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Geoinformatics – A Versatile Tool for Planning and Management of Infrastructure and Resources

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Abstract

Geoinformatics is a rapidly evolving field that brings meaningful insights to solve real world problems by bringing together technologies and tools required for acquisition, exploration, visualization, analysis and integration of various spatial data. There are several components of Geoinformatics that include cartographic geovisualization, GIS, Remote sensing, photogrammetry, GPS, spatial statistics, geostatistics, multivariate statistics and other advanced tools and techniques. Spatial and non-spatial datasets are crucial for studies on environmental and sustainable development planning. World-wide, geoinformatics tool is being used in a large number of mega projects for better planning and management of resources. The emerging need of geospatial technology has created an unprecedented demand of trained manpower, who can contribute to production and analysis of these datasets. Geoinformatics combines photogrammetry, remote sensing, image processing as well as other digital spatial data collection methods, like GPS, field measurements, digitizing and scanning of maps, spatial data analysis algorithms and geographical data management, and visualization. This paper highlights the growing uses and applications of geoinformatics in planning and management of infrastructure and resources in India and world-wide.

Keywords

Geoinformatics, Photogrammetry, Remote Sensing, GIS, GPS, Planning and Management, Infrastructure and Resources

1. Introduction

In a rapidly changing world, *Geoinformatics* has a special significance, and is used for monitoring environment and human activities on the Earth's surface. Geoinformatics consists of two words; "*Geo"* which refers to *"Earth"* and *"Informatics"* which refers to *"Information Processing"*. Hence, geoinformatics can be understood as the union of Earth sciences and Informatics (IGNOU, 2012). Wikipedia defines geoinformatics as "*...the science and the technology which develops and uses information science infrastructure to address the problems of geography, geosciences and related branches of engineering*". The art, science and technology dealing with the acquisition, storage, processing, production, presentation and dissemination of geoinformation is called geoinformatics [1]. According to [2] it is a powerful set of tools for collecting, storing, retrieving, transforming and displaying of spatial data from the real world.

Prakash [3] defined geoinformatics as "the collection, integration, management, analysis, and presentation of geospatial data, models and knowledge that support disciplinary, multidisciplinary, interdisciplinary and transdisciplinary research and education". The four main tasks of geoinformatics are: (i) collection and processing of *geodata* (geodata is the contraction of geographic data), (ii) development and management of databases of geodata, (iii) analysis and modelling of geodata, and (iv) development and integration of logic and computer tools and software for the first three tasks. Geoinformatics may be defined in a relatively broad term as a number of different *technologies, approaches, processes, and methods* dealing with the issues mostly related to the Earth's surface for collaborative decision making [4].

The term '*Geoinformatics*' is believed to have come in existence just few decades back as a result of the integration of four major disciplines; *Photogrammetry, Remote Sensing, Global Positioning System (GPS)* and *Geographical*

Information System (GIS). Geoinformatics is a multidisciplinary science which can combine different types of dataset from various branches of *cartography, geodesy*, *photogrammetry, remote sensing, Laser, GPS, field, web-mapping, socio-economic, computer science, computer vision, mobile and game technology, intelligent system*, and *internet of things*, to generate results in the form of maps or reports which allow better *interpretation, management and decision making* about various human activities on Earth's surface [5].

For analyzing information related to Earth, geoinformatics combines geospatial analysis, geospatial models, geospatial databases, human-computer interaction, both wired and wireless networking technologies which are referenced to geographic location. It is the advancing science and technology, which can be used as a powerful tool for research and development to generate geocoded data and attribute database to help taking appropriate decision for planning [5]. Geioinformatics research involves the use of modern information methods and technologies. Application programs, databases, the internet and software development constitute the foundation for the deployment of geoinformatics.

Geoinformatics is a valuable tool for planning and monitoring social, economic and technical processes. The dynamic progress of geoinformatics is strongly connected to the rapid development in information technology, especially software and computer graphics. The problem solving of geoinformatics is accomplished through GIS. The GIS is firstly introduced by Canadian researcher, Roger Tomlinson in 1968 [6]. It is used to *visualize, query, analyze, and interpret geospatial data to understand the relationships, patterns, and trends, mostly* employed in the field of geographyto explore and find the answers [4]. GIS being a powerful tool in spatial analysis; many disciplines have recently employed GIS to answer their research questions. Conceptualisation of geoinformatics is represented in Figure 1 (a).

There is another term i.e., '*Geomatics*', which was first used in Canada at Laval University in the early 1980s to describe the Geodesy, Engineering and Mathematics disciplines [1] realising the increasing potential of computing which was revolutionising surveys and representation sciences (Figure 1b). According to many sources, Geomatics is related to acquire and manage spatial data from the *engineering point-of-view*. It consists of two words; "*Geo*" which refers to *"Geodesy"* and, "*Matics"* which refers to *"Mathematics"*. As per Wikipedia, "*Geomatics (or geomatics engineering), also known as surveying engineering (or geospatial science or geospatial engineering or geospatial technology), is the discipline of gathering, storing, processing, and delivering geographic information or spatially referenced information*". In other words, it consists of products, services and tools involved in the collection, integration and management of geographic data. According to Konecny [7] geomatics, composed of the disciplines of geopositioning, mapping and the management of spatially oriented data by means of computers, has recently evolved as a new discipline from the integration of surveys and mapping (geodetic engineering), merged with the remote sensing and GIS".

