

A Comprehensive Review of the Recent Advancement in Integrating Deep Learning with Geographic Information Systems

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Abstract

The integration of deep learning (DL) techniques with geographical information system (GIS) offers a promising avenue for gaining novel insights into environmental phenomena by using the capabilities of spatial, temporal, and spectral resolutions, as well as data integration. The integration of these two technologies can result in the development of a highly efficient system for assessing environmental conditions by analyzing the interplay between texture, size, pattern, and process. This viewpoint has gained appeal across various academic disciplines. GIS heavily relies on processors, especially for tasks such as 3D computations, map rendering, and route calculation. In contrast, DL has the capability to efficiently analyze vast quantities of data. DL has garnered significant attention in recent times due to its potential for delivering a wide range of promising outcomes. Moreover, there is clear evidence of the increasing utilization of deep learning techniques across various fields, including GIS. The objective of this study is to provide an overview of the application of DL techniques in the field of GIS. This paper presents a concise review of the fundamental DL ideas that are pertinent to GIS, with a focus on the most current research findings. The present study investigates the various uses and technology of remote sensing in diverse domains, including mapping, hydrological modeling, disaster management, and transportation route planning. This study offers insights into contemporary framework approaches and proposes avenues for further research.

Keywords: Deep learning; GIS; Remote sensing; Neural network; Integration.

1 Introduction

The utilization and administration of geographical resources and data are becoming more prevalent due to the abundance of available resources (Iglesias et al., 2022). The spatial data presented below offer vital geographical information. Consequently, in order to effectively analyze and utilize this information, it is imperative to develop optimal strategies and relevant techniques (Lei et al., 2023). The data has the potential to provide in-depth information regarding events or locations, which is achieved through the process of modeling and analysis. The aforementioned statement posits that there are multiple opportunities for enhancing government services through the implementation of effective governmental segmentation, improved consumer interaction, and optimized processes (Bahramian et al., 2022). Artificial intelligence, including DL methodologies, represents a viable approach for the assessment and administration of enormous volumes of data (Ezugwu et al., 2022). In recent years, there has been significant progress in the field of DL, surpassing human performance in several tasks such as recognition, detection, translation, and others (Srinivas et al., 2022). The field of DL has produced a wide range of captivating tools across several fields, with a special emphasis on the application of GIS. The convergence of DL with GIS presents significant opportunities (Sikakwe,

2023).

The field of GIS allows individuals to gain a comprehensive understanding of spatial dimensions and their connection to real-world geographical attributes or occurrences (Zhao, 2022). GIS is a robust and intuitive platform that facilitates efficient data storage and retrieval (Chen et al., 2023). GIS has a wide range of applications, such as disaster management and monitoring, demographic research, watershed management, risk evaluation, urban sprawl assessment, food productivity analysis, and irrigation supply and management (Balogun et al., 2022). GIS enables the storage of substantial volumes of data within a database, facilitating its retrieval from any location and at any given time (Kimothi et al., 2023).

The study of multidisciplinary topics, such as those involving environmental processes characterized by ongoing change and interconnections, requires the formulation of innovative methodologies and resolutions (Davronovich & Mansurjonovich, 2023). Numerous comprehensive examinations have been conducted on the application of DL in multidisciplinary approaches, including its utilization in remote sensing as demonstrated by Ferchichi et al. (2022). In their study, Zhang et al. (2016) provide a comprehensive examination and overarching structure of DL techniques applied to remote sensing (RS) data, namely in the domains of image processing, spectral feature classification, pixel-based classification, pan-sharpening, and target recognition. The predominant focus of review papers in the field of RS pertaining to DL pertains to various aspects of image pre-processing. These include pan-sharpening, registration, image fusion, scene classification, segmentation, object recognition, and object-based classification. This observation is supported by the works of Ma et al. (2019), Neupane et al. (2021), and Qin & Liu (2022). In their comprehensive study, Ball et al. (2017) conducted an extensive assessment of the application of DL techniques to RS imagery. The study focused on the integration of DL within the context of RS investigations, highlighting its potential and significance in this field. The paper by Hoque et al. (2021) and the study conducted by Kaur and Singh (2022) provide a comprehensive overview of various domains in which DL techniques have been applied in RS. The authors discuss key areas such as classification, traffic sign recognition, 3D analysis, object identification and tracking, object detection, weather forecasting, depth estimation, and image enhancement. These domains are briefly examined, highlighting the potential of DL in RS. Additionally, the authors acknowledge the existing challenges and identify opportunities for further research and development in this field.

Moreover, Liu et al. (2023) have conducted a comprehensive study of the many applications of DL in the domain of RS. However, the exploration of DL in conjunction with the integration of GIS using RS data has received comparatively less attention. The integration of DL techniques within the RS and GIS communities has become more essential across diverse domains of GIS applications (Han et al., 2023). Consequently, a comprehensive review is necessary to gain a thorough understanding of the integration between DL and GIS. Therefore, the primary focus of this study revolves around a review of the various applications that arise from the integration of DL techniques with GIS. This study offers insights into contemporary framework approaches and proposes avenues for further research. The study is structured into the subsequent sections: methodology, DL neural networks, the incorporation of GIS and DL, applications of the amalgamation of DL with GIS, identified gaps and potential future trends, discussion, and conclusion.

