A Review on Innovations in Soil Remediation Techniques Using Machine Learning

Manu Hajari[1], *Gowtham* Raj R[2*], *H* Pal Thethi[3], *Ravi* Shankar Raman[4], Praveen[5], *Mustafa* Abdulhussein Al-Allak[6], *Yelamasetti* Balram[7]

[1]Department of CSBS, GRIET, Bachupally, Hyderabad, Telangana, India.
[2]Department of Mechanical Engineering, New Horizon College of Engineering, Bangalore, India.
[3]Lovely professional University, Phagwara, India.
[4]Department of Mechanical Engineering, ABES Engineering College, Ghaziabad, UP, India.
[5]Lloyd Institute of Engineering & Technology, Knowledge Park II, Greater Noida, Uttar Pradesh, India.
[6]College of Medical Technology, The Islamic University, Najaf, Iraq.
[7]Department of Mechanical Engineering, MLR Institute of Technology, Hyderabad, Telangana, India.

Abstract. The discharge of wastewater into the ecosystem has an impact on fish and human health, therefore the toxins needs to be removed. It is sustainable to remove pollutants from wastewater by utilizing biochar made from lignocellulosic biomass (LCB) that has undergone thermal degradation. Because of it's large surface area, hollow structure, the oxygen groupings, and relatively low cost, bio Char is now known as a change rival in catalytic processes. Biochar was used in conjunction with a number of cutting-edge, creative technologies to treat wastewater efficiently. Details collected soil sampling, such as facts about the toxins current, the nature of the soil, its surrounding circumstances, and the efficacy of various rehabilitation methods, can be used to training machine learning methods. Through data analysis, machine learning models are able to spot relationships and trends which human beings might miss, which improves the accuracy of projections regarding the results of soil cleanup. The review paper outlines the challenges facing biochar-based enzymes using immediate and new technologies, along with emphasizes the application of algorithmic learning in pollution removal. Limitations and likelihoods for additional investigation are examined.

Keyword-: soil, ecosystem, aquatic life, machine learning, biomass,enzymes.

1 Introduction

One of the most important problems associated with ecological management pertains to soil therapy, which is the process of returning polluted soil to a safe and useful status. Conventional techniques can entail expensive and time-consuming procedures including excavating and disposal. With the incorporation of machine learning into remediation of soil,

* Corresponding author: gowthamiitdh19@gmail.com

there is hope for improved, affordable, and ecologically sound management techniques. One of the most important problems associated with ecological management pertains to soil therapy, which is the act of returning polluted soil to a safe and useful status. Conventional techniques can entail expensive and time-consuming procedures including excavating and disposal. To maximize clean-up strategies, ML algorithms can evaluate enormous volumes of biological information including pollutant levels, soil type, and ecological variables [1]. ML algorithms can evaluate enormous volumes of biological information including pollutant levels, soil type, and ecological variables to maximize clean-up strategies,. Research and environmental managers can create prediction models that direct choices, rank regions for rehabilitation, and maximize the use of assets by utilizing machine learning algorithms. However, there is a lot of promise for more effective and focused rehabilitation tactics with the development of ML (machine learning) strategies. Scholars and sustainability managers are able to develop forecasting models that direct choices, rank regions for rehabilitation, and maximize utilization of resources by utilizing machine learning algorithms. There is hope for improved, affordable, and ecologically sound management techniques with the incorporation of machine learning into the remediation of soils. Poorer countries encounter considerable obstacles in their endeavour to achieve economic expansion [1]-[2], considering that their factories are more conventional than those of wealthy nations [2]. Therefore obvious that these nations would look for fresh innovations to apply to many facets of society in an effort to enhance and enhance their present capabilities for generating items and services.

Technologies for the transmission of information (ICTs) are thought of as instruments that raise efficiency and competitiveness in businesses and manufacturing facilities. The more ICTs are used and adopted, the greater these advantages are [3]. In a comparable manner, quality and safety regulations are driving pressure on agricultural businesses to implement technologies for communication and information.

