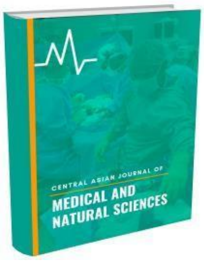

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Article

Innovative Methods in Remote Sensing for Health Impact Assessment of Environmental Pollution

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Abstract: This study explores innovative remote sensing approaches to assess the impact of environmental pollution on public health. The methodology relies on integrating sensor technologies with data analysis models to determine the relationship between pollution levels and various health outcomes. By analyzing diverse environmental and health data, new analytical tools were developed that enhance the accuracy of health assessments in multiple regions. The results highlight the importance of these approaches in providing reliable information to support environmental decision-making and policies, contributing to enhancing public health and raising awareness of pollution risks. The study suggests the potential application of these techniques in future research, providing opportunities to improve understanding of the impact of the environment on health. These innovations are an important step towards better assessment of pollution risks and enhancing strategies to mitigate its negative impacts on communities.

Keywords: Environmental Pollution, Health Assessment, Data Analysis, Public Health Impacts, Environmental Policies

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1. Introduction

Remote sensing is a powerful technique for gathering information about the earth's surface and its atmosphere. It involves the acquisition of data from a distance using satellite or airborne sensors. The collection of remotely sensed data has become easier with the advent of geo-information technology, a combination of remote sensing, geographic information systems, and global positioning systems. This paper presents new ways of using remote sensing and spatial analysis technology to check or monitor the health hazards associated with environmental pollution. More specifically, the emphasis is on the investigation of water pollution, its health impacts, and the application of remote sensing and GIS for health risk assessment studies. Remote sensing imagery is used to assess the water pollution status. Considerable efforts are made to explain the development of new health databases for health impact analysis through geocoding and systematic coding methodology. A novel module is developed for the spatial analysis of health impact assessment studies. This new module can be used to find the health impacts through the geoprocessing of relevant environmental and health databases. It is expected that the research results can be of immense use to health planners, decision-makers, and researchers to assess the health hazards associated with various environmental pollutants. Thus, this work would give a practical direction to the sustainable management of natural resources, especially water resources, and in developing healthy environments in ecologically vulnerable areas. It is anticipated that with the immense acceptance of remote sensing and GIS in environmental planning and management, this research methodology could also be adopted for impact analysis studies in relation to other environmental pollutants, chemical industries, urbanization, and so forth, which would assist in developing strategic planning for the mitigation of environmental hazards (Chen et al.,2022; Yang et al., 2022).

Fundamentals of Remote Sensing

Remote sensing (RS) is a technique of data acquisition and evaluation free of contact, utilizing recording devices that capture the reflected or emitted radiation from objects across channels of the electromagnetic spectrum. Perceived as a technological marvel and heavily dependent on airborne and spaceborne systems, RS is also firmly rooted in the very human experience of seeing and observing, an extraordinary ability to understand complex phenomena across time and space through the spontaneous dissemination of ideas and notions. Being a multi-faceted and intricate process, RS typologies are numerous, primarily collating definitions based on the employed system, applied instrument, informative channel, environmental context, and the stakeholders involved in the process. Essentially, RS refers to a system that collects data about environmental phenomena, constraining the number of multi-spectral images needed for deciphering myriad processes across the Earth. Satellite imagery consists of a myriad of pixels arranged in columns and rows representing a square of the Earth's surface containing a variety of phenomena (Mather & Koch., 2022; Elachi & Van Zyl., 2021; Chuvieco., 2020).

Hence, at least two discrete and independent processes must occur in obtaining images across the electromagnetic spectrum: the perceived phenomenon must radiate energy or reflect energy imparted by the sun, and such energy must be captured by the RS system. An image is produced when the signal falls onto electronic detectors sensitive to specific wavelengths of the electromagnetic spectrum. Thus, RS images are encoded digital matrices recorded on the Earth's surface, which enclose unique radiative energy falling onto pixel areas. The latter creates the basis for the interpretation and quantitative analysis of the RS feature's radiative energy, allowing the exploration of a myriad of phenomena of variable objects, such as their surroundings, spatial distribution, and temporal development (Sabins Jr & Ellis., 2020; Domínguez et al., 2021).

While radiative energy from the Earth's surface is sensed in a completely passive way, it must be noted that without a mechanism converting the transmission of data into the reception of a readable signal at the RS system, the RS method would also be incapable of providing useful information about ubiquitous phenomena on the Earth's surface. Such aids could be either spaceborne or airborne. Spaceborne RS systems are generally satellite systems, and airborne systems are usually small vessels and tethered balloons or hot-air balloons (Bu et al., 2024; Yu et al.,2022).

2. Materials and Methods

Remote sensing is the acquisition of observed information from an object or a phenomenon in the environment, without any direct contact with the object. There are three steps for capturing a remote sensing image:

- Data acquisition from the remote sensing platform.

- Preprocessing of the acquired data. - Interpretation of the data for extracting useful information. (Xu et al., 2021; Haut et al., 2021).

Data Acquisition

Data can be acquired from the ground, aerial, or satellite platforms. Initially, the data is captured from ground-based platforms. The technology is gradually improved towards aerial photogrammetry. The first Earth resources satellite was launched, which motivated many developing countries to initiate their first space programs. The Global

Positioning System (GPS) constellation is very well established with global coverage. The GPS technique is used in many applications such as logistics, disaster management, and smart cars. GPS systems are installed in vehicles for smooth navigation. The presently available satellites with remote sensing sensors are in four configuration orbits:

- Higher Synoptic orbit (5,000 km)
- Geostationary (36,000 km) - Medium (1,000 - 10,000 km) - LEO (Low Earth Orbit, 600 - 1,000 km)

The highest remote sensing satellites are at 36,000 km, like Geostationary satellites, which apparently remain stationary over the Earth. For security purposes, many countries launched remote sensing satellites from lower configurations like 5,000 km, with high-resolution cameras. (Ejemeyovwi et al., 2023; Fu et al., 2020).