2 Methodology

This paper aims to present a concise overview of the utilization of DL methods in GIS, with a focus on the most current research findings. The present study employed the systematic literature review

methodology as suggested by Tawfik et al. (2019). According to Benita (2021), the systematic literature review framework is considered to be a dependable approach. A preliminary review of the literature was conducted to identify pertinent articles, validate the proposed idea, avoid redundancy with previously covered issues, and ensure the availability of sufficient articles for conducting a comprehensive analysis of the subject matter. Moreover, the focal point of the themes was to investigate the integration of DL and GIS across multiple research disciplines. According to Tawfik et al. (2019), it is crucial to enhance the retrieval of results by acquiring a comprehensive understanding and familiarity with the study topic through the examination of pertinent materials and active engagement in relevant debates. This objective can be achieved by conducting a thorough examination of pertinent literature and actively participating in pertinent academic conversations.

An in-depth review was undertaken on a total of 61 scholarly articles obtained from the Scopus, Web of Science, and Google Scholar databases. The manual search results were initially enhanced and polished through the process of examining the reference lists of the included publications. Subsequently, the investigation also engaged in the practice of citation tracking, a method involving the systematic monitoring of all the scholarly works that reference each of the papers incorporated in the collection. In conjunction with the manual search, an online search of databases was also undertaken as an integral component of the comprehensive search process. The evaluation and categorization of scholarly articles were performed by taking into account their specific domains of application. The publications were classified into the subsequent categories: categorization and mapping, traffic and route planning, hydrological models, disaster management, and urban planning. Following the identification of each subject, a comprehensive review was conducted, primarily on the presented issues. The emphasis was given in order to underscore the importance of deep learning and its prospective advancements in the domain of GIS.

This study exclusively relied on research articles published in peer-reviewed journals, ensuring the reliability and validity of the findings. The publications were thereafter evaluated to ascertain whether their main subject matter bore a resemblance to that of the present inquiry. Priority consideration was given to papers published after the year 1990. The primary justifications for the elimination of papers are their lack of relevance, duplication, incomplete textual content, or limited presence of abstracts. The predetermined exclusion criteria were established to safeguard the researcher against potential biases that could influence their findings. Figure 1 illustrates the progression of review criteria employed for the selection of suitable documents for review analysis. Moreover, Figure 2 presents the systematic review procedure utilized in the current study. After the research topic was chosen, this study proceeded to find and locate relevant articles, do an analysis and synthesis of diverse literature sources, and create written materials for article review. The synthesis phase encompassed the collection of a wide range of publications, which were subsequently amalgamated into conceptual or empirical analyses that were relevant to the finalized research.

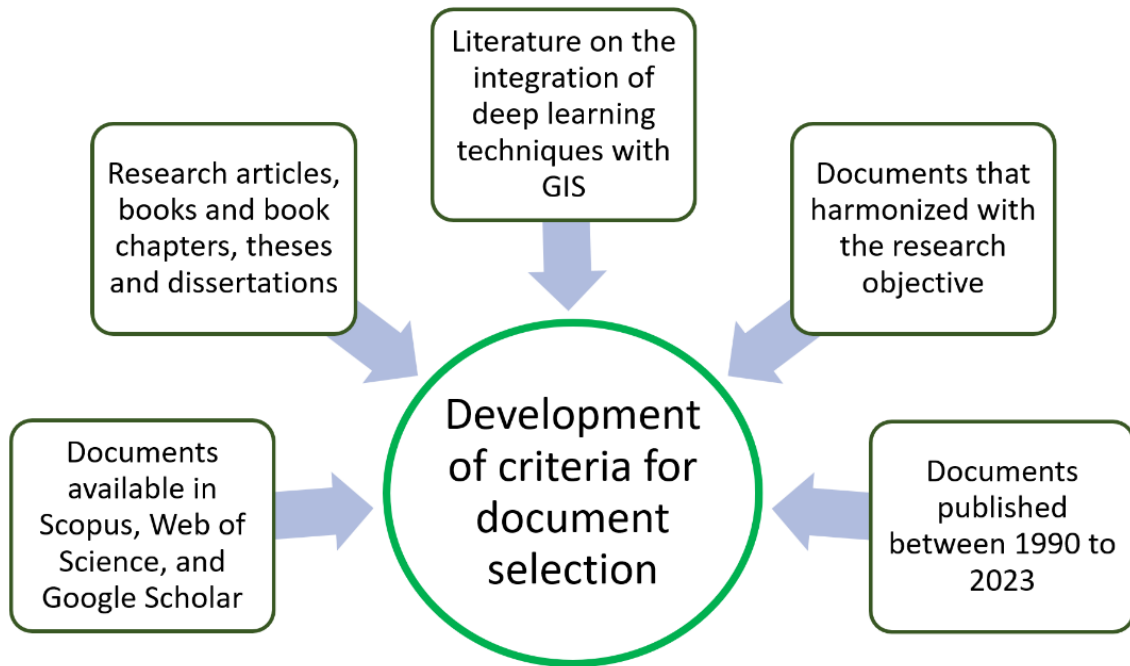


Figure 1. The development of criteria for the selection of documents.

