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Geospatial Technologies for Environmental Management

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ABSTRACT

Whether in the medical field, architecture, engineering, urban and regional planning, archaeologists, conservation professionals, environmental agencies, climatology, oceanography or utility providers, Geographic Information Systems (GIS) has become an important tool to maximise efficiency and result. GIS, a computer-based tool used to analyse and display geographic data, integrates database operations with map visualisation and geographic analysis. It is used to gather, store, manipulate, analyse, manage, and visualise spatial information. GIS connects the 'what' with 'where' using geographical data to analyse and solve problems. The first link to the 'what' with 'where' dates back to 1854 during a cholera outbreak. While people believed that the disease was airborne, an English Doctor, Jon Snow thought differently. He decided to map the outbreak locations, the roads the property boundaries and the water pumps and he made a shocking discovery. And that was the birth of a pattern. This pattern proved that the disease was not airborne but was contracted through infected pump water. John Snow's cholera map was a major event connecting the what with where. And that was the beginning of spatial analysis, it also marked a whole new field of study: Epidemiology, the study of the spread of disease. Snow's work demonstrated that GIS is a problem-solving tool. He put the what on a map to show the where and made a life-saving discovery (Bcs.org). The period between 1960 -1975 led 3 major technological advancements in computer technology which gave birth to the modern GIS. Environmental management involves the management of natural and environmental resources which naturally exist and are part of complex ecosystems. These ecosystems must be protected even as human beings exploit natural resources for development and improved lifestyles. To ensure sustainable utilisation of these resources and maintenance of ecosystems, GIS is deployed to gather relevant information, integrate this information into a database and manipulate these data to analyse scenarios and possible impacts of development programs on the environment and ecosystems. This process helps to make informed decisions in various aspects of environmental management.

Keywords: Geographic Information Systems, environment, ecosystems

INTRODUCTION

Geographic Information Systems (GIS) is a technology that helps organisations collect, analyse, and distribute information about the environment, which can be used in a variety of ways to support environmental management. Whether it's about decision-making, conflict resolution, conservation, modelling or monitoring, geographic information systems play an important role in informed decision-making regarding the environment and environmental management. If you have ever used Google Maps or tracked your freight using your phone, you have used GIS services.

Our environment is an important aspect of our lives. With climate change and changing weather patterns, the world at large has worked hard to address these challenges; however, there is more to be done and a lot can be done with Geographical Information System (GIS) technology. GIS in environmental studies and management is a powerful tool for data analysis and planning. It can be overlaid with data or other layers of information into a map to view spatial information or relationships. GIS also can be used to display and analyse aerial photos. Digital information can be overlaid on photographs to provide environmental data analysts with relatively familiar views of landscapes and associated data. GIS can enable a quick, comparative view of hazards (highly prone areas) risks (areas where high risk may occur) and areas to be safeguarded.

Effective Identification, planning and management of our environment depends a lot on GIS technology.

What is GIS?

Geographic Information Systems (GIS) is a tool that helps organisations collect, analyse, and distribute information about the environment to support environmental management. GIS connects data to a map, integrating location data (where things are) with all types of descriptive information (what things are like there). This provides a foundation for mapping and analysis that is used in science and almost every industry. GIS helps users understand patterns, relationships and geographic context. The benefits include improved communications, efficiency, management and decision-making (esri.com, n.d.)

In simple terms, GIS is the bridge that connects geography, data, and advanced technology. It enables the visualisation, understanding, and interpretation of data to reveal relationships, patterns, and trends.

GIS Data Format:

There are 2 categories of GIS format: the vector and raster format;

Vector format: This involves the use of components of a vector; the length of the unit vector along each axis in 2 or 3 dimensions (distance) and magnitude. Cell grids or polygons can be used to identify the location of vectors. Mapping between data models and data structure takes the form of polygons, TIN, contours or point grids (Ummaneni & Tatiparthy 2021).

Raster format: This format makes it easier to perform overlays and operations than with vector data structures. Each grid cell is referenced by a row and a column number representing the type or value of the attribute of interest. When data are input into the GIS, the axis is aligned in the NS direction and the origin is identified with the universal transverse Mercator (UTM) grid to facilitate referencing (Ummaneni & Tatiparthy, 2021).

