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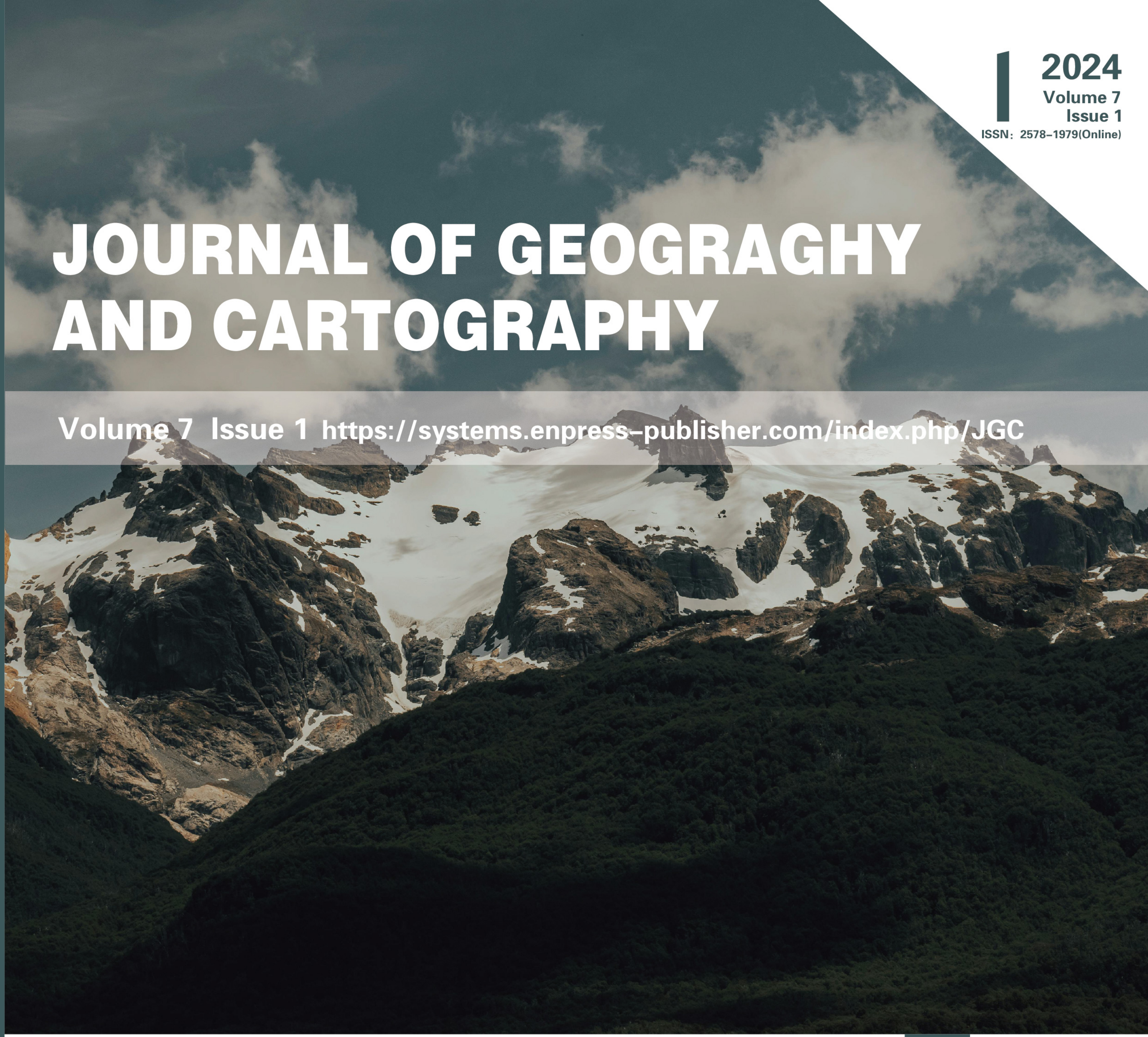

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Contents

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Article

An integrated urban water resources management approach for infrastructure and urban planning

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Abstract: Transportation projects are crucial for the overall success of major urban, metropolitan, regional, and national development according to their capacity by bringing significant changes in socio-economic and territorial aspects. In this context, sustaining and developing economic and social activities depend on having sufficient Water Resources Management. This research helps to manage transport project planning and construction phases to analyze the surface water flow, high-level streams, and wetland sites for the development of transportation infrastructure planning, implementation, maintenance, monitoring, and long-term evaluations to better face the challenges and solutions associated with effective management and enhancement to deal with Low, Medium, High levels of impact. A case study was carried out using the Arc Hydro extension within ArcGIS for processing and presenting the spatially referenced Stream Model. Geographical information systems have the potential to improve water resource planning and management. The study framework would be useful for solving water resource problems by enabling decision makers to collect qualitative data more effectively and gather it into the water management process through a systematic framework.

Keywords: integrated water resources management; urban water system integration; geographical information systems; hydro tool

1. Introduction

Theories and political frameworks for comprehending change in cities, the environment, policy, and infrastructure influence the form of study and activity. Integrated water management, sustainable water management, water-sensitive cities, and other formulations are often presented as the latest in a series of paradigms of water management [1]. A series of challenges has led to the continual evolution of the water management field. Practitioners and scholars have been promoting the need for a new "integrated" and "sustainable" water management paradigm. Such a paradigm is broadly defined to include many different objectives and methods. Integrated approaches, in different forms and identified by different names, have gradually become widespread in the field of water management over the past few decades [2].