Despite being vital to maintaining humanity on a global scale, farmland frequently uses methods which result in unanticipated negative effects on our surroundings. Such behaviors can result in the overuse of chemical pesticides and fertilizers, the decrease of available water supplies, and the release of greenhouse emissions into the environment, all of which can contaminate soil. There are many Harmful algal blooms (HABs), that exert detrimental effects on both aquatic habitats and human societies, can result from this extreme algal development and damage the soil. As a result of the death and decomposition of these algae, resulting in dead the level of oxygen of the water decreases. This chapter aims to contribute consequently, to delineate the scope of this contamination and its importance within the wider framework of environmental deterioration. The paper defines various aspects of crop pollution, such as shifts in land utilization, farm practices, and socioeconomic variables influencing agriculture and farming. The nitrogen inflow has the potential to cause depletion in rivers, lakes, and coastal regions. Because flooding encourages rapid development of algae, it upsets the natural equilibrium of aquariums. Areas as salmon and other living things fail to live. The main sources of contamination by nutrients in soil from agriculture are high phosphate and nitrogen from fertilizers. The nitrates are transported across fields in surrounding lakes of water after it rains.

Harmful algal blooms (HABs), that exert detrimental effects on both aquatic habitats and human societies, can result from this extreme algal development. The amount of oxygen of the water decreases as a result of the death and decomposition of these algae, resulting in "dead zones," regions as salmon and other living things fail to live.

To achieve optimal the effectiveness of resources, accurate farming makes use of cutting-edge gear, data interpretation, and software. It assists producers in making well-informed choices on the best times and locations for planting, irrigation, fertilizer and pesticide application. The focused strategy lowers waste as well as lessens the impact that agriculture has on the planet by maintaining the integrity of the soil and minimizing the abuse of agricultural chemicals. The block diagram of soil recommendation system is shown in figure 1.

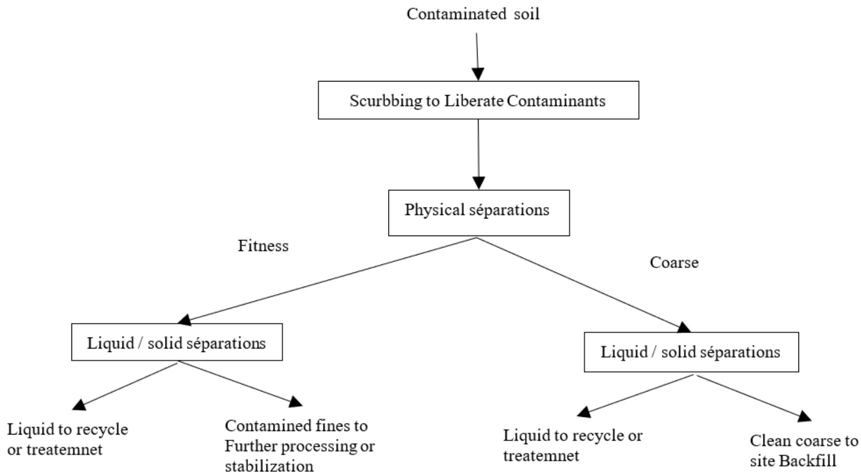

Fig. 1: Soil Recommandation system

Modern farming methods which emphasize on production as well as effectiveness through focused and controlled practices, reflect a paradigm change in agricultural. This strategy entails close controlling different facets of veterinary care and growing crops to increase labor and profitability. Modern approaches in cropping frequently involve high seed densities, regulated irrigation, and heavy application of synthetic herbicides and fertilizers. These techniques are meant to maximize plant development while decreasing pest and disease-related losses. Enhanced outputs are also a result of the employment of sophisticated equipment and advances in technology, such as transgenic crops and precision agriculture equipment. Furthermore, water pollution and soil deterioration are results of industrial agriculture's significant reliance on synthetic fertilizers and pesticides. These substances are carried into surrounding lakes and streams mainly runoff from crop residue, where they eutrophicate and damage aquatic life. Overuse of fertilizers also adds to phosphorus and nitrogen pollution, which can cause "dead areas" in waters where there is insufficient oxygen.