What does GIS do?

While mapping may seem like a primary goal for GIS, it offers a lot more; GIS can be used as a tool in both problem-solving and decision-making processes, as well as for the visualisation of data in a spatial environment (Jaimme, 2024). Geospatial data can be analysed to determine.

- Data management
- Spatial analysis
- Communication
- Mapping and visualisation
- the location of features and relationships to other features
- where the most and/or least of some feature exists,
- what is happening inside an area of interest (AOI),
- what is happening near some feature or phenomenon, and
- and how a specific area has changed over time and in what way
- the density of features in a given space,

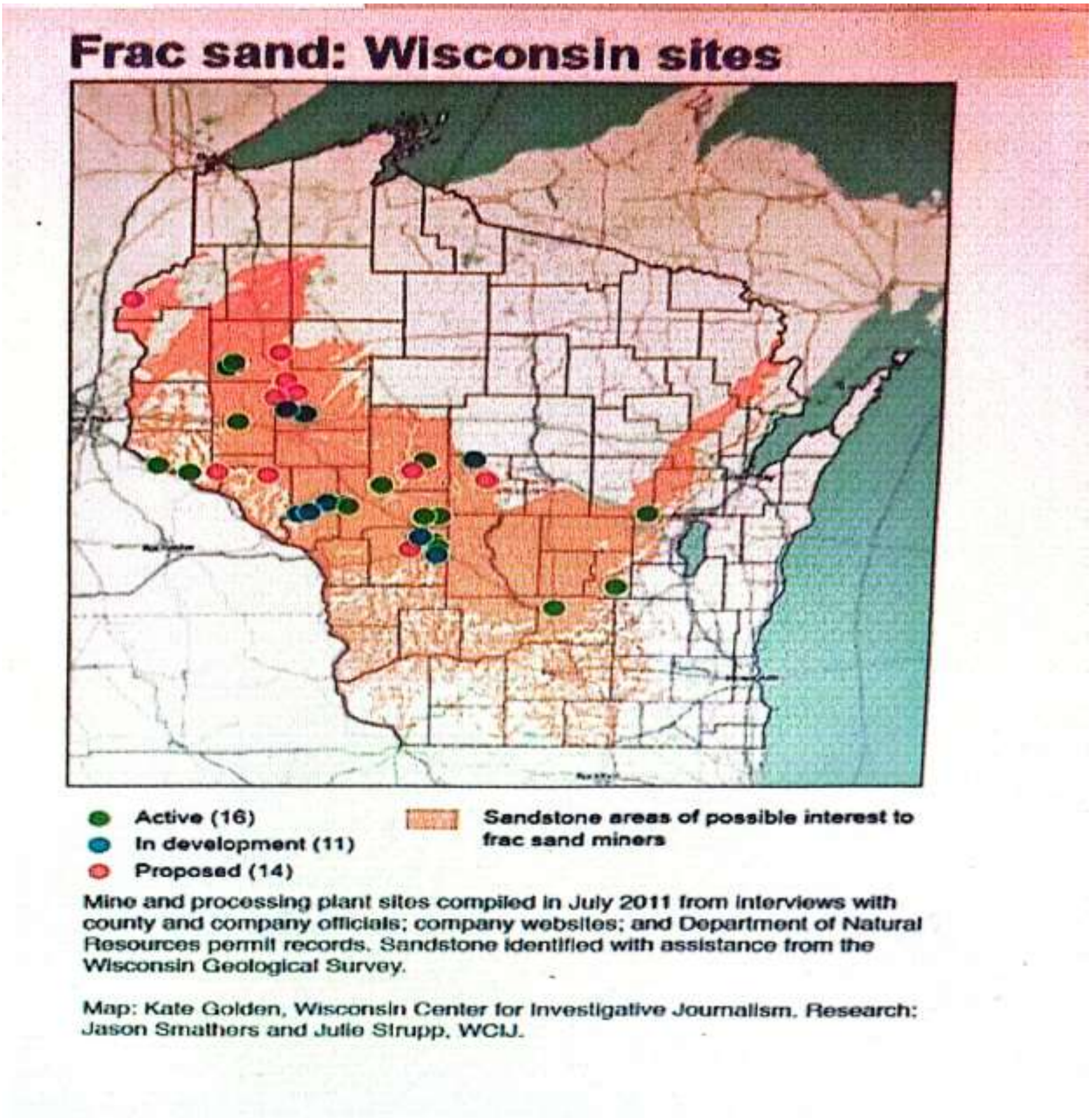
Data management: GIS is a fundamental system of record. Information from authoritative sources and business systems can be stored and integrated to magnify the data's usefulness.