The literature has a variety of terminologies that, when applied to urban water management, have definitions similar to IUWM. Integrated water cycle management, comprehensive water management, integrated urban water resource management, and integrated water cycle management are some of these terms. The IUWM idea is comparable to integrated water resource management (IWRM), which was first introduced by the UN in 1992. The application sector and spatial size are the main distinctions between IUWM and IWRM. The IUWM strategy focuses on managing water resources sustainably in urban environments, including stormwater, wastewater, and water supply. A multidisciplinary method for managing water and related resources, integrated water-resources management (IWRM) connects the multiple levels at which management occurs. The study commences with an examination of comprehensive methods for managing water resources at many scales, such as basin management, agricultural water management, watershed management, national policies and governance, and global decision-making [3].

The IWRM concept is separated by three levels of definition: (1) IWRM as a “principle” suggests balancing the social, economic, and environmental aspects of water resources. (2) The IWRM implementation’s methodological components are referred to as a “framework” in this context. (3) IWRM as a “process,” often called a “policy,” that is predicated on a learning process [4].

The capacity to create plans and the authority to carry them out are prerequisites for spatial planning. Different planning agencies (national, regional, and local) are able to “establish visions and scenarios for the future, carry out urban projects, write policies, strategize to deal with emergent opportunities and problems, and design specific aspects in detail” thanks to the force of statutory decision-making powers. Spatial planning may control the kind, location, timing, and urban design of water-using activities in urban environments, as well as the corresponding infrastructure requirements [5].

Developments affecting water resources and efficient integrated water resources management (IWRM) are acknowledged as essential elements of environmentally sustainable development [6]. The following definition of IUWM has been approved by a number of prominent organizations, most notably the World Bank and the Global Water Partnership: A set of guidelines known as integrated urban water management (IUWM) supports more efficient, adaptable, and sustainable methods for managing resources. This approach takes into account water sources, water use sectors, water services, and water management scales. It seeks to protect, conserve, and use water at its source; it recognizes alternative water sources; it makes a distinction between the attributes and potential applications of those sources; it views the storage, distribution, treatment, recycling, and disposal of water as components of the same cycle of resource management; and it considers non-urban users who rely on the same source, harmonizes formal institutions (organizations, laws, and policies) with informal practices (norms and conventions) that govern water in and for cities, acknowledges the connections between water resources, land use, and energy, concurrently pursues economic efficiency, social equity, and environmental sustainability, and encourages participation by all stakeholders [2].

The water management performances are evaluated using the City Blueprint Framework. When it comes to comparing cities in terms of the sustainability evaluation of their IWRM, the City Blueprint is a useful and efficient tool. There are 24 performance metrics in the City Blueprint, which can be divided down into seven categories: (I) standard water utilities, (II) quality of the water, (III) water infrastructure, (IV) treatment of waste water, (V) solid waste, (VI) climate change mitigation, and (VII) plans and activities [7].

Analyzing the performance of the entire metropolitan water system across a variety of areas, including hydrological, ecological, engineering, social, economic, and environmental, is known as integrated systems analysis [3].

The first step in deciding on goals is identifying an issue, which is then turned into a "problem statement." For considering the IUWM approach, Measures are required according to the IUWM objectives. From an economic point of view, examples of measures can include net present value, annualized capital value, infrastructure operation, maintenance, and replacement costs, as well as community benefits including returns on investment, externalities, and regional economic growth. From an environmental point of view, example measures can be listed as: urban streams and rivers' environmental flows; the quality of the contaminants' water levels in these waterways and rivers; changes to the local environment's biodiversity and habitats; energy consumption emissions of greenhouse gases Examples of social measures include the following: the quality of drinking water; the extent of flood mitigation and protection; hygiene; supply stability, accessibility, and fairness; the provision of drainage and wastewater services; the recreational and amenity features of green places and waterways; domestic gardening; Level of public involvement in the decision-making process [3].

As a case study of the Mediterranean region, Leeuwen [6] conducted a baseline evaluation of Istanbul's integrated water resources management (IWRM). Included in the European Innovation Partnership on Water of the European Commission, it is a component of the City Blueprint Action Group's water governance initiative. As a first step toward better understanding IWRM and the difficulties ahead, the City Blueprint indicator methodology and process have been adopted.

The concepts of Yellow and Blue Footprints were created as part of the "Blue Cities" project, "Blue for Smart Cities Footprint: A Method for Integrating the Water and Waste Sectors within the Framework of EIP Smart Cities and Communities." [8]. In the mentioned study, blue footprint and yellow footprint values were calculated for Istanbul province. Blue Footprint considers water quality, solid waste disposal, basic water services, wastewater treatment, infrastructure, climate change durability, and water management parameters, while Yellow Footprint considers parameters such as energy, transportation, information, and communication technologies. These are definitions that digitize through indicators for smart city applications.