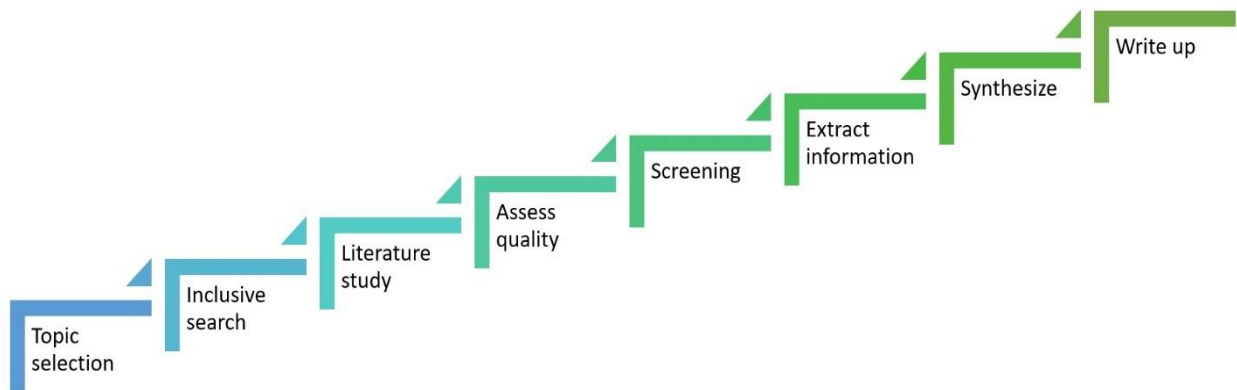


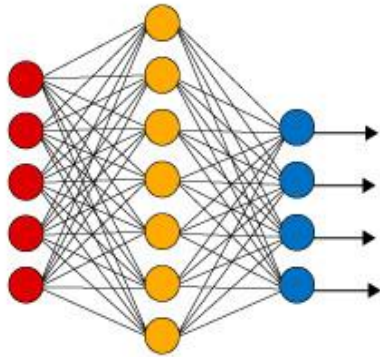
Figure 2. The procedure of systematic review conducted by the study.

3 Deep Learning Neural Networks (DLNN)

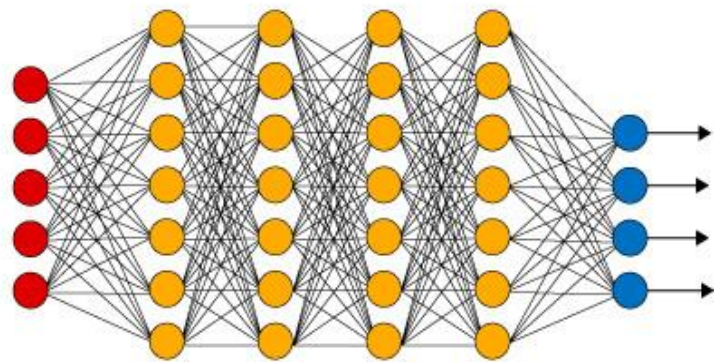
DL is a subfield of machine learning that focuses on the development of algorithms inspired by the structural organization and functioning of the brain, known as artificial neural networks. Neural networks have been utilized for the purpose of classifying remote sensing data since the 1980s (Abdi, 2020). Numerous research have progressively accumulated evidence to support their efficacy, as exemplified by Boulila et al. (2021), Wu et al. (2021), Shirmard et al. (2022), and Giang et al. (2023). DL is a computational approach that addresses problem-solving and prediction tasks by employing artificial neural networks that exhibit similarities to and are inspired by the human brain. A DL structure consists of extensive quantities of data, and advanced computational resources including algorithms, graphics processing units (GPUs), and network architectures. The two steps of neural networks, namely training (or learning) and interpretation (or prediction), can be seen as analogous to the processes of development and production, respectively. Figure 3 illustrates different layers in a

simple neural network and deep learning neural network. The selection of the number of layers and kind of neural network is at the discretion of the developer, whereas the determination of the weights is accomplished through the process of training. There exist various sorts of DL algorithms that are now available, and this discussion will focus on the most commonly utilized ones.

Simple Neural Network



Deep Learning Neural Network



● Input Layer ● Hidden Layer ● Output Layer

Figure 3. Different layers in a simple neural network and deep learning neural network.

3.1 Autoencoders

Autoencoders are a type of neural network architecture that consists of three layers: an input layer, a hidden layer, and an output layer. The autoencoder has the capability to acquire and comprehend various coding patterns. In an autoencoder, the number of nodes in the output layer is equal to the number of nodes in the input layer. The autoencoder is required to recognize its input data rather than relying on the output vector to determine target values (Li et al., 2023).

3.2 Multi-layer perceptrons (MLP)

The MLP is an example of an artificial neural network that operates in a feedforward manner. The MLP is considered to be a fundamental DL model, characterized by a series of completely connected layers. Every subsequent layer in the neural network consists of a set of nonlinear functions that are computed using the weighted sum of the outputs from the preceding layer. These networks are extensively employed in voice recognition and various other applications of machine learning (Shaji et al., 2023).

3.3 Convolutional neural networks (CNN)

CNN can be described as a type of feedforward multilayer perceptron model. The early layers of a deep neural network are responsible for detecting low-level features, whereas the later layers integrate these features to form higher-level representations of the input. CNN has exceptional proficiency in visual identification and the discernment of diverse visual patterns. In addition to their application in image processing, CNNs have demonstrated successful utilization in video identification as well as several tasks within the field of natural language processing (Xiao et al., 2020).

3.4 Recurrent neural networks (RNN)

The convolutional model receives a specified number of inputs and generates a vector of fixed size

following a predetermined number of iterations. Recurrent neural networks facilitate the processing of vector segments in both the input and output domains. In contrast to a conventional neural network, a recurrent network has the capacity to incorporate connections that form loops, either within preceding layers or within the same layer. This feedback facilitates the ability of RNNs to maintain a memory of past inputs and replicate sequences over a duration. The Long Short-term Memory is a well-established type of RNN. This particular network architecture is employed in the development of chatbot applications and text-to-speech systems (Gu et al., 2018).