Spatial Analysis: most data have location components and everything happens somewhere (esri.com). The finding of hidden relationships and the generation of new insights from data are enabled by spatial analysis.

Communication: science and data build common understanding and support collaboration as well as problem-solving. Complex ideas are communicated simply in maps and dashboards.

Mapping and visualisation: this helps with a clear understanding of problems and problemsolving through the help of GIS, data is brought to life in real-time using digital dashboards, 3D and satellite imagery.

Mapping where things are: things like the spatial location of real-world features and visualising the spatial relationships among them can be mapped. Example: the map below shows frac sand mine locations and sandstone areas in a place called Wisconsin. Patterns in the data can be visualised by determining that frac sand mining activity occurs in a region with a specific type of geology (Research Guides, 2021).



Quantity Mapping: quantities, such as where the most and least can be mapped, to find places that meet the criteria or to see the relationships between places.

Finding what is inside. GIS technology can be used to determine what is happening or what features are located inside a specific area/region. Characteristics of "inside" can be determined by creating specific criteria to define an area of interest (AOI). Example: Below is a map showing a flood event and the tax parcels and buildings in the floodway. The use of CLIP can help to determine which parcels fall inside the flood event. Furthermore, attributes of the parcels can be used to determine potential costs of property damage.

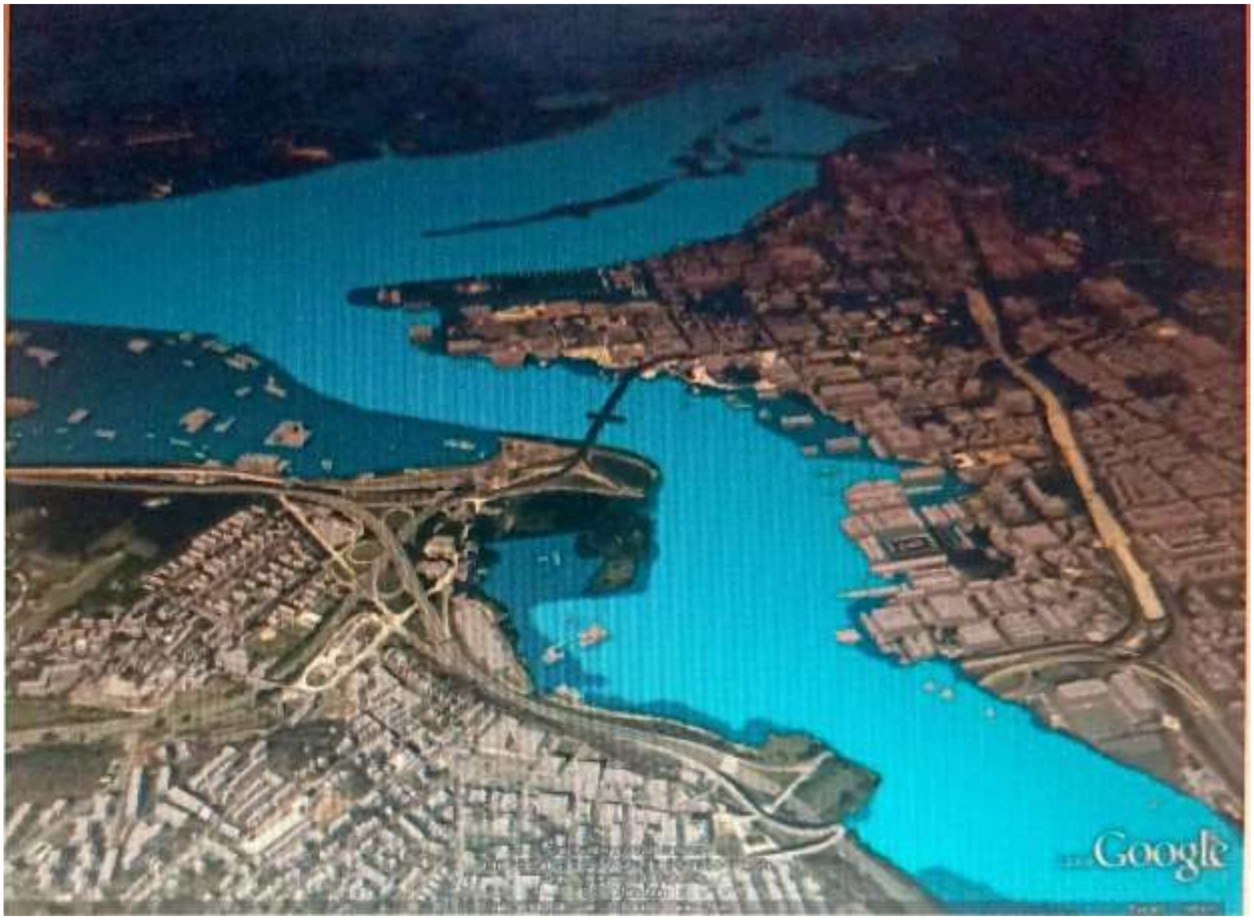


Image source; research guides, 2024

Finding what is nearby: to find out what is happening within a set distance of a feature or event by mapping what is nearby using geoprocessing tools like BUFFER. Example: finding out a drive time from a central location like CMS Lagos, using streets as a network and adding specific criteria like speed limit and intersection controls to determine how far a driver can get in 10, 20 or 30 minutes.

Mapping change. To map the change in a specific geographic area to anticipate future conditions, decide on a course of action, or evaluate the results of an action or policy. Example: below we see land use maps of Barnstable, MA showing changes in residential development from 1951 to 1999. The dark green shows forest, while bright yellow shows residential development. Applications like this can help inform community planning processes and policies (Research Guides, 2024).

