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SFMToolbox: an ArcGIS Python Toolbox for Automatic Production of Maps of Soil Fertility

Abstract: SFMToolbox is an ArcGIS Python toolbox developed in ArcGIS Desktop (ArcMap) to perform preprocessing tasks for the automatic creation of maps of soil fertility parameters. Through SFMToolbox, users can automatically produce 12 soil fertility parameter maps as a batch at one time. It is easy to use, where users can only provide input; the output files are automatically created from the name of the sample point and saved in the defined workspace. During the execution of the tools, various processes, such as Inverse Distance Weighted (IDW) – a technique of interpolation, reclassification, adding color, merging, projection, area calculation, and legend are done automatically for all 12 parameters at the same time. The SFMToolbox was validated as part of the following case study: village – Kashipur, tehsil – Balrampur, district – Balrampur, state – Uttar Pradesh, Country – India. The results show that the user can quickly generate maps and save time, improve accuracy, and reduce human intervention and ensure uniformity among maps. This toolbox also applied to Cycle II data from the Government of India's Soil Health Card (SHC) scheme and timely produced 12-parameters soil nutrient maps for 630 districts in a uniform format. The toolbox may be used by public and private organizations to make timely decisions on agricultural and environmental issues.

Keywords: ArcGIS, GIS, Python, ArcPy, ArcMap, soil fertility, toolbox, soil health card

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1. Introduction

Soil fertility is essential for efficient nutrient management, environmental protection, and beneficial crops. Soil fertility information is required for fertilizer needs and managing soil and plant resources to increase agricultural productivity [1–3]. The spatial distribution of soil properties is necessary for decision makers to plan and take appropriate action [4]. Site-specific nutrient management is essential for soil fertility and productivity, reducing the vulnerability of the food production system to climate change [5]. Farmers do not use fertilizers in a balanced way because they do not know the physical and chemical properties of the soil. Due to nutritional deficiencies or excesses, the quality and production of agriculture do not meet expectations [6]. An effective tool for improving productivity is fertility management, which is based on soil analysis. However, in most developing countries, major restrictions prohibit the widespread use of soil studies [7]. A major challenge in managing soil fertility in India is stabilizing the amount of nutrients needed for the crops of choice [8]. To deal with these challenges, the Government of India introduced the Soil Health Card (SHC) scheme in 2015 to provide soil health cards to farmers to help them know their soil health status. In this research paper, a new toolbox namely SFMToolbox is introduced, which is fast, convenient, and used to automatically generate soil fertility maps for a short time with improved uniformity and accuracy. The SHC scheme is briefly discussed in Section 2. A literature search is available in Section 3. SFMToolbox was developed using the ArcPy site package of ArcGIS version 10.x, discussed in Section 4. The required materials and methods are listed in Sections 5 and 6. The results of the toolbox and discussion are given in Section 7 and 8. Sections 9–11 present SFMToolbox's limitations, future scope, and conclusions.

2. Soil Health Card (SHC) of the Government of India

The Government of India (GOI) introduced the Soil Health Card (SHC) on December 5th, 2015 to understand the soils and available nutrients in farmers' fields [6]. For the soil sampling under the SHC scheme, the cropped area is divided into grids of 2.5 ha for irrigated areas and 10 ha for rainfed areas [6]. The government will provide soil health cards in every two years to farmers to apply nutrients based on soil testing. It not only improves long-term soil health and fertility but also assists farmers in deciding which crops to cultivate for increased yield and income [9]. In this scheme, soil health is assessed through 12 important soil parameters, namely:

- the macro-nutrients: available nitrogen (N), phosphorus (P), potassium (K), secondary-nutrient sulphur (S);
- the micro-nutrients: zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), boron (B);
- the chemical parameters: pH, electrical conductivity (EC), soil organic carbon (OC) [6, 9, 10].

The SHC data is available for the years 2015–2016 to 2016–2017, 2017–2018 to 2018–2019 and 2019–2020 to 2020–2021, respectively [10].

3. Literature Review

A Geographic Information System (GIS) is computer-based software used in the collection, storage, transformation, analysis, and display of spatial data [11]. The GIS is implemented worldwide in the spatial distribution of soil nutrient properties [8, 12, 13]. A GIS-based soil fertility map can be used as a decision-making tool for nutrient management and fertilizer recommendations. Soil fertility information is necessary for fertilizer requirements and management of the soils and crops. Soil fertility evaluation and spatial distribution play a vital role in nutrient management and fertilizer recommendations [7, 14]. Soil fertility maps using GIS are limited in India [15]. Modern technologies in geographic information systems may allow spatial data manipulation [16]. Different tasks of agricultural information systems are estimated using new technologies [17]. Macronutrients and micronutrients determine soil fertility because it is the soil's inherent capacity to provide nutrients to plants [18]. New technologies may be applied to the assessment of soil fertility for quick results [19]. Many studies have developed soil fertility maps using GIS and remote sensing techniques. Yang and Zhang [3] developed a model for spatial distribution maps of soil nutrients using ArcView GIS and the kriging interpolation method. Barman et al. [5] generated homogeneous soil fertility maps through GIS for site-specific nutrient management. Papadopoulos et al. [20] presented GIS-based modelling for site-specific nitrogen fertilization toward soil sustainability. Kumar et al. [21] explained the delineation and GIS mapping of soil nutrient status of sugarcane growing tracts. AbdelRahman et al. [22] used GIS and remote sensing techniques for soil fertility estimation in physically land-degraded areas. Banerjee et al. [23] used GIS technology to assess the soil nutrient status in three agro-climatic zones of Belgaum district, Karnataka, India. Ren et al. [24] developed a universal workflow model to evaluate soil fertility based on Open Geospatial Consortium (OGC) Web Service. Kashiwar et al. [25] used thematic maps of soil nutrients using an interpolation technique of kriging in the ArcGIStoolbox of the ArcGIS 10.4.1. Biradar et al. [26] developed soil fertility maps through GIS techniques in the micro-watershed of Hassan, Karnataka. Pratibha et al. [27] produced soil fertility maps using soil health card data, which is available at [10], ArcGIS 10.3 software, and the Inverse Distance Weighted (IDW) interpolation technique for land use planning in sub-tropical humid region of Meghalaya State. Li et al. [28] discussed the evaluation and spatial distribution of soil fertility in grasslands in the Qilian mountains nature reserve of the eastern Qinghai-Tibetan plateau.

Preparation of soil fertility maps in a traditional manner (drag and drop tools from ArcToolbox) takes various steps such as IDW, reclass, color adjustment, projection, pivot, summary statistics, etc. To perform these tasks knowledge of GIS is required. Automated workflow development in the GIS environment is growing widely for multi-environmental purposes [29–32]. Several researchers developed a toolbox using ArcGIS, commercial software for various purposes [33–36].

Building upon the mentioned literature, the present study has developed an ArcGIS-based SFMToolbox for the preparation of soil fertility maps which will be used for producing maps on time, with less cost, and the minimum human resources.

Limitations of literature review

Many authors in the literature review in this paper show that they developed maps and spatial analysis conventionally with the help of drag-and-drop tools of ArcGIS (a commercial Geographic Information System – GIS). Although the ArcGIS tools are powerful, they are time consuming and consist of several steps, with knowledge of ArcGIS software required. Due to the lack of automation and complexity in manually using tools, it may take more time to make decisions. Utilization of the new technique can improve the quality of maps. Many studies are reluctant to use advanced technologies while generating maps of soil fertility, which may be because of the lack of knowledge or the expensive cost of ArcGIS software, or a lack of awareness about the advantages of these technologies. The workflow technology may automate the processing of data to improve efficiency [24]. Workflow modelling facilitates automatic or semi-automated business execution by incorporating workflow operations into models [37, 38]. Therefore, it was necessary to develop a new tool to automate the process of soil fertility mapping.

4. ArcGIS and ArcPy

4.1. ArcGIS

ArcGIS is commercial GIS software developed by ESRI (Environmental Systems Research Institute). ArcMap is the component in ArcGIS to create spatial analysis, graphical user interface, batch calculation possibilities, and to analyze geospatial data. ArcGIS 10.8.2, released on December 9, 2021, is the current release of ArcGIS Desktop for ArcMap. ArcGIS provides various toolboxes that can be chained together with custom Python scripts. Using ArcGIS, users can create customized toolboxes using the ArcPy library [39–42].

4.2. ArcPy

ArcMap for automated SFM creation was developed with the Python 2.7.x programming language and the ArcGIS environment to access tools, manage geographic databases, and automate internal processes [43]. ArcPy scripting was introduced in the version ArcMap 10.0, a site package based on the Python programming language that helps to build access to the geoprocessing tools of ArcGIS [44].

ArcPy can be widely used for map automation, data analysis, management, and conversion, including modelling with the ArcGIS interface [44, 45]. ArcPy is extensively used in the modelling and automation of applications by various authors to create applications in a simple and easy way [46–48]. ArcPy scripting tools can be used for spatial analysis and to automate the production of maps by reducing repetitive tasks to save time, labor, and costs. ArcPy has been widely used by several authors for modelling to solve complex spatial analyses. The research literature indicates that the ArcGIS-based toolbox has not been used to automatically generate soil fertility maps. The maps generated based on the toolbox may save time, human resources, and cost, especially the user's time in the iterative process required for each soil fertility parameter.

ArcPy mapping

ArcPy mapping is a Python scripting module that is part of the ArcPy site package and is used in automatic map production [49–51]. However, it is only used to modify existing elements in the created layer files (.lyr) or map documents (MXD). The ArcPy mapping module was introduced in the ArcGIS 10.0 version to modify the existing maps, layers, and export and cannot be used to create new objects. In this study, we used ArcPy mapping when adding layers, iterating layers, and exporting a map document (MXD) to an image format (JPEG).

5. Materials

5.1. Study Area

The SFMToolbox applied at village – Kashipur (173246), tehsil – Balrampur (925), district – Balrampur (127), and state – Uttar Pradesh (9). A number given in brackets is a unique identifier according to the Local Government Directory, Government of India [52]. The data downloaded for 2017–2018 to 2018–2019 cycles from the website https://soilhealth.dac.gov.in/ [10]. The reference map of study area is given in Figure 1.

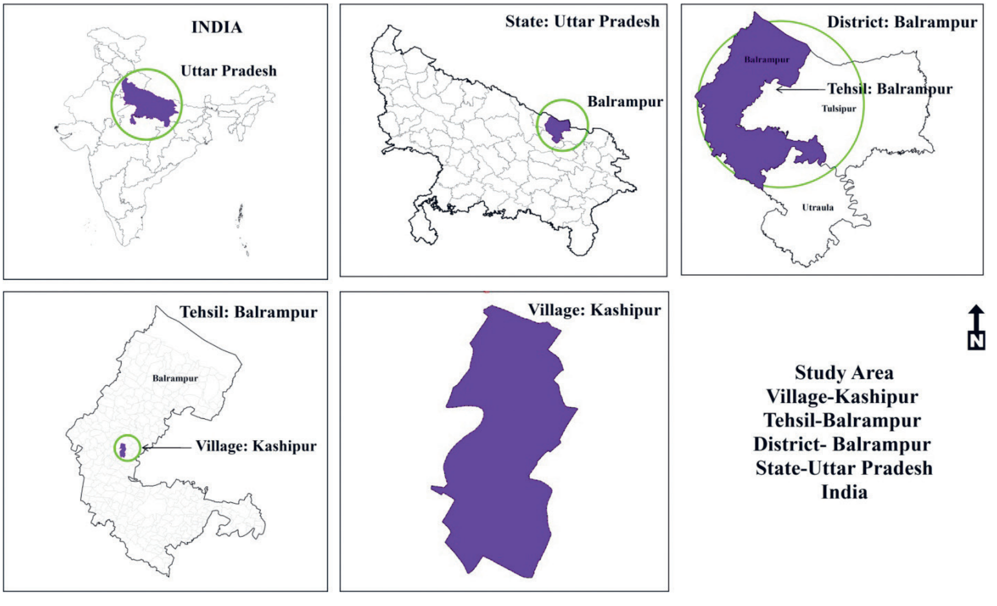

Fig. 1. Reference map of study area

5.2. Data and Technology Requirements

To generate maps, the data and technology requirements are as follows:

- Obtain a cadastral map of the study area to be digitized, if the map is not available in digital form (Figs. 2, 3).
- Soil laboratory analysis data of 12 parameters (Fig. 4, Appendix D).
- Miscellaneous village file which includes elements of the topography of the terrain like rivers, roads, canal, water bodies, tank and built-up areas etc. (Fig. 5).
- Village outer boundary file (Fig. 6) to be used in IDW for processing extent.
- Village file without the miscellaneous features (Fig. 7) to be used in IDW for masking.
- Administrative layers of state, district, and tehsil for the creation of a reference map (Fig. 1).
- DBF files of 12 soil parameters needed to create legend files automatically (an example of the data structure of the DBF file of parameter EC is available in Appendix B).