Basic Water Services, Infrastructure and Water Management categories were selected from blue footprint findings, and transportation, information, and communication technologies were selected from yellow footprint findings for our study's initiative contents. The scores of the indicators calculated for Istanbul are shown in **Table 1**.

Table 1. Category-based indicators and points for Istanbul.

	Category	Number	Indicator	Point
Blue footprint	Basic Water Services	7	Access to drinking water	10
		8	Access to clean drinking water	10
		9	Drinking water quality	10
	Infrastructure	14	Average sewerage	8
		15	Operating cost recycling	3.6
		16	Water leaks	5
		17	Rainwater split systems	2.4

Table 1. (*Continued*).

	Category	Number	Indicator	Point
	Water Management	22	Management and implementation plans	4
		23	Public participation	2
		24	Measurement of water efficiency	4
		25	Attraction of water	7
Yellow footprint	Transportation	8	Commuting time	3.5
		9	Use of public transportation	0
		10	Bicycle network	0.3
		11	Transportation accidents	10
		12	Use of clean energy in transportation	6
		13	Pollution from transportation	10
		14	Transportation infrastructure investments	0
	Information and communication technologies	15	Access to information and communication technologies	5
		17	Use of information and communication technologies in the field of water services	8.3
		19	Use of Information and communication technologies in the field of transportation services	7.8
		22	Information and communication technologies infrastructure investments	7.2

2. Urban water systems integration

Urban water systems integration is defined as “the physical, social, and institutional interlinking of the urban water system with other urban systems." Urban water systems integration is distinguished by four types of geographical, physical, informational, and project-based systems integration, as shown in **Table 2**.

Table 2. Features of the various kinds of urban water system integration [9].

	Type of systems integration	Object of integration	Description	
1	Geographical	Space	Urban systems’ spatial alignment in the same region	The goal of geographic systems integration is to prevent (undesired) interference between various urban infrastructure systems by arranging them spatially aligned.
2	Physical	Resources	Using a resource jointly for several purposes	When there is resource-based integration, the output– or product—of one system is necessary for the operation of another, or input.
		Infrastructures	Shared use of an infrastructure system	When two infrastructures are integrated based on their mutual use, each infrastructure performs its own role.
3	Informational	Data	Utilizing information from various urban systems to run such systems	Information systems integration, sometimes known as smart-city or digital-city efforts, is predicated on merging data from various urban systems.
4	Project-based	Planning	Plans for building and repair that are in line with several urban systems	The goal of project-based systems integration is to identify potential areas of overlap between the design and rehabilitation of urban infrastructure systems. This includes scheduling maintenance and replacement projects for various infrastructures such that they occur concurrently or right after one another, for example.

Recently, several nations have turned their attention to the management of water resources. The world's water and energy usage has grown over the past century. It is expected that this trend will persist in the ensuing decades. The unmanaged industrial operations that are destroying the environment in the name of a higher standard of living are one of the main causes.

Management, technology, green, and governance tools are suggested to organize solutions for floods and storms, lack of safe drinking water, ineffective drainage systems, absence of "green" infrastructure, and deficiency in the wastewater treatment system [10]. For instance, management tools are strategic management tools, foresight projects, scenario building, urban stormwater management systems, flood mitigation systems, and water resources management systems. Governance tools include things like comprehensive wastewater treatment programs with better policies (like effluent standards), frameworks for protecting ecological services at the local and city levels, recommendations for urban drainage, "hydrosocial" connections, standard language for communication, agendas and aspirations for citizen politics, and reasoning processes for making decisions.

In order to implement community goals for water management, an efficient governance model is required. The Victoria State Government proposed a development process prepared by the Department of Environment, Land, Water, and Planning, as shown in **Figure 1**. A cooperative planning strategy known as integrated water management unites organizations that have an impact on several aspects of the water cycle, such as stormwater management, wastewater treatment, alternate and drinkable water supply, water treatment, and waterways and bays.

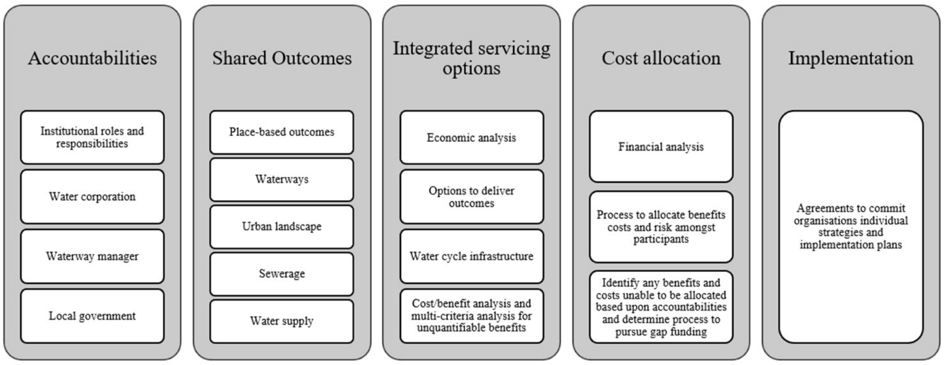

Figure 1. Integrated water management plan development process [11].