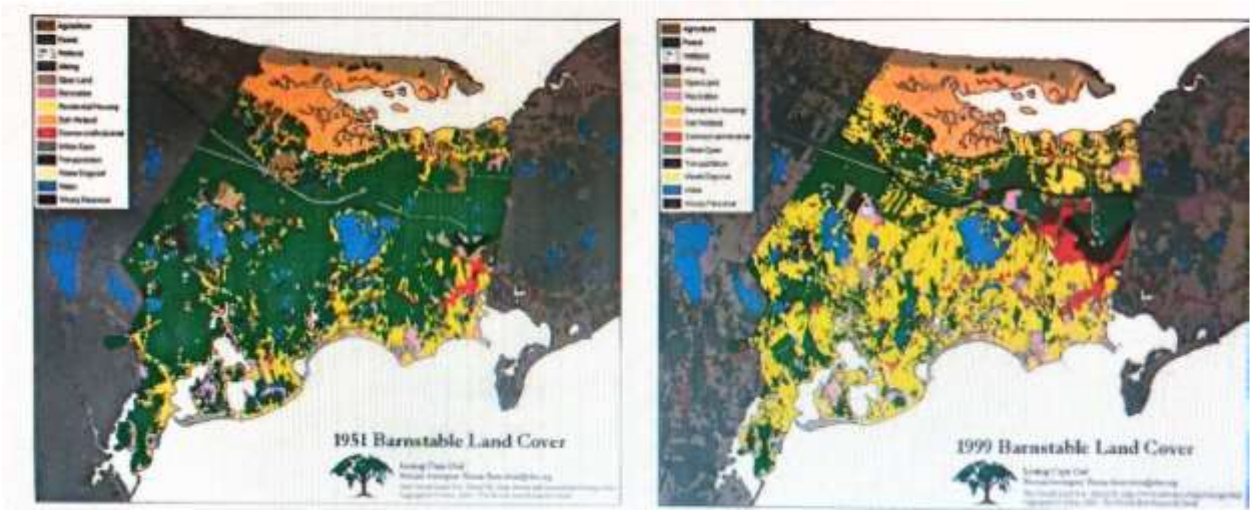


Image source: research guides, 2024

Density Mapping: Sometimes it is more important to map concentrations or a quantity normalised by area or total number. Example: Below we have mapped the population density of Manhattan (total population counts normalised by the area in sq. miles of census tracts).

What is Environmental Management?

Environmental management is the practice of managing the impact of human activity on the environment. Environmental Planning and Management (EPM) is defined as the initiation and operation of activities to direct and control the acquisition, transformation, distribution, and disposal of resources in a manner capable of sustaining human activities with a minimum disruption of physical, ecological, and social processes (Okusimba, 2019).

Environmental management involves processes that minimise humanity's impact on its surroundings. The main objective is to create and maintain conditions in which society and nature coexist. Since its formal recognition in the 1970s, it has become a mandatory practice for governments and organisations, with individuals earning professional qualifications to ensure its successful implementation (University of Bolton, n.d.)

The role of GIS in environmental management

GIS is like a bridge that connects geography, data, and advanced technology. It enables us to visualise, understand, and interpret data to reveal relationships, patterns, and trends. Environmental management, on the other hand, is a strategic approach to understanding and addressing environmental concerns. It ensures the sustainable use of resources and the protection of ecosystems (Cypress Environment, n.d.). GIS provides environmental managers with the spatial intelligence required to make data-driven decisions about the environment. It supplies the tools and insights required to balance development with preservation while minimising negative impacts on the environment. The role of GIS in environmental planning management includes;

Data Collection and Management: Information enables informed decision-making. This information is processed from data collected in the field and as such the data collection must be accurate, complete and relevant to a particular environmental issue being addressed. Why is there a strong coupling between EIS and GIS? The customary claim is that most environmental problems are spatial and therefore GIS is the most appropriate technology for dealing with these problems. The establishment of an EI (environmental information) database is therefore the first step and requires a lot of attention as this will form the basis for subsequent analysis. In a GIS environment, it is called a geodatabase and contains both spatial and aspatial