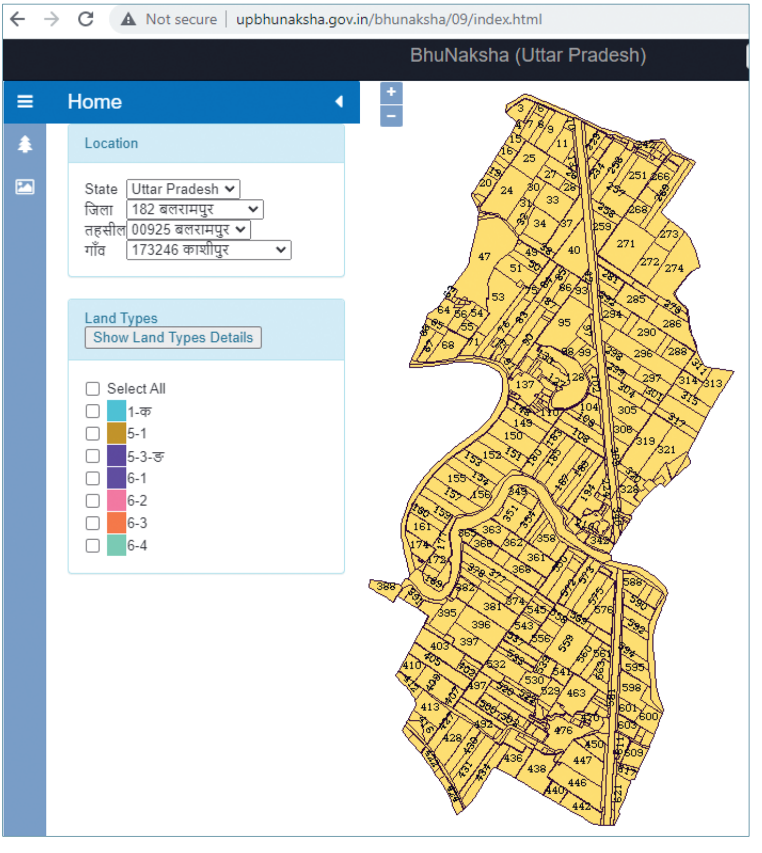

Fig. 2. Downloaded image of village

Fig. 3. Digitized cadastral map of village

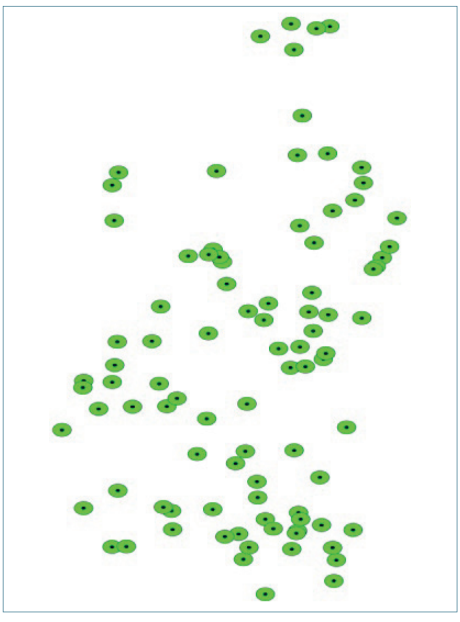

Fig. 4. Sampling points having 12 parameters laboratory data values

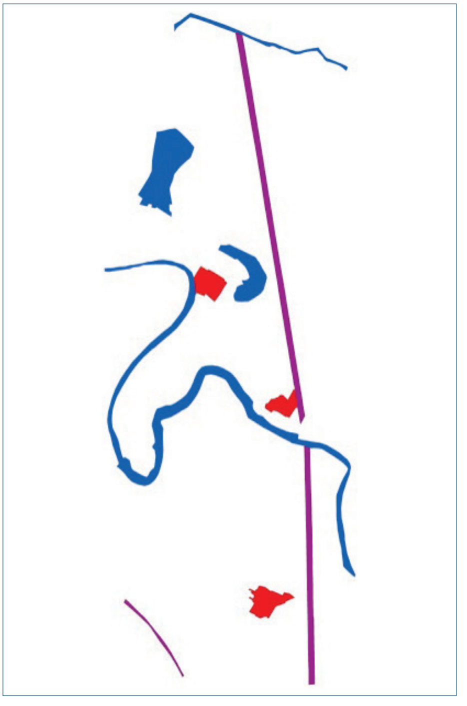

Fig. 5. Miscellaneous layer

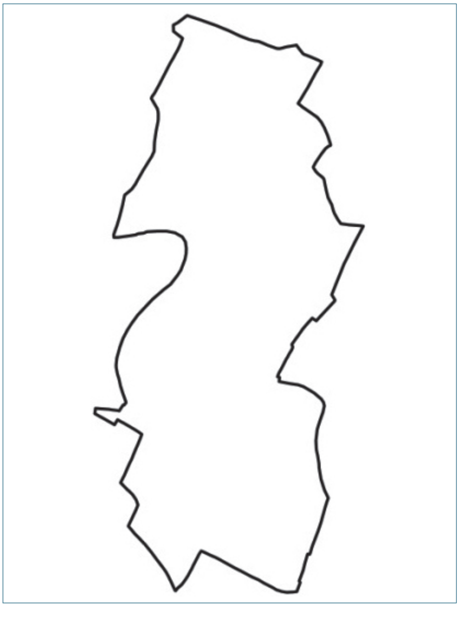

Fig. 6. Village layer outer boundary

Fig. 7. Village layer without miscellaneous

IDW interpolation method is applied to predict unknown values from the point data. The IDW is a weighted moving average [53] and this technique interpolates a raster surface from points.

5.3. Data Preparation

The cadastral map of the village is available in image format at the Uttar Pradesh state BhuNaksha website (see http://upbhunaksha.gov.in/bhunaksha/09/index.html). The information can be obtained by selecting the district, tehsil, and village (Fig. 2). The cadastral map is needed to digitize according to the survey numbers. Digitization of the cadastral map with a survey number (Khasra in Hindi) is available in Figure 3. The dataset including 92 sample locations in the study area is shown in Figure 4.

The soil samples of the study area were collected from the government agency concerned. This Excel file contains the village name, survey numbers, and soil properties of 12 parameter numbers. The data structure of the soil sampling file is given in Appendix D. The data was cleaned, and outliers were examined and validated before joining the soil sampling file with the sampling points of the shape file.

5.4. Software Environment

The technologies used in the generation of automated soil fertility maps (SFM) are listed below:
– hardware: system compatible with ArcGIS Software,
– software: operating system Windows version 7 and above,
– application software: advanced license of ArcGIS Desktop (ArcMap) with spatial analyst extension,
– ArcPy: a site-package available within the ArcGIS Desktop (ArcMap),
– HTML: the HyperText Markup Language (HTML) which is a standard markup language for documents designed and displayed in a web browser.

6. Methods

6.1. Architecture and Description of the SFMToolbox

The SFMToolbox's architecture has three divisions:
1) data,
2) ArcToolbox,
3) HTML (Fig. 8).

Data division

Data division includes the collection of data from different sources like government or private organizations, cleaning, and processing of received data. Then this data will be digitized with the help of GIS software and this data converted to a spatial data format. The next step was the collection of soil analysis data from a laboratory for the samples, which were collected from different places in the study area along with their longitude and latitude values and having a specific survey number for each sampling point. Based on the survey number the soil laboratory data will be joined with the cadastral map shape file. The joined shape file will be used for further analysis and map preparation. The steps of the data division are as follows:
1. Collecting or gathering data from different sources.
2. Cleaning, outliers management, and processing.
3. Collecting laboratory analysis of soil samples, digitization of cadastral maps and administrative layers.
4. Joining the cadastral map with the soil analysis data by using survey number as a unique ID in both files.

ArcToolbox

The purpose of the SFMToolbox is to create the required files automatically. The toolbox was designed based on ArcPy, a scripting language available with ArcMap for ArcGIS Desktop.

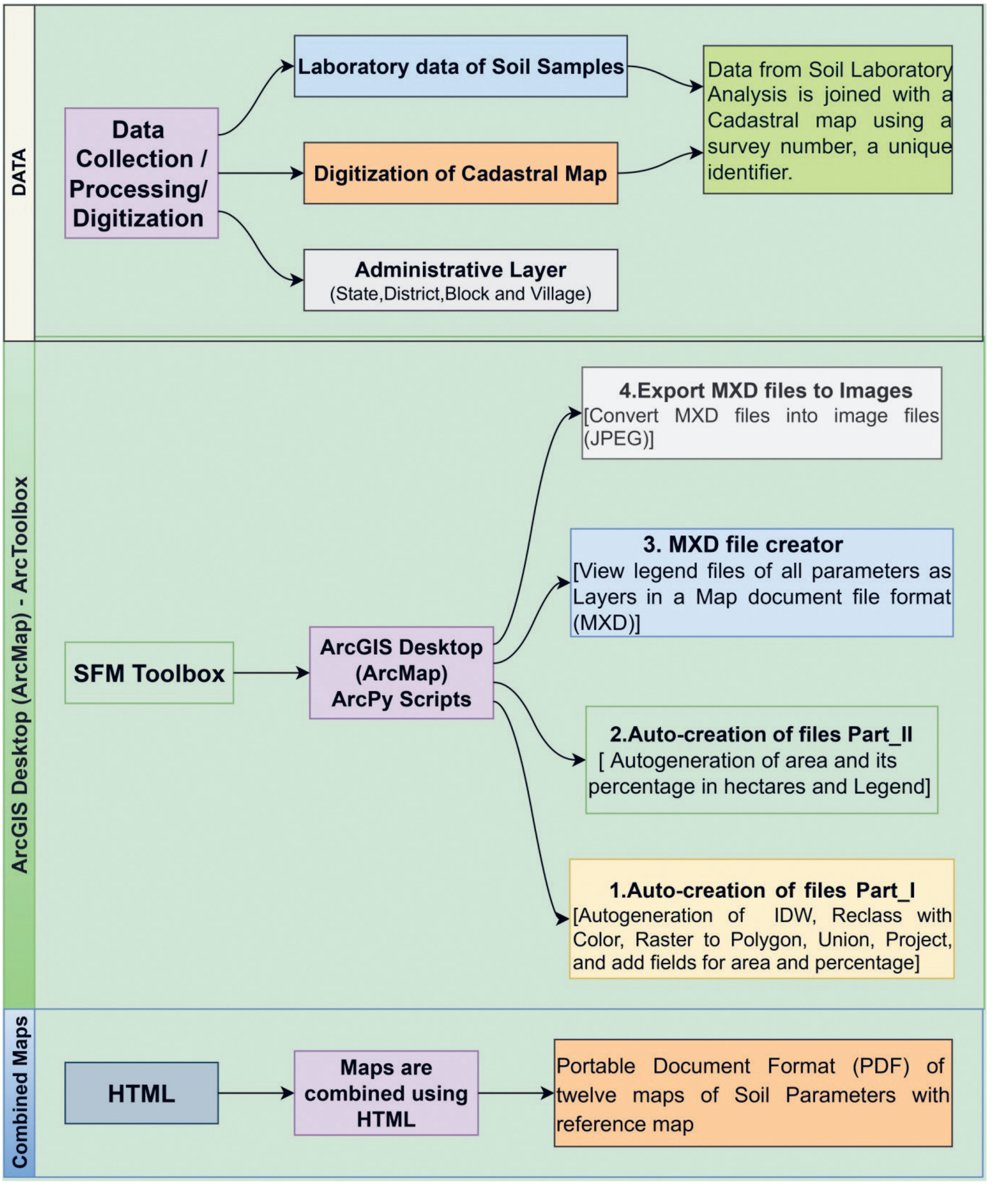

Fig. 8. Architecture of the SFMToolbox

This toolbox has four Python scripts:

1) Auto-generated files Part I,
2) Auto-generated files Part II,
3) MXD File Creator,
4) Export MXD to JPEG.

Auto-generated files Part I. The purpose is to generate Inverse Distance Weighting (IDW) interpolation, reclass, add color to reclass, raster to polygon file conversion, union files, project, and add fields to store area and its percentage [ha] for all 12 soil parameters at a time as a batch file. The values of reclass and color are as per the specifications given in this paper. Only input (source) files are needed to provide the output files are generated automatically based on the first five characters of the sampling points file to save time and avoid human intervention.

Auto-generated files Part II. The purpose is to calculate the area [ha] and its percentage, summary statistics (pivot tables), join DBF files (defined in this paper), and the reclass (with color) files to generate automatic legend. Note that you manually insert the title, legend (auto-generated), north arrow, and scale bar for map publication.

