Advances in Geographic Information Science

Tanupriya Choudhury · Bappaditya Koley ·
Anindita Nath · Jung-Sup Um ·
Atul Kumar Patidar *Editors*

Geo-Environmental Hazards using AI-enabled Geospatial Techniques and Earth Observation Systems

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Advances in Geographic Information Science

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The ***Advances in Geographic Information Science*** series aims to: present current and emerging innovations in GIScience; describe new and robust GIScience methods for use in transdisciplinary problem solving and decision making contexts, illustrate GIScience case studies for use in teaching and training situations, analyze GIScience tools at the forefront of scientific research, and examine the future of GIScience in an expanding knowledge-based economy. The scope of the series is broad and will encompass work from all subject disciplines that develop and use an explicitly spatial perspective for analysis and problem-solving.

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*The editorial team extends their heartfelt dedication of this volume to **God Almighty** who has granted countless blessing, knowledge, and opportunity.*

Preface

Geo-environmental hazards like landslides, floods, flash floods, soil erosion, and tropical cyclones are extremely destructive natural calamities that result in significant harm to both natural landscapes and man-made structures. These natural threats pose a serious risk to human lives, properties, and infrastructure. The aftermath of such disasters often leads to substantial economic losses and introduces pathogens into the environments, fostering the growth of harmful microbes that can cause diseases. These combined natural and societal dangers hinder the progress of human civilization and sustainability efforts.

The book offers a comprehensive exploration of various aspects of geo-environmental hazards using geospatial techniques and machine learning to promote sustainable development. This volume has considered 17 chapters associated with mapping, monitoring, hazard and risk assessment, mitigation strategies, and sustainable development; readers will find a chapter-by-chapter summary helpful in navigating the content before delving into it.

Chapter "An Introduction to Artificial Intelligence and Its Applications Towards Remote Sensing" serves as an introduction to the discussion on artificial intelligence (AI) applications in remote sensing (RS). It highlights the significant role that algorithms have played in remote sensing over recent years. The chapter discusses both machine learning and deep learning approaches using satellite imagery for remote sensing data. Additionally, it explores how machines can learn autonomously through rewards and penalties while also introducing ensemble algorithms such as Bagging, Boosting, and Stacking for machine learning purposes. In the upcoming chapter (i.e., chapter "GIS and Remote Sensing Application for Vegetation Mapping"), an analysis has been conducted to detect and map vegetation cover using data from remote sensing images. To achieve this, it is often essential to establish a classification system for vegetation, either at the community or species level, while also considering environmental sustainability. This research presents the results of monitoring and mapping plant cover through remote sensing technology. Moving forward to chapter "Spatiotemporal Trends of Tropical Cyclones in Bay of Bengal Basin, India", the focus shifts toward examining trends in cyclonic storms, including their frequency and intensity in coastal districts and counties within the

Bay of Bengal (BoB) basin. This chapter illustrates how changes in cyclonic storms distribution offer valuable insights for community adaptation, prioritizing relief efforts, and designing effective disaster management plans specific to the BoB basin.

Chapters "Application of Geospatial Technologies and AHP Technique in the Identification of Soil Erosion-Prone Zones in the Rift Valley, Southern Ethiopia" to "Assessment of Groundwater Potential Using an Integrated Approach of GIS, Fuzzy AHP, and Remote Sensing: A Case Study of Madurai City in India" showcase a range of modeling techniques and algorithms used in geospatial applications for assessing and monitoring geo-environmental hazards with a goal of achieving sustainable development. Additionally, chapter "Application of Geospatial Technologies and AHP Technique in the Identification of Soil Erosion-Prone Zones in the Rift Valley, Southern Ethiopia" demonstrates the process of identifying areas prone to soil erosion using geospatial application and analytical hierarchy process (AHP) to ensure sustainable land management. This chapter provides valuable insights for decision-makers and policy developers, enabling them to create and execute effective water and soil conservation plans based on this information. Chapter "Shoreline Changes Along Bhitarkanika Sanctuary, North Odisha Coast, India" delves into studying shoreline movement by employing Digital Shoreline Analysis System (DSAS) modal changes as a tool, whereas chapter "One-Dimensional Shoreline Evolution Modeling at Sea Turtle Nesting Ground Near the Rushikulya Estuary, Southern Odisha Coast, India" takes on re-evaluating shoreline changes along with making predictions using LITDRIFT and LITLINE modules. Those study would be immensely valuable to coastal researchers, managers, and stakeholders prior to any development operations at the study site. Chapter "Analysis of Sea Surface Temperature and Chlorophyll-a Concentration Along the Coastline of the Indian Peninsula Using Remote Sensing Data" delves into the examination of how this research utilizes remote sensing datasets from MODIS (AQUA and TERRA) to quantitatively showcase and monitor water quality indicators like water surface temperature and chlorophyll-a. Moving on to chapter "Landslide Susceptibility Mapping Through Hyperparameter Optimized Bagging and Boosting Ensembles: Case Study of NH-10, West Bengal, India", it delves into exploring landslide susceptibility mapping through the application of Hyperparameter Optimized Bagging and Boosting Ensembles model with the aid of remote sensing and GIS. The effectiveness of a model in predicting landslide susceptibility heavily relies on selecting appropriate predisposing features for slides. The subsequent chapter (i.e., chapter "Flash Flood Assessment in Hilly Regions") focuses on evaluating hazard zones prone to flash floods in hilly regions using geospatial tools. This evaluation aims to strategically allocate financial resources and other assets where they are most needed, thereby aiding in planning efforts that enhance community well-being and sustainability. Furthermore, chapter "Mapping Flood Hazard in Marinduque, Philippines, Using Maximum Entropy Approach" examines flood hazards mapping utilizing a maximum entropy model in Marinduque, the Philippines. This study equips local disaster risk reduction officers with crucial insights to formulate effective plans for managing flooding risks sustainably within the province. Chapter "GIS Mapping and Groundwater Quality Assessment Near Solid Waste Dump Site" scrutinizes groundwater quality near solid waste dump sites by leveraging GIS technology. This analysis provides detailed information regarding different characteristics' distribution patterns within the research area, facilitating easy identification of wells for accessing clean water suitable for domestic as well as agricultural purposes and take precautions to protect the site's resources in the future. The next chapter (i.e., chapter "Assessment of Groundwater Potential Using an Integrated Approach of GIS, Fuzzy AHP, and Remote Sensing: A Case Study of Madurai City in India") evaluates groundwater potential zones using an integrated approach of GIS, Fuzzy AHP, and remote sensing applications. This study is feasible to formulate policies for groundwater conservation, perform scientific planning, restrict residential and industrial usage, and improve groundwater storage by situating the groundwater potential zones and its recharge regions.