information about features on the surface of the earth. Environmental geodatabase contains all the data relevant to a particular project, both spatial and a spatial. The GIS allows for the integration of these two sets of datasets (Okusimba, 2019). To build an environmental database, a lot of data is required from various sources such as satellite images, field ground surveys, topographic maps, aerial photographs, research organisations, statistical data from government agencies etc. Each user's assessment requires relevant specific data.

Display and Visualization of Environmental Information: GIS technology is an effective tool for studying the environment, reporting on environmental phenomena, and modelling how the environment is responding to natural and man-made factors. Role of GIS as a tool for Environmental Planning and Management International Journal of Research in Environmental Science (IJRES, pg. 8). GIS stores data in what is referred to as layers, each layer containing a particular theme. These layers can be displayed and visualised in a digital environment, usually the computer screen and preliminary analysis of information can be assessed. A good example would be the relationship between population density and forest cover depletion. A dataset of population distribution overlaid overland cover data set will be able to reveal the relationship between population growth and forest cover depletion. Furthermore, the results of in-depth analysis and plans are usually displayed and visualised in map formats-products of GIS analysis (Okusimba, 2019).

Planning for the future: GIS technology can identify for instance where adding green grasses can reduce extreme heat for the most vulnerable or where expected population growth can support business expansion. Whether it is about making predictions and informed decisions that can benefit the planet or modelling possible scenarios to address complex situations like climate resilience and sustainability, GIS is a fundamental tool for all.

Modelling Scenarios Goodchild (2008) defines modelling in the context of GIS as occurring whenever operations of the GIS attempt to emulate processes in the real world, at one point in time or over an extended period. Models are useful in a vast array of GIS applications, from simple evaluation to the prediction of future landscapes. Models can be static if the input and the output both correspond to the same point in time, or dynamic if the output represents a later point in time than the input. The common element in all of these models is the operation of the GIS in multiple stages, whether they be used to create complex indicators from input layers or to represent time steps in the operation of a dynamic process (IJRES,2019).

