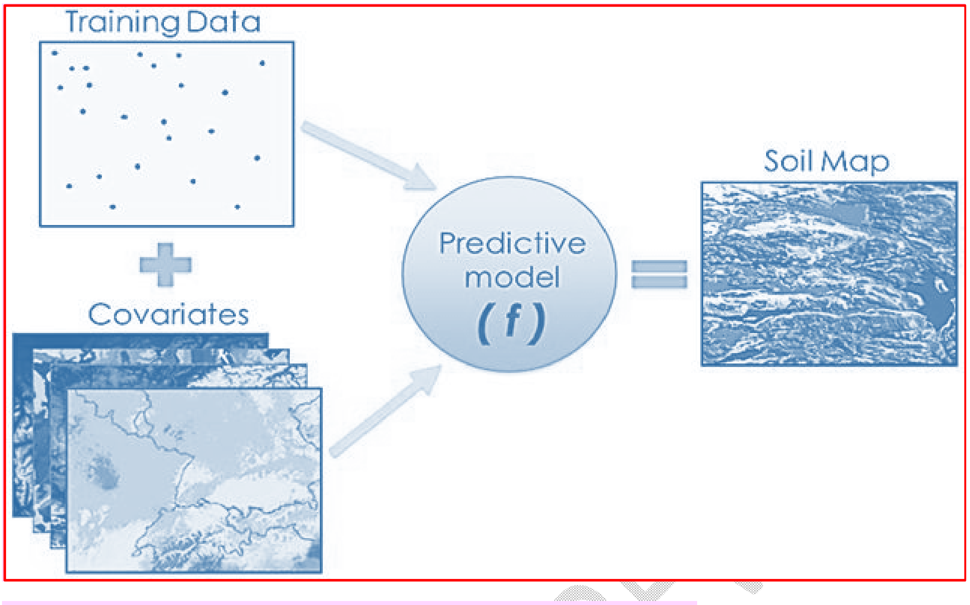

Fig a: Pictorial representation of digital soil mapping

2.1Digital elevation models (DEMs)

A digital elevation model (DEM) provides a three-dimensional depiction of a terrain's surface within a geographical area, derived from elevation data of the terrain. DEMs find primary utility within geographic information systems (GIS) and serve as the fundamental basis for generating digitalized relief maps. These models encompass two main types: Digital Surface Models (DSMs) and Digital Terrain Models (DTMs). DSMs are particularly valuable for landscape modelling, digital soil mapping, and visualization purposes. Conversely, DTMs find application in flood modelling, drainage modelling, land use studies, and various geographical applications. One of the major differences between the digital surface models and digital terrain models is that, DSMs incorporate structures such as buildings and other objects within the modelled area, whereas DTMs solely represent the bare ground surface, excluding vegetation, buildings, and other objects. The digital elevation models are used as a generic term for digital surface models and digital terrain models. Datasets and aerial imagery captured by satellites, airplanes, or other airborne platforms initially manifest as digital surface models (DSMs). Subsequently, digital terrain models (DTMs) are derived from high-resolution DSM datasets using sophisticated algorithms. Digital elevation models (DEMs) play a pivotal role in calculating Altitude above Channel (AAC) and Topographic Wetness Index (TWI). The accuracy and quality of digital elevation models (DEMs) are influenced by several factors, including the roughness parameter of the terrain, grid resolution or pixel size, interpolation algorithm, terrain analysis methods, and sample density. DEMs serve various purposes such as precision farming, digital soil mapping, geographic information systems (GIS), and generating relief parameters