The lack of a good national and local database about water resources hinders the creation of management strategies that are effective in Turkey. Insufficient databases prevent monitoring activities. Above all other relevant institutions and organizations, the State Hydraulic Works (SHW) is the top authority in Turkey for the planning, management, development, and operation of water resources [12]. In Turkey, the institutional framework is divided into three levels: user (which includes both governmental and non-governmental organizations involved in project operation and maintenance) and executive (which includes governmental organizations under the ministries and the prime ministry, DPT, and ministries). Despite the existence of a conventional state planning method, the nation as a whole lacks a comprehensive strategy for sectoral and intersectoral water use and management [13].

3. Linking GIS and water resources management models

Systems of water resources can be represented spatially using Geographic information systems. An integrated global picture can be presented via a GIS, which can add spatial dimensions to the conventional water resource data base. This is achieved by merging different environmental, social, and economic aspects pertaining to the spatial components of a water resources issue and making them accessible for utilization in a decision-making procedure [14].

Geographic information systems (GIS) typically integrate hydrologic models together with the corresponding flooding, water pollution transportation, and water supply models for distributed hydrologic stimulations. For hydrological analysis and water resource management in GIS, it is crucial to extract the watershed's features, such as the stream network and catchment delineation. Watershed characteristics, or hydrologic and topographic parameters, can be obtained from digital elevation models (DEMs) and form the basis of these hydrologic models [15].

GIS is a useful tool to integrate with because of its data management, spatial analysis, and visual display capabilities, even if predictive modeling and GIS were not meant to be used together. Creating interfaces or connections between GIS and other watershed models, hydrologic software, and geographic datasets can help enhance the characterization and modeling of watersheds. As an illustration, flood modeling within a watershed can be accomplished by integrating hydraulic models and a GIS [16].

Planning is an essential tool to improve and support operational management and supplies an opportunity to analyze the current condition of the water bodies and the priorities over their use; prepare visions, set targets and goals, and orient the management; produce a structure for organizing law and policy, related research, and public participation; enhance the policy, public acceptance of water allocation, and water control, especially in times of stress; simplify the interaction and coordination among stakeholders and managers; and create a management plan [17].

4. Materials and methods

The following research topics are covered in this paper: (1) an analysis of integrated water resources management (IWRM) and the integration of geographical, physical, informational, and project-based urban water systems; (2) how to describe in a geographic information system (GIS) the data and functions of a model for managing water resources; (3) how to combine analytical operations, data manipulation, and problem definition in a GIS environment; (4) developing a modelbuilder flow for the construction of stream networks; and (5) how to use a geographic information system (GIS) to apply the Arc Hydro model.

4.1. Study area and data materials

Istanbul, which has a surface area of 5340 km^2, is the most populous city in Turkey. Fatih district was selected for a case study for applying the water management model. Fatih district covers an area of 15.62 km^2.

The demographics, average household size, average income, average length of education, average socio-demography, and average socio-economic status indicator points for the Fatih study region are displayed in **Table 3**.

Table 3. Study area population, socio-economic and socio-demographic characteristics.

District name	Population (2019)	Average income ($)	Average household size	Average education time (year)	Socio-demography indicator point	Socio-economy indicator point	Average socio-economic status point
FATIH	443,090	300.55	3.59	8.37	51.30	52.08	45.93

^ 1$ = 8.36 TL.

^ Source: Social vulnerability research report (2018) [18] and Turkish Statistical Institute Data Portal (2019) [19].

Digital elevation models

A crucial dataset for watershed modeling and characterization is elevation or topography data. A raster DEM, a TIN, or vector contour lines are a few examples of the data structures that can be used to describe topographic data. A DEM is conceivably the most widely utilized elevation data model for managing and studying watersheds [16]. The computer depiction of natural topographic characteristics is known as a digital elevation model (DEM). DEMs have been widely used for resource management, earth sciences, environmental evaluations, urban planning, transportation planning, and Geographic Information System (GIS) applications during the past few decades. The hydrologic community is also entering a new phase of leveraging GIS technology for spatially explicit eco-hydrological and hydraulic modeling, where the major and necessary input is the DEM of the area of interest [20].

Digital topographical maps (Contour Lines) obtained from Istanbul Metropolitan Municipality, The Directorate of Geographic Information Systems [21]. The following steps were taken for conversions.

Step: TIN model was created from contour lines shown in **Figure 2**. (Arc Toolbox—3D Analyst—Data Management—TIN—Create TIN)

Step: Raster map was created from TIN model (**Figure 2**). (Arc Toolbox—3D Analyst—Conversion—From TIN—TIN to Raster)