3.5 Neural networks with deep reinforcement learning

This approach has a distinct methodology. The concept establishes a particular context for an entity, delineating permissible and impermissible behaviors, as well as an overarching objective to be attained. In certain respects, it exhibits similarities to supervised learning, wherein programmers are required to furnish algorithms with clearly specified objectives and delineate positive and negative reinforcement. The learning algorithm adjusts the entity's behavior during the training process. The primary goal of the learning algorithm is to determine the optimal course of action that maximizes the cumulative reward over an extended period of time during the task. The application of deep reinforcement learning has the potential to be employed in various planning and control scenarios.

4 The Integration of DL with GIS

Significant advancements in computer power are swiftly opening up new avenues, particularly in the field of DL, and GIS heavily depends on these computational capabilities. The integration of GIS with DL has demonstrated significant potential as a valuable tool, namely in the domains of 3D modeling, map production, and route calculation (Boguslawski et al., 2022). The integration of remotely sensed data with additional geographical variables inside a GIS framework enhances the analytical capacity of the system (Bilotta et al., 2023). GIS plays a crucial role in several stages of the Artificial Intelligence (AI) workflow. For instance, photographs that are identified by DL techniques can be assigned geographic coordinates through the use of GIS plays. Additionally, an algorithm can be employed within GIS to identify and analyze images. Artificial Neural Networks (ANNs) necessitate a compatible environment for data storage, retrieval, analysis, and visualization. The integration of artificial neural networks (ANN) with GIS has been proposed as a potential solution (Liao et al., 2023).

The incorporation of GIS with DL holds significant potential in diverse domains, including but not limited to the categorization of RS imagery and the analysis of attribute data (Francini et al., 2023). The integration of a GIS database with advanced DL models has the potential to facilitate improved environmental mapping and the identification and retrieval of objects inside an integrated database (Chen, 2022). Neural network classifiers provide the ability to function as broad pattern recognition systems and exhibit flexibility in integrating diverse data kinds, owing to their independence from prior statistical models for input data. Consequently, they can be employed to integrate GIS data into the process of classifying remote-sensing images (Firat et al., 2023). Numerous studies have been previously documented, which have employed GIS data in their research. An illustration of this can be seen in the study conducted by Benediktsson et al. (1990), where they employed topographic data in combination with Landsat Multi-spectral Scanner (MSS) data for the purpose of ground cover mapping. In a separate study conducted by the Joint Research Committee in 1991, the inclusion of landscape height data derived from a digital terrain model (DTM) was utilized as a supplementary input for a multi-layer perceptron neural network. This neural network was trained using two sets of SPOT HRV images captured at different time points. The objective of the project was to classify land

cover in satellite imagery. In this particular instance, the incorporation of DTM data within a GIS framework resulted in a notable enhancement of the overall accuracy of the classification process. Furthermore, this integration also led to a significant reduction in the training time required for the neural network, effectively halving the duration. The utilization of GIS data in neural networks is a very nascent subject, characterized by limited empirical investigation. Nevertheless, the limited availability of data implies that this approach may prove to be a lucrative course of action (Huang et al., 2022).

5 Applications of DL Integration with GIS

RS is a valuable tool that offers a constant and reliable flow of data pertaining to the Earth's characteristics. In conjunction with RS, GIS serves as a systematic approach for managing and analyzing this vast amount of geographic data (Bilotta et al., 20234). The integration of RS and GIS has proven to be valuable in facilitating decision-making processes across various domains. This includes but is not limited to sustainable natural resource management, the construction of protected areas within networks, and addressing challenges related to global change (Tom, 2023; Raihan & Tuspekova, 2022; Raihan et al., 2022). GIS possesses the capability to gather and analyze data in real time. The aforementioned advancement facilitated the development of research and mapping systems. However, it is noteworthy that real-time geospatial data can also be of significant benefit to consumers. According to Goel et al. (2023), the utilization of real-time geospatial intelligence has the potential to monitor and assess the advancement of natural disasters. The examination of several subjects, ranging from climatic variability to social media posts, provides recommendations that require urgent intervention.

GIS enables the manipulation and analysis of both raster and vector data, facilitating their seamless transformation and utilization. It is feasible to integrate satellite, airborne, and terrestrial RS systems utilizing current technology and operational systems, resulting in the production of a set of observations that vary in scale (Hirschmugl et al., 2023). According to Leggieri et al. (2022), the process of generating picture statistics within polygons and afterward integrating this information as polygon attributes into the GIS database appears to be a straightforward task. Rezvani et al. (2023) conducted an investigation into the potential utilization of RS and GIS for the purpose of visualizing and improving the representation of statistical data. Additionally, they aim to find and provide various prospects to the research community focused on GIS. GIS has undergone significant advancements and is now considered an indispensable tool for the processing, analysis, and visualization of geographical data. The significance of geographic data and GIS in environmental disciplines is well recognized, to the extent that they are now regarded as indispensable elements in research, teaching, and policy (Jaafar et al., 2020; Azam & Rahman, 2022). A wide array of software applications is accessible to facilitate decision-making in the field of GIS. GIS software is designed to cater to particular types of decision-making processes. Consequently, the program is made accessible in accordance with the user's requirements. These software systems exhibit efficient responsiveness to individual inputs and may be applicable to multiple broad-domain applications; nevertheless, they also include inherent limitations. The performance or failure of geoprocessing tools may be adversely affected by the presence of extensive and intricate data sets containing several features. Consequently, the execution of a complex GIS model may be impracticable, leading to the occurrence of output inaccuracies (Meraj et al., 2022). DL approaches are utilized in this context due to their ability to execute algorithms on intricate datasets with great precision, resulting in accurate outcomes.