Michalak [8] considers the term 'Geomatics' to be interchangeable with 'Geoinformatics'. However, some researchers are of the opinion that both Geomatics and Geoinformatics include geographical information and rely heavily upon the theory and practical implications of geodesy. The main focus of geomatics is on spatial information while the geoinformatics deals with the structure and nature of spatial information and also addresses the problems related to geography and geo-sciences. In time-line, GIS is the oldest one, followed by Geomatics, and the youngest is Geoinformatics, as shown in the Figure 2.

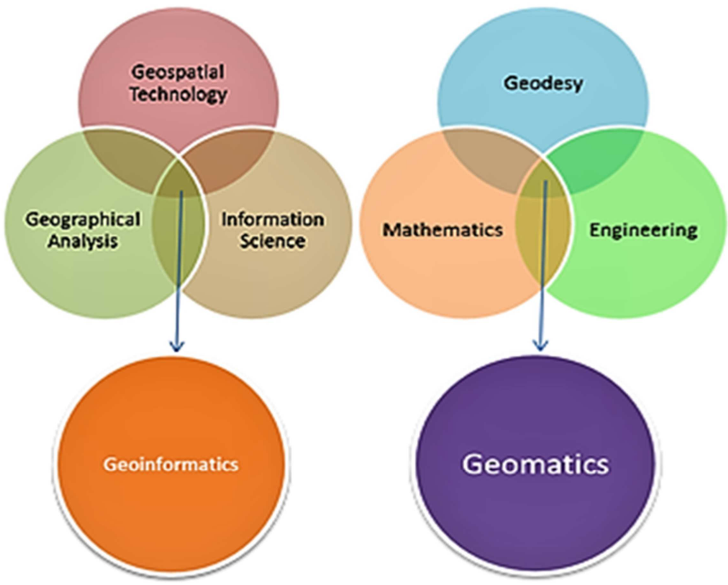


Figure 1. *Concept of (a) Geoinformatics, and (b) Geomatics (Source: [9]).*

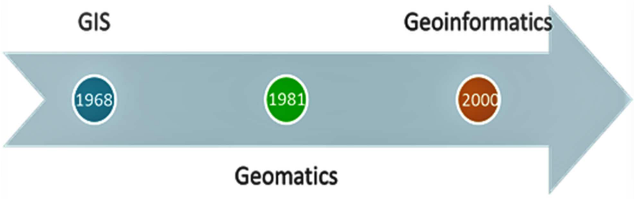


Figure 2. *Timeline of GIS, geomatics and geoinformatics.*

Oledzki [5] believes that the term geoinformatics is more easily understood, and is much better at conveying the essence of spatial research focusing on informatics. In about last four decades, geoinformatics has grown as a major tool for collecting information on almost every aspect on the Earth. In fact, with the availability of very high spatial resolution satellites in the recent years, applications of geoinformatics have increased manifold for a wide range of applications related to emergency services, public health, traffic & transportation, infrastructure, mineral and oil exploration, urban planning, land use, watershed management, environmental modelling, agriculture, meteorology, climate change, oceanography, business, atmospheric modelling, crime mapping, location based planning, telecommunications, navigation systems, military etc.

2. Major Disciplines of Geoinformatics

2.1. Photogrammetry

Photogrammetry is the art, science and technology of obtaining reliable information about physical objects and the environment, through processes of recording, measuring, and interpreting photographic images and patterns of recorded electromagnetic energy and other phenomena [10]. It is heavily dependent on developments in software, computer science and electronics. This becomes especially evident in the shift from analog to analytical and digital methods. Images used in photogrammetry can originate from a special (metric) camera, an ordinary camera or from digital sensors, captured by aerial cameras from an airplane (aerial photogrammetry), or on a tripod (terrestrial photogrammetry) which is set up on the ground.

The photogrammetric process consists of project planning, image acquisition, image processing, and control data for image orientation, data compilation and derivation of results. The end product from the photogrammetric process can be the coordinate values of individual points, a graphical representation of the ground surface (topographic map, thematic map, etc.), or a rectified image with map-like characteristics (orthophotos) which can be used in GIS. Photogrammetry requires certain skills, techniques and judgments to be made for taking reliable measurements by the specialists and experienced interpreters [11].

2.2. Remote Sensing

Remote sensing refers to obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation [12]. Remote sensing can be defined as the "*art of science & technology of obtaining reliable information about the physical objects and environment through the process of recording, measuring & interpreting images/data obtained from remotely distant sensor systems*".