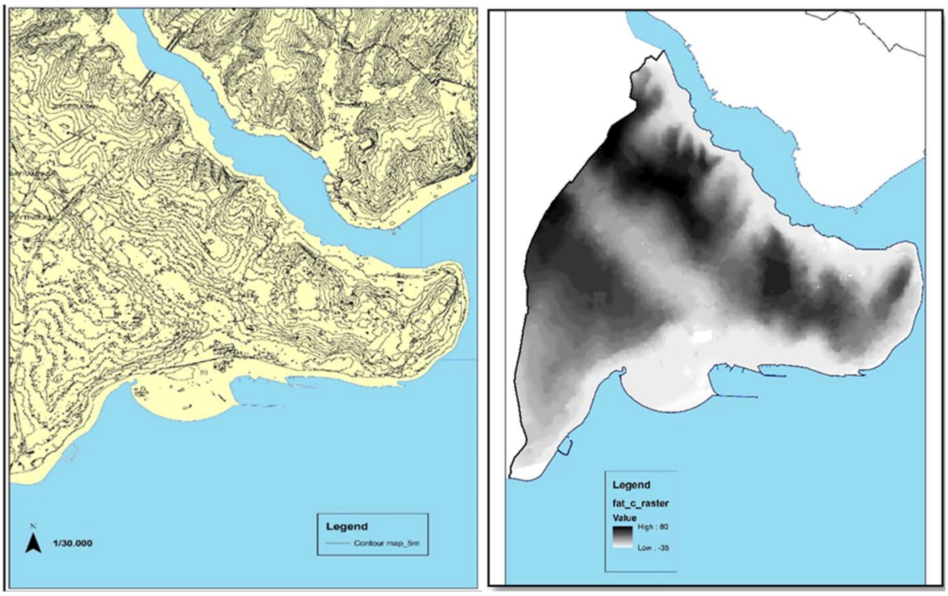

Figure 2. Contour map-raster map for Fatih district.

4.2. ArcGIS Hydro data model

The automated delineation of drainage zones based on a land-surface topographical model is made easier by the Arc Hydro Data Model Toolset. A triangulated irregular network (TIN) or a digital elevation model (DEM) can be used as the model. Arc Hydro is an ArcGIS-based spatial and temporal data model for water resources. Information regarding the network of rivers, watersheds, waterbodies, and monitoring stations is stored in the Arc Hydro framework. It is predicated on notions and ideas that are flexible enough to be developed and tailored to specific uses [22].

The Arc Hydro framework offers a straightforward, compact information structure for storing the most crucial geographic data that characterizes a water resources system. Basic models and studies on water resources can be supported by this framework. A collection of feature classes for water resources (such as watersheds, monitoring points, and classes having point, multipoint, polyline, polygon, annotation, or network features) are defined by Arc Hydro in ArcGIS along with the relationships between these classes, and the data is stored in a geodatabase. A geodatabase is a specialized type of relational database that holds GIS layer spatial coordinate data in a single field within a relational data table. Five categories—network, drainage, channel, hydrography, and time series—are used in the whole model to separate the various components of water resources [23].

The concept and methodology described in this paper are applicable to connecting GIS with models in hydrology fields that have a spatial dimension, and hence GIS can provide a useful data structure as a collection of spatial features and thematic maps. The main watershed features for the Fatih District's catchment area are built using the ArcGIS Geoprocessing model. The ArcHydro tool in ArcGIS was used to produce this model for the Fatih District. Stream Model Flowchart. Geoprocessing and GIS analysis of information-derived data play a crucial role in organizing the GIS as a whole. A mechanism for structuring transactions is provided by the model builder, which uses geoprocessing procedures to create mixed interactive GIS. The Arctool box tool operates within the ArcGIS geoprocessing utility package. Model builder, designed for applications that require more than one operation by changing and updating the input data used in the models [24].

The following steps were needed to convert the elevation data into flow direction and accumulation data, and finally into streams and watersheds.

(1) step Filling Tool: This method fills sinks in a grid. If cells of higher elevation surround a cell, the water becomes trapped and cannot flow. The fill sink function alters the elevation value to eliminate these issues [25]. Considering the basic fact that water flows downhill, grids with a higher value will flow to grids with a lower value [26].

(2) step Flow Direction: The drainage network cannot be created without flow direction. In this stage, a 3 × 3 grid is created around each cell to determine the direction it travels in. The direction of flow is determined by the lowest value surrounding the cell. The cell is subsequently given a numerical value according to the direction of flow. This number is solely utilized since the raster data in ArcGIS software needs to have numerical values; it has no other relevance beyond the flow direction [26].

(3) step Flow Accumulation: The next stage of the procedure is to create the flow accumulation layer. The Flow Accumulation tool determines the number of upstream cells that pass through each cell by using the flow direction raster. A value equal to the total number of upstream cells is assigned to each cell [26]. Each cell with higher flow accumulation values should be designated in areas of low elevation, such as valleys [25].

(4) step Stream Order: Linkages in a stream network can be numerically arranged using a technique called stream ordering. Using this arrangement, streams can be identified and categorized according to the quantity of their tributaries. Knowing a stream's sequence alone can reveal some of its properties. First-order streams are characterized by concentrated upstream flow, or overland water flow.

(5) step Stream to feature: Flow to vector is the process of converting river beds in raster format into vector data format. The resulting map is a linear map in vector format converted from raster format (**Figure 3**).

(6) step Watershed creation: The functions of Watershed Processing aid in the delineation of the watershed. The input data required was the definition of the stream, the catchment, the adjoint catchment, and the flow direction that was obtained during the terrain preprocessing. The Watershed Point feature class and the Watershed feature class were the outcomes.