Emergency Response: during disasters or emergencies like fire outbreaks, or earthquakes, GIS can help responders to understand what is happening at the moment and where it's happening so they can deliver help where needed. Emergency management teams use GIS technology before and after emergencies for planning and recovery.

Land-use planning and conservation: Effective land-use planning is essential to balance urban and regional development with environmental conservation. GIS provides the tools to make informed decisions about land allocation, zoning, and identifying areas for conservation. Environmental planners use GIS to study the impact of development on ecosystems, helping to minimise harm and protect sensitive areas. In addition, GIS is instrumental in urban planning to ensure efficient land utilisation and infrastructure development while preserving green spaces and natural habitats (Cypress Environment, n.d.).

Pollution control and monitoring: One of the critical challenges in environmental management is controlling and monitoring the effects of pollution. GIS assists in pinpointing sources of pollution, such as industrial discharges or runoff from urban areas. It aids in the assessment of the spread of pollutants, enabling effective containment and cleanup strategies. Real-time monitoring using GIS technology helps environmental agencies respond swiftly to pollution incidents, protecting ecosystems and public health.

Natural resource management: This is a critical aspect of environmental preservation. GIS plays a significant role in understanding, conserving, and sustainably utilising these resources. It assists in tracking forest cover, monitoring wildlife habitats, and assessing changes in land use. GIS also helps manage water resources, from tracking water quality to optimising the distribution of water for irrigation.

For instance, GIS aids in mapping aquifers, monitoring water levels, and even evaluating the impact of climate change on water sources (Cypress Environment, n.d.).

Spatial Analysis of Environmental Information: Major GIS software offers tools for in-depth analysis of environmental information hence providing insights that are useful to environmentalists and managers for decision making. This is made possible by the capability of GIS systems to integrate different layers of information within a given reference system. With spatial analysis systems, you can find suitable locations, perform land-use analysis, predict fire risk, analyse transportation corridors, determine pollution levels, determine erosion potential, and perform demographic analysis (IJRES, pg 8). Some of the analyses enabled by GIS include;

Query functions: After a functioning GIS containing spatial information has been established, environmental managers can begin to ask questions such as Where are all the sites suitable for building new houses? What is the dominant soil type for oak forests? If I build a new highway here, how will traffic be affected? Etc. Both simple and sophisticated queries utilising more than one data layer can provide timely information to decision-makers.

Temporal analysis: This is a time series analysis that is meant to monitor the variation of an environmental phenomenon over a period of time. A typical example is monitoring the rate of desertification. These analyses give trends that are used to predict the situation in the future.

Surface interpolation analysis: When representing data over a given area e.g. temperature variation, it is not possible to measure the temperature for every point. In practice, data is collected at sample points that are representative of the whole area. A temperature variation surface is then generated from the sample points. GIS software has tools for surface generation and analysis and these tools are very useful when analysing environmental information that requires representation as surfaces (Okusimba, 2019).

3D analysis: this is applicable when analysing terrain information, most times digital terrain models (DTM) are necessary. DTM generated and visualised in a GIS environment can provide insights into environmental phenomena. These models can be used in modelling other environmental issues such as watersheds. Data on elevation is necessary for the generation of DTMs. It is derived from field surveys, aerial photographs, satellite imagery etc.

GIS for wildlife: man-made destruction such as habitat loss, invasive species introduction, pollution, and climate change are all threats to wildlife health and biodiversity. GIS technology is an effective tool for managing, analysing and visualising wildlife data to target areas where international management practices are needed and to monitor their effectiveness. GIS enables wildlife professionals to examine and envision (Ummaneni & Tiparthy, 2021).

Soil mapping: This provides resource information about an area. It helps in the understanding and management of soil suitability for land use activities. It helps to monitor and prevent environmental deterioration that could result from land misuse. GIS helps to identify soil types in an area and to delineate soil boundaries. This further helps in the identification and classification of soil types. For advanced farmers, soil mapping helps them to manage and retain soil nutrients for maximum yield.