MXD File Creator. This script is for viewing all auto-generated legend files into layers, created in Auto-generated files Part II. The MXDs of parameters create by selecting or deselecting layers.

Export MXD to JPEG. This script is used for exporting MXD files (map document files) into an image file format (JPEG) with a paper size of A3, but the paper size may be A0 or A4, and also for exporting into a Portable Document Format (PDF) as well.

HTML

The HyperText Markup Language, or HTML, is a markup language used to view all soil fertility maps at a glance with a reference map.

Once the 12 parameter maps are generated, the next step is to combine all maps along with the reference map (administration/location map). Using ArcGIS the user can combine 12 parameter maps along with a reference map, but it takes longer and sometimes the system may hang, hence we chose HTML. Using HTML we have created a table where we can combine maps and export it to a single PDF. We have used only cascading style sheets (CSS) for flexibility in PDF size (A0/A3/A4). The default size of the PDF is A0 size.

6.2. The Process Involved in Creating Files through the SFMToolbox

The process involved in creating files through the SFMToolbox is carried out in fourteen steps as follows:

1. The creation of a digital cadastral map with a survey number as a unique identifier.
   1.1. Development of a village sampling file.
   1.2. Development of a village outer boundary file for use in the IDW extent.

   1.3. Village file creation without miscellaneous files to be used in the IDW mask.
   1.4. Creation of the village file with the miscellaneous files (rivers, roads, canal, water bodies, tank and built-up areas etc.) to be used to get the area of the village.
   1.5. Collect soil information of 12 soil parameters (as mentioned in this paper, along with survey numbers of the study area).
2. Soil analysis of laboratory data joined with a digital cadastral map (survey number as a common attribute for joining files).
3. The IDW interpolation technique is applied to compute an average value for un-sampled locations using values from nearby weighted locations, including processing extent. The properties of IDW, processing extent (village outer boundary), and mask (village without miscellaneous) are needed to set up.
4. Reclass according to the specifications given in Appendix A, which is inbuilt in ArcPy script.
5. Add color to the reclassification files according to the specifications given in Appendix A. Reclassification and addition color files are inbuilt within the ArcPy script.
6. Conversion of reclassification (raster) files to polygon files.
7. Merging the polygon and miscellaneous files (union).
8. The project of union files.
9. Add two fields, namely area [ha] and percentage, needed to create.
10. Calculate area [ha] and its percentage, by grouping grid values (pivot table) using summary statistics files.
11. To get the legend along with the area, including miscellaneous files, join the DBF file (see Appendix B) of the parameters with the summary statistics files generated in step 11.
12. The process is automatic for above mentioned steps 1–12 for all 12 soil parameters, as a batch file at one time.
13. To produce a final map, go to the layer properties of the desired parameter of the legend file, created in above mentioned step 12, then go to Symbology → Unique values → choose Value field → select Legend – click Apply and save it as an MXD file (map document file of ArcMap). Repeat the same process for the remaining parameters as well. Next, insert the title, north arrow, and scale manually, due to the limitations of "arc.mapping". At this stage, an assumption is that 12 MXD files (raster) are created for all soil parameters.
14. Export all 12 MXD files into JPEG files at one time as a batch (A3 size chosen in this study).

The description of required source files (S) and auto-generated (A) files are in Table 1.

Table 1. The description of the required source files (S) and the auto-generated (A) files

Name of file (folder)	Format	Description	No. of files/tables	Input (source file, S) and output (automatically created file, A)	Where folder (files) are used
Sampling file	Point	The soil sampling points of the study area for analyzing soil fertility status	1	S	Auto-generated files Part I
Village file	Polygon	This file is used in the process extent of IDW interpolation	1	S	Auto-generated files Part I
Miscellaneous file	Polygon	Area such as habitation, river, water bodies, roads, etc., is used in masking, where interpolation is not required	1	S	Auto-generated files Part I
DBF files (folder)	DBF	The DBF files are joined with raster files to generate legend. The description of DBF files is provided in Appendix B	12	S	Auto-generated files Part II
Raster files	Raster	Generated raster files from IDW files (the ranges of raster files and values of colors applied to the raster files are in-built with the SFMToolbox – see Appendix A)	12	A	Auto-generated files Part I
Raster to polygon files	Polygon	Converts raster files into a polygon file format	12	A	Auto-generated files Part I
Union of raster to polygon files with miscellaneous files	Polygon	The converted files (raster to polygon) are merged with miscellaneous files to calculate area and its percentage	12	A	Auto-generated files Part I
Project files	Polygon	The UTM projection is in-built within the SFMToolbox, but it can be any zone by replacing the value of the central meridian and UTM zone in the Python file	12	A	Auto-generated files Part I
Summary statistics	Table	The summary statistics purpose is to crate as a pivot table of grid values	12	A	Auto-generated files Part II
Legend files	Raster	The legend files in a raster format having description classification of parameters	12	A	Auto-generated files Part II
Map document file	MXD	The map document file (MXD) for viewing all soil parameters at once as a layers	1	A	MXD File Creator
MXD to JPEG	Python	This script is applied to convert all MXD files into an image file format (JPEG)	12	A	Export MXD to JPEG
SFM Combined Maps	HTML	The HTML is used to combine 12 soil fertility maps along with a reference map in Portable Document Format (PDF)	1	A	Combined SFM Maps

6.3. Implementation of Toolbox

In this study, the soil fertility maps were generated based on the specifications mentioned in the scheme of the Soil Health Card (SHC) of the Government of India (see Appendix A), which can be used to estimate the requirement of fertilizers required for the farmers. Accordingly, with the help of soil fertility status, the government may take timely decisions on the judicious use of fertilizers that will help improve the economic condition of farmers and also reduce the excessive use of fertilizers. Thus, this study developed a new toolbox using ArcPy programming, a site package in ArcGIS compatible with ArcMap 10.x for the automatic generation of soil fertility maps which was achieved easily, quickly, efficiently, accurately and reduced the time required tremendously. Any non-GIS person with limited skills can operate the proposed toolbox so that we can save time, human resources, and costs.

To set up the SFMToolbox tools, the user needs to download the compressed file "SFMToolbox.zip" and unzip it. Then they need to start ArcGIS, an open panel of ArcToolbox, right-click on "ArcToolbox", and select "Add Toolbox", then add a new toolbox, "SFMToolbox", to the ArcToolbox panel having four tools, namely: Auto-generated files Part I, Auto-generated files Part II, MXD File Creator, and Export MXD to JPEG (Fig. 9).

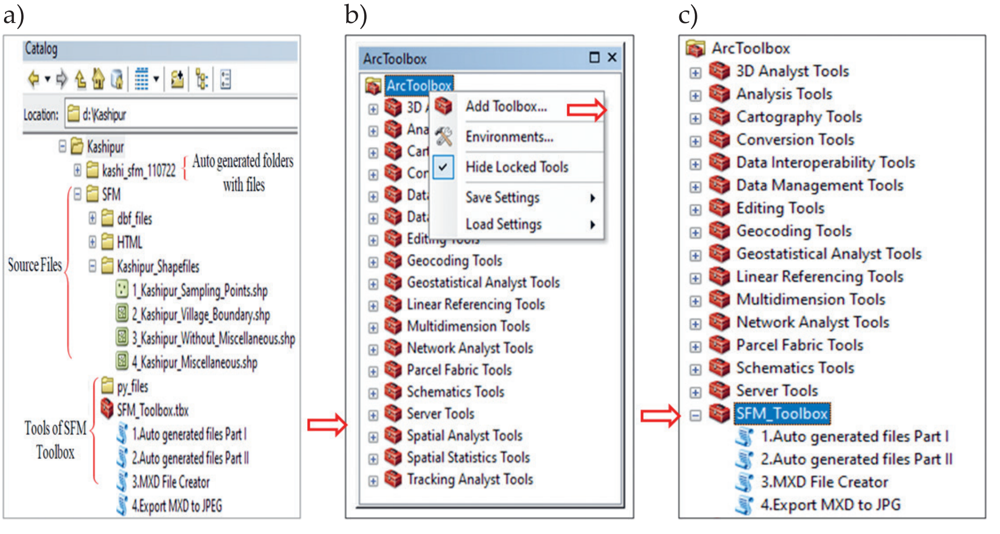

Fig. 9. Description of folder, files and tools: a) folders and files of SFMToolbox; b) adding tools into ArcToolbox; c) adding SFMToolbox

The folder contains three more folders named: "py", "DBF", and "HTML". The details of Python files (.py) and HTML files are visible outside of ArcGIS. The Auto-generated files Part I Python script file can only be opened to change the projection and the central meridian. There is no need to change the other source code. The required user input and output are described in user interface of the toolbox in detail.

User interface of the SFMToolbox

The SFMToolbox was developed based on the ArcPy site package of ArcGIS Desktop (ArcMap) with a valid spatial analyst license as an extension, which is essential for the automatic map generation of soil fertility of 12 parameters as a batch file. The toolbox interfaces are user-friendly; users need to provide the only required inputs, and it automatically created output files based on the first five characters in the sampling points file due to the size limitation of raster files in ArcGIS software. The toolbox simplifies the spatial distribution of soil parameters by reducing repetitive and time-consuming processes. Since producing 12 parameters in a traditional manner takes 3–5 hours, it has both time and manpower costs. Hence the proposed toolbox reduces the time required to 10–15 minutes with minimum human intervention. The toolbox simplifies the spatial distribution of soil parameters by reducing repetitive and time-consuming processes. The SFMToolbox has four tools, namely: Auto-generated files Part I, Auto-generated files Part II, MXD File Creator, and Export MXD to JPEG. An ordinary user can run it without knowledge of GIS. The user interface of the SFMToolbox is given in Figure 10.

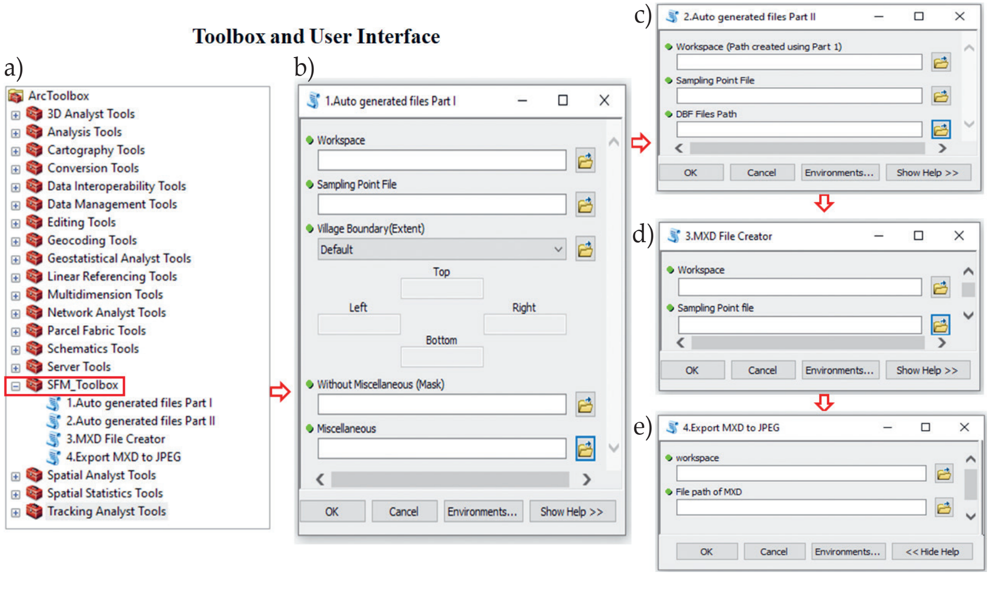

Fig. 10. The user interface of the SFMToolbox: a) tools of SFMToolbox and interfaces; b) Auto-generated files Part I; c) Auto-generated files Part II; d) MXD File Creator; e) Export MXD to JPEG

Auto-generated files Part I is an interface for auto-generate Inverse Distance Weighting (IDW) interpolation, reclass, add colors to reclass, raster to polygon file conversion, union files, project, and add fields to store area [ha] and its percentage for all 12 soil parameters at a time as a batch. The values of reclass and color are as per the specifications described in Appendix A. The user needs to supply input (source) files; it created the output files automatically based on the first five characters of the sampling points file to save time, uniformity, and avoid human intervention.

Auto-generated files Part II is an interface for calculating the area [ha] and its percentage. Summary statistics (pivot tables), joining DBF files (see Appendix B) with reclass (along with color) files to generate an automatic legend. Due to ArcPy mapping limitations, users must manually (drag-drop) insert the title, legend (auto-generated), north arrow, and scale bar for map publication.

The ArcPy script of the MXD File Creator interface is for viewing all auto-generated legend files in the layers created in Auto-generated files Part II.