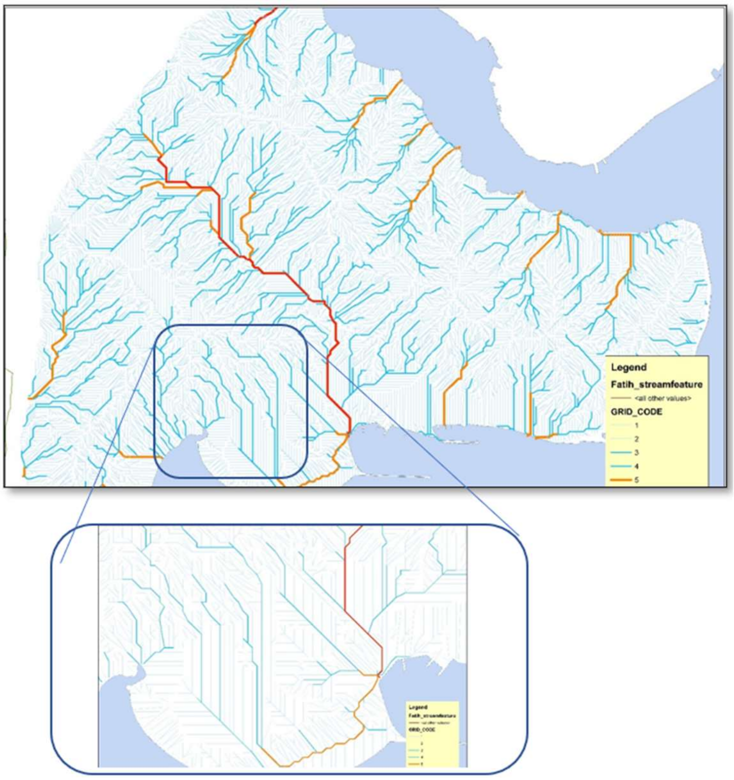

Figure 3. Fatih area-stream features.

"Stream model" is automated by using Arc GIS-Arc Hydro tools; a spatially linked database encompassing geographic and hydrographic data, including basin and stream networks, was generated for the study region (**Figure 4**).

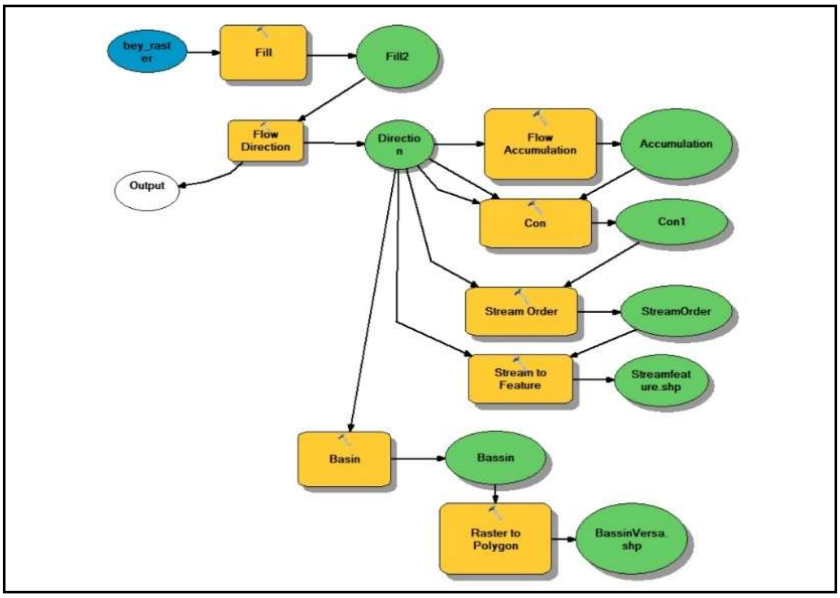

Figure 4. Stream model builder.

5. Results and discussion

In our study, the number of cells with code 1 was 8105, the number of cells with code 2 was 3358, the number of cells with code 3 was 1558, the number of cells with code 4 was 637, the number of cells with code 5 was 227, and the number of cells with code 6 was obtained as 98. Those with cell codes 5 and 6 represent the densest river beds. **Figure 5** shows the graphical distribution of grid codes by shape lengths and the grid code value frequency distribution.

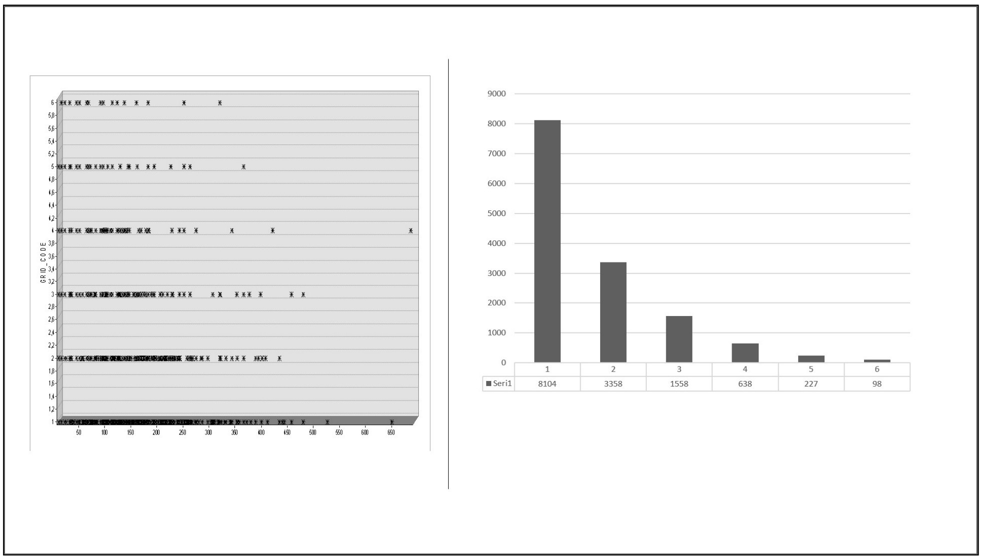

Figure 5. Study area grid codes and frequency distribution.