Electromagnetic Spectrum

In contrast to seismic and acoustic waves, electromagnetic waves can travel in a vacuum at the speed of light. Thus, these waves can travel from source to sensor, which can be separated by large distances. The electromagnetic spectrum ranges from very short radio waves to very long radio waves, respectively. Visible light is responsible for the conspicuous colors of flower petals, birds, and fish, which tend to aggregate in greater hues for beauty. For color photography, view cameras are used that simulate the visible colors that the human eye can see. These considerations cover the visible optical wavelength band of 0.4 to 0.7 μm. However, there are other colors or bands like Ultraviolet (UV), Near Infrared (NIR), Thermal Infrared (TIR), etc., which are outside the visible light portion of the spectrum. For remote sensing applications, various sensors are used that simulate the above wavelength bands such as UV, NIR, and TIR. These sensors operate outside the perception of human vision. Thus, remote sensing images are in “false colors” or colored pictures that cannot be distinguished by the eye. Although pilots particularly use blue or green tinted glasses or optical filters to make the haze vanish in clear air photography. Similarly, airborne inconspicuous NIR camera sensors can show the spectral difference between healthy and dry leaves in a field. Thus, it should be understood that each band of the electromagnetic spectrum must be studied in conjunction with the applications involved. There are certain atmospheric windows that are transparent to radiations of certain wavelengths. An understanding of the atmospheric transmission corrected gauge conversion error in remote sensing would help in appreciating the capabilities, limitations, and advantages/disadvantages of each kind of remote sensing detection system and the required corrections and aggregation estimates that must be made of gauge point data (Elachi & Van Zyl., 2021; Liu et al.,2020).

3. Results

With a rapid industrialization and urbanization process around the world, environmental pollution has emerged as a major global concern, especially for developing countries. Air and water pollution have adverse implications for human health, including respiratory disease, developmental impact on the fetus in pregnant women, and cancer. The most detrimental group of pollutants is particulate matter, especially fine particulate matter. Most of the particulate matter is solid or liquid materials generally smaller than 10 μm or 2.5 μm in aerodynamic diameter and can penetrate deep into the human airways. Sources of particulate matter can be natural, such as sea salt and dust storms, or anthropogenic, such as waste incineration, biomass burning, industrial emissions, and cooking. The exposure to pollutants like particulate matter is often assessed in epidemiological studies with the integration of long-term remotely sensed data and simulation data for local particulate matter. However, such an approach has limitations, including temporal and spatial mismatch between data, which might incur false associations. There is also a lack of knowledge regarding health impacts from hazardous metals in particulate matter, which hinders the effective implementation of public health responses. Remote sensing of health burden from environmental pollution has been an innovative idea around the world. A systematic and comprehensive review of recent advances during the last decade has provided guidelines for future compliance analyses. Current existing studies mainly focus on estimating relative risk or cohort size in epidemiological studies, while less effort will be devoted to concrete policy designs. Given this, novel methods based on the state-space statistical framework are proposed to derive more concrete health impact estimates with compliance scenarios in a spatial setting. Global or multi-region compliance with certain pollution standards can be defined, predicting concurrent health impacts in adherence to comprehensive policies. With a reduction in pollution exposure, such innovations in model design, data hierarchy, and spatio-temporal predictive settings might quantify pollution health impacts more comprehensively in the compliance analysis context (Khan et al., 2022; Morin-Crini et al., 2022; Ukaogo et al., 2020).

Types of Environmental Pollutants

As human activities have broadened, environmental pollution resulting from toxic materials has drawn even greater concern. The main groups of environmental pollutants considered here are gas pollutants, land pollutants, noise pollutants, and the most pernicious and invasive agents – water pollutants. All these pollutants have various health impacts, apart from their harmful effects on the environment. The health impacts have been interpreted in terms of health parameters that include chronic health impacts, hospital admission due to asthma, and other diseases, respiratory and cardiac diseases, death, general health, skin cancer, and leukemia. All kinds of pollutants under deliberation have their own modes of transmission and uptake through one or more routes, which include the food chain, inhalation through respiratory organs, dermal contact, and direct or indirect usage of contaminated water and land (Xu et al., 2022).

Air pollution is an issue in all communities around the globe, but especially in the developing world where rapid urbanization, population growth, and industrialization focused in one region threaten the safety of human populations. As such, environmental impact assessments have become an important tool in aiding decision-making to improve the sustainability of developments and ensure the safety of human populations (Khan et al., 2022).

Air pollution can take many forms, both visually observable like smoke and soot, and those imperceptible to human vision like a complex cocktail of chemicals, vapors, and gases such as oxides of sulfur, nitrogen, lead, hydrocarbons, and many others. These may have different effects on both ecology and health depending on their concentration, persistence, and reactivity. A number of common diseases and health hazards have been associated with air pollution or other environmental pollutants, including lung cancer, asthma, coronary heart disease, birth defects, or low birth weight babies, and many more (Intisar et al.,2022).

Water pollution from waste discharge into rivers and lakes, leaking underground storage tanks, and past industrial practices laden with toxic chemicals that washed into nearby rivers or lakes have led to the contamination of land, drinking water aquifers, and crops. Contact with contaminated water can lead to a number of adverse health impacts often associated with E. coli and other bacteriological pathogens, heavy metals, chronic diseases like cancer, typhoid fever, intoxication, and a number of other diseases (Siddiqua et al., 2022; Bhatt et al., 2022).

Traditional Methods of Health Impact Assessment

Health impact assessment is a widely used decision support tool with a rapidly growing tradition in the public sector as a means of evidence-informed health policy. Although an initial scoping study of health impact assessment in Scotland concluded that the approach was not being implemented, by 2008 there were several HIA case studies reported as having been undertaken in Scottish local authorities, health boards, and the public sector more broadly. Health impact assessment is the assessment of the potential effects of a plan, project, programme, or policy on the health of a population, and the distribution of those effects within the population. Conducting an HIA provides an opportunity to promote health and reduce inequalities by informing decision-makers, developing new partnerships within and beyond the health sector, and enhancing stakeholders' capacity to assess the health impacts of their actions **(Vasey et al., 2022).**

A variety of methods have been developed and applied for health impact assessment. The methods range from relatively simple tools for prospective assessment of health impacts on policies to more sophisticated modeling of health effects using large datasets. Health effects dealt with include physical, social, well-being, and economic health effects, as well as valuation of health effects. HIA tools are also used within environmental impact assessments and social impact assessments. Nevertheless, HIA tools were not in widespread use to assess health impacts of projects. Recently, other tools have emerged. Development of tools to assess health impacts of climate change is on the rise. Research is still required to validate health impact assessment tools concerning applicability in various planning and decision-making contexts, usability, acceptability, and responsiveness (Kuziemski & Misuraca., 2020).