Chapters "Developing Sustainable Livelihood Index for the Coastal Belt of Indian Sundarbans" and "A Geospatial Approach for the Development of Sustainable Watershed Management" discuss the importance of sustainable development in coastal regions and watershed management, highlighting their significance for achieving Sustainable Development Goals (SDGs). Chapter "Developing Sustainable Livelihood Index for the Coastal Belt of Indian Sundarbans" focuses on creating a Sustainable Livelihood Index (SLI) specifically for the Coastal Belt of Indian Sundarbans. This research demonstrates that livelihood sustainability is influenced by factors such as reliance on natural resources, financial support from the government, family size, and ownership of assets like fisheries and land. Additionally, chapter "A Geospatial Approach for the Development of Sustainable Watershed Management" explores methods for identifying potential recharge areas in watershed regions using geographical information system (GIS) and remote sensing technology. In chapter "An Efficient Image Compression Algorithm Using Neural Networks", a modeling technique involving the 'Convolution neural network' algorithm is utilized to generate high-resolution images through machine learning. The subsequent chapter (i.e., chapter "Computer Vision-Based Autonomous Underwater Vehicle with Robotic Arm for Garbage Detection and Cleaning") introduces an autonomous underwater vehicle (AUV) designed to detect and clean garbage using Computer Vision-Based Autonomous Underwater Vehicle with Robotic Arm. The final chapter (i.e., chapter "Visual Media Super-Resolution Using Super-Resolution Generative Adversarial Networks") presents an application that offers a comprehensive solution for converting low-resolution images and videos into high-resolution formats. The aim is to democratize artificial intelligence (AI) and deep machine learning by providing it through an application programming interface (API) that seamlessly integrates with web applications for user convenience, so that users can experience the benefits of the method of super-resolution using deep learning without reinventing the wheel.

We express our gratitude to the diligent authors who have successfully finalized their works in a timely manner, contributing to the creation of an enlightening and valuable publication. We offer special thanks to reviewers across the world who have diligently scrutinized each chapter to uphold the book's high standards. Our sincere appreciation goes out to all involved parties for their dedication and

readiness to undertake tasks that stretched them beyond their usual scopes of comfort. We are confident that this book will serve as a valuable resource for professionals in various fields such as Geography, Geology, Geospatial Science, Computer Science, Hydrology, Environmental Science, Soil Science, Remote Sensing and GIS, Agricultural Science, as well as those involved in geo-environmental hazards and management. This book is aimed at researchers, academicians, professionals, and policymakers involved in addressing geo-environmental hazards and seeking solutions. We eagerly anticipate reuniting with you in the forthcoming edition of our publication.

Dehradun, Uttarakhand, India — Tanupriya Choudhury
South 24 Parganas, West Bengal, India — Bappaditya Koley
South 24 Parganas, West Bengal, India — Anindita Nath
Buk-gu, Daegu, Korea (Republic of) — Jung-Sup Um
Dehradun, Uttarakhand, India — Atul Kumar Patidar

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About the Editors

Tanupriya Choudhury completed his undergraduate studies in Computer Science and Engineering at the West Bengal University of Technology in Kolkata (2004–2008), India, followed by a Master's Degree in the same field from Dr. M.G.R University in Chennai, India (2008–2010). In 2016, he successfully obtained his PhD degree from Jagannath University Jaipur. With a total of 15 years of experience in both teaching and research, Dr. Choudhury holds the position of a Visiting Professor at Daffodil International University, Bangladesh. Currently, he is working as a Professor (Research) at Graphic Era Deemed to be University, Dehradun, India, and also serving as Associate Dean of Research.

Prior to this role, he served Symbiosis International University, Pune, India; Graphic Era Hill University, Dehradun (Research Professor), UPES Dehradun (Professor and Research Head Informatics), Amity University Noida (Assistant Professor Grade 3 and International Dept. Head), and other prestigious academic institutions (Dronacharya College of Engineering Gurgaon, Lingaya's University Faridabad, Babu Banarsi Das Institute of Technology Ghaziabad, Syscon Solutions Pvt. Ltd. Kolkata, etc.). He was recently recognized for his outstanding contributions to education with the Global Outreach Education Award for Excellence in Best Young Researcher Award at Global Outreach Education Award for Excellence (GOEAC) 2018.

His areas of expertise encompass Human Computing, Soft Computing, Cloud Computing, and Data Mining, among others. Notably accomplished within his field thus far is filing 25 patents and securing copyrights for 16 software programs from MHRD (Ministry of Human Resource Development). He has actively participated as an attendee or speaker at numerous National and International conferences across India and abroad. With more than 100 research papers (Scopus) authored to date on record, Dr. Choudhury has also been invited as a guest lecturer or keynote speaker at esteemed institutions such as Jamia Millia Islamia University, Maharaja Agersen College (Delhi University), Duy Tan University Vietnam, etc. He has also contributed significantly to various conferences throughout India serving roles like TPC member and session chairperson.

As an active professional within the technical community, Dr. Choudhury holds a lifetime membership with IETA (International Engineering & Technology Association) along with being affiliated with IEEE (Institute of Electrical and Electronics Engineers), IET (UK) (Institution of Engineering & Technology, UK), and other reputable technical societies. Additionally, he is associated with corporate entities and serves as a Technical Adviser for Deetya Soft Pvt. Ltd., Noida, IVRGURU, and Mydigital360. He is also serving as an editor in reputed journals.

He currently serves as the Honorary Secretary in IETA (Indian Engineering Teacher's Association-India), alongside his role as the Senior Advisor Position in INDO-UK Confederation of Science, Technology and Research Ltd., London, UK, and International Association of Professional and Fellow Engineers-Delaware-USA.

Bappaditya Koley is currently working as Head of the Department of Geography at Bankim Sardar College, West Bengal, India. In 2021, he successfully obtained his PhD degree in Science from Jadavpur University, Kolkata, India. His areas of research interest include applied geomorphology, geo-informatics, natural hazards and disasters, climate change, coastal management, environmental issues, land use modeling, and sustainable development. He has also completed a minor research project on "*Forestry, Fishery and Sustainable Livelihood: An Assessment for some selected areas of Indian Sunderbans*" as a co-director, funded by the Indian Council of Social Science Research

(ERC, Kolkata), Govt. of India. As a centre co-coordinator at Bankim Sardar College, he conducted two courses in Indian Institute of Remote Sensing (IIRS) Outreach Programmes during 2019–2023, organized by the Indian Institute of Remote Sensing (ISRO), Dehradun. He has also contributed several national and international research articles and book chapters in international reputed. He has been associated as the reviewer of some reputable journals published by Elsevier, Springer-Nature, and Taylor & Francis. He has been associated as a Guest Editor of the Special Issue “Designing of AIML (Artificial Intelligence and Machine Learning) and Convolutional Neural Network (CNN) Based Architectures and Its Various Applications in the Field of Engineering” under *Designs*, an open access journal by Multidisciplinary Digital Publishing Institute (MDPI).