The user interface of the tool Export MXD to JPEG applies to exporting a map document format (MXD) into an image file format (JPEG).

Appendices C.1, C.2, C.3, and C.4 contain details about the parameters, data type, and explanations for the Auto-generated files Part I, Auto-generated files Part II, MXD File Creator, and Export MXD to JPEG, respectively.

7. Results

This section discusses the user interface, execution, and results of the SFMToolbox. The user interface, execution, and results of the ArcPy script for Auto-generated files Part I are available in Figures 11–13, respectively. After successfully running Auto-generated files Part I, a folder, namely "kashi_sfm_110722", was created under the workspace folder, namely "Kashipur" (Fig. 17a), was created with the first five characters of the sampling point file. The user needs to refresh the workspace to view folders and files. The "Kashipur" folder contains 60 output files, namely: IDW – 12, reclass – 12, raster to polygon – 12, union files – 12, and project – 12, of 12 soil parameters (Fig. 18b–f). These auto-created files are applied in Auto-generated files Part II.

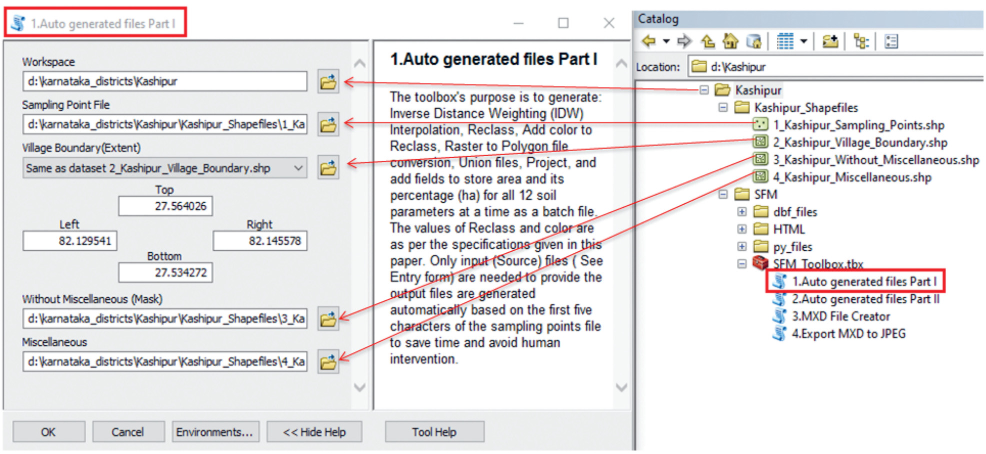

Fig. 11. User interface of Auto-generated files Part I with input files and folders

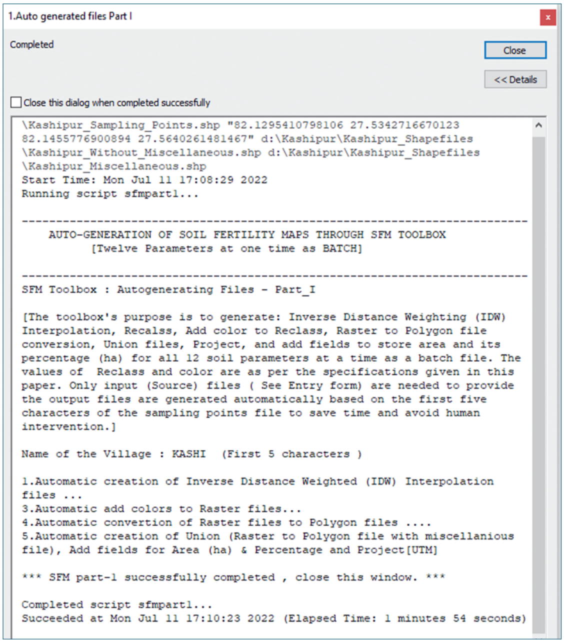

Fig. 12. Execution of ArcPy script of Auto-generated files Part I

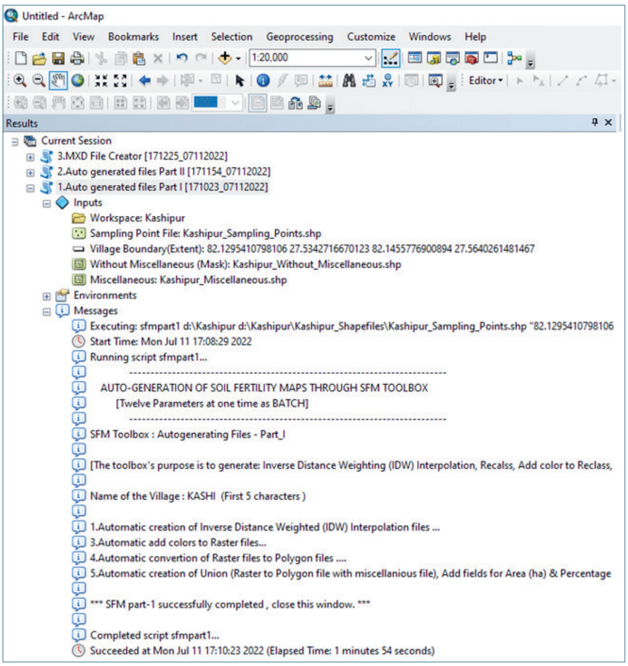

Fig. 13. Results of ArcPy script of Auto-generated files Part I

After running the script for the Auto-generated files Part I, the user needs to run the Auto-generated files Part II. The user interface, execution, and results of the ArcPy script for Auto-generated files Part II are available in Figures 14–16.

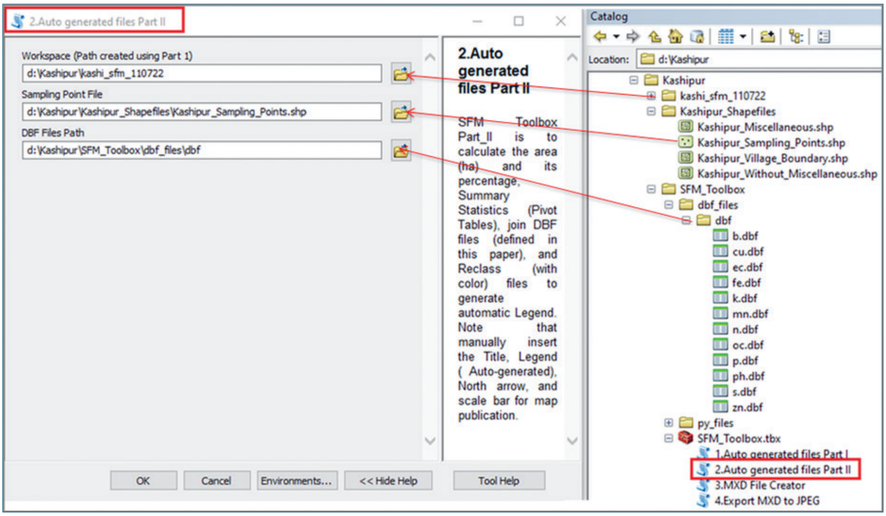

Fig. 14. User interface of Auto-generated files Part II with input files

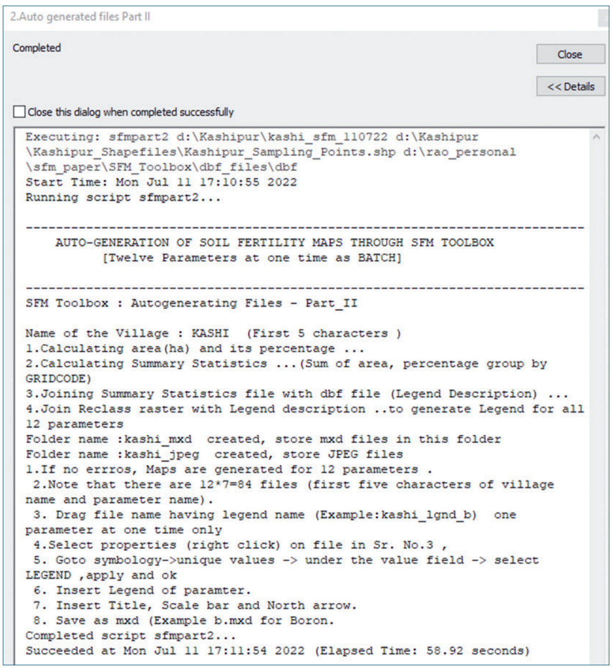

Fig. 15. Execution of ArcPy script of Auto-generated files Part II

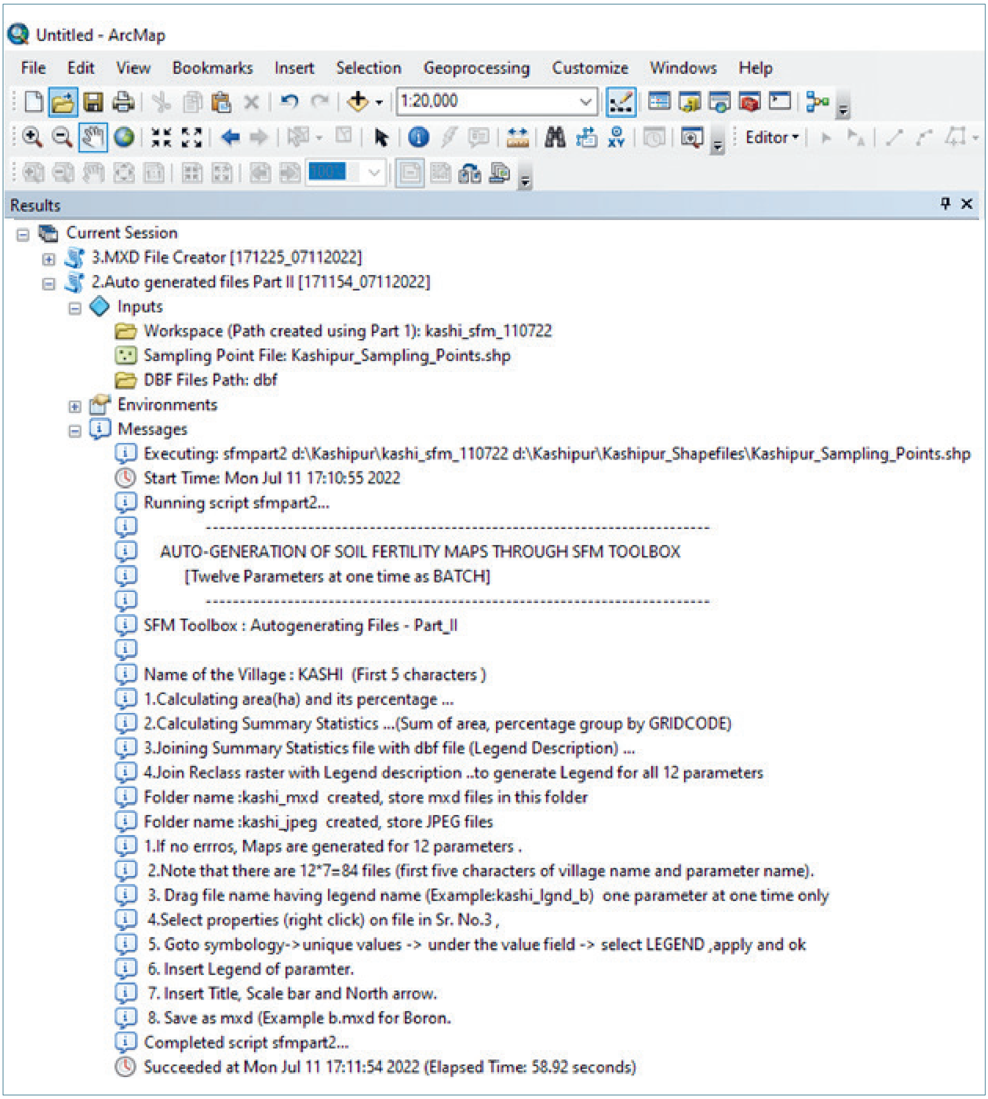

Fig. 16. Results of ArcPy script of Auto-generated files Part II

Three folders were auto-created during execution, namely "kashi_temp", "kashi_mxd", and "kashi_jpeg" (Fig. 17b–d). The folder "kashi_temp" to store map document files (MXD) has layers of all parameters to view at a glance as a single MXD file; the "kashi_mxd" to store 12 MXD files; and a third folder, "kashi_jpeg" is used to store image files (JPEG). The auto-created files under these three folders are available in Figure 17. There are 24 auto-crated files, namely summary-statistics (12), and legend (12) (Fig. 18g, h). 84 numbers of output files are generated using the tools for Auto-generated files Part I and II (Fig. 18).