5.1 Classification/mapping

The categorization of RS photographs is a widely practiced application. Image classification is a technique used to assign labels or categories to individual pixels inside an image. The spectral and spatial resolutions of the images vary depending on the detectable and categorizable aspects within them. GIS has been employed for a significant duration to carry out picture classification tasks. Additionally, DL techniques have also been utilized for the purpose of image classification. ANNs serve as a valuable tool for emulating the intuitive reasoning process of the human brain. They are capable of effectively mapping complex systems even in the absence of prior knowledge or expertise. The integration of ANN with GIS has facilitated the management and analysis of geographic information. In their seminal work, Yang and Rosenbaum (2001) successfully established a linkage between ANN and GIS through the utilization of the Nonlinear Regression and Spatial Extrapolation (NRSE) algorithm. This integration yielded a powerful tool capable of offering decision support in addressing various technical obstacles and facilitating effective harbor management. The application of sediment prediction within Gothenburg port has been employed as a means to exemplify its practicality. Due to the inherent complexity of natural systems, the task of constructing a deterministic model is sometimes arduous. However, it remains imperative to provide quantitative representation. The merging of DL with GIS has also been utilized in the field of agriculture.

Mansourian et al. (2017) employed GIS-based Logistic Regression (LR) models to generate zonation maps for the Kurdistan province in Iran. The purpose of these maps was to predict the prevalence of dominant weed species in dryland chickpea and winter wheat fields. ANNs have the potential to generate very accurate models for forecasting the occurrence of many common weed species, as indicated by their high mean squared error (MSE) values. In their study, Xiong et al. (2018) employed big data analytics and deep learning techniques to conduct a comprehensive mapping of mineral prospectivity. The findings indicate that the prospectivity regions that were mapped exhibit a notable spatial correlation with established mineralization locations. These findings suggest that the utilization of big data analytics, coupled with deep learning approaches, holds considerable potential for the investigation and implementation of mineral prospectivity mapping. Demertzis et al. (2020) proposed a revolutionary geographic object-based scene classification system for remote sensing photos. The system utilizes a Residual Neural Network (ResNet) architecture, which has been found to be very effective in achieving successful classification outcomes. The network in question also employs a method for analyzing Large-Scale Geospatial Data that utilizes ResNet to handle issues related to latency, throughput, and fault tolerance. It achieves this while simultaneously maximizing the effectiveness and efficiency of learning processes.

Zhao et al. (2020) utilized GIS and DL techniques to generate land use characteristics for the Bay Area. The study involved the extraction of four indices related to land use characteristics from a GIS. These indices were then combined with planning information using a Deep Neural Network (DNN) technique. The dataset consisted of 122 zones. According to the analysis of error distribution in the study, the findings indicate that the suggested technique exhibits a high level of accuracy and shows promise and resilience. The level of inaccuracy is relatively little. In their study, Wu and Biljecki (2021) conduct a comprehensive investigation of the implementation of sustainable roofing practices within urban areas. The motivation for this study was derived from a similar project called Treepedia, which focuses on urban green spaces. This study proposes an automated system that integrates DL techniques with GIS technology to identify sustainable rooftops within urban areas. The initiative achieved a 100% accuracy rate in identifying sustainable roofs. The precision of the models enables realistic evaluations of sustainable rooftop devices in terms of their spatial distribution and quantitative impact at a city-wide scale. Multiple studies that integrate DL and GIS suggest that the development of accurate and efficient scene classification methods can greatly enhance the development of novel

decision support systems (Demertzis et al., 2020).

5.2 Traffic and route planning

The significance of transport infrastructure in the context of national development cannot be overstated, as it fulfills a fundamental necessity in human life and exerts influence on various aspects of human existence (Mattioli et al., 2020). The act of transitioning between different locations within a metropolitan area presents a formidable challenge, irrespective of an individual's financial resources or social status. The circumstances surrounding commuting have become progressively more demanding. The utilization of GIS in the context of road and highway safety facilitates the systematic gathering and examination of accurate and dependable data pertaining to vehicular accidents. The utilization of historical information facilitates comprehension of prior incidents' locations and enables the identification of preventive measures to mitigate their recurrence in the future.

Campbell et al. (2019) employed DL and GIS techniques to detect and map traffic signs in Google Street View photographs. The objective of their research was to develop an autonomous system capable of identifying traffic signs, thereby facilitating the monitoring and maintenance of traffic assets. The experiments carried out on the road network within the study area resulted in a detection accuracy of 95.63% and a classification accuracy of 97.82%. The proposed automated method for detecting and localizing street sign technology has demonstrated significant promise for implementation by local government agencies. In their study, Mubin et al. (2019) successfully identified oil palms using a combination of GIS and DL techniques. The objective of this project is to address the existing disparity by employing two separate CNNs to autonomously identify juvenile and adult oil palm, in conjunction with GIS throughout the data processing and analysis. In their study, Li et al. (2019) introduced a U-net-based approach for the purpose of extracting building footprints through semantic segmentation. The integration of high-resolution satellite imagery was performed by using multiple public sources containing GIS maps of the four cities. The building footprint was derived from multi-spectral resolution pictures using the SpaceNet dataset. The technique that has been proposed demonstrates a total F1-score of 0.704, indicating a 1.1% enhancement compared to the initial value of 12.5%.