In remote sensing, interactions between the Earth surface and the electromagnetic energy take place. Detection and discrimination of objects or surface features are done through recording of radiant energy reflected or emitted by objects or surface material. Various sensors gather the data and efficiently absorb the reflected energy from the object on the Earth surface. These sensors onboard remote sensing satellites play an important role in data capture and dissemination.

Remote sensing systems provide a very important source of spatio-temporal information on Earth surface processes at scales ranging from regional to global. A wide range of parameters can be measured from remote sensing images, including land use, vegetation types, surface temperatures, soils, water, geology, forestry, surface elevation and snow. Sequential remote sensing images are useful in monitoring flood, water pollution, deforestation, extent of forest fire, snow cover, urban sprawl studies, crop acreage and yield estimation, drought monitoring and assessment, wasteland mapping, mineral prospects, forest resource survey etc [13]. Today, remote sensing image have become an integral part of the resources management system.

2.3. GPS

The Global Positioning System (GPS) was designed to show the exact position of objects on the Earth anytime, anywhere, and in any weather condition. It is the most advanced and popular system of navigation. This system was launched into space in 1978 with the first GPS satellite [14]. In the early 20^{th} century, ground-based radio-navigation systems were developed.

Today, the technology has benefitted various applications like, Highways, Remote sensing, GIS, Railroads, Mining/Geology, Surveying and mapping, Agricultural, Environmental management, Geodesy, Resources, Power, Telecommunications, Health, Law enforcement, Emergency, Crustal movement, Disaster response, Weather, Aviation, Maritime, Precise timing, Automobile, Tracking objects, Sports, Construction, Recreation, etc. Now a days, GPS are used extensively mainly by navy, airforce, army, coast guard, rescue & relief personals, civilian carriers, surveyors, commercial transport, hikers, and trekkers [15]. World-wide, there are a large number users of GPS enabled gadgets, like mobile phones, wrist watches etc., for a variety of utility [16].

2.4. GIS

A Geographic Information System (GIS) is defined as an information system which is capable of integrating, storing, editing, analysing, sharing and displaying spatially referenced data of the Earth [17]. GIS can be used to visualize, query, analyze, and interpret data to understand relationships, patterns, and trends. In a simple way, GIS consists of images that are geo-referenced to the Earth or have x, y coordinates and their attribute values that are stored in the table. GIS can use any information that includes location. These locations can be expressed in many different ways, such as latitude and longitude, address, or ZIP code [18].

GIS - a geospatial technology - can be used to create spatial databases, analyze spatial patterns, and produce maps that communicate more effectively [19]. GIS application tools allow end users to perform spatial query, analysis, edit spatial data and create maps. The spatial data generally is in the form of maps, such as topography, geology, soil types, forest and vegetation, land use, water resource availability etc., stored as layers in a digital form. Integrating a database of multiple information layers can produce new thematic maps. Thus, GIS can be used to create maps, integrate information, visualise scenarios, solve complicated problems and develop effective solutions. These capabilities distinguish GIS from other information systems and make them valuable to a wide range of modelling applications, such as assessing trends and patterns of the events, predicting outcomes, and planning strategies [18].

There are lot of applications where GIS can be used. GIS technology integrates common database operations, such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. It can be used for updating maps much easier than updating maps manually. GIS system can be used to produce three-dimensional images or view of the terrain. It has the potential to help decision makers and planners by further developing it as an Expert System or Decision Support system (DSS) to provide best solution to make decisions and solve problems [20].

3. Applications of Geoinformatics

The geoinformatics technologies have witnessed significant developments over the last few decades, which have led to widespread use of the technologies in different fields and disciplines. Geoinformatics is central to all the disciplines which use spatial data recognised by their locations. It has now become an important tool for decision makers across a wide range of disciplines, researchers and academia, national survey & mapping organisations, industries, environmental agencies, and local & national governments [21]. Its applications are mainly oriented to real-world management problems pertaining to natural and man-made environments.

Geoinformatics is most useful for Government planning, like urban planning and land use management, agriculture etc. Other areas where the geoinformatics can bring revolutionary changes are climate change, oceanography, business location planning, archeological reconstruction, telecommunications, criminology, navigation etc. Geoinformatics today has become an important technology for industries and organisations as it enables them to acquire, process, analyse, visualise spatial information and produce outputs. For example all major Telecom companies use geoinformatics technologies to lay their cables and locate mobile towers. Power sectors have identified geoinformatics technologies as the decision support tool for locating the electrical assets in towns to reduce the transmission loss and reduce electrical theft through consumer mapping.