After running the script of the MXD File Creator, the user interface, execution, and results of the ArcPy script are given in Figures 19–21, respectively. One should double-click "kashi_temp.mxd", a map document file (MXD) created under the folder, namely "kashi_sfm_110722", to view the content in the auto-generated legend files (Fig. 22) of 12 parameters as layers (Fig. 18h).

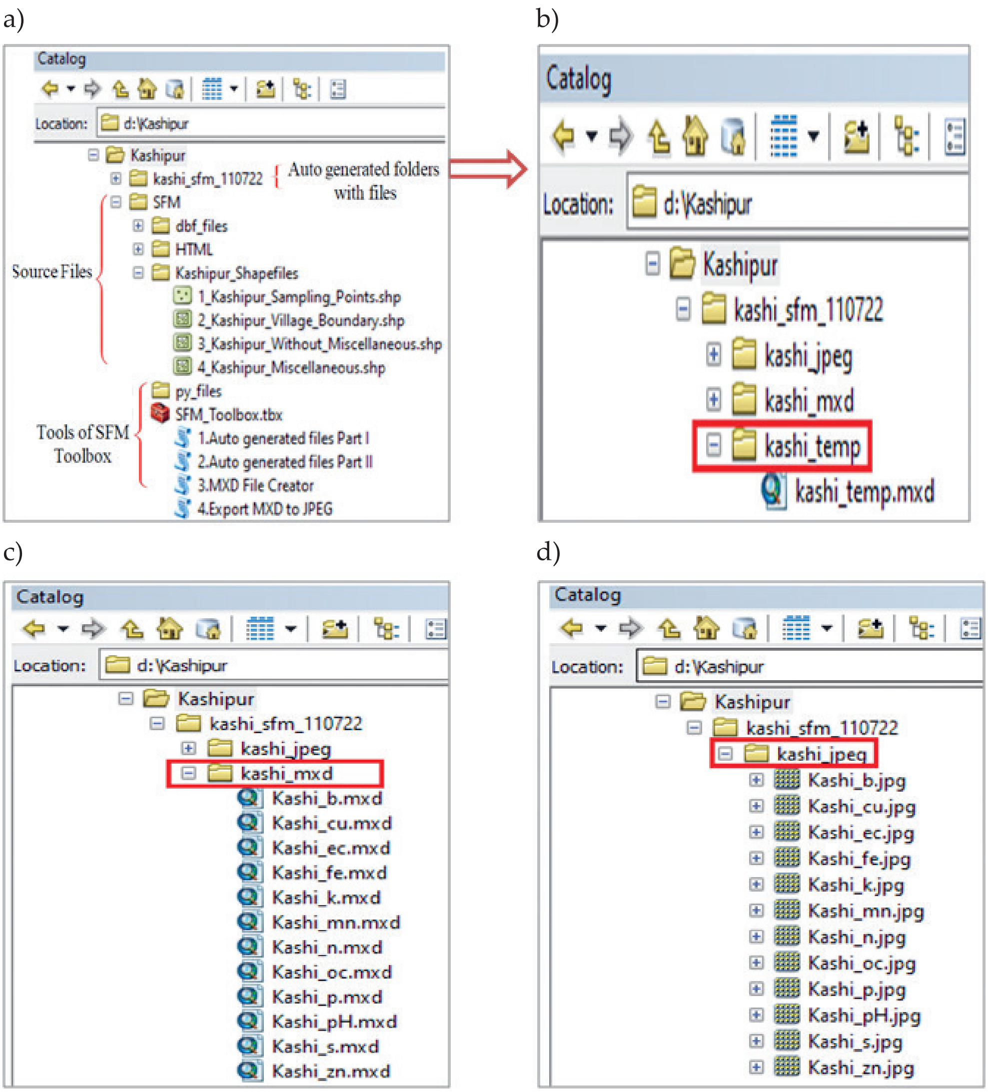

Fig. 17. Required and auto-generated folders and files:
a) required folders and files for SFMToolbox;
b) auto-created map document file (MXD) having layers of all parameters;
c) MXD files of soil parameters; d) auto-created image files (JPEG)

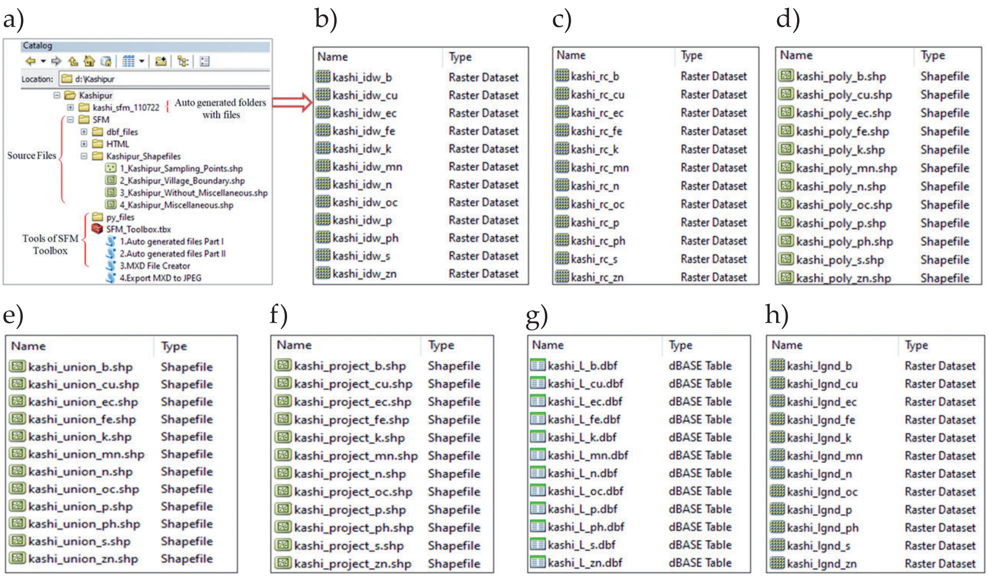

Fig. 18. Description of auto-generated files: a) names of source files and auto-generated folder; b) IDW files; c) reclass (with color) files; d) polygon files (after raster conversion); e) union files (polygon files with miscellaneous files); f) projection files (UTM); g) summary statistics (pivot table of grid); h) legend

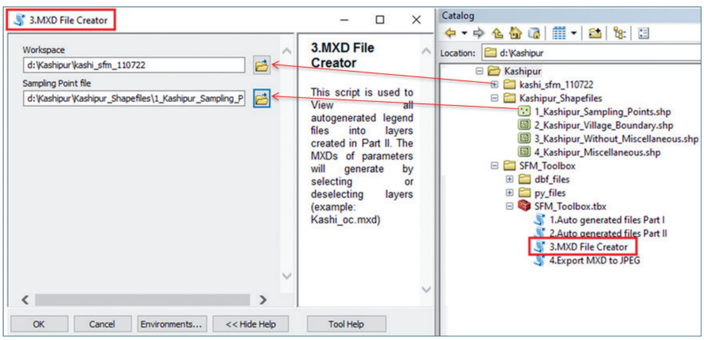

Fig. 19. User interface of MXD File Creator with input files and folders

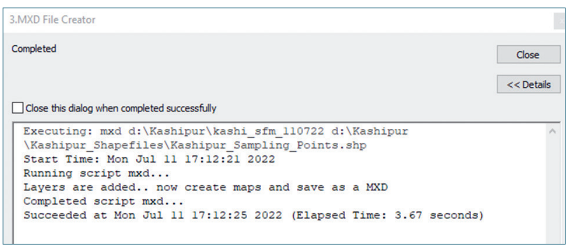

Fig. 20. Execution of ArcPy script of MXD File Creator

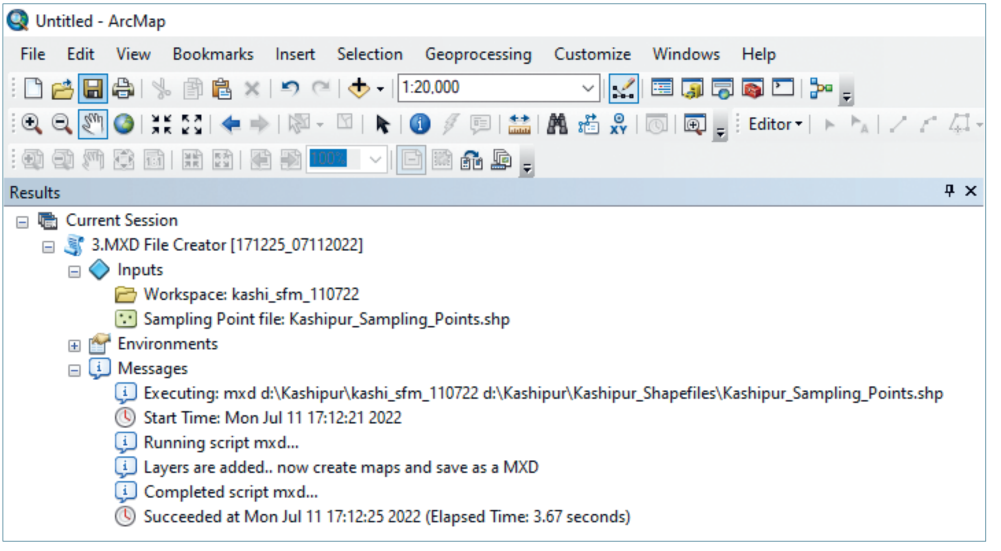

Fig. 21. Results of ArcPy script of MXD File Creator

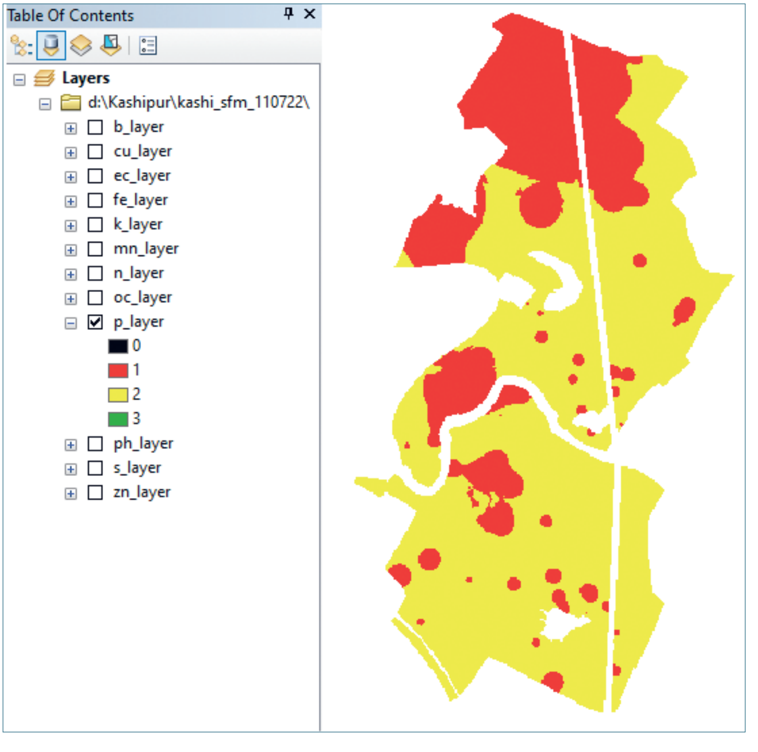

Fig. 22. A view of layers of all 12 parameters
(showing example of phosphorus by selecting layer)