Kearney et al. (2020) employed the use of RapidEye imagery, participatory GIS, and DL techniques to extract and subsequently update information pertaining to unpaved roads. The present study devised and evaluated a methodology for the automated extraction of unpaved road pixels throughout a large, wooded area in Western Canada, employing a convolutional neural network. The results obtained by CNN were subsequently employed to modify an established governmental road network, with the aim of assessing the potential impact and modifications that would ensue. Enterprises that are presently operational and operating inside the region have obtained images and a ground-truth dataset utilizing smartphones. The utilization of participatory methodologies for the collection of primary data yielded several benefits in the acquisition of training and validation data over a large geographic area, while maintaining a cost-effective approach. The road extraction performance demonstrated parity with previous studies utilizing exceptionally high-resolution imagery, with recall accuracy rates ranging from 89% to 97% and precision rates ranging from 85% to 91%. In their study, Servizi et al. (2020) employed geographical context and artificial neural networks as a means to identify stops inside smartphone-based trip surveys. In order to mitigate these uncertainties, the researchers integrated geographical time-series data, specifically GPS data, with spatial context information obtained from Open Street Map. This integration resulted in the creation of multi-dimensional tensors. The key contribution lies in the incorporation of geographical context into a multidimensional representation of time-series fusion, alongside the utilization of a specific ANN classifier. The findings demonstrate a notable enhancement of 3 to 6.5% in stop detection scores compared to the baseline measurements.

The acquisition and maintenance of precise and current road network data holds significant importance in the realms of land management and disaster response. Generating unpaved roads, particularly in rural communities and wooded regions, poses challenges when relying on conventional procedures (Kearney et al., 2020). In their study, Malaainine et al. (2021) developed a deep learning model that incorporates GIS-based vehicle tracking methods. CNN analyzed high-resolution satellite data to construct the spatio-temporal trails of moving vehicles in the GIS. In their study, Bi et al. (2021) developed a methodology for sustainable urban road management through the integration of GIS and neural network techniques. The integrated model is responsible for determining the optimal routes, travel times, and recommended courses of action for individuals navigating across an urban network. In contrast to empirical trip data, the bi-level optimization approach exhibits the potential to reduce the mean travel duration by around 20% and energy consumption by 10%.

5.3 Hydrological models

The spatial patterns of geographical distributions on the Earth's surface exhibit a high degree of intricacy and complexity. To represent these distributions as a replica, it is necessary to consider many variables and time-dependent data. The spatial depiction of these distributions has significant importance, and the utilization of GIS and DL techniques can effectively evaluate and forecast this intricate issue with a notable level of precision. In their study, Yang and Rosenbaum (2003) presented a concise summary of deep learning neural networks, focusing specifically on the GIS overlay mechanism. The proposed methodology employs ANN in conjunction with GIS for the purpose of mapping. In this work, the researchers employed a methodology to predict silt levels in the harbor of Gothenburg. In a study conducted by Dixon (2005), a groundwater vulnerability model was formulated utilizing the neuro-fuzzy approach in conjunction with GIS. The primary objective of this study is to examine the responsiveness of neuro-fuzzy models employed for the prediction of groundwater vulnerability within a geographical framework. The utilization of neuro-fuzzy models should be limited to a comprehensive assessment of groundwater vulnerability, which incorporates several methodologies such as GIS, remote sensing, solute transport modeling, as well as functional, mechanistic, and stochastic models.

The nitrate load in groundwater was predicted by Almasri and Kaluarachchi (2005) using modular neural networks (MNN). The field data pertaining to nitrogen loading and recharge, as well as the preparation of said data using GIS tools, were conducted. Subsequently, a forecasting model was developed using the MNN approach. The approach employed in the preparation and processing of the MNN input-output data heavily relies on the utilization of GIS tools. The long-term models employed by MNN accurately identified the areas characterized by comparatively elevated nitrate concentrations, hence facilitating the assessment of the effectiveness of prospective management strategies. In their study, Rohmat et al. (2019) introduced a decision support system known as River GeoDSS. This model encompasses several components such as database administration and graphical user interfaces. The software is seamlessly included within a GIS to facilitate geospatial modeling and analysis. Subsequently, the ANN that underwent training was reintegrated into River GeoDSS, enabling the simulation of river basin management. The revised version of River GeoDSS facilitates the complete construction of all DNN models. In their study, Apaydin and Sattari (2020) employed a combination of GIS and DL techniques to develop a precipitation modeling framework that takes into account spatiotemporal variables. The use of the hybrid model was employed to derive precipitation data along the coastline of Turkey. The research employed DL techniques to predict the quantity of precipitation, and subsequently generated a distribution map by integrating DL with GIS.

Patault et al. (2021) utilized a deep neural network and a GIS model to forecast sediment discharge across different land scenarios. The model yielded a standard deviation that precisely aligned with the

Generalized Extreme Value (GEV) distribution. The model additionally functions as a decision-making instrument for drinking water providers and land use planners. The development of urban flood modeling employing deep-learning techniques was conducted by Lei et al. (2021). The generation of flood hazard mapping was accomplished by the utilization of a deep convolution neural network model in conjunction with a GIS. The GIS database was utilized to obtain a flood inventory consisting of 295 flooded sites. The flood inventory served as the response variable, while the predictor variables consisted of flood-impacting elements in DL. Hydrological models, such as those used for flood modeling, can exhibit enhanced efficiency and dependability when a substantial inventory is accessible.