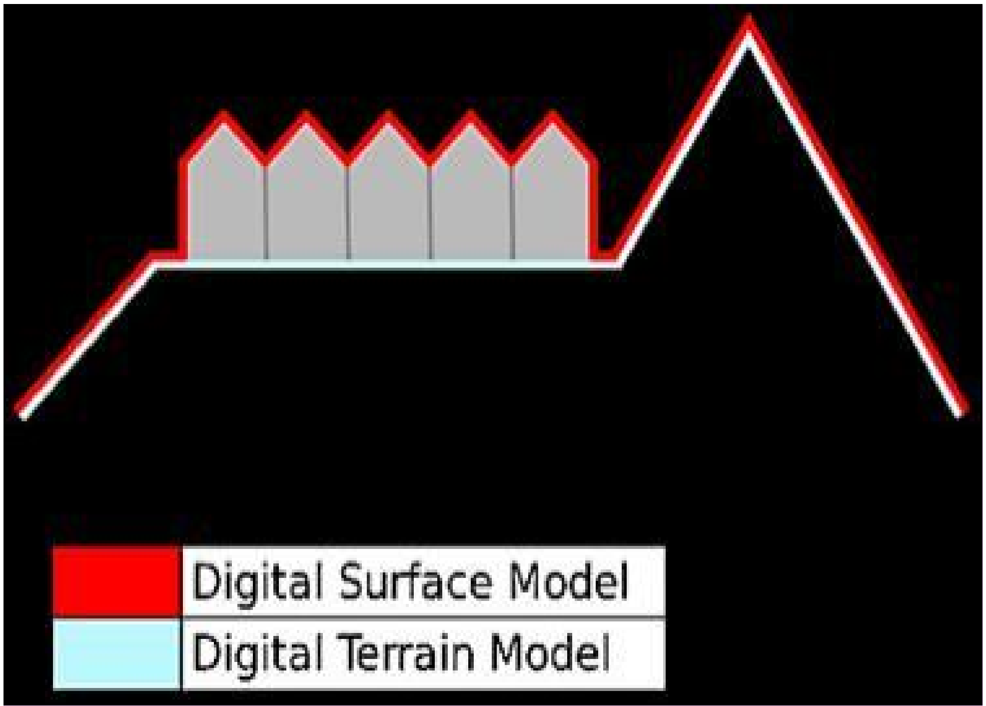

Fig b: Pictorial representation of digital elevation model

2.2 Universal transverse mercator (UTM) coordinate system

The Universal Transverse Mercator (UTM) system provides a method for assigning precise coordinates to locations on the Earth's surface. Widely utilized in digital soil mapping, it represents horizontal positions and does not account for altitude, treating the Earth as a perfect ellipsoid. The UTM system divides the Earth into 60 zones, each projected onto a plane to establish coordinates. Essentially, it consists of a standard set of map projections, each with a central meridian for every six-degree-wide UTM zone. The scale factor at the central meridian is set at 0.9996 of true scale for the UTM system. Additionally, the UTM coordinate system commonly employs the World Geodetic System ellipsoid (WGS84) to model the Earth's surface, resulting in the combined term "UTM WGS84" coordinate system.

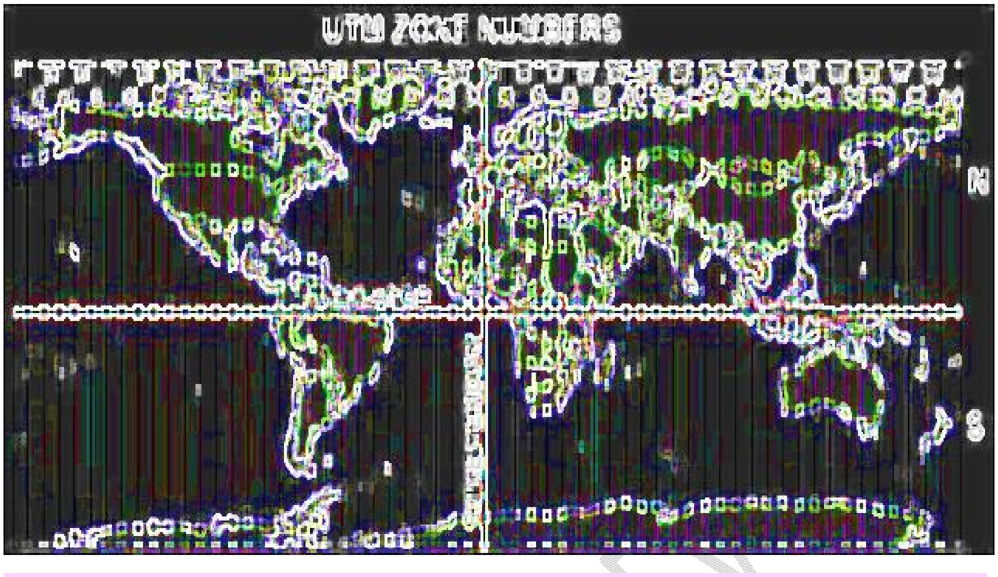

Fig c: Universal Transverse Mercator (UTM) coordinate system is a standard set of map projections with a central meridian for each six-degree wide UTM zone