According to Zhu et al [22] Building Information Modelling (BIM) and GIS both have their roots in different knowledge areas. While BIM serves the architecture, engineering, and construction/facility management domain by providing detailed 3D building models that could be used throughout the lifecycle of a construction project, including plan, design, construction, operation, and dismantling [23], the GIS analyses and visualizes location-related problems in geospatial science by integrating heterogeneous spatial and various attribute data, and deriving knowledge through various spatial analysis tools and modelling approaches [24]. A recent report from P&S Market Research shows that the global GIS industry had a value of $8.98 billion in 2016, and is estimated to grow at a compound annual growth rate of 10.1%, to reach $17.51 billion by 2023 [25]. The BIM world is also expanding, and it is estimated that the global BIM market will grow from $3.16 billion in 2016 to $7.64 billion by 2022 [26].

According to Report on India's Geospatial Market and Prospects [27] the applications of geospatial technology has definitely found new avenues in recent times. Availability of real-time/updated information about assets and consumers is a key driver in usage of geospatial technologies. Satellite imagery and GIS are two of the most used technologies in the agriculture sector. Policy mandates drive usage of GPS, remote sensing and GIS in the areas of disaster management. Visualization and interpretation of disasters is the key to usage of digital maps. Majorly geospatial technologies are implemented for forest cover assessment and environmental modelling. GIS is widely used for asset management and network planning in electric utilities. Infrastructure development is aided by surveying & mapping related technologies, like total stations and GPS. Adoption of geospatial technologies in urban development is more towards data creation and monitoring. Usage of GIS and GPS is deriving help in project management and resource allocation in the water sector.

There are large number of benefits of using geospatial technologies, such as (i) better precision and accuracy, (ii) enhanced data safety, security and control, (iii) faster decision making, (iv) improved cost efficiency, (v) improved productivity, and (vi) increased transparency and planning [27].

4. Status of Geoinformatics in India

India has long been a leader in using modern spatial technologies and started its tryst with satellite images and GIS in the 1980s by having its own Indian Remote Sensing satellites and image-based mapping, and thus creating GIS databases for various applications. Geoinformatics is fast expanding its presence in India, and has become an important component of planning & decision making in various sectors, such as urban planning, natural resources, infrastructure, agriculture, forestry or location-based services. The emergence of Web 2.0 with the power of mapping and collaborative initiatives has helped change the way the geoinformatics tools & technologies can be used to generate maps, create interactive queries, analyse and visualise information for decision making purposes. There are many resource planning and business activities now which are unimaginable without input from geoinformatics [21].

The *Digital India* project could help in connecting various projects, past and present, to bring India on a global platform. In various programs of the government, such as *Digital India, Smart Cities, Skill Development, Start-Up India, Make in India, National Mission for Clean Ganga, Interlinking of Rivers, Delhi Mumbai Industrial Corridor, Smart Power, and Agriculture*, geospatial technologies are poised to play a critical role [28, 29]. For instance, geospatial technology will act as the backbone for Smart City initiatives for Tier 1 cities and AMRUT for Tier 2 cities (Figure 3). Such projects of national significance would have major challenges related to project planning, conceptualization, design, implementation and monitoring. In all these phases of infrastructure and construction projects, geospatial technologies have a significant role to play.

India's '*Vision 2020'* envisages the nation evolving into an information society and knowledge economy built on the edifice of information and communication technology (ICT). ICT, including geospatial technologies is being integrated into planning and management to monitor, evaluate and apply spatial planning of natural resources, utilities, infrastructure and urban development and transport sectors, as well as developing decision support systems (DSS) in India [30].