5.4 Disaster management

Various regions of the world, including India, are susceptible to the occurrence of both natural and man-made disasters. GIS, RS, and DL have proven to be valuable tools in the context of disaster management and decision-making scenarios. One such application involves the creation of disaster maps, which serve to visually represent areas of danger and potential effects. GIS and DL have proven to be advantageous tools for mapping, taking into account many factors that impact natural disasters. This can contribute to an enhanced comprehension of site vulnerability and facilitate more effective risk assessment and planning processes. The validity of the technique is demonstrated by Stassopoulou et al. (1996) through the determination of parameters for a Bayesian network. This network incorporates GIS data to assess the probability of desertification in burnt forest regions within the Mediterranean region. In their study, Choi et al. (2012) integrated ANN with GIS in order to develop landslide susceptibility maps. The Digital Elevation Model (DEM), Normalized Difference Vegetation Index (NDVI), and land cover classifications were obtained by processing ASTER imagery inside a GIS environment. The relationships between the identified landslide locations and six associated variables were analyzed and quantified using frequency ratio (FR), LR, and ANN models, utilizing the geographical database that was established. The integration of GIS with ANN yielded maps that exhibited greater accuracy compared to the standalone landslide maps.

Hamdi et al. (2019) utilized GIS and DL techniques to assess forest degradation using high-resolution data. The research employed CNN within GIS software, using an algorithm designed to identify and delineate instances of forest degradation. The findings exhibited a level of precision amounting to 92%. The significance of these findings is underscored by the challenges associated with identifying areas where trees have fallen. The study showcased the rapid effectiveness of GIS and the significant capabilities of DL in analyzing high-resolution maps for the purpose of assessing damage after a disaster. In their study, Bui et al. (2020) employed a DLNN in conjunction with a GIS dataset to predict the susceptibility to flash floods. The data from the flash flood inventory is utilized to compute the flash flood susceptibility at the pixel level for the designated study area using DLNN. Consequently, the proposed integration of GIS and DLNN could potentially serve as a feasible option for supporting governmental entities and stakeholders in the implementation of effective strategies for flash flood mitigation and land-use planning. In their study, Radke et al. (2019) developed the FireCast program by integrating DL and GIS methodologies. According to the FireCast, it is anticipated that the wildfire would propagate across the region. FireCast has the capability to effectively predict the potential spread of wildfires in neighboring regions by utilizing historical fire data and limited computational resources. The algorithms developed by Nhu et al. (2020) were designed to forecast the probability of landslides occurring in a tropical setting. A deep neural network was employed to generate variables and polygons representing the factors and areas affected by landslides in the context of GIS. This approach facilitated the mapping of all possible locations susceptible to landslides. The algorithm partitions the given area into two discrete categories, namely landslide and non-landslide.

Wu et al. (2020) conducted an assessment of the extent of urban floods by employing DL techniques in conjunction with GIS. The flood condition map in GIS was generated by employing the rainfall return period, while the prediction of flood depth was accomplished by the utilization of a regression model in DL. The results of this study provide strong support for the use of urban flood management and drainage strategies. The `r.landslope` tool was developed by Bragagnolo et al. (2020) with the purpose of mapping the susceptibility of landslides. The application utilizes open-source GIS tools in conjunction with ANN. Python is employed as an integrated software tool in conjunction with ANN to process environmental variables and landslide databases. RS technology, namely the use of `r.landslope`, has the capability to accurately identify and delineate areas that are susceptible to landslides. The significance of disaster risk mitigation is escalating due to the increasing frequency and severity of natural disasters. GIS and DL have been shown to be highly valuable tools in the implementation of mitigation and preparedness strategies. The utilization of real-time spatial data can enhance the efficiency of reaction resource allocation. Furthermore, it functions as a valuable tool for decision-making in the field of catastrophe management. There is a need for global governments and enterprises to engage in collaborative efforts aimed at the development of innovative tools and methodologies for the purpose of establishing a robust disaster management plan. This strategy should incorporate the integration of DL and GIS approaches.

5.5 Urban planning

Urban planning involves the strategic design and formulation of comprehensive plans for cities, encompassing both their existing structure and the anticipation of future growth and development. GIS and DL have the potential to provide crucial information and improve strategic decision-making by offering a unified platform for accessing both current and historical data and maps. In their study, Ma and Cheng (2016) conducted an analysis of building energy use by integrating GIS with big data. This research paper introduces a theoretical model for determining the Energy Use Intensity (EUI) of buildings at the metropolitan level. The model utilizes a combination of GIS and data mining techniques, incorporating several stages such as data pre-processing, feature selection, and algorithm optimization. In their study, Li et al. (2019) devised a GIS and DL model for the purpose of estimating the valuation of urban land. The determination of urban land prices involves the examination of several factors that influence these prices, as well as the incorporation of spatial characteristics, which are then integrated using a DL approach. The detection of the linear relationship and causal link between influencing elements and land price is achieved by the creation of a deep hybrid neural network that incorporates geographical properties.

Cecconi et al. (2019) employed GIS and ANN as tools to evaluate the potential for energy retrofits in educational facilities. The assessment of energy efficiency potential was conducted through the utilization of eight ANNs. Ultimately, the data was geolocated and thereafter subjected to further analysis in order to facilitate the formulation of energy retrofit programs for the most crucial regional areas. The findings of the case study indicate that energy retrofit solutions for school buildings are predominantly implemented and advanced through the utilization of open data, neural networks, and GIS. In their study, Kucklick et al. (2021) employed a combination of GIS and CNN to assess the impact of location data on property valuation within the context of Philadelphia. The research findings revealed that the inclusion of substantial geographical data and the utilization of high-quality photos were imperative in enhancing the correctness of the model. The utilization of many datatypes presents a complex and intriguing task, although it offers enhanced robustness in mitigating significant irregularities. In their study, Zhang et al. (2021) employ DL techniques and extensive street-view datasets to detect and visually represent diverse urban environments. The utilization of landsense indicators facilitated the quantification of the correlation between public perception and urban landscapes. The results of the model indicate a favorable performance in natural landscapes within the

urbanized regions of Beijing, while revealing a detrimental psychological influence on industrial areas. This novel methodology possesses the capacity to contribute to urban planning and administration through the lens of inhabitants.