2 Related work

Experimental research was done to examine the impact of varying the rate of descent and rising time of the pulse voltage on the parameters of soil discharge. The system underlying this laboratory result was explored based on the spectral diagnoses, volt-ampere traits such as and typical discharges images. The outcomes of the study have some guiding implications for lower temperatures plasma soil remediation techniques [1]. The primary function of surfactants in the correction of non-aqueous stages substances (NAPLs) is to reduce the liquid-solid tension. As concentrations rise above its urgency micelle level, organic matter in a surfactant solution significantly improves and pollutants are removed. Surfactants also play a role in the remediation of heavy metal-contaminated soils through ion exchange, chemical complexity, and absorption [2]. Protecting agricultural assets and cleaning up polluted areas are two benefits of soil analysis. For optimal land use, analysis of soil fosters biodiversity and soil wellness. In order to assess the resilience of an ecological system, it considers organic matter, soil structure, and the helpful bacteria. By researching the characteristics of the soil, preserving water, and storing carbon, administrators of land may both limit and react to changes in the climate. Measuring soil fertility, identifying nutrients deficits, addressing sustainability concerns, and advancing sustainable land use all depend on soil analysis. It assists land managers, farmers, and environmental professionals in making accurate choices that protect natural systems, improve yields from agriculture, and maintain the world's finite soil resources [3]. Concentrated on the sybarite addition for oil-contaminated soils. To assess the degree of contamination, the oil-contaminated soils were described using several methods and contrasted with the underlying soils. The findings showed that the soils had significant oil contamination, which had a negative impact on the soils' porosity, ventilation, and bio accessibility. The physical-chemical characteristics of soils may be impacted by the insertion of bentonite and and potential pathways have been studied. It was shown that adding bentonite might enhance the ratio of sticky particulates, air respiration, and preservation of water in the soil. However, using sand caused the neutral pH level to slightly rise. Hematite addition may accelerate the breakdown of the oil [4]. Explores the attributes of the corona discharge caused by high-voltage pulsed stimulation in soil. An innovative technique is utilized to get pictures of electric currents in soil, and the discharge occurrences are examined. The waves for voltage and current are examined. Using studies, the consequences of the voltage utilized and width of pulse are investigated. There is a discussion of the mechanisms underlying the experimental phenomena [5]. The significance of the phenol pent (PCP) precipitation and tenacity in three kinds of Romanian properties was assessed by utilizing the Underground Ubiquity Score (GUS) to analyze the leaching propensity into groundwater. According to the GUS index, the results indicated that PCP has an extremely large leaching potential, which significantly increases the danger of groundwater contamination. The findings demonstrate a substantial correlation between leaking on emigration possibilities and soil adsorption capacity, which is mostly influenced by the physical and chemical characteristics of the soil [6]. With a testing voltage of 0.5V/cm, the percentage of lead removal effectiveness in the soil near the positive electrode was 62.24%. And by adding EDTA solution to the contaminated soil at a concentration of 0.01mol/L, the effectiveness of elimination of lead in the soil near the positive electrode significantly enhanced to reach 79.03%. [7]

2.1 Based on Support Vector Machine-

SVM idea was initially put forward by [8]. For the purpose of differentiating between class who overlap but remain linearly distinct, an SVM is the capacity to reduce the organizational error (i.e.) and, ideally, segregate hyperspace. Although it was designed for grouping, it may similarly be applied to regressive resolution. The models based on SVM come in two flavors: classification and regression models [9]. Models for classification are used for solving data categorization problems. Regression techniques are used to tackle forecasting problems. One advantage of the SVM is that it performs incredibly well in spaces with many dimensions [10].

2.2 Based on Random Forest

Created a random forest (RF) by combining the method of random 20-variables [11] picking alongside the packing methodology [12]. A collection of "weak educators" were to be combined in order to create a "strong learner." Bootstrap samples is used on every RF tree, and its binary split data requirements are different for tasks involving either classification or regression [13]. Based on the idea that team models are far more accurate than solo models, collaborative learning often aims to increase the correctness of other trained models [14]. Without requiring any trimming. Usually impervious to excess fitting and not requiring standardizing or normalization, and RF is unaffected by the variation of data. For the RF model, it is necessary to modify both the number of tree (ntree) and the degree characteristics collected at random at each division. [15]. This modelling method is frequently employed in the mapping of soil studies due to its ability to evaluate the significance of variables, resistance to excess fitting, and ability to generate reliable and reproducible results. [16]. A easily comprehended output is necessary for the MLP to gain knowledge and train the network; this type of neural network that learns and trains is also referred to as a controlled network. Using training data, MLP builds a framework that correlates the data being provided to the conclusion and then utilizes its predictions to anticipate the output in situations when its result is uncertain. On occasion, this architecture is utilized in lieu of a feed-forward system [17]. An ANN model created using a network of feed forwards is characterized by a weight tensor training process. After weights are allocated at randomized to the proper ranges, they are modified using a variety of workout procedures. An expansion of the M5 branch model, the cubist architecture is a rule-driven model [18]. A framework with a tree-like dependent feature and an MLR model are combined to form the rectangular regression paradigm's framework. The constraints are pruned or removed in order to simplify the conceptual framework. The main benefit of the cubist method is the fact it enables you to increase the number of exercises performed by committees and modify the number of pounds to achieve a more fair system [19].