Among the most prominent earlier methods are health risk assessment. Rather more sophisticated health risk assessment methods and tools exist to deal with health risks associated with direct exposure to chemical pollutants. These risks generally follow cause-effect chains that can be dissected and quantified using deterministic exposure-response models. There exist epidemiological studies from which probabilistic relationships between exposure and risk can be reconstructed. Nevertheless, much public expenditure has gone to waste with respect to applied risk assessment because the esoteric models developed by statisticians have very rarely been statistically validated in practice (Govindan et al., 2020; Yakovlev et al., 2020; Yannis et al., 2020; Deveci et al., 2022).

Remote Sensing Technologies in Health Impact Assessment

Innovative methods in remote sensing for the assessment of health impacts of environmental pollution will be described. The social and economic context of countries in transition from a planned to an open market economy and the development of a computerized information system on health and environmental data were the starting point for developing the innovative methods. Telemetry-based satellite remote sensing now allows assessing changes in the urban and rural environment under large-scale pollution. Remote databases on health data can be processed by developing various modules of the computerized information system for aggregating health impacts due to traffic, air pollutants, drinking water, urbanism, and other economic activities. The satellite and health impact data are spatially matched by the computerized information system in the geographical information system to produce health impact maps. Innovative methods in remote sensing are described to assess health impacts due to urban development and environmental pollution. These methods are based on the idea of integrating state-of-the-art telemeter satellite remote sensing technology with computerized information systems on health and environmental data (Burnett& Dore et al., 2023; Yuan et al.,2022). This development targets many expected changes in the social as well as in the economic context of countries in transition from a planned to an open market economy. The rapid urbanization, industrialization, and large-scale motorization will cause drastic environmental changes. Urban areas are of particular interest since they develop most rapidly. Health hazards assessment methods are needed to assess the impacts of rapid development on health. Since environmental changes are due to socio-economic activities over time, units of territory to be monitored for health risks are various socio-economic units spanned by populations rather than global average regions. Industrial point sources of pollution, drinking water catchments and treatment plants, transport routes, metropolitan areas, etc. are examples of such socio-economic units. On the other hand, population data, health, and environment databases of concern are usually demanded by health hazard assessment models for regional or macro geographical units, i.e., administrative units irrespective of their socio-economic characteristics. Thus, there is an incompatibility in space and abundance of data, both health and environmental, for countries in transition. Computerized information systems, health impact assessments, and health risk assessments involve large amounts of data and are computationally intensive. This vision and the expectation of improved technical possibilities assure working in the above-mentioned innovative direction (Ganie et al.,2024; Bhat & Sidiq., 2020).

a. Satellite Remote Sensing

Satellite remote sensing is a well-established method of gathering information about the Earth and its atmosphere. By obtaining optical and thermal spectra of reflected and emitted electromagnetic radiation from the Earth's surface and atmosphere, satellite remote sensing allows for the identification and mapping of terrestrial land cover and land use change. This, in turn, enables assessments of environmental epidemiology as well as quantitative health impact assessments. Since international space programs became widely implemented beginning in the late 1960s, optical and thermal images have been provided through the utilization of fixed and non-fixed orbital satellites. Satellite images have become a major source of environmental data for geographical information systems, and they can be obtained at a relatively low cost compared to other sources, such as aerial photographs (Navin and Agilandeeswari., 2020).

In recent years, with the introduction of new technologies and the launch of new satellites, applications of satellite remote sensing have significantly advanced. Importantly, satellite remote sensing now has the ability to obtain images of cities with a 1-10 m resolution through the use of high-resolution satellite images, along with enhanced modeling tools. Very high-resolution satellite images have become available since the early 2000s. Good quantitative agreements have been found between satellite-derived and field-measured land surface biophysical parameters such as LAI, surface moisture, surface temperature, and surface albedo, indicating that space-borne sensors may provide an important complement to local observations. The high spatial and temporal resolution of satellite images, or satellite data, is beneficial over the use of other data sources in the estimation of a health impact metric due to the rapid health surveillance capacity. Moreover, satellite remote sensing is capable of providing an image of urban land cover for a broad area ranging from tens of thousands to millions of hectares, which is critical for modeling nonlocal climatic and health effects (Pande et al., 2021).

Above all, more than 50 years' worth of optical and thermal satellite images of the Earth's surface now exist, having become easily accessible. Compared to databases of air pollution concentrations, which are not uniformly collected or made available, atmospheric health exposures assessed by satellite remote sensing may add temporal continuity and consistent spatial structure—by nature, global. Though satellite remote sensing does not, in and of itself, indicate a health effect, exposure assessments derived through satellite remote sensing may provide a bridge between the health and environmental sciences. Alternatively, as increasing numbers of spatially detailed data become available, health scientists must be aware of the strengths, limitations, and assumptions that accompany each of those data sources (Macarringue et al., 2022; Fahad et al.,2020; Abebe et al., 2022).

Innovative Remote Sensing Techniques

To ensure the safety of people's health from environmental pollution, which hinders economic prosperity and social development, researchers have paid more attention to health and pollution studies. In order to mitigate the impact that human, animal, and environmental health studies face, the use of remote sensing has broad feasibility for ongoing studies. As a cornerstone of their application, the feasibility of remote sensing varies depending on the research goal, with different sensors and methods employed accordingly. Notably, ground-based data are frequently integrated with remote sensing techniques to enhance the robustness of health and pollution studies, and this integration is essential for building mathematical relationships between environmental conditions and health and pollution gain or loss. However, such designs may not easily and comprehensively cover broad areas. Ground-based data resources could be considered substitutes (Mertikas et al.,2021).