Anindita Nath is currently working as a faculty in the Department of Geography at Bankim Sardar College, West Bengal, India. In the year 2021, she obtained her PhD degree in Science from Jadavpur University, Kolkata. Her research interests include coastal hazards and management, geospatial application, climate change, land degradation and management, landslide hazards and management, flood assessment and riverbank erosion, land use modeling, environmental issues, and sustainable development. She has published numerous research papers in leading national and international journals and book chapters to international reputations. She is associated as the reviewer of reputed journals published by Elsevier and Springer-Nature.

Jung-Sup Um Professor, Department of Geography, College of Social Sciences, Kyungpook National University, South Korea. He works as an Editor-in-Chief of Spatial Information Research (Springer-Nature) since 2015. He shares his interest in drones by maintaining strong links with international editorial boards, authors, and reviewer communities. He was awarded Outstanding Research Award 13 times for significant and lasting research contributions. He is also the author of a recent book on *Drones as Cyber-Physical Systems, Concepts and Applications for the Fourth Industrial Revolution*, coauthor of seven books on Spatial Information, and the author of more than 100 journal publications (including two patents registered). He has tried to promote the importance of drones as a core infrastructure of the 4th Industrial Revolution era while offering online lectures on the contents of this book. His current research work is on unmanned aerial vehicle (UAV) remote sensing as a cyber-physical system, the use of satellite data (Greenhouse Gases Observing Satellite (GOSAT), Orbiting Carbon Observatory-2 (OCO-2)) for UN-REDD (United Nations' collaborative program on "Reducing Emissions from Deforestation and Forest Degradation") MRV (Measurement, Reporting and Verification) requirements, and synergistic application research that combines with various disciplines such as law, economics, political science, environmental science, etc. As a photographer and remote sensing practitioner, he began to intensively occupy himself with drones by the revolutionary prospect of being able to take aerial photographs at any time or any place. Over time, a great deal of enthusiasm for this technology let him publish a book about drones (2019, Springer-Nature). He was a principal investigator in the various research projects that led to promoting geographic information to the general public. He was the program co-chair of the Organizing Committee of FOSS4G (Free and Open-Source Software for Geospatial) Seoul from 2013 to 2015. He was an associate editor and member of the editorial board of Spatial Information Research from 1995 to 2015. He worked as a government official in the Ministry of Environment in Korea, with a focus on the application of remote sensing and geographic information system (GIS). His experience includes projects with related central governments in Korea, and he is frequently invited as a consultant for zero-carbon Geomatics planning to local and central governments.

Atul Kumar Patidar completed his BSc degree (1998–2001) at the Holkar Science College (DAVV) Indore, Madhya Pradesh, India, followed by an MSc degree in Geology (2001–2003) at the same institute. In the year 2010, he obtained his PhD degree from the M.S. University of Baroda, Vadodara, Gujarat, India. During his doctoral studies, he worked on the neotectonic evolution of the southern mainland Kachchh basin using ground penetrating radar (GPR) and remote sensing techniques. He has reconstructed the chronology of paleoseismic events (timing and magnitude) and comprehended the reasons for recurrent seismic activity along the Katrol Hill Fault. He established fault segmentation and scarp retreat model for the active faults of the Kachchh basin.

Dr. Patidar has 15+ years of experience in both industry and academia. As an exploration geoscientist, he has spent 11 years (2007–2018) in Reliance Industries Limited, a multinational hydrocarbon exploration and production company in India. In 2018, he joined the Department of Petroleum Engineering and Earth Sciences, University of Petroleum and Energy Studies, Dehradun, as a Sr. Associate Professor (Industry Fellow). Dr. Patidar has accomplished numerous national and international projects during his corporate tenure in the areas of regional-scale basin analysis and 3D seismic interpretation. He has received numerous awards for his contribution to industry, academia, and research. His core areas of specialization are Geoinformatics, Tectonic Geomorphology, Neotectonics, Paleoseismology, GPR, Seismic interpretation, and Basin analysis. He has published 40+ research papers in high-impact, prestigious SCI/Scopus-indexed journals/proceedings.

An Introduction to Artificial Intelligence and Its Applications Towards Remote Sensing

B. Vijayakumari and V. S. Benitha

1 Introduction

The use of artificial intelligence is becoming increasingly prevalent in the field of remote sensing. It can apply to various fields like agriculture, archaeology, business, crime, climatic change, ecology, environment, engineering and construction, silviculture, government, hydrology, disasters, military, extractive metallurgy, navigation, oceanography and weather. It is listed in Fig. 1.

Remote sensing applications can be performed with two major algorithms: machine learning and deep learning. Both these techniques are able to mimic the human brain. Statistical techniques are utilized in machine learning; a computer science subfield that enables computers to learn from data without explicit programming, and it is part of the broader category of artificial intelligence. By using these techniques, computers will be enabled to perform actions without the need for explicit programming. The success of this lies in selecting the appropriate features and constructing the appropriate models that can accomplish the desired tasks. The field of machine learning involves the methodical exploration of algorithms and systems that enhance their knowledge or performance through experience. Over the last 10 years, machine learning has enabled the development of autonomous vehicles, functional speech recognition, powerful web search algorithms, and significantly enhanced comprehension of the human genome. Machine learning is so dominant today that everyone uses it regularly without knowing it. The concept map of machine learning can be summarized as shown in Fig. 2.