Table 1: Several significant characteristics associated with soil and the related soil processes

Soil property	Soil Processes
Soil structure	Water and mineral movement, pupil retention, agglomeration, and microbial turnover
Porosity	Moisture entrance, oxygenation, soil crusting on them, and crop accessible ability to soak
Infiltration	quantity and flow of groundwater, nutrient leaching, and weathering
Bulk density	Condensation and soil foundation factors
Available water	Irrigation flow, capacity for the field, and a constant wilting point
pH	Physiological ph chemical metabolic thresholds, soil strength, salting, and acid
Electrical conductivity	Limits to agricultural and microbiology. activity, sodium leaching, or the deterioration of soil integrity, and salting
Plant available N, P, and K	Emissions from the soil-plant system and a supply of vitamins and minerals for plant absorption.
Soil organic matter	The quality and storage of dirt, the breakdown of plant leftovers, the metabolic activity of soil creatures, the renewal of acidification and the immobilization process the growth of bacteria, and the availability of micronutrients.
Total soil C and N	Geological organization, N and C bulk and harmony, and accessibility of nutrients

The cubist framework is similar to the technique of "enhancing" by building a series of forests with sequentially changing weights in that it incorporates boosts with trained boards, usually consisting of many members [20]. Reducing the application of herbicides should have long since been a top national objective, particularly given view of the consequences of altering genes on human health and the decline in species. Numerous pesticides made from chemicals may pose a short-term or long-term risk to the well-being of people. Absorption to pesticides can result in acute poisoning or other potentially lethal illnesses [21]. Worldwide, accidental acute poisonings result in more than 355,000 death every year. Two-thirds of those fatalities take occurred in developing countries, where illnesses are connected to either improper usage or inappropriate consumption of herbicides and other dangerous chemicals who are present in homes as well as workplaces [22]. The aggregate health impacts that result from human exposures to a range of long-term medical difficulties and illnesses, such as malignancies, of reproductive, endocrine, immunological, inherited, and developmental defects, may have an impact on these conditions.

3 Soil Pollution in Agriculture

The contaminating of the outermost layer of soil on Earth with toxic materials is known as soil contamination, and it is a complicated problem resulting from a combination of natural and human-caused processes. Humans as well as nature can contaminate soil. Nonetheless, nearly all of environmental contamination is caused by humans, especially significant manufacturing and agricultural utilization of pesticides.

3.1 Causes of Soil Pollution

Pesticides**-** Pesticides include man-made, noxious substances that kill a variety of pests and insects that harm crops,they are often not biodegradable and soluble in water. But they also have a number of adverse environmental consequences. As a result, these substances won't break down over time and continue to build up in the soil. Chlorinated Organic toxins-The emergence of less permanent compounds molecules and more recyclable materials like carbonates and organ phosphates was prompted by the detrimental effects of Insecticides as well as additional pesticides. Nevertheless, these substances tend to be more hazardous to people since they damage neurons by acting as poisons. It resulted in poisons being linked to several farm fields' field labourers' deaths. Herbicides-: Herbicides have a few decades to degrade. Even yet, they have a detrimental impact on the environment and are not eco-friendly. Herbicides are such as sodium hydroxide (NaClO3) and calcium arsenite (Na3AsO3) were gradually produced by factories. Whilst not being as dangerous as organo-chlorides, the majority of herbicides nevertheless include poisonous ingredients. Birth anomalies are known to be caused by them. Inorganic Fertilizers Overuse of fertilizers made of inorganic nitrogen contaminates crops and causes soil acidity. Also called contamination from agrochemicals.