Popular water quality indicators, such as chlorophyll-a and total suspended solids, are usually collected in light wavelengths, while geological and soil survey indicators are determined through thermal infrared spectra for water quality pollutants. Different common settings of the remote sensing system are implemented with simulated hybrid ensemble empirical mode decomposition, which increases the interpretability of the dataset. The mutual information provides a parameter to assess the efficiency of remote sensing-enhanced designs versus non-remote sensing-enhanced designs. Moreover, variance analysis is conducted to compare the water quality prediction accuracy of remote sensing-enhanced versus non-remote sensing-enhanced designs. Remote sensing-enhanced designs could extract detailed spatial information to improve prediction accuracy for large studies with spatially heterogeneous conditions. In comparison, non-remote sensing-enhanced designs are rarely feasible for small tasks. Consequently, it is challenging to collect data series with adequate preprocessing, spatial resolution, and coverage over large studies because of high costs and labor requirements (Yang et al., 2022; Avtar et al.,2020).

Hyperspectral imaging technology is a satellite-based sensing system capable of obtaining spectral signatures in hundreds of contiguous bands. Carrying hyperspectral imaging sensors on satellites can provide an unprecedented temporal resolution of spectral data of global coverage. Recent advancements in remote hyperspectral imaging technology have created a novel opportunity for daily monitoring and surveillance of vegetation health and the environmental parameters used for vegetation growth. Similar to remote sensing, the feasibility of hyperspectral imaging varies depending on the objective of the study. Besides imaged remote sensing systems, a hyperspectral imager could be an option to monitor wildland fires and smoke plumes over the air with contiguous bands covering a specific range. Hyperspectral imaging signatures are also validated using spatiotemporal remote and in situ datasets. Other hyperspectral imaging implementations utilize a spectral mixture analysis to estimate the contents of atmospheric and mineral constituents in hyperspectral pixel images (Liu et al., 2022; Song et al.,2020).

a. Hyperspectral Imaging

Environmental pollution poses significant threats to human health and is one of the most critical issues in today’s world. Therefore, it should be assessed promptly to avoid possible health risks to people. Conventional data collection methods for pollution assessment, such as using land-based sensors, laboratory tests, and sample collection, are time-consuming, cumbersome, resource-intensive, prone to sampling errors, and often insufficient for spatial interpolation on a wider scale. Remote sensing provides a very suitable alternative to these conventional health impact assessments of environmental pollution. However, most of the remote sensing methods employed for this purpose are relatively old because of the limitation of early remote sensing instruments. Fortunately, with the recent advancements in remote sensing, more innovative technologies have emerged that have great potential in health impact assessments of pollution but have seldom been explored. Hyperspectral imaging falls in this category (Mukundan et al., 2022).

Hyperspectral imaging is a cutting-edge remote sensing technique that collects and processes information across the electromagnetic spectrum to analyze the spectral characteristics of objects. Its mechanism is somewhat similar to multispectral imaging, but unlike multispectral imaging that uses a limited number of bands within the visible and infrared ranges of the spectrum, hyperspectral imaging uses a continuous range of wavelengths divided into hundreds of spectral bands. Such broadband characteristics allow hyperspectral images to generate detailed images of different types of features based on their spectral fingerprints. Therefore, hyperspectral imaging outperforms multispectral imaging in identifying or classifying complex objects (Khan et al., 2022).

Due to the breadth of the electromagnetic spectrum being utilized, hyperspectral imaging is highly suitable for pollution detection and health impact assessment. Within the visible and near-infrared ranges of the spectrum, pollutants and harmful substances such as heavy metals, pesticides, and other toxic chemicals have unique spectral signatures which allow for their identification amidst the noise from the background. Hyperspectral imaging with a high number of continuously collected spectral bands can be used for the proper discrimination of toxic pollutants, even in low concentrations. The identification of sources and characterization of pollution types can also be done using the spectral imaging technique (Mukundan et al., 2022; Tan et al., 2020; Lu et al., 2020; Khan et al., 2022).

Integration of Remote Sensing Data with Health Data

The integration of remote sensing data with health data has emerged as a powerful approach for assessing the health impacts of environmental pollution. Remote sensing data provide a wealth of information related to land cover, land use change, and surface and atmospheric conditions. These data, when complemented with in-situ measurements and ground-based environmental health data, enhance health impact assessments of environmental pollution, particularly particulate matter of 10 micrometers or less (PM10) air pollutants. Advances in computational power and the availability of remote sensing data facilitated this integration. During the past decade, there have been increasing applications of this integration for health impact assessments, especially in developing countries (Estoque et al.,2020).

This integration involves several steps. First, the acquisition and processing of remote sensing data are performed, which may include atmospheric correction, surface temperature retrieval, and land cover classification. Second, steps to calculate pollutant exposure from those remote sensing data or matrix-type pollutant datasets obtained from remote sensing data are undertaken. Third, health data are matched with remote sensing data at different spatial scales, including time-series matching. Fourth, statistical analysis is performed using those integrated datasets, which may include count regression analysis, Bayesian hierarchical modeling, or generalized additive modeling (Himeur et al., 2022).

In recent years, various innovative applications of this integration have been reported. These applications include assessing population exposure to PM10 from land cover change and urbanization using remote sensing data. The health impact of PM10 is evaluated using a distributed lag nonlinear model on a time-series dataset of daily hospital admissions, showing a significant association with meteorologically adjusted PM10. Another application involves assessing the health impact of PM10 and NO2 in Paris using the same integration framework, where the health effects of PM10 are stronger in warm seasons and health impacts of NO2 were evident in the post-2001 period. This integration is also used to assess the impact of climate change induced air pollution on premature mortality in major cities of South Asia. Such advancements in this integration will play a vital role in ensuring a safe environment, especially with the rapid spatio-temporal spread of COVID-19 in recent years (Estoque et al., 2020; Barboza et al., 2021; Malathi et al., 2024; Zhao et al., 2022).