Detection of coal mine fires: According to Kun Fang's GIS analysis in the rescue of coal, GIS technology is applied in the area of safe production of coal mines. Coal mines have developed an information management system; the administrator can monitor the safe production of coal mines and improve the ability to make decisions. Fire outbreaks are common in coal mines but with the help of GIS technology, spontaneous combustion risk is accessed early and managed.

Wetland mapping: Wetlands contribute to a healthy environment by helping to retain water during the dry season by keeping the water table high and relatively stable. Wetland helps to reduce flood levels by trapping suspended solids and also attaching nutrients to the soil during flooding. GIS technology provides options for wetland mapping and also helps to provide designs for wetland conservation.

Forest Fire Hazard Zone mapping: Forest plays an important role in our local climate; it is one of the important elements of nature. Forest fire causes extensive damage to our communities and environmental resources base. GIS technology can assist with forest fire hazard zone mapping and also estimate damage or loss. It can also help to capture real-time monitoring of fire-prone areas using GNSS and satellite remote sensing.

GIS has a vast contribution, not just to environmental management but to a wide range of industries and management. It helps to envision, detect, approach and make informed decisions about situations and events. GIS is of a wide range of importance and like everything that has the advantage, it has its limitations however, it's minimal and avoidable.

KEY Advantages of GIS on environmental management.

GIS (geographic information systems) is a valuable tool in the realm of environmental management, offering a wide range of advantages that elevate the decision-making process and overall effectiveness. Here are some **key** benefits:

Spatial visualisation: GIS allows environmental data to be represented geographically, providing an intuitive and easy-tounderstand visual context for decision-makers. This enables better comprehension of complex environmental factors.

Data integration: Environmental issues are often multifaceted, involving data from various sources. GIS can integrate diverse data sets, making it easier to analyse relationships, correlations, and trends within the data.

Efficient resource allocation: With GIS, environmental resources can be allocated more efficiently. For instance, it can assist in identifying the optimal location for a conservation area, maximising its benefits while minimising environmental impact.

Impact assessment: GIS supports environmental impact assessment by modelling and predicting the potential consequences of a project or policy on the environment. This enables better decision-making by minimising negative impacts.

Monitoring and response: Real-time monitoring of environmental data is made possible through GIS, allowing for immediate response to environmental changes or incidents. It's crucial for managing issues such as air quality, water quality, and natural disasters.

Public engagement: GIS can enhance public engagement and participation in environmental decision-making. Interactive maps and data visualisation tools make it easier for the public to understand complex issues and provide input (cypressei.com).

Limitations of GIS and challenges to consider

While GIS is a powerful tool, it's important to acknowledge that it has limitations and challenges and to make conscious efforts to mitigate these challenges.

Interdisciplinary collaboration: to effectively manage the environment requires collaboration between multiple disciplines. GIS integration may influence overcoming communication barriers between experts in various fields.

Data accuracy: The quality and accuracy of GIS data are crucial as they inform standard decisions. Errors or inaccuracies in data input can lead to wrong conclusions and lead to potentially flawed environmental decisions.

Data volume and complexity: Environmental data are extensive and can be complex. Handling and processing large data sets can strain computational resources and therefore require specialised expertise.

Resource requirements: Implementing and maintaining GIS systems requires intensive resources. These resources include the costs of software, hardware, data acquisition, and even staff training.

Data privacy and security: every technology requires data privacy and security and they are of great concern. Care must be taken to ensure the protection of sensitive environmental data when using GIS.

CONCLUSION

Geographic Information System tools have limitless applications; however, they play a significant role in the management of our environment. From day-to-day applications like tracking freight and, use of digital maps to drive to our location, to solving bigger problems like identifying potential hazards, to query functions that could lead to analysis and making informed decisions on environmental planning and management. The above has shown the huge potential of GIS in environmental management. By enabling advanced data analysis and visualisation capabilities, GIS empowers stakeholders to make informed decisions that protect ecosystems. Amidst avoidable limitations that may exist, the spatial intelligence and predictive modelling GIS provides are potential assets for continuous development in environmental management. GIS is an important component of the environmental information system.