4 Limitations for applying cutting edge tools to evaluate the pollution in soil

The implementation using novel methods for evaluating the contamination of soil exhibits significant potential in tackling economic and farming predicaments. However, there are some complications as well as challenges involved with its implementation. The listed below are just a few of the key issues surrounding the incorporation of modern methods into assessments of soil environmental impact:

4.1 Cost or Ease of access

This novel technology in agriculture also creates much expense in hardware, software, and manpower, besides maintenance, so it becomes all the more necessary to make such tools available to the small-scale business income earner. Not only this, special skill sets are also sought to use this technology and read data from it and may even be unavailable. There has to be data standardization and quality to keep track of its reliability. Breach of data by any unauthorized source requires the implementation of safety and protocol confidentiality.

Integration with the traditional methods demands data integrity, whereas lack of regulation and administrator's accountability are the administrative issues that have to be discussed. With such huge data volumes being generated, the management of data imposes issues regarding storage and retrieval whereby their preservation has always to be done continuously. It is of importance to overcome resistance to change and promote knowledge about soil pollution-that considers ecological factors in the processdaq of technology adoption..

4.2 Ecological Effects:

There may have some adverse effect on the environment by manufacturing and destruction of gadgets, sensors, and related facilities, hence casting doubt on the techniques' long-term viability. These impediments need to be addressed in order to fully realize the potential of contemporary systems for assessing soil pollutants and improving land use practices. So to handle such issues there may be possibility to develop software that works together to resolve these issues, experts spanning academia, politicians, corporate executives.

4.3 Transactional partnership for the safety of the environment

International collaboration would be necessary to address the complex and interwoven issues relating to the health of the planet and its effects on agriculture, diets, sustainable growth, and other disciplines. Global issues pertaining to earth's health go across national boundaries and have an impact on ecosystem and human well-being everywhere. The following represent a few essential elements of global partnerships for soil health:

4.4 The Sharing of Data and Information Transfer:

Projects like the Global Soil Information (GSI) initiative exemplify collaborative efforts aimed at gathering, organizing, and disseminating soil knowledge and data worldwide. These platforms facilitate the exchange of information among stakeholders, policymakers, and scientists, enhancing our understanding of soil systems globally. They will be provided with the opportunity to contribute information for open-access soil databases from anywhere in the world, which will further enhance knowledge of the characteristics and state of soil. International organizations like the Global Soil Partnership also advocate for integrated monitoring efforts involving networks that can highlight trends in soil conditions and new emerging issues. Such international networks of expert researchers in diverse states are also mandated to uninhibitedly explore soil health, emissions, and environmentally friendly management options, which set the stage for the engagement in total soil science that integrates soil health and balance worldwide.

4.5 Improving Capability and Instruction:

This is realized through transnational conferences and instructional programs at the regional level within and across the regions, hence equipping farmers, scientists, and agronomists with additional skills and knowledge. Partnership initiatives are also accomplished through global exchange programs that facilitate exposure together with hands-on to the field by academics, practitioners, and students in various soil management technologies. Harmonization of policies and lobbying, for instance by the UNFCCC, accepts that there is a potential for healthy soils in climate mitigation and promotes environmentally friendly soil management. Joint efforts produce global guidelines for ecologically based soil preservation and management supposed to facilitate the reaching of national and regional implementations. Comprehensive agricultural management strategies emphasize cross-sectoral collaboration, integrating land use, water management, forestry, and farming practices. Ecosystem-based solutions advocate for environmentally sustainable approaches to agricultural management, recognizing soil health as a fundamental component. International financing campaigns and public-private partnerships provide financial support for research, capacity-building initiatives, and soil health programs, particularly in developing countries. These efforts align with the goals of sustainable development, fostering global cooperation towards achieving sustainable soil management and environmental conservation.