2.3 Geo statistical modeling

Geo statistics, a branch of statistics, specializes in analyzing spatial or spatiotemporal datasets through the application of geo statistical algorithms. Geo statistical modeling employs various tools such as kriging, splines, simulation, semi-variance functions, and variograms. These techniques enable the reduction and estimation of errors associated with unknown or missing datasets, making geo statistical modeling particularly crucial in digital soil mapping.The general model equation utilized in geo statistical modeling to determine unknown datasets is:

$$\sigma_0^2 = 1/3\,(T_0 - T_1)^2 + 1/3\,(T_0 - T_2)^2 + 1/3\,(T_0 - T_3)^2$$

Were,

σ_0^2 = Mean Square Error,
T_0 = unknown data set,
T_1, T_2 and T_3 = known datasets

This equation employs different statistical methods to estimate and minimize errors, thereby facilitating accurate predictions of soil properties and distributions in digital soil mappingendeavours**.**

3.Tools used in geostatistical modeling

Several tools are employed in geostatistical modeling to analyze spatial or spatiotemporal datasets effectively. Some of the commonly used tools include:

Kriging

Kriging is a method of spatial interpolation of the datasets, in which the interpolated values are modeled by a Gaussian process governed by prior covariance. It is otherwise known as 'Gaussian process regression'. Kriging gives the Best Linear Unbiased Prediction (BLUP) of the intermediate values and that estimator of the unknown values is called as Best Linear Unbiased Estimator (BLUE). The theoretical basis for kriging method was developed by Georges Matheron (1960) based on the

Master's thesis of Danie G. Krige. The thesis was based on plotting of distance-weighted average of different gold grades in gold mines of South Africa. The general equation of kriging is:

$$Z(s) = \mu + \varepsilon'(s)$$

Where,

μ = Constant stationary function (global mean)
$\varepsilon'(s)$ = Spatially correlated stochastic part of the variation

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Splines

A spline is a special type of piecewise polynomial, which is preferably used for simple polynomial interpolations due to its ability to define more number of parameters including 'smoothing' of the original data. The smoothing spline function also assumes that there is a measurement error in the original data that needs to be smoothed locally. The smoothing splines are function estimates, f'(x) obtained from a set of noisy observations, yi of the target f(xi), in order to balance a measure of goodness of fit of f'(xi) to yi

with a derivative based measure of the smoothness of f'(x). The general equation of regularized spline function is:

$$Z(s0) = a1 + \Sigma\, wi.\, R(vi)$$

Where,
a1 = constant stationary function (global mean)
wi = weighted average factors
R(vi) = the radial basis function

Variogram

In geostatistical modeling, the variogram is a function describing the degree of spatial dependence of a spatial random field. In digital soil mapping, a variogram will give a measure of how much the two soil samples taken from a location will vary in different soil properties like cation exchange capacity (CEC), soil fertility, bulk density, water holding capacity etc. depending on the distance between those samples and their distances from the reference point. Soil samples taken far apart will vary more than soil samples taken closer to each other

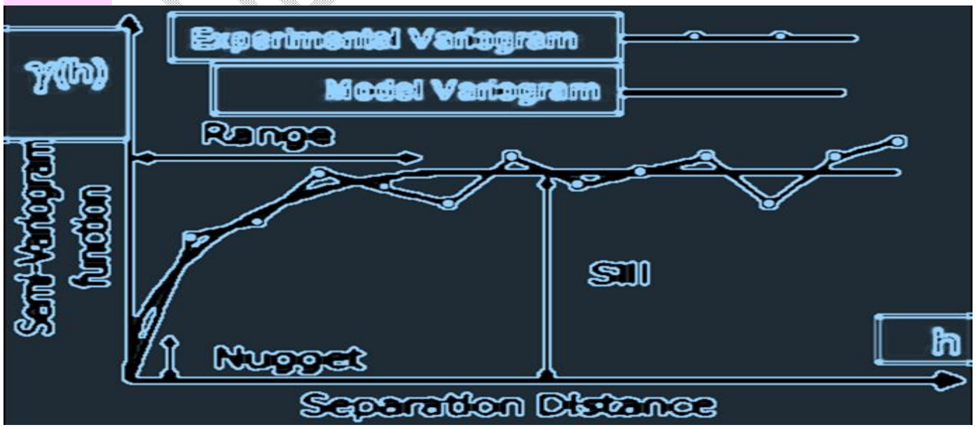

Fig d: Parameters of Semi-Variogram

Simulation

Monte Carlo simulation techniques are often utilized to generate multipole realizations of spatial datasets based on statistical models, allowing for uncertainty analysis and risk assessment