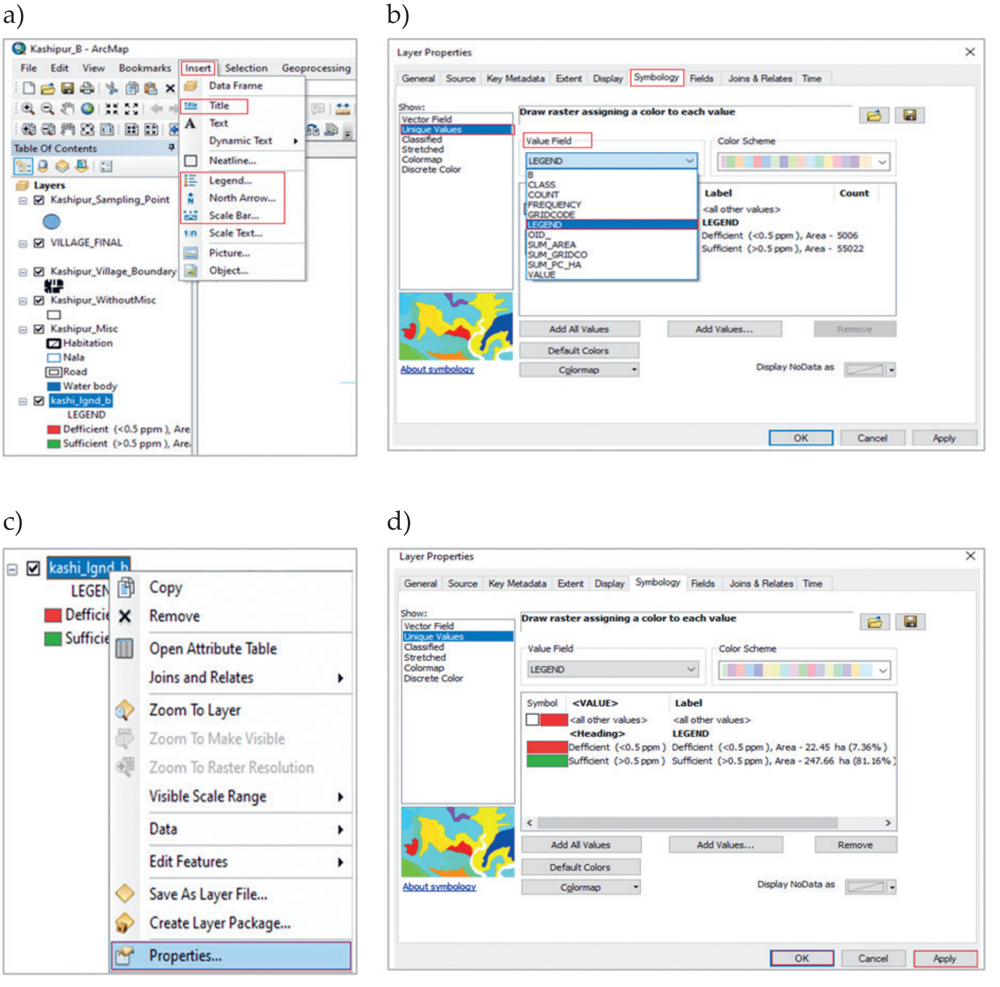

Fig. 23. Description of legend insert process:
a) process for manually insert – Title, North Arrow, Scale Bar and Legend;
b) click on Properties to show Symbology;
c) click on Symbology → Unique values → Value field → select Legend;
d) click Apply and OK to insert legend into map

Next, select any parameter layer → go to properties by right-clicking → go to Symbology → Unique values → choose Value field → select Legend → click Apply and OK to insert the legend.

Due to the limitation of "arc.mapping" as discussed in the section "Limitations of Literature Review", to view the details of the legend on the map, manually insert legend, title, scale bar, etc., and save to an MXD file, namely "kashi_b.mxd", similarly created MXD files for other parameters also (Fig. 23).

After running a script to Export MXD to JPEG, the user interface, execution, and results of the ArcPy script are given in Figures 24–26, respectively. The created output images (JPEG) are available in the folder, namely “kashi_jpeg”.

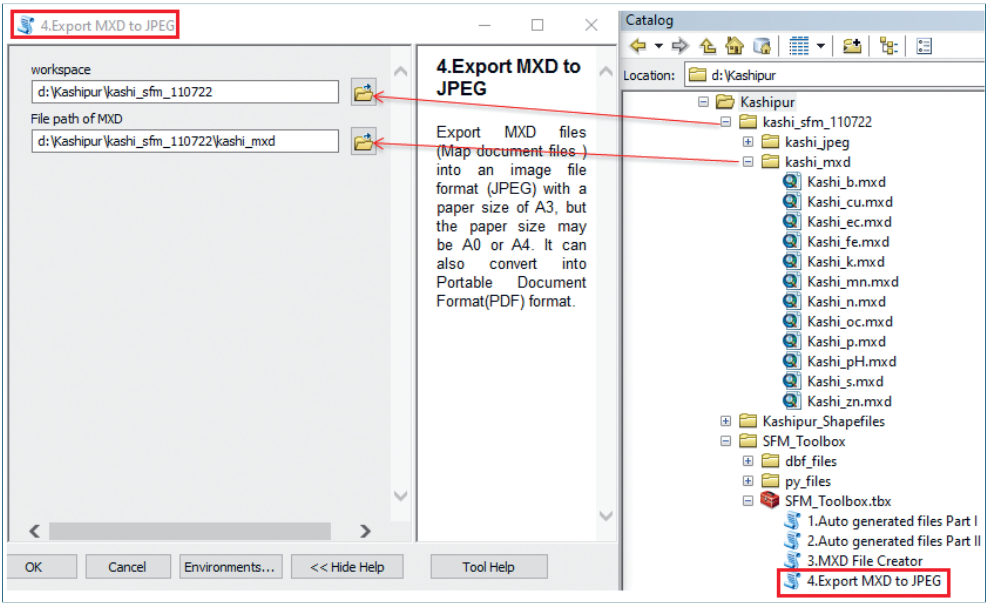

Fig. 24. User interface of Export MXD to JPEG with input files and folders

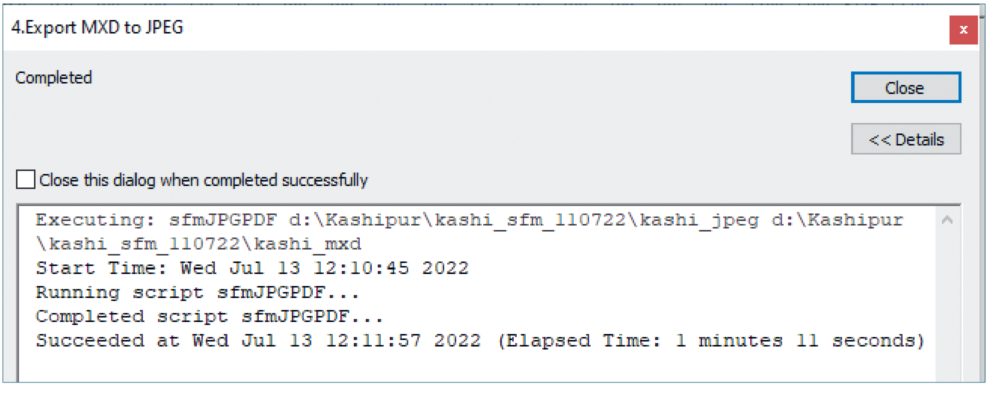

Fig. 25. Execution of ArcPy script of Export MXD to JPEG

HyperText Markup Language (HTML) is applied to combine maps of 12 soil parameters along with a reference map. The output of the HTML is available in Figure 27. It can be exported by a print option to save the result as a pdf by selecting print options, it can be downloaded in sizes A0, A3, or A4 (default A3 size).

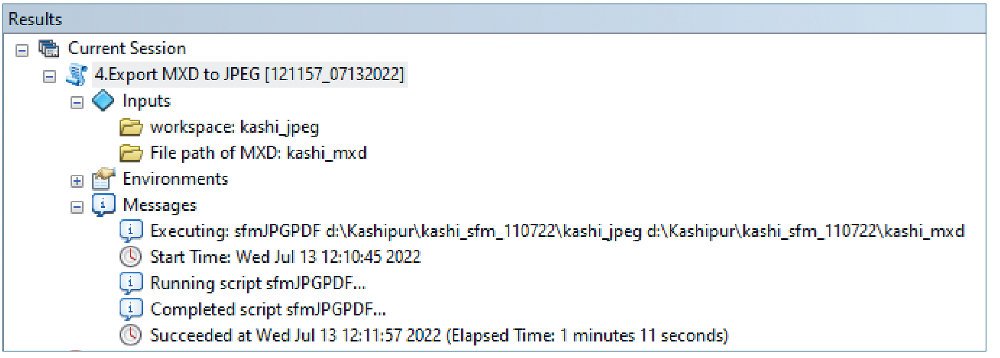

Fig. 26. Results of ArcPy script of Export MXD to JPEG

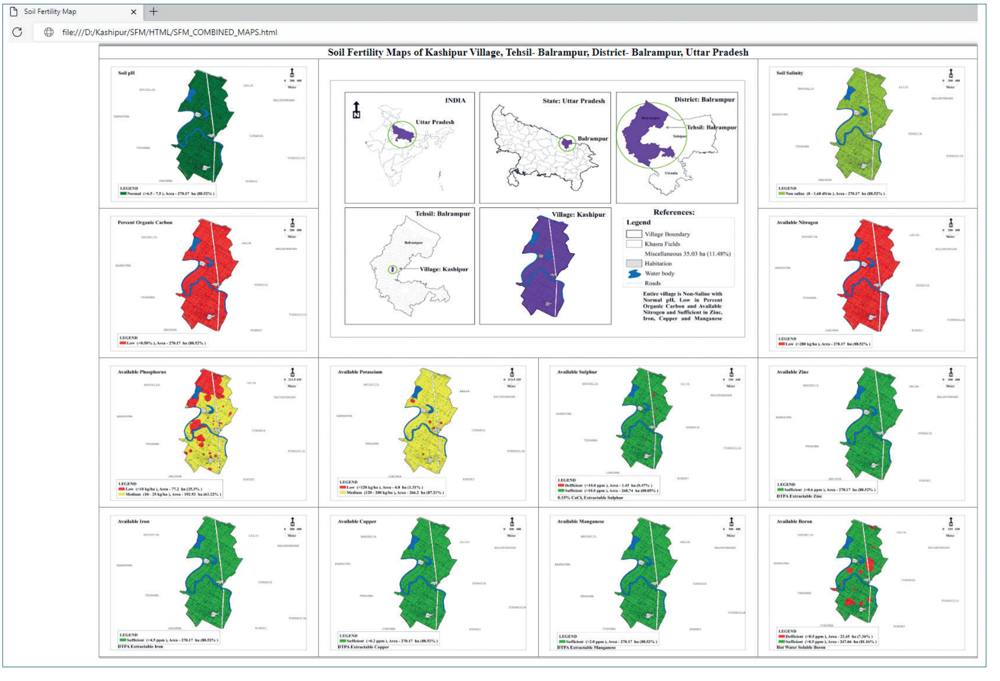

Fig. 27. Twelve parameters soil fertility maps of village – Kashipur, tehsil – Balrampur, district – Balrampur, and state – Uttar Pradesh, India

8. Discussion

One main advantage of the tool developed here is that it does not involve human intervention in providing the output files, which will be generated automatically by the toolbox itself based on the first five characters of the sampling point file and parameters to save time, speed, accuracy, and uniformity. A toolbox-assisted production of digital SFM maps has not yet been developed because of the requirements of a combination of software technologies. To date, there have been no known studies on the automation of repetitive tasks in soil fertility maps using ArcPy in ArcGIS. Therefore, there is a need for an automated or semi-automated tool that can generate maps quickly. Workflow technology automates data processing for improved efficiency. Thus, SFMToolbox, an ArcGIS Python toolbox developed in ArcGIS Desktop (ArcMap) to perform geoprocessing tasks for the automatic production of maps of 12 soil fertility parameters, namely: pH, EC, OC, available N, P, K, S, Fe, Mn, Zn, Cu, and B at a time. This toolbox was built using the Python programming language (v2.7.x) from ArcPy, which is a site package within the ArcGIS (a commercial geographic information system (GIS) environment). The toolbox is tested using ArcMap version 10.3 to 10.8.1 with an advanced licence and spatial analyst, but it may work with previous versions as well. The toolbox is user-friendly; users can only provide input; it automatically creates output files based on the name of the sampling point file and stored in the defined workspace. This toolbox can be used along with other decision support systems, such as those used for crops, soil, fertilizers, watersheds, weather, etc. The toolbox may be useful for both public and private organisations to make decisions on time. The SFMToolbox was compared with maps generated manually. It was found that the time for the generation of maps was reduced tremendously. On an average, using the model, it takes about 30 minutes compared with the manual method, which takes about 3 hours to generate 12 parameter soil fertility maps. Therefore, using the toolbox used in this paper can save time, costs, and human resources. The result shows the soil fertility status of Kashipur village and according to this status entire village is non saline with normal pH, low in percent organic carbon and available nitrogen, medium for available phosphorus and potassium, sufficient in zinc, iron, copper and manganese. It may give the general fertilizer prescription for a particular crop based on these values for obtaining higher production, reducing the costs of cultivation, and improving soil health.

9. Limitations

Due to the flexibility of the software, the proposed toolbox was developed using ArcGIS Desktop (ArcMap 10.x) with the spatial analyst extension. The ArcGIS Desktop (ArcMap) is a commercial Geographical Information System, so users must have an advanced license with a spatial analyst extension to run the SFMToolbox. The toolbox can only run on ArcGIS Desktop (ArcMap) version 10.x. The Python interaction with ArcGIS is mainly limited to reading and writing data, editing the properties of project files, and running the tools that are available in ArcGIS [54]. The ArcPy package doesn’t provide functionality for creating the map series, but it facilitates the export of an existing map series [55].