4. Discussion

A growing number of studies have been reported that evaluate how successful remote sensing and GIS applications are in AMS. Most studies applied exquisite data acquisition and monitoring approaches for impactful environmental attributes such as air quality and greenhouse gases. They successfully monitored environmental pollution over a time or space scale of interest and highlighted the pros and cons of the methods being adopted. However, only a few studies assessed how reliable, visionary, and transparent these approaches were in view of the ACA. The discriminatory transparency of the proxy evaluation models contributed to a misleading impression of the policy option, as did inherent attribute interdependencies. There is still room for improvement in terms of the methods' reliability, interpretability, and transparency, particularly for a mesh of indirect attributes. The cross-practice difference in public consideration was damaging to the openness of the evaluations. This domain has witnessed an exponential increase in published literature dealing with remote sensing and computer-aided technologies. However, studies on remote sensing and computer-aided approach applications in other full-disclosure venues are limited (Li et al., 2020; Apostolopoulos and Nikolakopoulos., 2021).

An increasing number of studies have been reported that are focused on AMS based on remote sensing and GIS. Ten journals dealing with AMS were selected as data sources. The advent of remote sensing and GIS technologies has provided a new approach for environmental monitoring and assessment due to their unrivaled advantages in broad coverage, cost-effectiveness, and time efficiency. Twelve types of presently available applications comprised of six data acquisition approaches, two data processing methods, and four monitoring techniques were first reported. Then, a total of 116 research articles were retrieved that applied remote sensing and GIS approaches in AMS studies to analyze the methodology selection and application. Results showed that such remote sensing and GIS approaches have been broadly applied for monitoring times of up to 103 years mostly in Europe, North America, and Asia. Moreover, vegetation and NDVI-based datasets are the most widely applied datasets (Avtar et al.,2020; Gyamfi-Ampadu & Gebreslasie., 2021; Dube et al., 2022).

Air Quality Monitoring

The protection and improvement of air quality are among the responsibilities of environmental authorities. Typically, this task is performed using a combination of state and local automatic air quality monitors and networks of more simplified devices. While satellite views of air quality are currently collectible, temporal studies of air quality using satellite data are often limited by cloudy weather. However, this opacity can be avoided by using the time series of non-zero spectral bands in cloud-covered conditions like multi- and hyperspectral imaging data. An innovative approach for the retrieval of air quality parameters has recently been suggested. It is based on the analysis of variations of remotely sensed spectral reflectance of the Earth's surface that are induced by the changes of aerosol state or composition and optical properties (de et al., 2021; Stirnberg et al., 2020)..

An application for satellite cell-based air quality monitoring systems is presented, with urban and rural modeling areas taken from a project. The modeling system allows monitoring of air quality parameters in both clear and cloud-covered conditions, as well as accounting for possibilities provided by different systems of satellites and types of the Earth's surface. The developed modeling system has been verified against ground weather, pollution, and satellite data. New multi-channel meteorological and air quality models are suggested (Bosveld et al., 2020).

In Mexico City, an example of monitoring using satellite data is demonstrated, and ground solutions showed their forecast and retrieval abilities. The monitoring results using perpetual environmental satellites and ground data are summarized for tropical rivers of East Malaysia and in the UK for catchments designed for rainfall-runoff models and monitoring pollution by sewer overflow (Singh et al.2021; Safarianzengir et al.,2020; Bosveld et al.,2020).

Challenges and Limitations in Remote Sensing for Health Impact Assessment

Despite the potential of remote sensing technology for health impact assessment of environmental pollution, there are several challenges and limitations that need to be addressed. One of the main challenges is the limited availability and accessibility of high-resolution remote sensing data in developing countries. Many low-income countries do not have the infrastructure and resources to acquire and process satellite imagery, which limits their ability to monitor and assess health risks from environmental exposures. Moreover, even when data is available, limitations such as cloud cover, poor image quality, and geometric distortions can affect the accuracy and reliability of remote sensing estimates (Huang et al., 2021; Pokhriyal et al., 2020).

Another challenge is the need for expertise and training in remote sensing and geographic information systems. These skills are often lacking in public health and environmental professionals, especially in low-income countries. There is a need for capacity building and knowledge transfer to enable public health researchers and practitioners to effectively use remote sensing tools for health impact assessment. Furthermore, there are also ethical and legal challenges related to the collection and use of satellite data in health research. Issues such as privacy, consent, and potential misuse of data need to be carefully considered and addressed.

Finally, there is the need for more validation studies to assess the validity and reliability of remote sensing-derived exposure estimates. Most studies that have applied remote sensing technology for health impact assessment have used the approach in an exploratory manner, without rigorous validation of exposure estimates. More research is needed to evaluate the accuracy of remote sensing data by comparing it with independent ground-based measurements. Addressing these challenges and limitations will not only enhance the use of remote sensing technology in health impact assessment, but also improve the understanding of the health effects of environmental pollution (Huang et al., 2021; Pokhriyal et al., 2020; Ali et al., 2020; Klemmer et al., 2020; Dinh et al.,2020).

Future Directions and Emerging Technologies

The field of remote sensing for studying environmental impacts on public health is rapidly evolving, with new methodologies and techniques being developed to improve health impact monitoring and assessment. Innovative methodologies using remote sensing, socio-economic and demographic data, and data-driven models are applied in the studies to facilitate health impact monitoring. Moreover, the potential of innovative technologies, new datasets, and the evolution of cloud computing platforms as a data ecosystem to access, analyze, and visualize the data to facilitate public health research are discussed. The aim of these research directions is to improve the accuracy and accessibility of health impact assessment investigations using an innovative bank of technologies.

However, several knowledge gaps are highlighted regarding the application of innovative methodologies. The need for a better understanding and decomposition of the contributing factors of health impacts is uncovered. Furthermore, the significant spatio-temporal heterogeneity of health impacts and the difficulties in matching fine-scale health impact assessment results with coarse-scale pollution datasets to extract meaningful information for model development are addressed. This need calls for advanced observational approaches fused by combining different datasets, such as participatory sensing, in-situ data collection, crowdsourced data collection using ubiquitous smart mobile devices, and advances in unmanned aerial vehicles. Those variable and parameter transfer learning models are needed for transferring knowledge from developed regions to developing regions that lack in situ observations. Improvements in personalized health impact assessment are another challenge in order to better take into account people's activity patterns, which are necessary for a better representation of public exposure. Such improvements can be achieved using smart mobile technology developments and continuous developments of simulated population databases (Ang et al.2023; Radutu et al.2021).