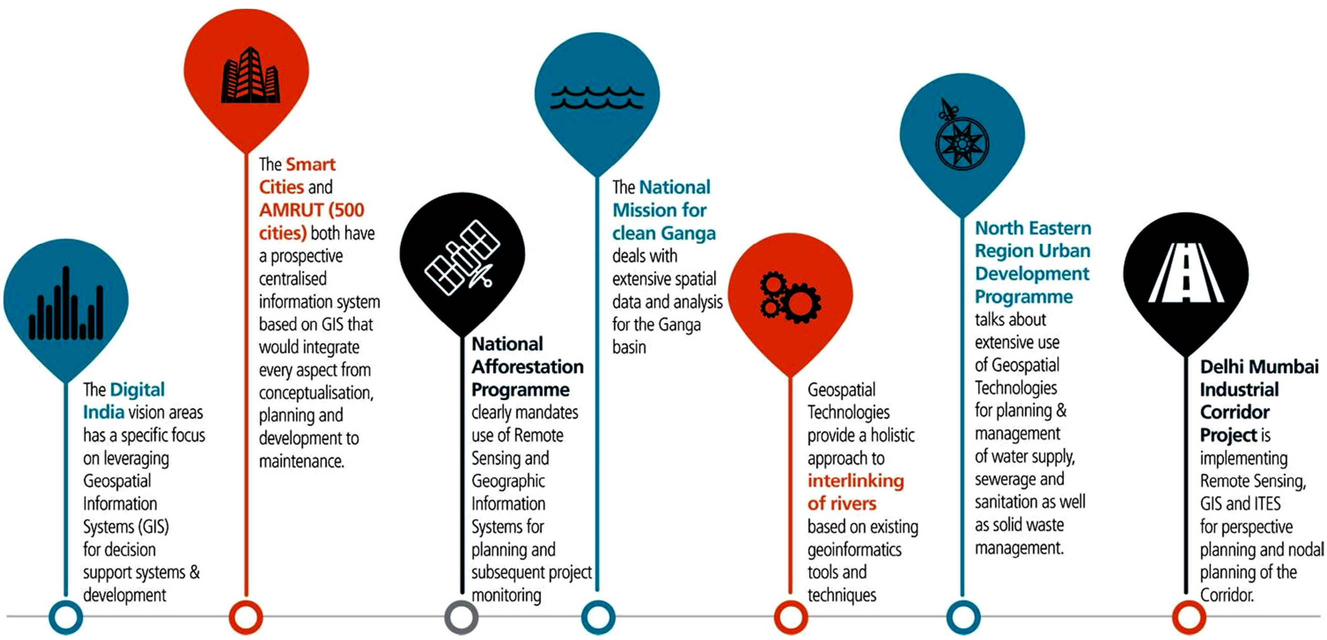


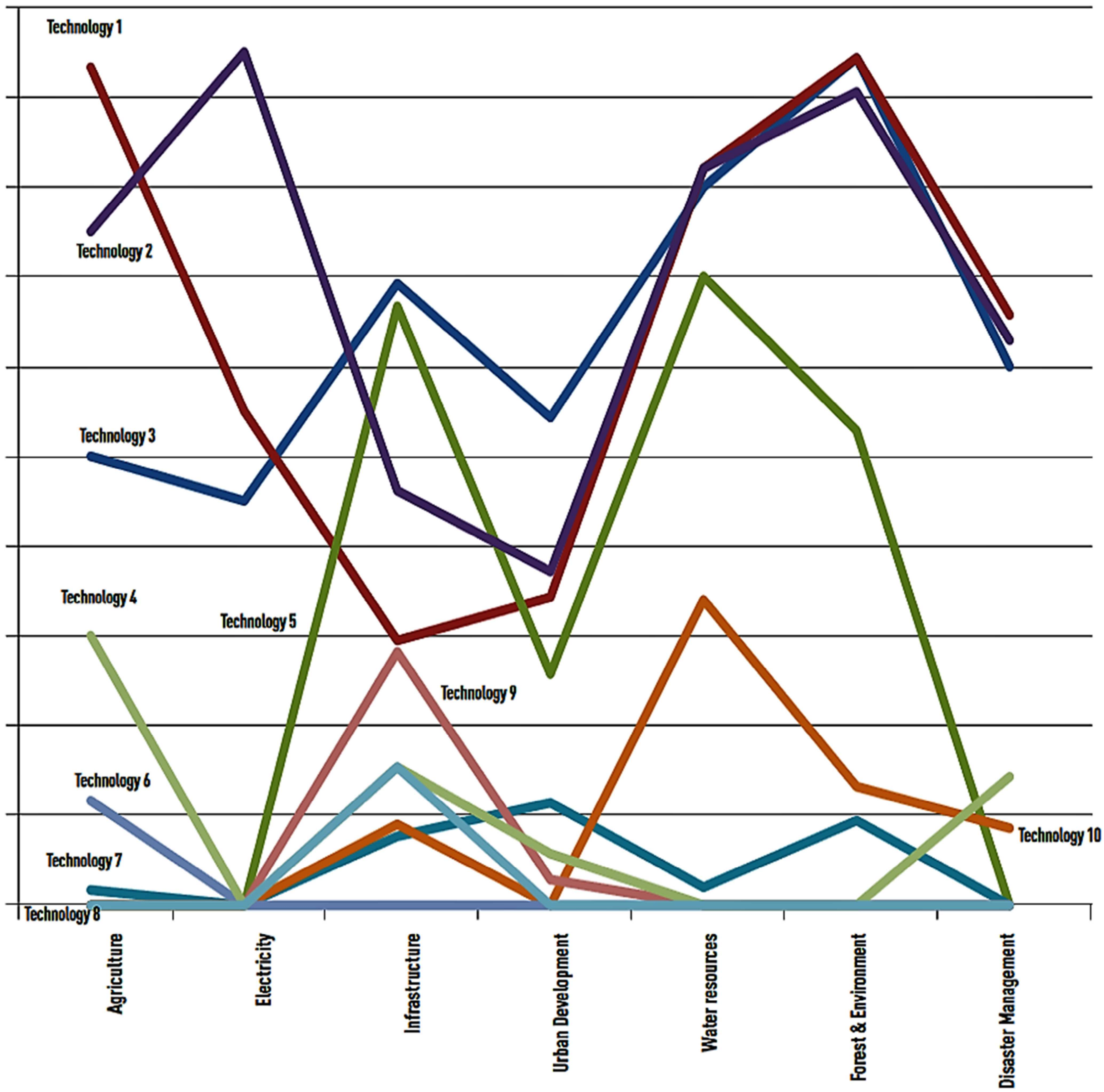
Figure 3. *Geospatial technology contributing to major ongoing projects in India (Source: [30]).*