4.6 Consistency with SDG Objectives:

The United Nations Sustainable Development Goals, in particular SDG 2 (Zero Hunger), SDG 15 (Life on Land), and SDG 13 (Climate Action), which are strongly tied to soil health and sustainable land management, are the focus of international cooperation.
International cooperation on the condition of the soil is essential for information exchange, resource mobilization, and the creation of group plans to deal with the world's soil issue. In combination, nations can enhance the administration of soil strategies, guarantee nutrition, slow down global warming, and protect the well-being of the earth for the generations to come. The block diagram of sources of soil pollution is shown in figure 2.

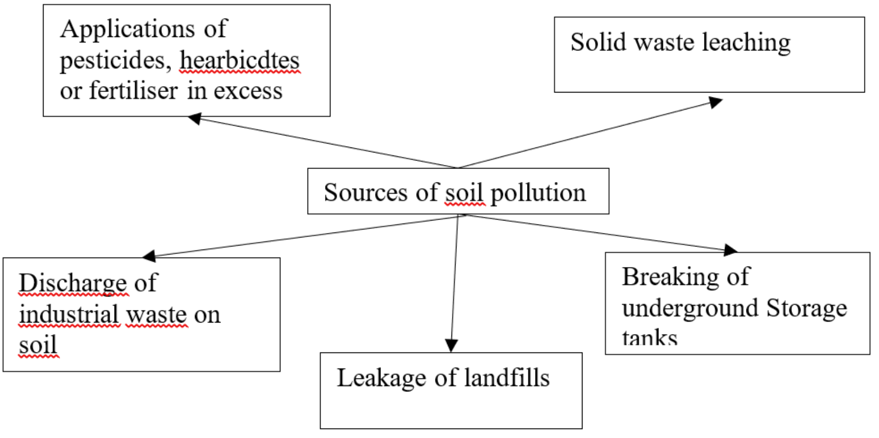

Fig. 2: Sources of soil pollution

5 Conclusion

- In summary, revolutionary innovations have brought about in an age of innovation in the investigation of soil contaminants, providing strong instruments and approaches to comprehend, track, and handle this pressing global problem. Through international collaboration, standardization, and environmentally conscious promotion, we may effectively utilize these instruments to protect our soils, maintain environmental systems, and ensure a wealthier as well as healthy coming for our children and grandchildren.
- Today, farmers and property owners may reduce wasted resources, enhance the utilization of the accessible land, and decrease the impact of contaminated soil on crop quality and output. This guarantees an appropriate amount of food and encourages agricultural methods that are more economical and environmentally friendly. Likewise, more resilient and sustainable tactics are now possible thanks to the use of the newest

technology in agriculture and landscaping. They include everything from sensing and maps to more complex data processing and forecasting.

- In summary, the widespread application of novel techniques and their further development are essential to the immediate future of environmental analysis. These advancements have completely changed our ability to assess soil pollution quickly and thoroughly. We can forecast global trends, identify the origins of pollution, and make educated judgments that safeguard the public and our environment with the use of analytics.