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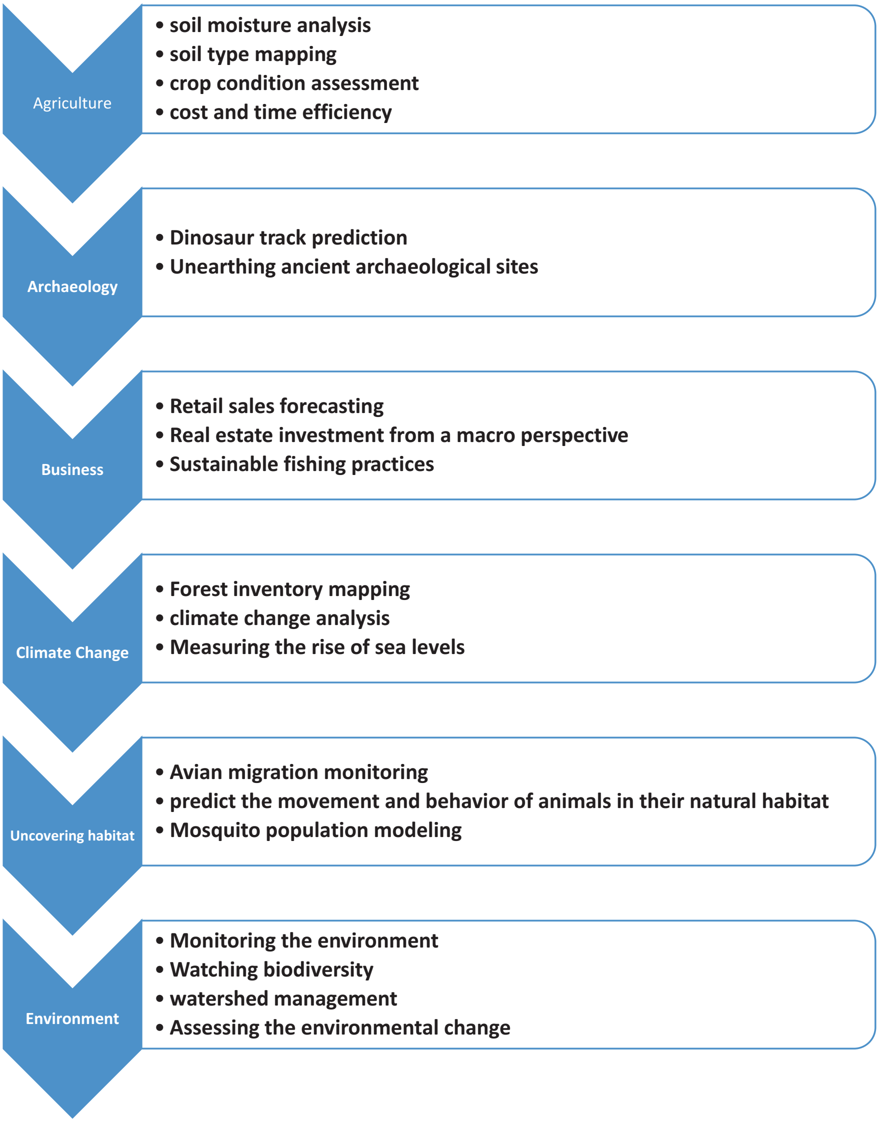


Fig. 1 Application areas of artificial intelligence in remote sensing

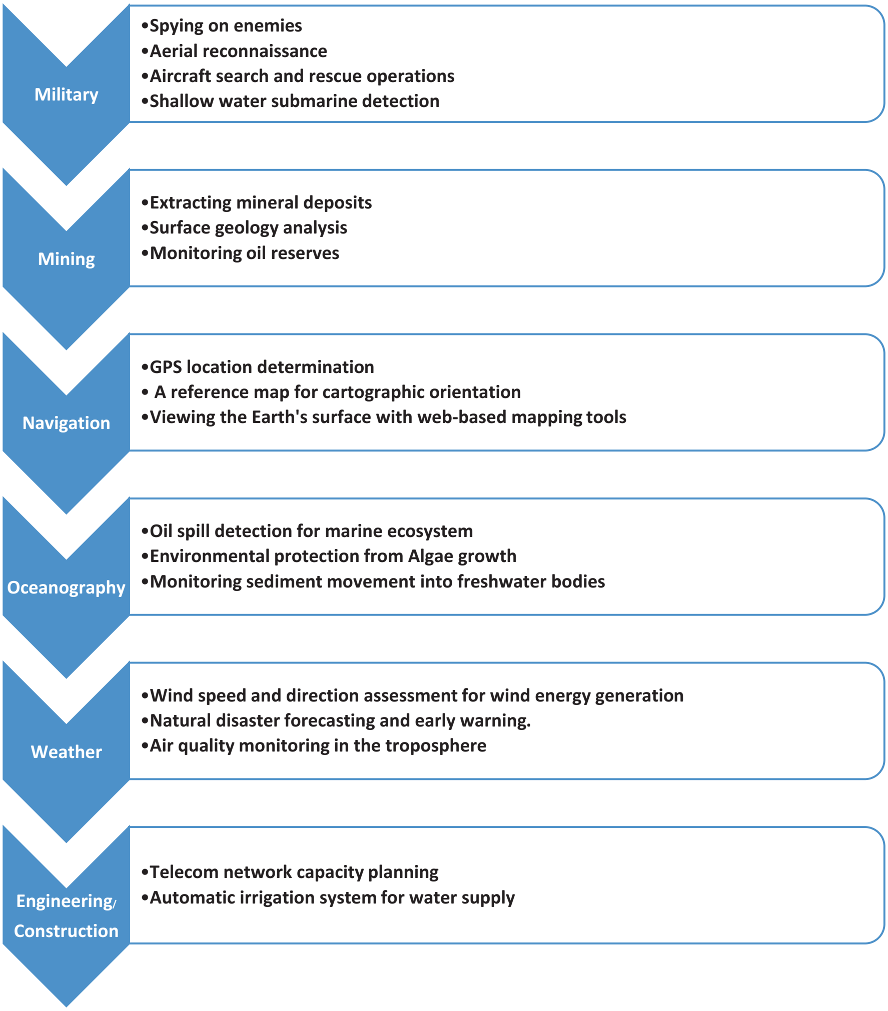


Fig. 1.1 (continued)

Several supervised, unsupervised and ensemble learning methods have been adopted for numerous remote sensing applications. It will be discussed later in this chapter. On the other hand, deep learning is a branch of machine learning that involves a neural network comprising at least three layers, which can enable the machine to 'learn' from larger data sets. The predictions using deep neural networks prove to be better than the single network prediction. Deep learning makes use of captured or pre-processed images rather than features as expected in machine learning. The various deep learning approaches used for remote sensing are shown in Fig. 3. The combination of deep learning and machine learning has recently been applied to specific tasks such as network analysis, spatial measurement,