4. Soil depth

The conventional approach to soil sampling involves segmenting a soil profile into horizons, guided by easily observable field characteristics like morphological properties. Each horizon is sampled, with the assumption that the collected bulk sample represents the average value of a soil attribute across the depth interval of that horizon. However, from a pedological perspective, soil properties typically exhibit continuous variation with depth. Representing attribute values as averages over horizon depth intervals results in discontinuous or stepped profile representations, making it challenging to ascertain attribute values at specific depths within the soil profile. This poses difficulties in digital soil mapping and modeling.To address these challenges, continuous functions can be derived using available horizon data as inputs. This involves utilizing techniques such as polynomials, exponential decay depth functions, and continuous depth functions like the 'equal-area quadratic spline function'. The spline function preserves the original data and enables retrieval through integration of the continuous spline. Its parameters represent attribute values at specified standard depths chosen by the user. By harmonizing soil profile data, the spline function facilitates modeling of data on a specified depth basis, ensuring 'mass preservation' of large databases collected.

5. Global Soil Map.net' Project

The 'GlobalSoilMap.net' project is a collaborative effort aimed at creating a comprehensive digital soil map of the world. Leveraging cutting-edge technologies and emerging methodologies, the project seeks to accurately predict soil properties at a fine resolution. This global soil map will not only provide spatial data but also incorporate interpretation and functionality features to support decision-making across various domains, including agriculture, food production, climate change mitigation, and environmental conservation. Led by the Digital Soil Mapping Working Group of the International Union of Soil Sciences (IUSS), this initiative aims to address critical soil-related challenges by considering six distinct soil depth functions across six soil depths within the soil profile: (0-5) cm, (5-15) cm, (15-30) cm, (30-60) cm, (60-100) cm, and (100-200) cm. By comprehensively mapping soil properties at different depths, the project aims to provide valuable insights for informed decision-making and sustainable land management practices worldwide.

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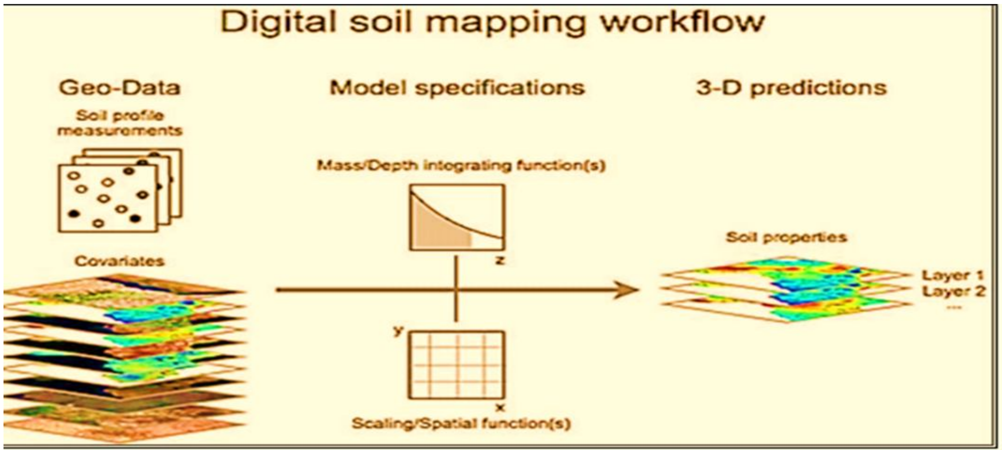

Fig e. Workflow of digital soil mapping

6.'R' Packages useful in digital soil mapping

R-Studio is a popular integrated development environment (IDE) for the R programming language. It provides a user-friendly interface for writing, executing, and debugging R code. R itself, along with its packages, can be downloaded from the Comprehensive R Archive Network (CRAN) website (https://cran.r-project.org).