10. Future Scope

The toolbox was developed using a standalone script of the ArcPy module in ArcGIS because of its flexibility. ArcGIS is licensed commercial GIS software, so the user needs to have a license for the ArcGIS software. The cost may be one of the main issues for getting a license of ArcGIS for implementation, especially in developing countries. In this study, the UTM projection is applied and needs to be changed to a central meridian as per the requirement. As a further study, the researcher may develop a new toolbox that can work for any projection. Therefore, the proposed toolbox may be designed using an open-source geographical information system so that it can be used across the globe. However, the toolbox may also be developed using web-based or cloud-based software to be incorporated into other agriculture-related decision support systems for decision making.

11. Conclusions

Several researchers and institutions have produced maps using the existing tools of ArcGIS, but it is time-consuming, requires knowledge of GIS, repeating drag tools, and more human intervention. Thus, we need a new toolbox for policy-makers to be able to produce maps on time, with less cost and the minimum human resources. Therefore, this paper proposes a new ArcGIS toolset, namely "SFMToolbox", which enables the automatic production of 12 soil fertility maps of macro, micro, and chemical parameters, as a batch file without repeating the same process again and again. The toolbox tools use the ArcPy site package of ArcGIS Desktop, a Python-based scripting language. A valid license of the ArcGIS software with a spatial analyst is required to run the toolbox and generate maps. The toolbox tested ArcGIS from 10.3 to 10.8.x, but it may run on earlier versions as well. The details of the reclass, color files, and DBF files are available in Appendix A. The reclass and color files are in built into the Python files. The user needs to provide source or input files, and the corresponding output files are auto created by the toolbox and stored in automatically created folders. It generated automatic folders and files based on the first five characters in the sampling point file. It may save time, cost, human resources, and ensure uniformity among maps. We apply a UTM zone for projection in this toolbox, but we may customize it as per the user's needs, including the required parameters. To illustrate the toolbox, we chose a case study at the village of Kashipur, tehsil – Balrampur, district – Balrampur, state – Uttar Pradesh, and country – India. The results show that the proposed toolbox has more advantages in the production of maps because it takes the minimum time, in a quick, accurate, and uniform manner with the minimum of human intervention as opposed to the conventional method of dragging and dropping ArcGIS tools. The toolbox automatically generates various files, namely: IDW interpolation, reclass, color, union, projection (from SFMToolbox

Part I) and area in hectares, its percentage, and legend (from SFMToolbox Part II). The toolbox was developed for the Soil Health Card scheme of the Government of India to generate maps quickly, accurately, and uniformly across the country. Using the toolbox, we produced SFM maps of 630 districts of India as per the specification of SHC in a timely and unified manner. The SFMToolbox results may be applied to other decision-support systems to generate real solutions for agriculture related issues.

Code Availability

The softcopy of the SFMToolbox can only be shared with government organizations for non-commercial use by sending a request to the corresponding author.

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Appendix A

Parameter name, range, color and its code used in this toolbox according to the specification of the Soil Health Card (SHC), Government of India

pH category	Range	Color	Color code
Strongly acidic	<4.5	brick color	203 65 84
Moderately acidic	4.5–5.5	grey	128 128 128
Slightly acidic	>5.5–6.5	orange	255 165 0
Normal	>6.5–7.5	dark green	0 100 0
Slightly alkaline	>7.5–8.5	pink	255 115 223
Moderately alkaline (sodic)	>8.5–9.5	camel	193 154 107
Strongly alkaline (highly sodic)	>9.5	violet	148 0 211
EC category	**EC [dS/m] in 1: 2.5 extract at 25°C**	**Color**	**Color code**
Non saline	0–1.68	apple green	1 141 182 0
Low salinity	1.68–3.36	khakhi	2 189 183 107
Mild salinity	3.36–6.72	lemon	3 255 244 79
High salinity	6.72–13.44	apricot	4 255 173 148
Sever salinity	>13.44	rosy green	5 0 200 160

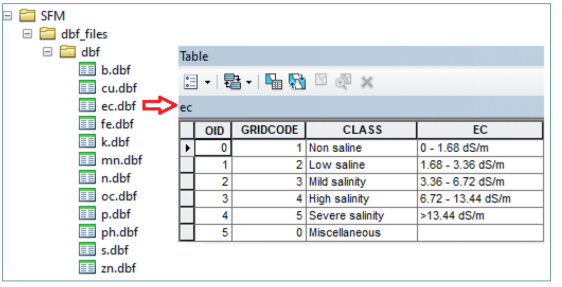
Micro-nutrients category	Color	Color code	Zinc (Zn)* [ppm]	Iron (Fe)* [ppm]	Copper (Cu)* [ppm]	Manganese (Mn)* [ppm]	Boron (B)** [ppm]	Sulphur (S)*** [ppm]
Deficient	red	250 50 50	<0.6	<4.5	<0.2	<2.0	<0.5	<10.0
Sufficient	green	50 150 0	>0.6	>4.5	>0.2	>2.0	>0.5	>10.0

Macro-nutrients category	Color	Color code	OC [%]	P [kg/ha]	K [kg/ha]	N [kg/ha]
Low	red	250 50 50	<0.50	<10	<120	<280
Medium	yellow	250 250 50	0.50–0.75	10–25	120–280	280–560
High	green	50 150 0	>0.75	>25	>280	>560

*DTPA extractable, ** Hot water soluble, *** 0.15% $CaCl_2$ extractable

Appendix B

Showing DBF file (ec.dbf) of EC with class and description as an example



OID	GRIDCODE	CLASS	EC
0	1	Non saline	0 - 1.68 dS/m
1	2	Low saline	1.68 - 3.36 dS/m
2	3	Mild salinity	3.36 - 6.72 dS/m
3	4	High salinity	6.72 - 13.44 dS/m
4	5	Severe salinity	>13.44 dS/m
5	0	Miscellaneous	

Appendix C.1

Parameter, data type, and its explanation of Auto-generated files Part I

1.Auto generated files Part I

Title 1.Auto generated files Part I

Summary
The toolbox's purpose is to generate: Inverse Distance Weighting (IDW) Interpolation, Recalss, Add color to Reclass, Raster to Polygon file conversion, Union files, Project, and add fields to store area and its percentage (ha) for all 12 soil parameters at a time as a batch file. The values of Reclass and color are as per the specifications given in this paper. Only input (Source) files (See Entry form) are needed to provide the output files are generated automatically based on the first five characters of the sampling points file to save time and avoid human intervention.

Usage
The toolbox's purpose is to generate: Inverse Distance Weighting (IDW) Interpolation, Recalss, Add color to Reclass, Raster to Polygon file conversion, Union files, Project, and add fields to store area and its percentage (ha) for all 12 soil parameters at a time as a batch file

Syntax
sfmpart1 (Workspace, Sampling_Point_File, Village_Boundary_Extent_, Without_Miscellaneous__Mask_, Miscellaneous)

Parameter	Explanation	Data Type
Workspace	**Dialog Reference** **Choose workspace to store folders and files** There is no python reference for this parameter.	Workspace
Sampling_Point_File	**Dialog Reference** **Select village sampling point file** There is no python reference for this parameter.	Feature Class
Village_Boundary_Extent_	**Dialog Reference** **Select village boundary (outer) polygon file** There is no python reference for this parameter.	Extent
Without_Miscellaneous__Mask_	**Dialog Reference** **Select without miscellaneous file** There is no python reference for this parameter.	Feature Class
Miscellaneous	**Dialog Reference** **Select miscellaneous file, where IDW interpolation is not required** There is no python reference for this parameter.	Feature Class

Code Samples
There are no code samples for this tool.

Tags
There are no tags for this item.

Credits
There are no credits for this item.

Use limitations
Limitation of the SFM Toolbox discussed in this paper.

Appendix C.2

Parameter, data type, and its explanation of Auto-generated files Part II

2.Auto generated files Part II

Title 2.Auto generated files Part II

Summary
SFM Toolbox Part_II is to calculate the area (ha) and its percentage, Summary Statistics (Pivot Tables), join DBF files (defined in this paper), and Reclass (with color) files to generate automatic Legend. Note that manually insert the Title, Legend (Auto-generated), North arrow, and scale bar for map publication.

Usage
SFM Toolbox Part II is to calculate the area (ha) and its percentage, Summary Statistics (Pivot Tables), JOIN DBF files (defined in this paper), and Reclass (with color) files to generate automatic Legend.

Syntax
sfmpart2 (Workspace__Path_created_using_Part_1_, Sampling_Point_File, DBF_Files_Path)

Parameter	Explanation	Data Type
Workspace__Path_created_using_Part_1_	**Dialog Reference** **Select workspace created in SFM toolbox part I** There is no python reference for this parameter.	Workspace
Sampling_Point_File	**Dialog Reference** **Select village sampling point file** There is no python reference for this parameter.	Feature Class
DBF_Files_Path	**Dialog Reference** **Select folder containing dbf files** There is no python reference for this parameter.	Folder

Code Samples
There are no code samples for this tool.

Tags
There are no tags for this item.

Credits
There are no credits for this item.

Use limitations
Limitation of the SFM Toolbox discussed in this paper.

Appendix C.3

Parameter, data type, and its explanation of MXD File Creator

3.MXD File Creator

Title 3.MXD File Creator

Summary
This script is used to View all autogenerated legend files into layers created in Part II. The MXDs of parameters will generate by selecting or deselecting layers (example: Kashi_oc.mxd)

Usage
To View all autogenerated legend files into layers created in SFM toolbox Part II. The MXDs of parameters will generate by selecting or deselecting layers.

Syntax
mxd (Workspace, Sampling_Point_file)

Parameter	Explanation	Data Type
Workspace	**Dialog Reference** **Select workspace created in SFM toolbox part I** There is no python reference for this parameter.	Workspace
Sampling_Point_file	**Dialog Reference** **Select village sampling point file** There is no python reference for this parameter.	Feature Class

Appendix C.4

Parameter, data type, and its explanation of Export MXD to JPEG

4.Export MXD to JPEG

Title 4.Export MXD to JPEG

Summary
Export MXD files (Map document files) into an image file format (JPEG) with a paper size of A3, but the paper size may be A0 or A4. It can also convert into Portable Document Format(PDF) format.

Usage
Export MXD files (Map document files) into an image file format (JPEG) with a paper size of A3 (default). The paper size may be customized to A0 or A4

Syntax
sfmJPGPDF (workspace, File_path_of_MXD)

Parameter	Explanation	Data Type
workspace	**Dialog Reference** **Select workspace created in SFM toolbox part I** There is no python reference for this parameter.	Workspace
File_path_of_MXD	**Dialog Reference** **Select Folder containing MXD files** There is no python reference for this parameter.	Folder

Appendix D

The data structure of the sampling points. Explanations: pH – hydrogen ion exponent, EC – electrical conductivity, OC – organic carbon percentage, N – available nitrogen, P – available phosphorus, K – available potassium, S – 0.15% $CaCl_2$ – extractable sulphur, Zn – DTPA extractable zinc, Cu – DTPA extractable copper, Fe – DTPA extractable iron, Mn – DTPA extractable manganese, B – hot water-soluble boron

Survey No.	Grid No.	District	Tehsil	pH	EC	OC	N	P	K	S	Zn	Fe	Cu	Mn	B
115	23	Balrampur	Balrampur	7.15	0.59	0.33	74.25	9.0	123	12.68	0.78	7.12	0.40	3.14	0.60
118	3	Balrampur	Balrampur	7.14	0.24	0.39	76.56	13.5	123	10.49	0.72	6.12	0.24	3.40	0.52
120	56	Balrampur	Balrampur	7.15	0.36	0.28	63.60	9.0	168	11.56	0.84	7.40	0.24	2.78	0.72
122	66	Balrampur	Balrampur	7.31	0.69	0.24	54.00	22.5	134	13.50	0.63	6.95	0.40	3.00	0.56
144	68	Balrampur	Balrampur	7.10	0.28	0.22	49.50	18.0	146	10.81	0.72	7.00	0.24	2.98	0.64
152	101	Balrampur	Balrampur	7.39	0.61	0.15	33.75	9.0	146	10.29	0.62	6.29	0.28	2.91	0.32
156	41	Balrampur	Balrampur	7.24	0.44	0.31	69.25	9.0	116	12.74	0.84	7.40	0.28	2.98	0.71
157	54	Balrampur	Balrampur	7.00	0.43	0.34	76.50	9.0	157	14.97	0.92	7.12	0.22	3.10	0.61
168	7	Balrampur	Balrampur	7.00	0.25	0.25	56.25	18.0	190	11.56	0.84	6.92	0.22	3.12	0.58
174	78	Balrampur	Balrampur	7.12	0.43	0.33	74.25	9.0	157	12.75	0.84	7.40	0.24	3.10	0.61
175	12	Balrampur	Balrampur	7.12	0.39	0.45	101.25	18.0	134	13.49	0.98	8.40	0.22	3.10	0.66
176	9	Balrampur	Balrampur	7.16	0.41	0.31	69.25	9.0	179	12.74	0.78	7.00	0.24	3.40	0.68
177	5	Balrampur	Balrampur	7.06	0.42	0.43	96.75	9.0	179	10.81	0.92	7.10	0.38	2.98	0.44
182	117	Balrampur	Balrampur	7.18	0.41	0.43	96.75	9.0	146	11.83	0.92	7.00	0.40	2.92	0.66
186	25	Balrampur	Balrampur	7.25	0.73	0.34	76.50	22.5	101	13.49	0.68	7.40	0.28	2.98	0.26
188	59	Balrampur	Balrampur	7.30	0.43	0.13	29.25	9.0	146	13.43	0.78	6.72	0.32	2.78	0.61
189	55	Balrampur	Balrampur	7.28	0.26	0.16	33.75	9.0	134	13.68	0.98	7.14	0.28	3.12	0.68
195	91	Balrampur	Balrampur	7.29	0.29	0.36	81.00	9.0	101	13.61	0.98	7.14	0.40	3.10	0.68
205	57	Balrampur	Balrampur	7.29	0.41	0.36	81.00	9.0	123	12.73	0.72	6.48	4.00	2.74	0.73