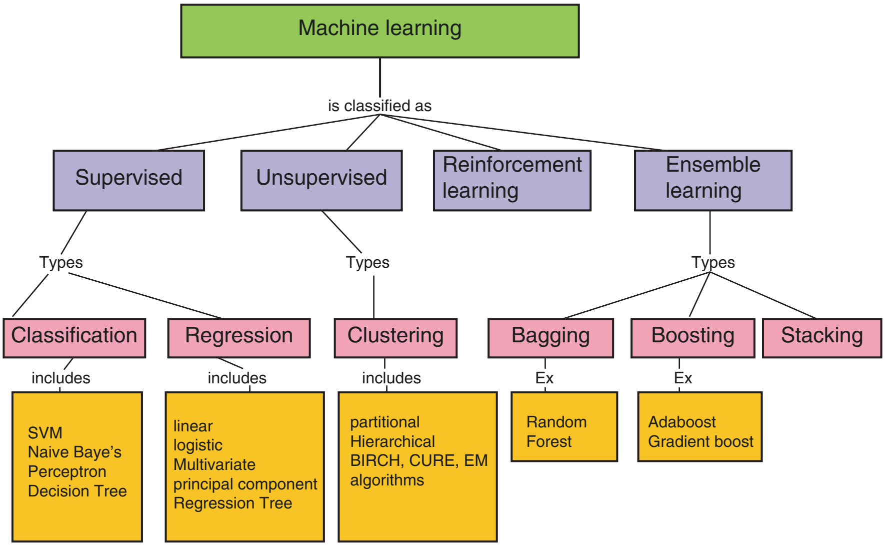


Fig. 2 Concept map of machine learning

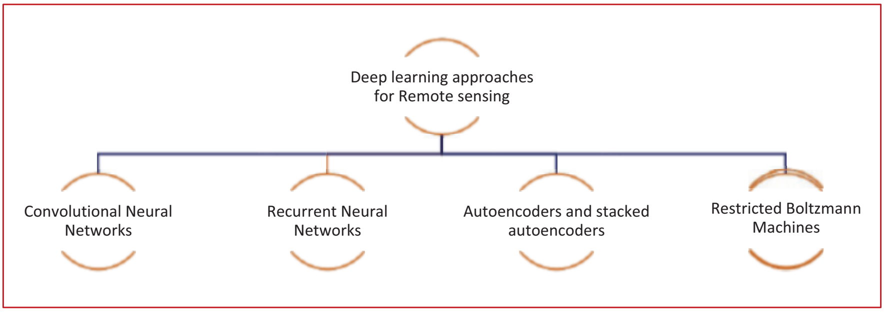


Fig. 3 Deep learning approaches for remote sensing

transportation and logistics routing, resource exploration, facility management, watershed analysis and site selection, among others.

2 Machine Learning Algorithms

For remote sensing, the more often used methods are linear discriminant analysis (LDA), K-nearest neighbour (KNN), decision trees (DT), random forest classifier (RFC) and support vector machine (SVM). The linear discriminant analysis as shown in Fig. 4 may be either linear or quadratic. Linear LDA involves the utilization of a multivariate Gaussian distribution for each class, represented by a shared

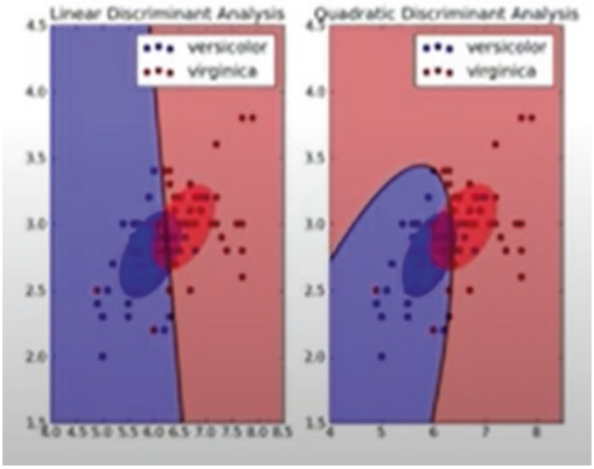


Fig. 4 LDA representation

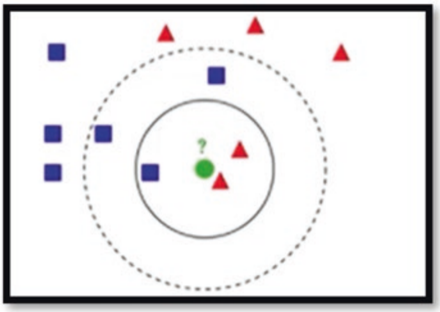


Fig. 5 KNN representation

covariance matrix. Quadratic LDA applies a multivariate Gaussian distribution to each class, with each class being represented by a distinct covariance matrix.

K-NN is a memory-based, non-parametric classification algorithm that utilizes the stored information from training data to classify new data points. Hence, it is called a lazy algorithm. Based on the K-value and within a circle of K, the distance between each data point from its centroid categorizes the data as shown in Fig. 5. The K value can be decided by the user based on the application.

Random forest classifier as shown in Fig. 6 is an ensemble learning algorithm that produces a combined output of weak decision trees. The optimal decision trees are selected based on high information gain, least total error or the least Gini index value. It trains a number of decision trees on randomly selected bootstrapped subsets of the training data and features. The final prediction is based on the aggregated responses of the individual trees.

Support vector machine is another popular machine learning tool used in remote sensing. It could separate the features in higher dimensional space with the hyperplane as given in Fig. 7. If the input is non-linear, kernel tricks will be used to categorize the given data is used. The features close to the margin are called support

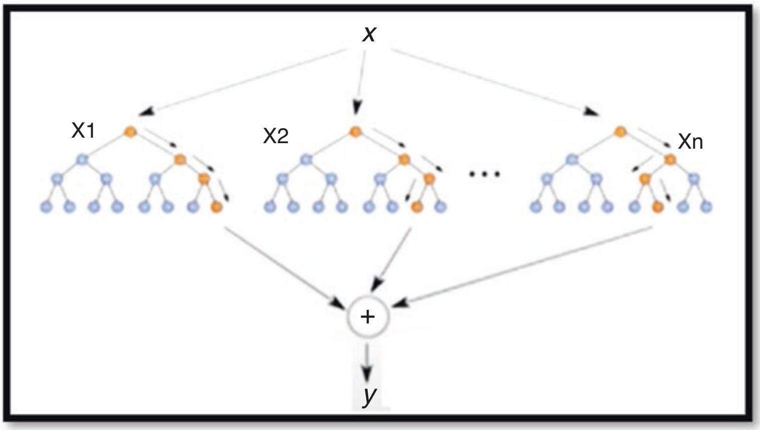
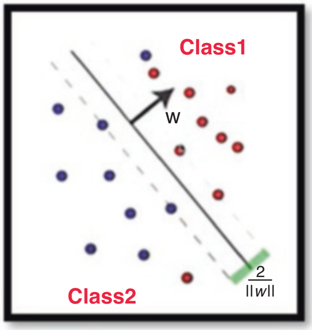


Fig. 6 Random forest classifier representation

Fig. 7 Support vector machine representation



vectors and aid in better prediction. Other features farther away from the margin can be even removed as they do not contribute to categorization. Figure 7 represents the SVM. The more the features are extracted, the better the expected result will be. In sample experimentation specifically for site selection, it is observed that out of all these machine learning (ML) methods, support vector machine is found to be a superior one since it gives better accuracy of classification even with less number of input training pixels. On the other hand, KNN algorithm is simple to implement, but performs better with a larger number of training pixels.