The results of our research provide a workflow to build a stream model and how to derive a suitability map according to stream levels. Transportation projects establish, develop, incorporate, and deliver effectively by selecting the best location for reducing construction, maintenance costs, and cost-effective solutions for drainage, landslides, and flood control.

Major infrastructure projects alter the natural landscape by creating sloped, impermeable surfaces and embankments, which are intended to facilitate transportation and prevent surface water accumulation, respectively. Examples of these projects include the construction of rail and road networks [27]. Roads are an essential component of the infrastructure for the planning and design process, especially highway crossings that pass-through streams and rivers. Roads will therefore inevitably have an influence on how stream corridor's function. Stream corridors are impacted by roads in hydrological, geomorphological, chemical, and ultimately ecological ways. However, these impacts can be lessened or eliminated by the location, construction, and maintenance of roadways [28]. To avoid flooding and increasing water tables during storm events, roadways in flat areas are frequently raised or realigned, resulting in an artificial gradient and subsequent runoff channel. The road-building regulations regulate the input of crossfalls, also known as cambers. The carriageway design incorporates an angle, typically 3% for paved roads, to facilitate water mobilization from the road surface by the shortest path, thereby changing the terrain [27]. An appropriate landform not only saves money on construction and maintenance, but it also decreases environmental risks like erosion and flooding. Steeper slopes normally incur higher expenditures, although too-small slopes may cause drainage problems [29].

Roads, pipelines, levees, streambank protection, and storm-water infrastructure are examples of streamside infrastructure, whereas stream crossing infrastructure includes bridges and culverts, pipelines, grade control structures, dams, reservoirs, and surface water diversion structures [28]. Impacts of construction on highways include runoff pollution from pavements and rights-of-way and excessive sediment yield during construction. For instance, stream channel instability brought on by hydrologic changes brought on by site preparation, grading, increased imperviousness, and landscape maintenance may result in habitat loss and stream bank erosion. Furthermore, deicing compound-containing runoff is poisonous to plants, fish, and other wildlife. Tracer metals, oil and grease, pesticides, and fertilizers are some of the other dangerous pollutants found in roadway runoff. It has been discovered that some petroleum hydrocarbons cause cancer. Additionally, aquatic fauna's ability to travel could be hampered by highway culverts near stream crossings [30].

6. Conclusion

This review begins with a definition and principles of integrated urban water management as a combination of policy and technical proposals. Within the growing paradigm of integrated urban water resource management, there are several approaches to identifying the nature of the problems to be addressed, viable solutions, and how to implement them. The City Blueprint indicator method is addressed as the first step toward a deeper understanding of IWRM and the problems that lie ahead. Four forms of urban water system integration—geographical, physical, informational, and project-based—are used to demonstrate the characteristics of the various types.

The study's workflow demonstrates how a scientific approach can be applied to the investigation of water resources with GIS as a tool, simplifying and improving decision-making. This paper explores the potential of Arc Hydro modeling techniques by utilizing the spatial capabilities of a GIS, specifically: (1) how to use a GIS to represent the spatial and thematic characteristics of the information and capabilities of a model for managing water resources; (2) the way to combine the problem formulation, data processing, and analytical features in a geographic information system setting; and (3) the model's implementation and analysis of the outcomes. According to model findings, streamside and stream crossing infrastructure construction and maintenance priority areas can be determined for short-, medium-, and long-term investment and allocation of future development. For future research, this study can be extended to determine and prevent possible damage to sensitive areas, floodplain areas, and vulnerable zones supported by field investigations.

In summary, the research aims to address the following questions, which we present below for determining infrastructure and urban planning concerns related to urban water management:

- How can qualitative data collection more effectively gather existing situations and adjust this into a water management process?
- How can planners and managers create "technical" solutions to water disputes that are appropriate, practical, and fiscally sound while also utilizing innovative workflows and modeling techniques?
- Which techniques can procure integrated water resource management?
- Is geographical information system analysis sufficient to resolve water conflicts?
- How can designers, engineers manage infrastructure projects in the stream environment?

Conflict of interest: The author declares no conflict of interest.