Reference

1. S. M. A et al., "Environmental Impacts and Remediation in Soil Analysis Techniques," in 2023 International Conference on Sustainable Communication Networks and Application (ICSCNA), (2023): 666–672. doi: 10.1109/ICSCNA58489.2023.10370485.
2. S. Huichao, W. Heli, S. Liang, Q. Jingxian, and L. Xinying, "Research Progress of Surfactants Remediation in Contaminated Soils," in 2011 Third International Conference on Measuring Technology and Mechatronics Automation, 2011, 31, 49–152. doi: 10.1109/ICMTMA.2011.609.
3. C. Li, X. Pi, C. Li, and Y. Yang, "Electrical Breakdown Characteristics of Soil under Pulse High Voltage," in 2021 IEEE 4th International Electrical and Energy Conference (CIEEC), (2021): 1–4. doi: 10.1109/CIEEC50170.2021.9510900.
4. X. Pi, C. Li, M. Ran, C. Li, and Y. Yang, "Study on Corona Discharge Characteristics of Soil under Pulse High Voltage," in 2022 IEEE 5th International Electrical and Energy Conference (CIEEC), 2022, pp. 853–857. doi: 10.1109/CIEEC54735.2022.9846216.
5. C. Smaranda, L. Bulgariu, M. Rosca, R. Turculet, C. Ghinea, and M. Gavrilescu, "Evaluation of pentachlorophenol leaching potential in natural soils," in 2015 E-Health and Bioengineering Conference (EHB), 2015, pp. 1–4. doi: 10.1109/EHB.2015.739148
6. W.-T. Wang, C.-H. Wu, Y.-H. Wang, and J.-L. Zhao, "Characterization and bentonite amendment of oil contaminated soils," in 2011 International Symposium on Water Resource and Environmental Protection, 2011, vol. 3, pp. 1844–1846. doi: 10.1109/ISWREP.2011.5893611.
7. Vapnik V. The nature of statistical learning theory. Springer Science+Business Media; 1999.
8. Elisseeff A, Weston J. A kernel method for multi-labelled classification. Adv Neural Inf Process Syst. 2001;14.
9. Zhang G-l, Liu F, SONG X-d. Recent progress and future prospect of digital soil mapping: A review. J Integr Agric. 2017;16(12):2871-85.
10. Breiman L. Bagging predictors. Mach Learn. 1996;24(2):123-40.
11. Breiman L. Random forests. Mach Learn. 2001;45(1):5-32.
12. Zhang M, Shi W, Xu Z. Systematic comparison of five machine-learning models in classification and interpolation of soil particle size fractions using different transformed data. Hydrol Earth Syst Sci. 2020;24(5):2505-26.
13. Yousefi S, Pourghasemi HR, Avand M, Janizadeh S, Tavangar S, Santosh M. Assessment of land degradation using machine-learning techniques: A case of declining rangelands. Land Degrad Dev. 2021;32(3):1452-66.
14. Zhou T, Geng Y, Chen J, Pan J, Haase D, Lausch A. High-resolution digital mapping of soil organic carbon and soil total nitrogen using DEM derivatives, Sentinel-1 and Sentinel-2 data based on machine learning algorithms. Sci Total Environ. 2020;729:138244.

15. Wiesmeier M, Urbanski L, Hobley E, Lang B, von Lützow M, Marin-Spiotta E et al. Soil organic carbon storage as a key function of soils-A review of drivers and indicators at various scales. Geoderma. 2019;333:149-62.
16. Yang M, Xu D, Chen S, Li H, Shi Z. Evaluation of machine learning approaches to predict soil organic matter and pH using Vis-NIR spectra. Sensors (Basel). 2019;19(2):263.
17. Reda R, Saffaj T, Ilham B, Saidi O, Issam K, Brahim L et al. A comparative study between a new method and other machine learning algorithms for soil organic carbon and total nitrogen prediction using near infrared spectroscopy. Chemom Intell Lab Syst. 2019;195:103873.
18. Zhang Y, Sui B, Shen H, Ouyang L. Mapping stocks of soil total nitrogen using remote sensing data: A comparison of random forest models with different predictors. Comput Electron Agric. 2019;160:23-30.
19. Zhou T, Geng Y, Chen J, Sun C, Haase D, Lausch A. Mapping of soil total nitrogen content in the middle reaches of the Heihe River Basin in China using multi-source remote sensing-derived variables. Remote Sens. 2019;11(24):2934.
20. Bousbih S, Zribi M, Pelletier C, Gorrab A, Lili-Chabaane Z, Baghdadi N et al. Soil texture estimation using radar and optical data from Sentinel-1 and Sentinel-2. Remote Sens. 2019;11(13):1520.
21. Riese FM, Keller S. Soil texture classification with 1D convolutional neural networks based on hyperspectral data. ISPRS Ann Photogramm Remote Sens Spatial Inf Sci. 2019;IV-2/W5:615-21.
22. Keshavarzi A, Sarmadian F, Omran E-SE, Iqbal M. A neural network model for estimating soil phosphorus using terrain analysis. Egypt J Remote Sens Space Sci. 2015;18(2):127-35.
23. Bouslihim Y, Rochdi A, El Amrani Paaza NEA. Machine learning approaches for the prediction of soil aggregate stability. Heliyon. 2021;7(3):e06480.
24. Zhou T, Geng Y, Ji C, Xu X, Wang H, Pan J et al. Prediction of soil organic carbon and the C: N ratio on a national scale using machine learning and satellite data: A comparison between Sentinel-2, Sentinel-3 and Landsat-8 images. Sci Total Environ. 2021;755(2):142661.