Notably, these recent developments in innovative technologies and methodology improvements have tended to enhance the applications of data-driven models in studying environmental impacts on public health. To bring new insights into epidemiology studies and to facilitate the combination of remote sensing data and multi-source societal data, the development of a national cloud computing platform combined with a decision support system for environmental impacts on infectious diseases was initiated. In addition to becoming a data ecosystem for accessing, analyzing, and visualizing environmental datasets and health-related datasets, the platform implements several data-driven models to quantify the relationships between environmental impacts and the spread of infectious diseases. Those innovative technologies combined with innovative methodologies have the potential to provide new insights and improved capability for an environmental impact assessment on health (Murayama et al., 2021; Sun et al., 2022; Hu et al., 2024).

5. Conclusion

This study demonstrates that the use of remote sensing techniques is a powerful tool for assessing the impact of environmental pollution on public health. By integrating environmental data with health information, researchers were able to gain new insights into the complex relationship between pollution and rates of various diseases. The results highlight the urgent need to apply these innovative methods in future studies, which will help improve public health strategies. These methods not only enhance the accuracy of assessments, but also open up new avenues for understanding the environmental factors that influence health. Thus, environmental policies based on accurate data can contribute to reducing health risks caused by pollution. Ultimately, the integration of modern technology and health research is an essential step towards improving the quality of life in societies. Efforts must continue to develop these tools and expand their use to ensure a healthier and more sustainable future for all. Raising awareness of the importance of this relationship will contribute to taking effective steps towards protecting the environment and human health.

6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. Chen, J., Chen, S., Fu, R., Li, D., Jiang, H., Wang, C., ... & Hicks, B. J. (2022). Remote sensing big data for water environment monitoring: current status, challenges, and future prospects. Earth's Future, 10(2), e2021EF002289. wiley.com
2. Yang, H., Kong, J., Hu, H., Du, Y., Gao, M., & Chen, F. (2022). A review of remote sensing for water quality retrieval: progress and challenges. Remote Sensing. mdpi.com
3. Mather, P. M. & Koch, M. (2022). Computer processing of remotely-sensed images. [HTML]
4. Elachi, C. & Van Zyl, J. J. (2021). Introduction to the physics and techniques of remote sensing. academia.edu
5. Chuvieco, E. (2020). Fundamentals of satellite remote sensing: An environmental approach. researchgate.net
6. Sabins Jr, F. F. & Ellis, J. M. (2020). Remote sensing: Principles, interpretation, and applications. [HTML]
7. Domínguez, E. M., Small, D., & Henke, D. (2021). Deriving digital surface models from geocoded SAR images and back-projection tomography. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 14, 4339-4351. ieee.org

8. Bu, J., Wang, Q., Wang, Z., Fan, S., Liu, X., & Zuo, X. (2024). Land Remote Sensing Applications Using Spaceborne GNSS Reflectometry: A Comprehensive Overview. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. ieee.org
9. Yu, K., Han, S., Bu, J., An, Y., Zhou, Z., Wang, C., ... & Cheong, J. W. (2022). Spaceborne GNSS reflectometry. Remote Sensing, 14(7), 1605. mdpi.com
10. Xu, C., Du, X., Fan, X., Yan, Z., Kang, X., Zhu, J., & Hu, Z. (2021). A modular remote sensing big data framework. IEEE Transactions on Geoscience and Remote Sensing, 60, 1-11. researchgate.net
11. Haut, J. M., Paoletti, M. E., Moreno-Álvarez, S., Plaza, J., Rico-Gallego, J. A., & Plaza, A. (2021). Distributed deep learning for remote sensing data interpretation. Proceedings of the IEEE, 109(8), 1320-1349. umbc.edu
12. Ejemeyovwi, D. O., Achima, B. T., & Ogwu, C. (2023). Remote Sensing Satellite Systems and Capabilities in Mapping Environmental Resources. NIU Journal of Social Sciences. ijhumas.com
13. Fu, W., Ma, J., Chen, P., & Chen, F. (2020). Remote sensing satellites for digital earth. Manual of digital earth. oapen.org
14. Liu, D., Chen, B., An, J., Li, C., Liu, G., Shao, J., ... & Wang, Z. L. (2020). Wind-driven self-powered wireless environmental sensors for Internet of Things at long distance. Nano Energy, 73, 104819. google.com
15. Khan, S., Naushad, M., Govarthanan, M., Iqbal, J., & Alfadul, S. M. (2022). Emerging contaminants of high concern for the environment: Current trends and future research. Environmental Research, 207, 112609. [HTML]
16. Morin-Crini, N., Lichtfouse, E., Liu, G., Balaram, V., Ribeiro, A. R. L., Lu, Z., ... & Crini, G. (2022). Worldwide cases of water pollution by emerging contaminants: a review. Environmental Chemistry Letters, 20(4), 2311-2338. hal.science
17. Ukaogo, P. O., Ewuzie, U., & Onwuka, C. V. (2020). Environmental pollution: causes, effects, and the remedies. In Microorganisms for sustainable environment and health (pp. 419-429). Elsevier. [HTML]
18. Xu, H., Jia, Y., Sun, Z., Su, J., Liu, Q. S., Zhou, Q., & Jiang, G. (2022). Environmental pollution, a hidden culprit for health issues. Eco-Environment & Health, 1(1), 31-45. sciencedirect.com
19. Intisar, A., Ramzan, A., Sawaira, T., Kareem, A. T., Hussain, N., Din, M. I., ... & Iqbal, H. M. (2022). Occurrence, toxic effects, and mitigation of pesticides as emerging environmental pollutants using robust nanomaterials–A review. Chemosphere, 293, 133538. [HTML]
20. Siddiqua, A., Hahladakis, J. N., & Al-Attiya, W. A. K. (2022). An overview of the environmental pollution and health effects associated with waste landfilling and open dumping. Environmental Science and Pollution Research, 29(39), 58514-58536. springer.com
21. Bhatt, P., Pandey, S. C., Joshi, S., Chaudhary, P., Pathak, V. M., Huang, Y., ... & Chen, S. (2022). Nanobioremediation: A sustainable approach for the removal of toxic pollutants from the environment. Journal of Hazardous Materials, 427, 128033. [HTML]
22. Vasey, B., Nagendran, M., Campbell, B., Clifton, D. A., Collins, G. S., Denaxas, S., ... & McCulloch, P. (2022). Reporting guideline for the early stage clinical evaluation of decision support systems driven by artificial intelligence: DECIDE-AI. bmj, 377. bmj.com
23. Kuziemski, M. & Misuraca, G. (2020). AI governance in the public sector: Three tales from the frontiers of automated decision-making in democratic settings. Telecommunications policy. nih.gov
24. Govindan, K., Mina, H., & Alavi, B. (2020). A decision support system for demand management in healthcare supply chains considering the epidemic outbreaks: A case study of coronavirus disease 2019 (COVID-19). Transportation Research Part E: Logistics and Transportation Review, 138, 101967. sciencedirect.com
25. Yakovlev, S., Bazilevych, K., Chumachenko, D., Chumachenko, T., Hulianytskyi, L., Meniailov, I., & Tkachenko, A. (2020). The concept of developing a decision support system for the epidemic morbidity control. academia.edu
26. Yannis, G., Kopsacheili, A., Dragomanovits, A., & Petraki, V. (2020). State-of-the-art review on multi-criteria decision-making in the transport sector. Journal of traffic and transportation engineering (English edition), 7(4), 413-431. sciencedirect.com
27. Deveci, M., Mishra, A. R., Gokasar, I., Rani, P., Pamucar, D., & Özcan, E. (2022). A decision support system for assessing and prioritizing sustainable urban transportation in metaverse. IEEE Transactions on Fuzzy Systems, 31(2), 475-484. worktribe.com