Survey No.	Grid No.	District	Tehsil	pH	EC	OC	N	P	K	S	Zn	Fe	Cu	Mn	B
214	22	Balrampur	Balrampur	7.12	0.49	0.25	56.25	18.0	157	13.49	0.72	7.10	0.32	3.12	0.59
218	32	Balrampur	Balrampur	7.11	0.56	0.40	90.00	18.0	146	13.68	0.78	7.12	0.28	3.18	0.39
231	131	Balrampur	Balrampur	7.16	0.46	0.22	49.50	9.0	134	12.82	0.72	6.93	0.32	3.40	0.63
240	14	Balrampur	Balrampur	7.15	0.24	0.36	81.06	9.0	146	13.68	0.68	7.14	0.40	3.14	0.47
242	35	Balrampur	Balrampur	7.16	0.44	0.42	94.50	9.0	168	10.49	0.72	6.48	0.22	2.92	0.26
244	126	Balrampur	Balrampur	7.10	0.13	0.42	94.50	18.0	146	10.18	0.78	6.92	0.37	2.92	0.71
255	129	Balrampur	Balrampur	7.31	0.31	0.34	76.50	9.0	157	11.56	0.92	7.12	0.28	3.12	0.66
271	48	Balrampur	Balrampur	7.11	0.41	0.27	60.75	9.0	146	13.68	0.84	7.10	0.32	3.10	0.63
276	40	Balrampur	Balrampur	7.14	0.22	0.37	83.25	13.5	134	12.68	0.78	7.14	0.22	2.98	0.68
277	118	Balrampur	Balrampur	7.29	0.46	0.16	36.00	9.0	190	12.75	0.85	7.20	0.22	2.82	0.46
284	74	Balrampur	Balrampur	7.24	0.31	0.19	42.75	9.0	146	9.00	0.72	8.40	0.32	3.12	0.61
286	134	Balrampur	Balrampur	7.25	0.18	0.24	54.00	18.0	190	13.68	0.72	7.12	0.28	3.10	0.61
289	13	Balrampur	Balrampur	7.00	0.48	0.22	49.50	13.5	168	14.56	0.84	7.12	0.28	3.12	0.52
296	75	Balrampur	Balrampur	7.00	0.57	0.45	101.25	9.0	123	13.49	0.78	7.10	0.40	3.40	0.68
299	108	Balrampur	Balrampur	7.16	0.56	0.18	40.56	13.5	157	13.69	0.92	8.40	0.40	2.92	0.48
304	99	Balrampur	Balrampur	7.00	0.63	0.22	49.50	13.5	168	9.23	0.72	7.40	0.40	3.12	0.37
308	84	Balrampur	Balrampur	7.10	0.52	0.12	27.00	9.0	123	12.46	0.92	7.00	0.32	3.14	0.60
309	36	Balrampur	Balrampur	7.22	0.46	0.39	87.75	13.5	123	9.23	0.87	7.40	0.24	2.98	0.20
311	11	Balrampur	Balrampur	7.10	0.23	0.33	74.25	22.5	190	12.82	0.92	8.00	0.40	4.00	0.59
315	64	Balrampur	Balrampur	7.00	0.32	0.10	22.50	9.0	190	12.56	0.78	7.40	0.32	3.12	0.69
316	37	Balrampur	Balrampur	7.10	0.41	0.43	96.75	9.0	112	10.81	0.92	6.98	0.28	3.00	0.37
317	38	Balrampur	Balrampur	7.15	0.20	0.19	42.75	9.0	146	10.29	0.84	7.10	0.32	3.40	0.58
318	127	Balrampur	Balrampur	7.00	0.31	0.21	47.25	13.5	123	10.18	0.78	6.39	0.34	2.90	0.71
320	60	Balrampur	Balrampur	7.34	0.54	0.27	60.75	9.0	101	13.23	0.84	6.74	0.38	3.10	0.68

Survey No.	Grid No.	District	Tehsil	pH	EC	OC	N	P	K	S	Zn	Fe	Cu	Mn	B
325	19	Balrampur	Balrampur	7.29	0.23	0.19	42.75	18.0	190	14.97	0.84	6.48	0.22	3.40	0.49
330	50	Balrampur	Balrampur	7.16	0.41	0.33	74.25	9.0	157	10.29	0.78	6.48	0.22	3.14	0.69
336	65	Balrampur	Balrampur	7.13	0.69	0.24	54.00	22.5	134	13.87	0.62	6.92	0.40	3.00	0.74
338	73	Balrampur	Balrampur	7.13	0.36	0.12	27.00	9.0	112	13.23	0.84	8.00	0.24	3.10	0.73
348	39	Balrampur	Balrampur	7.29	0.40	0.45	101.25	9.0	157	11.56	0.72	7.12	0.40	2.44	0.66
366	95	Balrampur	Balrampur	7.16	0.54	0.12	27.00	13.5	134	12.56	0.62	6.98	0.40	3.10	0.59
370	17	Balrampur	Balrampur	7.12	0.41	0.21	47.25	9.0	179	11.56	0.98	6.40	0.40	3.12	0.65
372	107	Balrampur	Balrampur	7.21	0.68	0.12	27.00	9.0	168	14.56	0.78	8.00	0.32	2.94	0.47
377	98	Balrampur	Balrampur	7.16	0.13	0.10	22.50	9.0	179	10.49	0.84	7.14	0.24	3.10	0.52
384	119	Balrampur	Balrampur	7.40	0.33	0.39	87.75	9.0	168	13.49	0.78	6.48	0.28	2.72	0.52
389	100	Balrampur	Balrampur	7.18	0.59	0.31	69.25	18.0	157	10.81	0.78	6.98	0.23	3.40	0.44
405	72	Balrampur	Balrampur	7.17	0.42	0.43	96.75	9.0	134	12.74	0.98	6.84	0.28	2.98	0.74
412	42	Balrampur	Balrampur	7.11	0.41	0.18	40.50	9.0	123	13.23	0.72	6.72	0.24	3.10	0.59
416	80	Balrampur	Balrampur	7.00	0.4	0.22	49.50	9.0	146	13.81	0.78	6.84	0.40	3.40	0.49
427	71	Balrampur	Balrampur	7.10	0.54	0.21	47.25	22.5	157	12.68	0.92	6.72	0.22	2.62	0.72
440	130	Balrampur	Balrampur	7.06	0.42	0.4	90.00	9.0	179	13.25	0.84	7.14	0.24	3.14	0.52
449	105	Balrampur	Balrampur	7.26	0.33	0.19	42.75	13.5	146	12.68	0.84	6.84	0.24	3.14	0.60
455	93	Balrampur	Balrampur	7.33	0.46	0.25	56.25	9.0	123	12.75	0.72	6.48	0.24	3.40	0.59
458	61	Balrampur	Balrampur	7.15	0.52	0.12	56.25	9.0	179	11.81	0.98	7.10	0.22	2.98	0.60
462	109	Balrampur	Balrampur	7.12	0.28	0.42	94.50	9.0	112	12.73	0.98	7.12	0.22	2.98	0.49
464	121	Balrampur	Balrampur	7.11	0.15	0.18	40.50	9.0	112	11.56	0.98	6.98	0.28	2.9	0.44
468	45	Balrampur	Balrampur	7.00	0.48	0.16	36.00	9.0	157	13.68	0.92	6.40	0.40	3.40	0.59
471	94	Balrampur	Balrampur	7.11	0.23	0.50	76.50	9.0	157	13.68	0.78	6.92	0.32	2.98	0.50
472	97	Balrampur	Balrampur	7.12	0.52	0.33	74.25	22.5	123	12.56	0.98	7.12	0.28	2.98	0.46
480	47	Balrampur	Balrampur	7.12	0.56	0.15	33.75	9.0	123	13.49	0.92	6.40	0.28	2.98	0.60

Survey No.	Grid No.	District	Tehsil	pH	EC	OC	N	P	K	S	Zn	Fe	Cu	Mn	B
495	96	Balrampur	Balrampur	7.11	0.27	0.24	54.00	18.0	190	13.42	0.92	7.10	0.22	2.92	0.60
497	135	Balrampur	Balrampur	7.27	0.18	0.31	69.25	9.0	123	12.73	0.78	7.40	0.40	3.12	0.22
498	88	Balrampur	Balrampur	7.29	0.52	0.37	83.25	18.0	157	11.81	0.78	6.98	0.22	3.00	0.49
506	53	Balrampur	Balrampur	7.14	0.61	0.10	22.50	13.5	112	14.56	0.78	7.10	0.40	2.98	0.64
510	43	Balrampur	Balrampur	7.00	0.43	0.36	81.00	18.0	179	11.81	0.62	6.98	0.32	3.12	0.66
516	46	Balrampur	Balrampur	7.10	0.29	0.31	69.25	13.5	168	13.42	0.98	6.48	0.24	2.92	0.58
522	81	Balrampur	Balrampur	7.16	0.26	0.40	90.00	9.0	112	14.97	0.84	6.48	0.24	2.98	0.49
540	103	Balrampur	Balrampur	7.21	0.32	0.45	101.25	9.0	179	12.73	0.92	6.72	0.40	3.10	0.46
542	89	Balrampur	Balrampur	7.13	0.26	0.15	33.75	13.5	112	12.13	0.84	7.10	0.28	3.10	0.56
549	110	Balrampur	Balrampur	7.14	0.56	0.10	22.50	9.0	123	13.23	0.92	7.14	0.28	3.10	0.56
550	62	Balrampur	Balrampur	7.19	0.26	0.25	56.25	18.0	123	12.73	0.84	7.12	0.28	2.91	0.62
556	122	Balrampur	Balrampur	7.17	0.29	0.37	83.25	13.5	190	13.68	0.84	7.40	0.40	3.10	0.52
557	67	Balrampur	Balrampur	7.25	0.58	0.15	33.75	9.0	157	9.23	0.84	7.10	0.28	3.40	0.62
56	6	Balrampur	Balrampur	7.29	0.12	0.33	74.25	9.0	101	10.29	0.98	7.12	0.40	3.10	0.52
564	82	Balrampur	Balrampur	7.00	0.52	0.13	29.50	13.5	134	14.73	0.72	6.98	0.28	3.10	0.42
568	51	Balrampur	Balrampur	7.31	0.21	0.12	27.00	22.5	179	13.49	0.84	6.92	0.28	3.40	0.74
58	10	Balrampur	Balrampur	7.31	0.46	0.24	54.66	9.0	146	13.23	0.84	7.40	0.32	2.98	0.71
590	52	Balrampur	Balrampur	7.10	0.51	0.33	67.50	18.0	123	12.74	0.72	6.95	0.24	2.92	0.72
602	83	Balrampur	Balrampur	7.18	0.41	0.30	67.50	18.0	179	13.68	0.78	7.10	0.40	3.12	0.54
612	70	Balrampur	Balrampur	7.15	0.27	0.13	29.25	9.0	101	11.56	0.84	6.98	0.40	2.64	0.68
614	125	Balrampur	Balrampur	7.27	0.54	0.36	81.00	22.5	168	12.56	0.76	7.40	0.24	3.40	0.68
618	104	Balrampur	Balrampur	7.12	0.66	0.13	29.25	9.0	179	13.49	0.98	6.78	0.22	5.12	0.54
80	1	Balrampur	Balrampur	7.06	0.26	0.28	63.00	9.0	134	14.56	0.98	7.40	0.22	3.12	0.66
87	30	Balrampur	Balrampur	7.13	0.44	0.22	49.50	9.0	168	11.81	0.84	7.40	0.40	2.92	0.52