RECOMMENDATIONS

Drawing insights from available data on scenarios, case studies, research and reports, GIS technological tools are a roadmap that will make many jobs in every field a lot easier and as such make preserving our environment a lot easier and better. With GIS technology becoming a lot more accessible and affordable and system memories expanding, what this entails is that a lot more sets of data can be handled with GIS and making informed decisions about our environment becomes a lot faster and safer. As environmental managers make substantial efforts to solve human needs sustainably with minimum interruption of the environment, GIS is a reliable tool to effectively carry out these activities with minimal impact on the ecosystem.

REFERENCES

Application of GIS in Environmental Management–Retrieved from: https://cypressei.com/engineering/application-gis-environmental-management/ Accessed 20 November, 2024

Cypress Environment and Infrastructure, (n.d.). Retrieved from https://cypressei.com/

Esri.Com (n.d) Retrieved from https://www.esri.com/en-us/home

GIS in Environmental Studies – An overview. Retrieved from:https://geospatialworld.net/article/gis-in-environmental-studies-an-overview/ - Accessed 19 November, 2024

Goodchild, M.F. (2008). The use cases of digital earth, International Journal of Digital Earth, 1:1, 31-42, DOI: 10.1080/17538940701782528

History of GIS – Retrieved from: https://www.esri.com/en-us/what-is-gis/history-of-gis Accessed 20 November 2024.

How Can We Use GIS for Environmental Preservation? - Retrieved from: https://ellipsisdrive.com/blog/how-gis-helps-to-save-the-environment/ - Accessed - 20 November, 2024.

International Journal of Research in Education & Science (IJRES), 2019. Retrieved from https://www.ijres.net/index.php/ijres.

Jaimme Martindale (2024) - Mapping and Geographic Information Systems (GIS) : What is GIS? Retrieved from: https://researchguides.library.wisc.edu/GI Accessed 20 November, 2024.

National Centre for Geographic Information and Analysis. (n.d.). GIS and Modeling Overview. University of California: Goodchild M.F. – Retrieved from: http://www.geog.ucsb.edu/~good/papers/414.pdf - Accessed 21 November, 2024.

Okusimba, G. O. (2019) - Role of GIS as a Tool for Environmental Planning and Management - International Journal of Research in Environmental Science (IJRES) Vol 5 pp 4-9. Retrieved from: https://www.arcjournals.org/pdfs/ijres/v5-i1/2.pdf - Accessed 19 November, 2024.

Research Guides Home (n.d.) Retrieved from https://researchguides.case.edu/FacultyStaffPublications/2021-2024.

Role_of_Geographical_Information_System_GIS_in_Environmental_Management - Retrieved from: https://www.researchgate.net/publication/361609939_ - Accessed 21 November, 2024.

The history of the geographic information system. Retrieved from: https://www.bcs.org/articlesopinion-and-research/the-history-of-geographic-information-systems-gis/- Accessed 19 November, 2024.

Ummaneni & Tartiparthy, 2021 pp 4 - 8, Role of Geographical information system (GIS) in environmental management. Retrieved from: https://www.researchgate.net/publication/361609939_ Accessed 20 November, 2024.

Use of remote sensing and gis for sustainable land management. Retrieved from: https://wgbis.ces.iisc.ac.in/energy/HC270799/LM/SUSLUP/KeySpeakers/ASkidmore.pdf Accessed 22 November 2024.

University of Bolton, (n.d.). Retrieved from https://www.bolton.ac.uk/.

What is environmental management? Retrieved from: https://www.bolton.ac.uk/blogs/environmental-management-why-is-it-so-important - Accessed 20 November, 2024.

What is a geographic information system? Retrieved from: https://www.esri.com/en-us/what-isgis/overview Accessed 19 November, 2024.

What is a geographic information system (GIS)? Retrieved from: https://www.ibm.com/topics/geographic-information-system Accessed 19 November, 2024.