AQP

The AQP (Algorithms for Quantitative Pedology) R package is a valuable resource for quantitative soil science. It offers a range of algorithms and functions for various tasks related to soil resources, classification, profile aggregation, and visualization. Here's a breakdown of its key features:

1. **Soil Modeling**: AQP provides tools for modeling soil properties and attributes, allowing users to analyze and predict soil characteristics based on available data.
2. **Soil Classification:** The package includes functions for soil classification, enabling users to classify soil samples or profiles according to established taxonomic systems or custom criteria.
3. **Soil Profile Aggregation**: AQP offers algorithms for aggregating soil profile data, which is useful for summarizing and analyzing soil properties across multiple profiles or study areas.
4. **Visualization**: The package includes functions for visualizing soil data and profiles, allowing users to create plots, maps, and other visual representations to aid in data interpretation and communication.

SP

The SP R package is an essential tool for handling spatial data within the R environment. It offers classes and methods specifically designed for managing spatial information, both in two-dimensional and three-dimensional formats.

6.1GSIF (Global Soil Information Facilities)

The GSIF R package is a comprehensive resource for digital soil mapping. It provides a suite of tools, functions, and sample datasets specifically designed to support soil mapping and analysis. key features of GSIF are :

1. **Digital Soil Mapping Tools:** GSIF offers a range of tools and functions tailored for digital soil mapping tasks. These include methods for spatial interpolation, geostatistics, machine learning, and spatial analysis.

2. **Sample Datasets:** The package includes sample datasets that users can utilize to practice and explore digital soil mapping techniques. These datasets cover various soil properties and geographic regions, providing valuable resources for research and education.
3. **Global Soil Information:** GSIF facilitates access to global soil information by providing functions for retrieving and working with soil data from international databases and repositories.
4.**Spatial Analysis:** The package includes functions for spatial analysis, allowing users to perform spatial queries, overlay analysis, and other geoprocessing tasks on soil data.
5. **Documentation and Support**: GSIF comes with extensive documentation, including tutorials, vignettes, and reference manuals, to help users get started with digital soil mapping. Additionally, the package is supported by an active user community, providing opportunities for collaboration and support.

GSIF is a valuable resource for researchers, soil scientists, and GIS professionals working in the field of digital soil mapping. It offers a wide range of tools and datasets to support soil mapping efforts across different scales and applications. More information about the package and its documentation on the CRAN website at: https://cran.r project.org/web/packages/GSIF/index.html.

Raster

This R package designed to facilitate the handling of gridded spatial data, offering capabilities for reading, writing, manipulation, analysis, and modeling. With implementations of both basic and advanced functions, this package supports the processing of extensive datasets, making it particularly advantageous for managing large files. Further information about Raster can be accessed on its [CRAN page](https://cran.r-project.org/web/packages/raster/index.html).

RGDAL

`It is an R package that grants access to projection or transformation operations from the PROJ.4 library. With `RGDAL`, users can import both GDAL raster and OGR vector map data into R, and they can also export them to other programs. The package relies on classes defined in the 'SP' package for spatial data operations. It serves as a potent tool for managing geographic data in R, providing functions for reading, writing, and manipulating spatial datasets.

RSAGA

RSAGA, an R package, serves as a bridge for geo-computing and terrain analysis functionalities from SAGA GIS within the R environment. Leveraging the command line interface of SAGA, RSAGA empowers users to harness a diverse array of geo-processing and terrain analysis tools seamlessly within R. This package proves particularly beneficial for conducting spatial analysis, terrain modeling, and processing geospatial data. Further information regarding RSAGA can be accessed on its respective page on the Comprehensive R Archive Network (CRAN).

Cubist

Cubist is a software application tailored for regression modeling, utilizing rules supplemented with insurance-based corrections. The models, conceptualized by Ross Quinlan, introduce a distinctive methodology to regression analysis by integrating specialized corrections to augment predictive precision. For further elucidation, interested parties can refer to Rulequest's website at https://www.rulequest.com/.

C5.0

indeed is a popular algorithm for building decision trees and rule-based models, primarily used for pattern recognition and classification tasks. Developed by Ross Quinlan, it's an enhancement of the earlier C4.5 algorithm. C5.0 is known for its efficiency in handling large datasets and its ability to handle both numerical and categorical data.

The Rulequest website is a valuable resource for anyone interested in learning more about C5.0 and related decision tree algorithms. It likely offers documentation, tutorials, and possibly even software tools for utilizing these algorithms in various applications.