The Indian geospatial industry consists of two distinct but mutually supporting segments. The larger, international segment is geared to provide geospatial data and software development services for international organisations, primarily in North America and Western Europe. The other segment, i.e., the domestic segment which is largely funded, managed and controlled by national and state governments, caters to providing geospatial capabilities to the Indian data providers/users [30]. The geospatial industry is presently witnessing tremendous opportunity within the country as the government has initiated several infrastructure projects and mandated the use of geospatial technologies. There are various other fields, such as, construction and maintenance of roads, railways and waterways, civil aviation, public utility services, education, health, command area development, flood control and management, urban renewal, urban water supply, rural water supply, etc., that essentially use geospatial tools and technologies for spatial planning, management and decision-making.

The adoption of various geospatial technologies in different sectors are presented in Figure 4, whereas Figure 5 shows the sectors where geospatial service providers are focussing currently as well as for future.

Recent surveys suggest that the Indian geoinformatics industry is witnessing higher growth rate than the average global growth rate than any other nation. The significant rise in demand for geospatial information is likely to give it more weightage in both public and private planning across sectors.

Figure 6 shows the percentage growth for the Indian geoinformatics industry vis-a-vis worldwide growth. There is a significant increase expected in productive capacity after 2012 as India's geospatial industry builds out capacity for new international and internal markets. The growth of India's geospatial market will outpace growth rate for geospatial markets in the rest of the world [30]. Several trans-national companies have outsourced their operations to India in order to harness the significant technical expertise in the geospatial sector [21].



Legend			
Technology 1 GIS	Technology 2 GPS	Technology 3 LiDAR/Laser scanning	Technology 4 Satellite images
Technology 5 Aerial photographs	Technology 6 Total station	Technology 7 RADAR	Technology 8 CAD
Technology 9 UAV	Technology 10 BIM		

Figure 4. *Adoption of various geospatial technologies in different sectors in India (Source: [27]).*

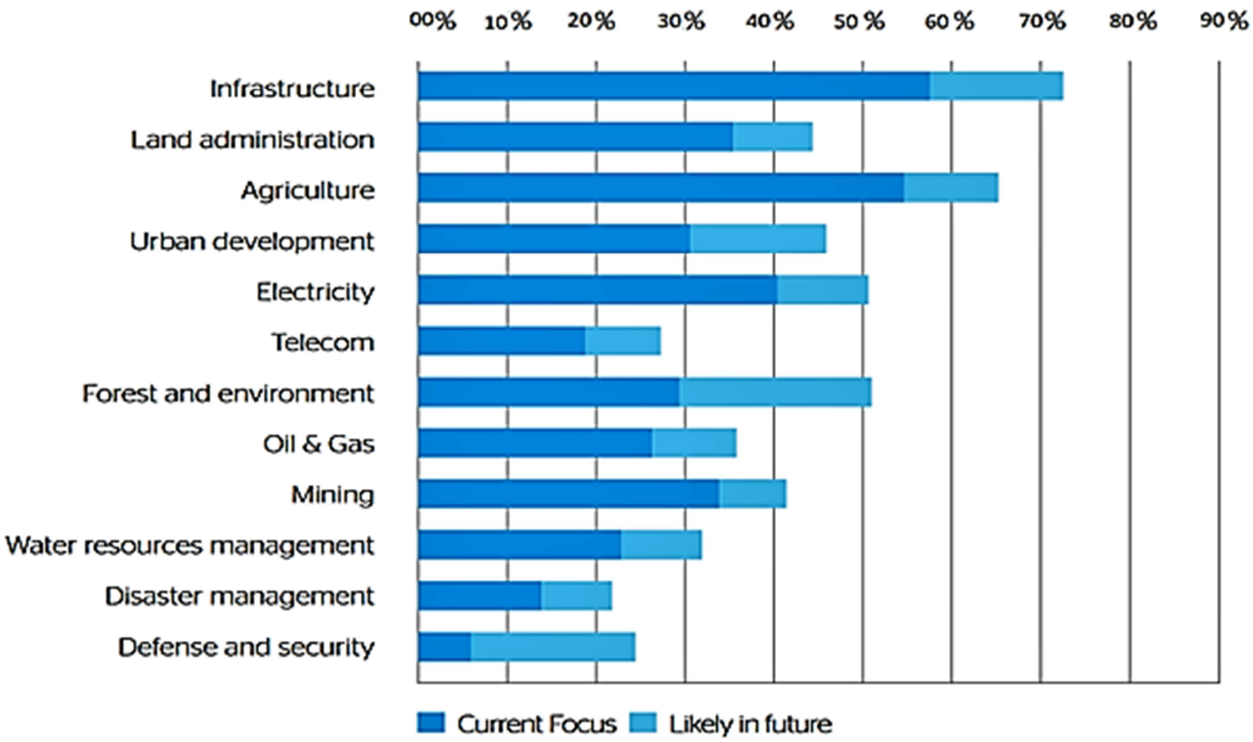


Figure 5. *Geospatial service providers focussing on various sectors in India (Source: [27]).*