Pepe et al. (2021) utilized deep learning techniques inside a GIS framework to generate a three-dimensional representation of an urban area by processing multispectral satellite imagery. Various methodologies in geomatics software were employed to derive building heights from DEMs for building polygons situated at different locations. A procedure was developed that involved the utilization of an algorithm within ArcGIS Pro for the purpose of pan-sharpening. This was followed by the creation of a digital surface model, and ultimately, the extraction of building height. The model rapidly produced three-dimensional structures in the form of prismatic solids featuring level rooftops. This distinctive approach is an additional method that supports stakeholders and administrations in the field of urban planning and design. GIS and DL offer urban planners enhanced data visibility. The tracking of changes over time, evaluation of the feasibility of new initiatives, and projection of their potential environmental impact are key activities performed.

6 Discussion

DL is a rapidly advancing field that empowers data scientists to leverage state-of-the-art research while harnessing the capabilities of a robust GIS. Due to its attractive attribute, neural networks are progressively employed for the representation of intricate physical phenomena, with a prevailing scarcity of exact field data (Almasri & Kaluarachchi, 2005). GIS technologies have the potential to support several stages of the data science workflow. These stages encompass data preparation and exploratory data analysis, model training, spatial analysis execution, and the dissemination of results through online layers and maps, as well as facilitating field operations. In contrast, deep learning algorithms have the potential to effectively tackle problems involving intricate data structures and modeling, resulting in elevated levels of accuracy, enhanced adaptability, and improved generalization capabilities. GIS offers a robust framework for conducting geographical data analysis, and ANNs can serve as a potent tool for facilitating decision-making processes. The integration of the ArcGIS Platform offers a streamlined workflow due to the ability to retrieve discoveries through mobile devices in the field, facilitating high-accuracy ground-truthing and diverse mapping that can be synchronized with the database (Hamdi, 2019). Consequently, one can deduce that the proposed integration of GIS and DL holds promise as a valuable instrument in aiding governmental entities and involving relevant parties in the realms of flash flood protection and land-use planning (Bui et al., 2020).

DL methods have the capability to develop classifications or predictions pertaining to a certain target by utilizing a set of input qualities. GIS can provide the requisite geographical input variables for such a DL model (Radke et al., 2019). Nevertheless, there exist limitations when these actions are executed in isolation. The avoidance of this issue can potentially be achieved by the integration of GIS with DL techniques. The utilization of big data technology enables the integration of several predictors and variables, a capability that is not attainable through the use of GIS. In order to do such modeling, DL necessitates a substantial geographical database, which can be acquired through the utilization of a GIS database. DL and GIS have the capability to effectively tackle challenging tasks involving intricate and ever-changing datasets. Geographical characteristics often exhibit dynamic behavior, which requires the utilization of sophisticated modeling techniques. These techniques may involve the application of neural networks and the integration of spatial data derived from the GIS database. The incorporation of this approach will contribute to the improvement of the precision of the modeling. Additional research on analogous matters is necessary.

RS and GIS have been utilized to investigate a wide range of topics related to environmental degradation indicators, environmental monitoring, climate change, hydrological models (including groundwater and surface water modeling), assessment of soil erosion, urban sprawl analysis, soil moisture, water distribution network analysis, coral reefs, site suitability, disaster risk analysis, and sustainability. Nevertheless, it is important to note that the accuracy of the findings could be compromised due to the utilization of a high-resolution database and intensive modeling techniques. The integration of GIS with deep neural networks presents an opportunity for future investigation and the potential to attain outcomes of high accuracy. The future utilization of DL in conjunction with GIS encompasses the mapping of susceptibility to diverse natural hazards, as well as the exploration of advanced techniques for feature selection or dimension reduction. These endeavors aim to enhance the predictive capabilities of DL methodologies. In future research, it is conceivable that scholars would integrate historical data from diverse geographical areas and do investigations utilizing a range of image resolutions, input variables, and scenario analyses. The integration of DL with GIS facilitates the advancement of an enhanced decision-making tool. The approach can serve as a valuable tool to assist companies engaged in disaster management, water resources, environmental studies, and land use planning in swiftly and effectively generating diverse maps (Bragagnolo et al., 2020).

7 Conclusion

This study examined various research domains in which DL and GIS have been combined. A comprehensive review was conducted on peer-reviewed papers retrieved from the Scopus, Web of Science, and Google Scholar databases. The publications were categorized into the following groups: categorization and mapping, traffic and route planning, hydrological models, disaster management, and urban planning. The concise evaluation of these scholarly articles highlights the importance of integrating DL and GIS in the analysis of diverse and dynamic datasets. The primary emphasis of the study revolved around five significant applications. A thorough and extensive evaluation of the methodology employed in the deep learning algorithm, together with its performance analysis, can be conducted. Additional research can be conducted to explore the application of DL and GIS in real-time geospatial intelligence for the analysis of natural disasters, climate variability, and ongoing rescue operations.

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