3 ML Applications in Remote Sensing

Remote sensing researchers have widely accepted non-parametric supervised machine learning algorithms [1–4] presently. Over the past decade, there has been a significant advancement in the development of machine learning-based methodologies for various Earth Science applications, encompassing a range of algorithms such as artificial neural networks (ANN), support vector machines, self-organizing maps (SOM) and decision trees. These algorithms have gained widespread acceptance within the remote sensing community [5–7]. Among them, the most frequently employed machine learning techniques for addressing geoscience problems and interpreting remote sensing data are ANN and SVM. For an in-depth review of the application of ANN and SVM in geoscience and remote sensing, the work done by Lary (2010) provides a comprehensive analysis. In the literature, the analysis of the applicability of neuro-computing, fuzzy logic and evolutionary computing in geosciences and oil exploration was done earlier [8]. This review also focuses on the successful application of combinations of neural network and fuzzy logic, fuzzy and genetic algorithm, genetic and neural-fuzzy-genetic as well in the field. The utilization of these hybrid technologies holds great potential for addressing challenges in geophysical, geological and reservoir engineering disciplines. One of the examples is the estimation of the typhoon rainfall over the ocean using meteorological satellite data [9], checking of reservoir water quality using remote sensing images [10], mapping of base-metal deposits [11], image processing for landslide detection [12] and soil moisture distribution analysis [25]. Texture and spectral information encoding play a major role in most of these applications.

As SVM is a non-parametric one, it efficiently handles an abundance of data [13, 14, 16], i.e. it is worth noting that this approach is not affected by issues related to the dimensionality of the data. For land cover classification, SVM can be trained on labelled remote sensing data to classify different land cover types such as forests, urban areas, water bodies and agricultural fields. SVM can effectively handle high-dimensional data and nonlinear relationships, making it suitable for remote sensing imagery analysis. In object detection, SVM can be used to identify specific objects or features within remote sensing images, such as buildings, roads or vehicles. By training an SVM model on annotated data, it can learn to detect and classify these objects accurately. Image segmentation is another application where SVM can be employed in remote sensing. SVM can be used to partition an image into meaningful regions based on spectral or textural characteristics. This can be useful for extracting land cover information or identifying specific features within an image. Change detection is a crucial task in remote sensing, and SVM can be utilized for this purpose as well. By training an SVM model on multi-temporal remote sensing data, it can identify areas where significant changes have occurred, such as urban expansion, deforestation or land degradation. In remote sensing, SVMs are particularly attractive because of their ability to produce high classification accuracy even with small training data sets [17–21]. The applicability of SVM for remote sensing data was studied in the existing works [23, 24]. The kernel tricks can be efficiently utilized to get accurate results and also have control of the decision boundaries, in turn improving performance. Though SVM has its own merits, some of the challenges faced are the selection of a suitable kernel, optimum kernel parameters and the relatively complex mathematics behind the SVM, especially from a non-expert user point of view, which restricts the effective cross-disciplinary applications of SVMs [16, 23].

Among the various methods of ML, genetic programming (GP) [24] offers a flexible and automated approach for solving complex problems in the remote sensing domain. GP is a computational technique that uses principles inspired by biological evolution to automatically generate computer programs. In the remote sensing domain, GP has been applied for various purposes, including feature selection, image classification, and data fusion. GP can be used to evolve a set of mathematical expressions or decision rules that effectively capture the relevant features from remote sensing data. By iteratively evolving and evaluating candidate solutions, GP can identify the most informative features for a given remote sensing task, such as land cover classification or change detection. By evolving classification algorithms or decision trees, GP can automatically generate models that accurately classify remote sensing images into different land cover classes. This can be particularly useful when dealing with large and complex data sets, as GP can adaptively search for optimal solutions. Data fusion is another area where GP has been applied in remote sensing. Data fusion involves combining information from multiple sensors or data sources to improve the accuracy and reliability of remote sensing analysis. GP can be used to evolve fusion algorithms that effectively integrate data from different sources, such as optical and radar imagery, to enhance the overall information content and extract more meaningful insights. In 2010, dos Santos et al. [26] explained the general steps involved in the classification process with remote sensing image (RSI) as shown in Fig. 8. The classification is carried out in two steps: image description and image classification. Out of the seven steps shown here, steps 1–3 focus on image content characterization and steps 4–7 describe the image classification process. GP has been used by dos Santos et al. to identify relevant partitions by combining the similarities provided by descriptors. The results obtained by this method are comparable with the existing algorithms.

Random Forest classifier is an ensemble learning normally comes under bagging was used in few of the already existing works [15, 27–29] and it suited better for

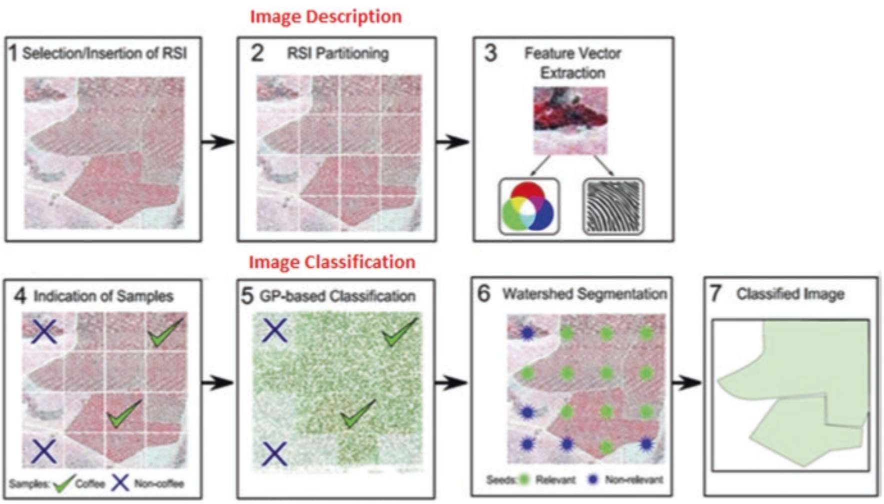


Fig. 8 Classification process of dos Santos et al. (2010)