The geospatial data usage in India is supported to a large extent by initiatives set out by the government through its ministries and various departments. While defence is the major user of geospatial technologies, the initial lead for the usage of geospatial technologies in India was taken by the natural resources sector [30]. Geographical information is a ubiquitous part of the governance. The primary role of Government is decision making in public interest which involves geographically related issues, therefore, GIS can play a critical role in all spheres of good governance. Several local governments have now come to depend on geospatial technologies to not only organise and manage spatial data, but also for dissemination of information and services to citizens [21]. Now, solutions such as decision support systems, asset management, enterprise wide risk assessment etc. have opened up avenues for this technology in almost every sector.

Despite the acceptability that this technology has found amongst different stakeholders and end-users in India, the benefits of this technology are yet to go beyond specific projects to find applicability within the entire gamut of governance, decision-making and nation-building [21]. In relation to the development in the country, the actual demand for the application of geospatial technology domestically is far from adequate. Several potential sectors are yet to adopt the technology and make optimal use of its huge potential for better and cost-effective planning and management. It continues to be seen as a niche technology requiring huge investment and specific expertise leading to an aversion to adopt geospatial tools. The long terms benefits such as economy of time, effort, resources and cost for data collection and analysis are to be understood by the end-users.

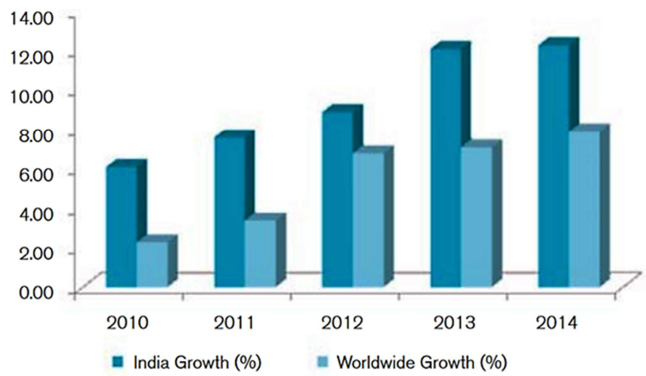


Figure 6. *The growth of India's geospatial market vis-a-vis rest of the world (Source: [30]).*

The National GIS (NGIS) project in India was supported by Sam Pitroda, the then adviser to the Prime Minister on information technology, and the Planning Commission, and listed 1:10,000 mapping of the country as one of its primary focus areas [29]. India visualizes starting of a National GIS as important step to map changes in natural resources, and to understand the complex interplay of social order and economic growth. GIS is technology-centric but needs to be decision-centric. This means that all types of decision makers, governments, enterprises, and citizens should have the ability to easily make use of readily available GIS data and applications that can help solve their problems [4].

India has recognized that a strong organizational framework is essential for bringing focus and for institutionalizing National GIS and promoting geospatial technology use by government, enterprises, and citizens. The process of establishing and implementing the state and national vision will also provide considerable opportunities for the private sector to contribute to and be part of this national endeavor. The national and state GIS will also boost education and research in GIS with specific school, university, and research programs focused on training the leaders of tomorrow in spatial thinking concepts and the core principles of GIS [4].

India is recognised for its IT skills and space programmes. It offers good infrastructure and expertise for collection of geospatial data. Capacity building is key to capitalise on the opportunities presented before the Indian geospatial industry. India has shortage of skilled human resource in the field of geoinformatics, so students can take this as hotspot career. Large numbers of institutions in the country offer courses in various disciplines of geographical information science at undergraduate as well as post-graduate levels to sustain technically sound human resource base. Geoinformatics is not only for the people studying surveying, remote sensing, GPS, GIS or geography, but recently more disciplines, like computer science, civil engineering, architecture, geology, environmental science etc., have included Geoinformatics as their minor or even as their major subject [31]. For that reason, it has become more important to develop the contents of Geoinformatics curriculum towards more scientific and less related with traditional surveying and mapping. Ongoing advances in GIS functionality and the convergence of network computing and wireless communications with geospatial technologies are expected to further unleash the hitherto untapped potential for applications in development planning.

5. Conclusion

In about last four decades, geoinformatics has grown as a major tool for collecting information on almost every aspect on the Earth. With the availability of very high spatial resolution satellites and associated technologies in the recent years, applications of geoinformatics have increased to a wide range of applications. Geoinformatics is fast expanding its presence in India and elsewhere. It has become an important component of planning and decision making in diverse sectors on Erath surface. Public perception towards geoinformatics industry has also changed. What was once considered an impenetrable domain is now easily understood by the common man. Geoinformatics tools and technologies have empowered us to generate maps, create interactive queries, analyse information with its different attributes and use the outputs for decision making purposes. There are many resource planning and business activities now, which are unimaginable without input from geoinformatics.