28. Burnett, M. J. (). Environmental monitoring of freshwater ecosystems using telemetered behavioural indicators from free-swimming fish in southern Africa. researchgate.net. researchgate.net
29. Dore, K. M., Gallagher, C. A., & Mill, A. C. (2023). Telemetry-based assessment of home range to estimate the abundance of invasive green monkeys on St. Kitts. Caribbean Journal of Science. [HTML]
30. Yuan, F., Fan, C., Farahmand, H., Coleman, N., Esmalian, A., Lee, C. C., ... & Mostafavi, A. (2022). Smart flood resilience: harnessing community-scale big data for predictive flood risk monitoring, rapid impact assessment, and situational awareness. Environmental Research: Infrastructure and Sustainability, 2(2), 025006. iop.org
31. Ganie, P. A., Posti, R., Kunal, G., Bhat, R. A. H., & Sidiq, M. J. (2024). Principle and Applications of Geographic Information System (GIS) in Coldwater Fisheries Development in India. In Aquaculture and Conservation of Inland Coldwater Fishes (pp. 469-495). Singapore: Springer Nature Singapore. [HTML]
32. Bhat, R. A. H., & Sidiq, M. J. Parvaiz Ahmad Ganie, Ravindra Posti, Garima Kunal. Aquaculture and Conservation of Inland Coldwater Fishes, 469. [HTML]
33. Navin, M. S., & Agilandeeswari, L. (2020). Comprehensive review on land use/land cover change classification in remote sensing. Journal of Spectral Imaging, 9. semanticscholar.org
34. Pande, C. B., Moharir, K. N., & Khadri, S. F. R. (2021). Assessment of land-use and land-cover changes in Pangari watershed area (MS), India, based on the remote sensing and GIS techniques. Applied Water Science. springer.com
35. Macarringue, L. S., Bolfe, L., & Pereira, P. R. M. (2022). Developments in land use and land cover classification techniques in remote sensing: a review.. embrapa.br
36. Fahad, K. H., Hussein, S., & Dibs, H. (2020). Spatial-temporal analysis of land use and land cover change detection using remote sensing and GIS techniques. In IOP conference series: materials science and engineering (Vol. 671, No. 1, p. 012046). IOP Publishing. iop.org
37. Abebe, G., Getachew, D., & Ewunetu, A. (2022). Analysing land use/land cover changes and its dynamics using remote sensing and GIS in Gubalafito district, Northeastern Ethiopia. SN Applied Sciences. springer.com
38. Mertikas, S. P., Partsinevelos, P., Mavrocordatos, C., & Maximenko, N. A. (2021). Environmental applications of remote sensing. In Pollution assessment for sustainable practices in applied sciences and engineering (pp. 107-163). Butterworth-Heinemann. [HTML]
39. Avtar, R., Komolafe, A. A., Kouser, A., Singh, D., Yunus, A. P., Dou, J., ... & Kurniawan, T. A. (2020). Assessing sustainable development prospects through remote sensing: A review. Remote sensing applications: Society and environment, 20, 100402. nih.gov
40. Liu, C., Xing, C., Hu, Q., Wang, S., Zhao, S., & Gao, M. (2022). Stereoscopic hyperspectral remote sensing of the atmospheric environment: Innovation and prospects. Earth-Science Reviews. [HTML]
41. Song, W., Song, W., Gu, H., & Li, F. (2020). Progress in the remote sensing monitoring of the ecological environment in mining areas. International Journal of Environmental Research and Public Health, 17(6), 1846. mdpi.com
42. Mukundan, A., Huang, C. C., Men, T. C., Lin, F. C., & Wang, H. C. (2022). Air pollution detection using a novel snap-shot hyperspectral imaging technique. Sensors. mdpi.com
43. Tan, K., Wang, H., Chen, L., Du, Q., Du, P., & Pan, C. (2020). Estimation of the spatial distribution of heavy metal in agricultural soils using airborne hyperspectral imaging and random forest. Journal of hazardous materials, 382, 120987. msstate.edu
44. Lu, Y., Saeys, W., Kim, M., Peng, Y., & Lu, R. (2020). Hyperspectral imaging technology for quality and safety evaluation of horticultural products: A review and celebration of the past 20-year progress. Postharvest Biology and Technology. kuleuven.be
45. Khan, A., Vibhute, A. D., Mali, S., & Patil, C. H. (2022). A systematic review on hyperspectral imaging technology with a machine and deep learning methodology for agricultural applications. Ecological Informatics. [HTML]
46. Estoque, R. C., Ooba, M., Seposo, X. T., Togawa, T., Hijioka, Y., Takahashi, K., & Nakamura, S. (2020). Heat health risk assessment in Philippine cities using remotely sensed data and social-ecological indicators. Nature communications, 11(1), 1581. nature.com