GAM

The ` package in R is indeed a powerful tool for fitting and analyzing Generalized Additive Models (GAMs). Generalized Additive Models are a flexible class of statistical models that extend linear models by allowing non-linear relationships between the predictors and the response variable.This package provides functions for fitting GAMs, conducting inference, visualizing model results, and making predictions. It's widely used in various fields such as ecology, epidemiology, economics, and more, where non-linear relationships are common and need to be accurately modeled.The CRAN website link you provided is a direct link to the GAM package's page on the Comprehensive R Archive Network (CRAN). It's a central repository for R packages where users can find detailed documentation, installation instructions, and examples for using the GAM package in their own R projects.

`NNET

The `NNET` package in R is indeed a versatile tool for building feed-forward neural networks with a single hidden layer and for fitting multinomial log-linear models. Neural networks, particularly those with a single hidden layer, are a popular choice for modeling complex relationships in data.With the `NNET` package, users can easily create neural network models and train them on their data for various tasks such as classification and regression. Additionally, the package provides functionality for fitting multinomial log-linear models, which are useful for analyzing categorical data with multiple categories.The link you provided directs to the `NNET` package's page on the Comprehensive R Archive Network (CRAN), where users can find detailed documentation, examples, and installation instructions for using the package in their R projects. It's a valuable resource for anyone looking to leverage neural networks or multinomial log-linear models in their data analysis workflows.

7. Portable X-ray Fluorescence Spectrometer

A portable X-ray fluorescence (PXRF) spectrometer is an advanced soil sensor used in digital soil mapping (Sharma *et. al.*, 2014). This instrument works by quantifying the energy released when inner shell electrons are replaced by outer shell electrons, a process known as fluorescence. The measurement is performed by a silicon drift detector located in the instrument's aperture. The typical scanning time per soil sample is between 60 to 90 seconds. The PXRF spectrometer is employed to determine various soil properties including soil pH, soil moisture content, soil organic carbon, electrical conductivity (EC), cation exchange capacity (CEC), and concentrations of essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), and other micro nutrients. Additionally, it measures gypsum concentration, base saturation percentage, heavy metal concentrations, parent material characteristics, profile horizonation, and geochemistry.This instrument is highly accurate and portable, making it suitable for field use. It can simultaneously compute the concentrations of approximately 20 to 30 nutrients in both soil and plant samples with high efficiency. Furthermore, it is utilized in Land Use/Land Cover (LULC) data surveys. The cost of a PXRF spectrometer ranges from $60,000 to $70,000. Examples of PXRF products include the PSR-3500 and the Vanta Series.

The wavelength of the fluorescent radiation can be calculated using Planck's Law.

$$E = nh\nu$$

Where:

$n = 1, 2, 3, \ldots$
h = Planck’s constant (6.626 x 10^-34 J·s)
ν = frequency

The portable X-ray fluorescence (PXRF) spectrometer operates in the visible near-infrared (VIS-NIR) region of the light spectrum, with wavelengths between 350 and 1000 nm. It features a ‘Spectralon Panel’ that ensures 99% reflectance due to its white surface, minimizing the effects of ambient temperature and relative humidity. This instrument combines elemental data with spectral data (VIS-NIR) to develop predictive algorithms for soil physical and chemical properties. The PXRF spectrometer is used in applications such as variable rate technology-based agriculture (precision farming) and environmental assessment, utilizing an X-ray probe as the light source. During soil sample scanning, the instrument illuminates the samples and records their reflectance data. This data is processed by the instrument's optical fibers to create holographic grated images through total internal reflection. These holographic grated data are then transferred to a ‘separation filter’ equipped with a 512 silicon photodiode array, covering the spectral range of 350 to 1000 nm. The separation filter converts incident photons into photocurrents (electrons). These photocurrents, under appropriate voltage provided by a 16-bit AC to DC converter, generate the digital signal output from the PXRF instrument. The control software receives this digital signal as an image, and the imagery data of all samples are used to plot various graphs of the geographical location under consideration, based on different soil properties.

Conclusion: Digital Soil Mapping (DSM) is a vital technology for soil survey and agricultural planning, leveraging field and laboratory data to create detailed spatial soil information. By providing insights into soil properties like pH, moisture content, organic carbon, nutrient levels, and more, DSM aids in efficient resource management and agricultural productivity. Utilizing tools such as digital elevation models, geostatistical modeling, and instruments like the Portable X-ray Fluorescence Spectrometer (PXRF), DSM ensures precise and comprehensive soil mapping. This integration of advanced technologies and statistical methods underscores DSM's importance in modern soil science and agricultural practices.

Comment [DHN7]: Summarize and focus on the conclusion only.

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