References

[1] IGNOU (2012) MGY_001 *Introduction to Geoinformatics*, IGNOU, School of Sciences, IGNOU, Delhi.

[2] Burrough P A (1986) *Principles of Geographical Information Systems for Land Resources Assessment*, Clarendon Press, Oxford, 194 pp.

[3] Prakash, A. (2006) Introducing Geoinformatics for Earth System Science Education. Journal of Geoscience Education. Volume 54, 2006 - Issue 5.

[4] ESRI (2014) *India's Vision for National GIS*, ESRI, California, USA, Jan 2014.

[5] Oledzki, J. R. (2004) Geoinformatics: An Integrated Spatial Tool, Miscellanea Geographica Warszawa. Miscellanea Geographica-Regional Studies on Development, 11, 323-331. http://www.wgsr.uw.edu.pl/pub/uploads/mcg04/35oledzki.pdf.

[6] Marble, D. F. and Peuquet, D. J. (1983) *Geographic Information Systems and Remote Sensing*, In R. N. Colwell (Ed.) Manual of Remote Sensing, Vol. 1, Falls Church, VA., ASPRS.

[7] Konecny, G. (2002) Recent Global Changes in Geomatics Education. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXIV, Part 6, pp. 9-14.

[8] Michalak, J (2000) Geomatics in Hydrology, Geological Quarterly, 47 (1), p 69-76.

[9] https://fatwaramdani.wordpress.com/2016/02/19/what-is-geoinformatics.

[10] Kraus, K., (1994), *Photogrammetry,* Verd. DümmlerVerlag, Bonn.

[11] Phillipson, Warren R. (1996) *Manual of Photographic Interpretation*, ASPRS Publication.

[12] Lillesand, T. M. and Kiefer, R. W., (1994) *Remote Sensing and Image Interpretation*, 3rd Ed. John Wiley & Sons, New York.

[13] Jensen, J. R. (2007) *Remote Sensing of the Environment: An Earth Resource Perspective*. 2nd Edition, Pearson Prentice Hall, Upper Saddle River.

[14] Herring, Thomas A. (1996) *The Global Positioning System*. Scientific American, February 1996: p. 44-50.

[15] El-Rabbany, Ahmed (2006) *Introduction to GPS: The Global Positioning System*, 2nd Edition, Artch House, Boston.

[16] Xu, Guochang (2010) *GPS: Theory, Algorithms and Applications*, Springer Verlag.

[17] Jones, C. (1997) *Geographic Information Systems and Computer Cartography,* Longman Publishers, Singapore.

[18] Bolstad, Paul V. (2002) *GIS Fundamentals*, Eider Press.

[19] Star, J., and Estes, J., (1990), *Geographic Information Systems: An Introduction*, Englewood Cliffs, NJ: Prentice Hall.

[20] Eldrandaly, Khalid. (2007) *Expert Systems, GIS, and Spatial Decision Making: Current Practices and New Trends*. Chapter 8 in Expert Systems Research Trends, A. R. Tyler (Ed), Nova Science Publishers, Inc., USA.

[21] Ramprasad (2013) Empowering India through Geospatial Technologies- select stories, FICCI, Editor-in-Chief and Publisher, Gateway Media Pvt. Ltd., Hyderabad 500004 (www.geospatialtoday.com).

[22] Zhu, Junxiang, Wright, Graeme, Wang, Jun and Wang, Xiangyu (2018), A Critical Review of the Integration of Geographic Information System and Building Information Modelling at the Data Level, International Journal of Geoinformation, Vol. 7, No. 66.

[23] Volk, R.; Stengel, J.; and Schultmann, F. (2014) Building Information Modeling (BIM) for existing buildings - Literature review and future needs. Autom. Constr, 38, p. 109-127.

[24] Longley, P. (2005) *Geographic Information Systems and Science*; John Wiley & Sons: Hoboken, NJ, USA.

[25] Markets and Markets (2017). Geographic Information System (GIS) Market; Markets and Markets: Seattle, WA, USA.

[26] Markets and Markets (2017). Global Building Information Modeling (BIM) Market: (2017–2021 Edition); Markets and Markets: Northbrook, IL, USA.

[27] Report on India's Geospatial Market and Prospects (2016), Published by Geospatial Media and Communications Ltd, Noida.

[28] Vardhan, Harsh (2015) How Geospatial Technologies are Contributing to Major Ongoing Projects in India?, Geospatial World, Oct. 2015.

[29] Datta, Anusuya (2016) Towards a National Geospatial Policy, Geospatial World, March 2016.

[30] Sonnen, Dave (2010) India on a Roll, Geospatial World, Sept 2010.

[31] Virrantaus, K. and Haggrén, H. (2000) Curriculum of Geoinformatics-Integration of Remote Sensing and Geographical Information Technology. International Archives of Photogrammetry and Remote Sensing, Vol. XXXIII, Part B6, p. 288-294.