47. Barboza, E. P., Cirach, M., Khomenko, S., Iungman, T., Mueller, N., Barrera-Gómez, J., ... & Nieuwenhuijsen, M. (2021). Green space and mortality in European cities: a health impact assessment study. The Lancet Planetary Health, 5(10), e718-e730. thelancet.com
48. Malathi, K., Shruthi, S. N., Madhumitha, N., Sreelakshmi, S., Sathya, U., & Sangeetha, P. M. (2024). Medical Data Integration and Interoperability through Remote Monitoring of Healthcare Devices. Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications (JoWUA), 15(2), 60-72. researchgate.net
49. Zhao, Q., Yu, L., Du, Z., Peng, D., Hao, P., Zhang, Y., & Gong, P. (2022). An overview of the applications of earth observation satellite data: impacts and future trends. Remote Sensing. mdpi.com
50. Himeur, Y., Rimal, B., Tiwary, A., & Amira, A. (2022). Using artificial intelligence and data fusion for environmental monitoring: A review and future perspectives. Information Fusion. [HTML]
51. Li, J., Pei, Y., Zhao, S., Xiao, R., Sang, X., & Zhang, C. (2020). A review of remote sensing for environmental monitoring in China. Remote Sensing. mdpi.com
52. Apostolopoulos, D., & Nikolakopoulos, K. (2021). A review and meta-analysis of remote sensing data, GIS methods, materials and indices used for monitoring the coastline evolution over the last twenty years. European Journal of Remote Sensing, 54(1), 240-265. tandfonline.com
53. Gyamfi-Ampadu, E. & Gebreslasie, M. (2021). Two decades progress on the application of remote sensing for monitoring tropical and sub-tropical natural forests: a review. Forests. mdpi.com
54. Dube, T., Rampheri, B. M., & Shoko, C. (2022). GIS and remote sensing analytics: assessment and monitoring. In Fundamentals of Tropical Freshwater Wetlands (pp. 661-678). Elsevier. [HTML]
55. de Leeuw, G., van der A, R., Bai, J., Xue, Y., Varotsos, C., Li, Z., ... & Zhang, Y. (2021). Air quality over China. Remote Sensing, 13(17), 3542. mdpi.com
56. Stirnberg, R., Cermak, J., Fuchs, J., & Andersen, H. (2020). Mapping and understanding patterns of air quality using satellite data and machine learning. Journal of Geophysical Research: Atmospheres, 125(4), e2019JD031380. wiley.com
57. Singh, D., Dahiya, M., Kumar, R., & Nanda, C. (2021). Sensors and systems for air quality assessment monitoring and management: A review. Journal of environmental management, 289, 112510. [HTML]
58. Safarianzengir, V., Sobhani, B., Yazdani, M. H., & Kianian, M. (2020). Monitoring, analysis and spatial and temporal zoning of air pollution (carbon monoxide) using Sentinel-5 satellite data for health management in Iran, located in the Middle East. Air Quality, Atmosphere & Health, 13, 709-719. [HTML]
59. Bosveld, F. C., Baas, P., Beljaars, A. C., Holtslag, A. A., de Arellano, J. V. G., & Van De Wiel, B. J. (2020). Fifty years of atmospheric boundary-layer research at Cabauw serving weather, air quality and climate. Boundary-Layer Meteorology, 177, 583-612. springer.com
60. Huang, L. Y., Hsiang, S. M., & Gonzalez-Navarro, M. (2021). Using satellite imagery and deep learning to evaluate the impact of anti-poverty programs. nber.org
61. Pokhriyal, N., Zambrano, O., Linares, J., & Hernández, H. (2020). Estimating and forecasting income poverty and inequality in haiti using satellite imagery and mobile phone data. iadb.org
62. Ali, D. A., Deininger, K., & Wild, M. (2020). Using satellite imagery to create tax maps and enhance local revenue collection. Applied Economics. worldbank.org
63. Klemmer, K., Yeboah, G., de Albuquerque, J. P., & Jarvis, S. A. (2020). Population mapping in informal settlements with high-resolution satellite imagery and equitable ground-truth. arXiv preprint arXiv:2009.08410. [PDF]
64. Dinh, M. N., Nygate, J., Thwaites, C. L., & Group, G. G. C. E. V. (2020). New technologies to improve healthcare in low-and middle-income countries: global grand challenges satellite event, Oxford University clinical research unit, Ho Chi Minh City, 17th-18th September 2019. Wellcome Open Research, 5. nih.gov
65. Ang, M. L. E., Owen, J. R., Gibbins, C. N., Lèbre, É., Kemp, D., Saputra, M. R. U., ... & Lechner, A. M. (2023). Systematic review of GIS and remote sensing applications for assessing the socioeconomic impacts of mining. The Journal of Environment & Development, 32(3), 243-273. sagepub.com
66. Radutu, A., Vlad Sandru, M. I., Nedelcu, I., & Poenaru, V. (2021). Change detection trends in urban areas with remote sensing and socio-economic diagnosis in Bucharest city. Proceedings of the 21st International Multidisciplinary Scientific GeoConference SGEM. researchgate.net

67. Murayama, Y., Simwanda, M., & Ranagalage, M. (2021). Spatiotemporal analysis of urbanization using GIS and remote sensing in developing countries. Sustainability. mdpi.com
68. Sun, Y., Li, Y., Ma, R., Gao, C., & Wu, Y. (2022). Mapping urban socio-economic vulnerability related to heat risk: A grid-based assessment framework by combing the geospatial big data. Urban Climate. [HTML]
69. Hu, T., Li, N., & Yang, Q. (2024). Evaluating the influence of COVID-19 pandemic on socioeconomic development in Wumeng Mountain area based on multi-source remote sensing data. International Journal of Digital Earth. tandfonline.com