remote sensing data. It involves forest of trees based on the available data and the tree reduction in RFC was done by pruning process. The number of trees and the number of randomly selected features have to be initially set for this algorithm. RFCs are reported to be less sensitive to the number of trees compared to their features [30]. There is a trade-off that exists between these two parameters. Reducing the number of features may result in faster computation, but it reduces the correlation between any two trees and the strength of every single tree in the forest and has a severe influence on the classification accuracy. The number of features can be set larger so that RFC is computationally efficient and does not overfit [31]. Both RFC and SVM find their role in remote sensing. The plot shown in Fig. 9 shows the number of studies released with SVM from 2000 to 2023. Fig. 10 shows the same plot with RFC.

SVM and RFC are compared against the availability of data and applications. SVM is a supervised learning algorithm that aims to find an optimal hyperplane that separates different classes of data points. It works by mapping input data into a high-dimensional feature space and finding the best decision boundary. SVM is known for its ability to handle high-dimensional data and its effectiveness in dealing with complex classification problems. However, SVM can be computationally expensive and may not perform well with large data sets.

On the other hand, RFC is an ensemble learning method that combines multiple decision trees to make predictions. Each decision tree in the forest independently classifies the input data, and the final prediction is determined by majority voting. RFC is known for its robustness against overfitting, as it reduces the variance by averaging the predictions of multiple trees. It can handle both categorical and continuous data, and it is generally faster than SVM. When comparing SVM and RFC for remote sensing applications, several factors should be considered. SVM is often preferred when dealing with high-dimensional data and when the decision boundary is not linear. It can handle both classification and regression tasks effectively. RFC,

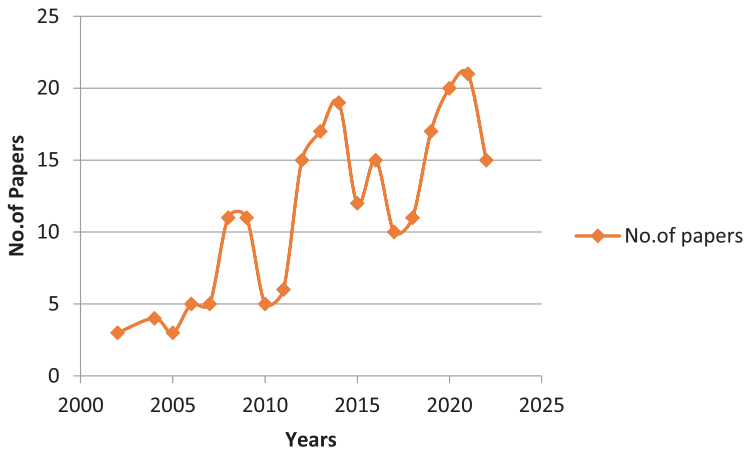


Fig. 9 Number of studies with SVM for remote sensing applications

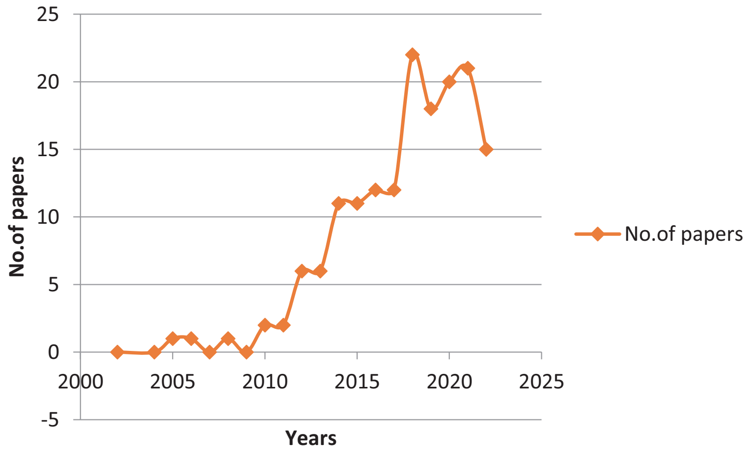


Fig. 10 Number of studies with RFC for remote sensing applications

on the other hand, is suitable for handling large data sets and can provide insights into feature importance. It is also less sensitive to outliers and noise in the data. Ultimately, the choice between SVM and RFC depends on the specific requirements of the remote sensing task at hand, such as the nature of the data, the complexity of the classification problem, and the computational resources available. It is recommended to experiment with both algorithms and evaluate their performance using appropriate metrics to determine which one is more suitable for a particular remote sensing application.

4 Deep Neural Network in Remote Sensing

Deep learning (DL) is now utilized for remote sensing applications by studying and analysing the study area by observing its classification accuracy. DL has been applied for remote sensing image analysis tasks including image fusion, image registration, scene classification, object detection, land use and land cover classification, segmentation, and object-based image analysis. Convolutional neural network is one of the most extensively used deep learning models for multiband remote sensing image data [32]. Traditionally, recurrent neural networks (RNNs) have been widely used for discrete sequence analysis tasks, such as natural language processing and speech recognition. RNNs are a type of neural network that can process sequential data by maintaining an internal memory state. This memory state allows the network to capture dependencies and patterns in the sequence. It is well utilized for solving complex remote sensing data [33]. Auto encoders (AE) is another DL model that is mainly applicable for dimensionality reduction and compression. In auto encoders, stacking can be done by combining several AEs. This will produce better results for feature representation while handling remote sensing data like spatial, spectral and radiometric resolution of landsat, colour signatures on standard false colour composite of earth surface features including healthy vegetation and cultivated areas, water bodies, built-up areas and wasteland/rock outcrops [34]. The restricted Boltzmann machine is also effectively utilized for analysing land cover data. Generative adversarial network (GAN) is another DL model that uses both generative and discriminative sections in the structure. GAN is being used to solve more computer vision problems and also handle remote sensing data. Lei Ma et al. [35, 36] carried out statistical analysis for the applicability of DL for remote sensing data. They have analysed a number of research works carried out using different DL models and also the specific use like land use land cover classification, object detection, scene recognition, segmentation, change detection, fusion image registration and others as shown in Fig. 11.

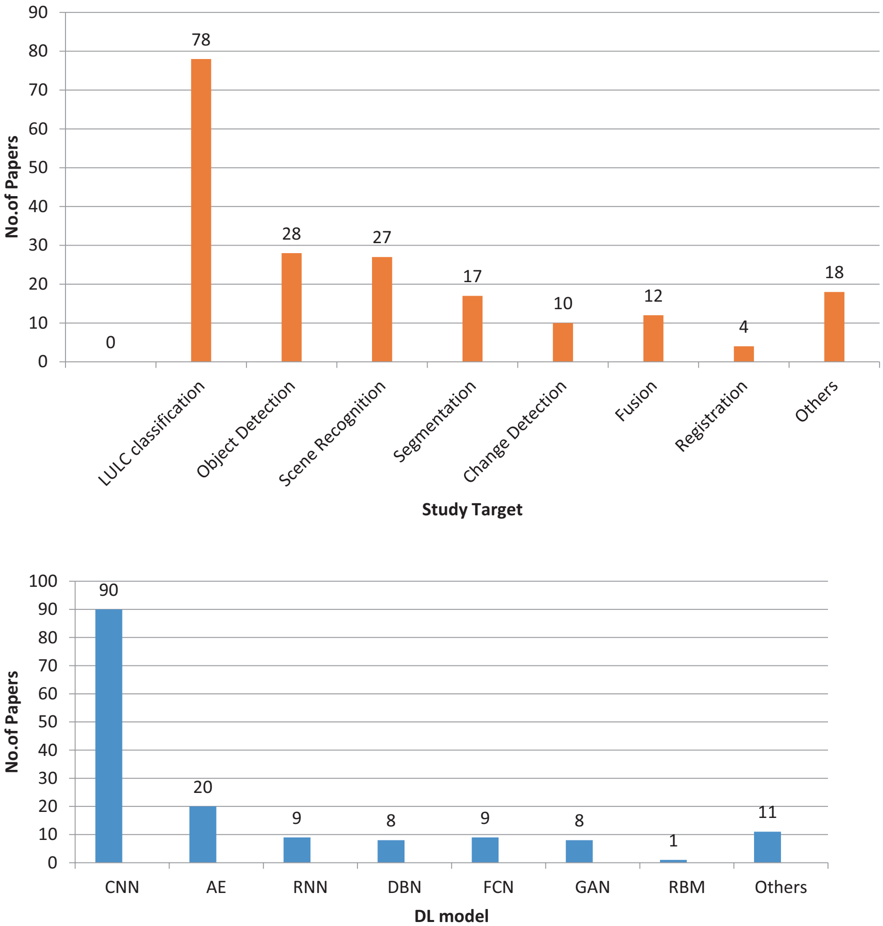


Fig. 11 Statistical analysis by Lei Ma et al. [36]

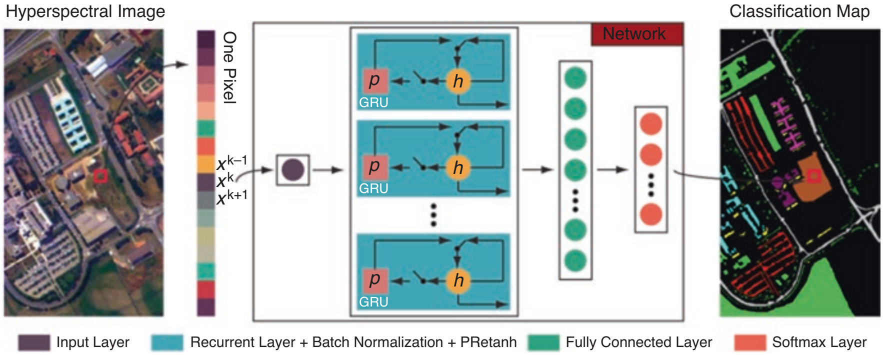


Fig. 12 Hyperspectral image classification using RNN [37]

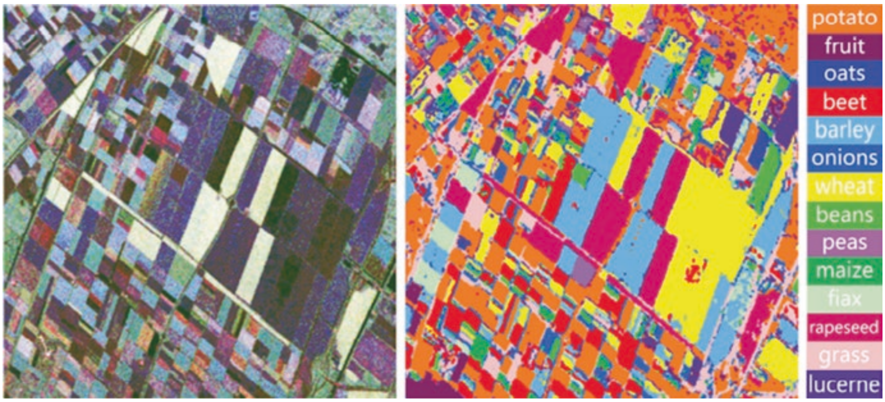


Fig. 13 PolSAR image classification using CNN [38]

From this analysis, it is observed that for high-resolution images, benchmark datasets are available. Whereas for medium- and low-resolution images, a ground truth data set has to be created before carrying out the analysis. Deep learning is well proven presently for most remote sensing applications. To highlight a few, the RNN used for hyperspectral image classification done by Mou et al. [37] is shown in Fig. 12.

Zhang et al. studied complex convolutional neural networks for PolSAR image classification [38]. By modifying conventional CNN, they were able to get better results as shown in Figs. 12 and 13.

5 Conclusion and Future Work

In this chapter, the state of the art in machine learning and deep learning for remote sensing has been discussed.

Machine learning finds its own place in analysing remote sensing data for several applications as mentioned earlier in this chapter. Both machine learning and deep learning are suitable for all remote sensing applications. But, based on data availability, type of information and abundance of images, one of these may perform better. Deep neural networks provide better results than classical approaches using hand-crafted features. However, the application of deep learning in the field of remote sensing is still in its early stages, and in the coming years, we anticipate significant advancements in deep learning techniques, particularly in areas such as groundwater prediction. It is observed that benchmark data sets for certain applications are not available. So, it may be useful to carry out research in those fields too. In future, with the availability of plenty of DL models, big remote Sensing problems can be solved by using multi-modal, multi-temporal and geo-located data.

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