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Article

Cartographical digital products: Maps, 3D models, diagrams

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Abstract: The current paper aims at spatial presentation in Cinque Terre. The purpose is to reconstruct digital products (maps, statistics, diagrams, and 3D models) and the spatial analysis of the five villages. The goals are the presentation of the geomorphology, geography, population, density, and area. Also, the Strength-Weakness-Opportunities-Threats (SWOT) analysis creates the disadvantages and advantages of the five villages in the region. The methodology is based on the software (G.I.S. Pro, QGIS, Zephyr 3D, Microsoft Excel, Generic Mapping Tool) and the bibliography study. For instance, the construction 3D terrain model shows the buildings, roads, green areas, and land cover of the five villages. The digital products help better "read" the region and emphasize the measurements and location of the region's elements. The final results contain a message about new technologies and spatial planning. The new technologies have given spatial solutions in the last few years. The innovative, understanding, and attractive cartographical digital products present the geomorphology of the traditional villages in Cinque Terre.

Keywords: maps; SWOT; geography; 3D terrain; statistics

1. Introduction

The current paper aims to construct cartographical products. Each digital product is an index and way measurement of the spatial analysis. For instance, the full paper suggests recommendations about the usefulness of maps, diagrams, and 3D terrain in better understanding the region of Cinque Terre.

The digital urban solutions are summarized in the following points:

Recommendation 1: Understanding the methods and techniques to construct digital products. The digital era is a new reality. There are significant benefits to creating cartographical products (maps, diagrams, figures, tables, and 3D models). The products need to be created in an attractive and innovative way.

Recommendation 2: The Cinque Terre region analysis is a mosaic of political analysis and decisions, stakeholders, the law frame, geography, and strategic long-term planning. The final result is the SWOT analysis of Cinque Terre's strengths and weaknesses. This table helps make policies and configure urban and political planning for the future.

Recommendation 3: Understanding the usefulness and significance of digital products and eras in better urban planning. The digital era offers new opportunities for making political and regional decisions. For instance, the distance observation of the mountains, sea, and geomorphology is a crucial index. This index helps in measurements of distance, length, and polygonal area. Also, it answers the question of the most suitable place for opening tourist activities. The nice panoramic view, the slope of the ground, and the nearby activities are criteria for better urban and environmental decisions.

2. Region analysis

2.1. Cultural heritage and democracy

Cultural heritage management is crucial because strategic planning creates long-term benefits for the sites. When making decisions, one must prioritize priorities, advantages, and disadvantages. Also, the multi-participation of organizations, companies, institutions, government sectors, and universities is an optimistic direction for successful management. Democracy is for all. Protection, preservation, documentation, and promotion are the responsibilities of the governance and level of citizens.

Nowadays, culture is an ecumenical term. The exchange of ideas, opinions, recommendations, and practice experience provides the framework. Sometimes, the acceptance of democratic rules is an influential factor in success. For instance, cyclical and balanced economic development benefits all people. The level of satisfaction and sustainability is the highest. To summarize, the vision of a better planet goes together with cultural heritage protection.

2.2. Cultural heritage in Cinque Terre

Cinque Terre National Park is one of Italy’s most valuable destinations for tourists worldwide. In addition, the park, inscribed on the World Heritage List as a cultural landscape, is an essential source of values that must be protected and exploited [1]. The site was added to the World Heritage List as a cultural landscape in 1997, and the Cinque Terre National Park was established in 1999 [2]. The management plan developed for this area needs to deal with different issues: abandonment of terraced cultivations and growth of secondary forests, hydrogeological risk, and high touristic pressure [3].

Recently, many Mediterranean cities have occasionally exceeded their carrying capacity, compromising their natural or urban environment, lifestyle, and cultural traditions [4]. Public participation is increasingly important in the decision-making process for incorporating the ideas and needs of the local communities, helping to find effective solutions for valorizing historic landscapes, and improving the quality of life [3].

2.3. Environmental heritage in Cinque Terre

The link between environmental strategy and firm performance may be affected by the managers’ interpretation of the environment, that is, by their opinions about the opportunities and threats linked to the environment within the framework of the environmental strategy [4].

This management needs to be systematic, reflexive, and cyclic to use multiple views and methods for an environmental management problem [5]. The management needs to emphasize the planning and the results. His measurements are significant tools for successful management. His indexes lead to the best solutions and a better understanding of the situations.

3. Region analysis

3.1. Geography

Tables 1–3 present the area, perimeter, population, density, and coordinates in Riomaggiore, Manarola, Corniglia, and Vernazza. The five traditional villages are unique destinations. The natural beauty and the geography have great benefits.

Table 1. Geography units Riomaggiore and Manarola [6–8].

	Riomaggiore	**Manarola**
Population	1332	No available
Coordinates	44°06′N 09°45′E	44°06′23″N 9°43′41″E
Average elevation	250 m	161 m

Table 2. Geography units Corniglia, Corniglia, Vernazza [6,9,10].

	Corniglia	**Vernazza**
Population	No available	730
Coordinates	44°7′10″N 9°43′00″E	44°08′N 09°41′E
Average elevation	180 m	255 m

Table 3. Geography units Monterosso al Mare [6,11].

	Monterosso al Mare
Population	1340
Coordinates	44°08′45″N 09°39′15″E
Elevation	186 m

3.2. Scenario planning

The SWOT analysis examines four factors in Cinque Terre. Tourism, culture, environment, and geography. SWOT analysis in Cinque Terre sometimes offers a better “reading” and governance of the situation. Every politician, urban planner, cartographer, and governor in the sector needs to make decisions. The decisions are very significant for the future. The purpose of this chapter is to examine the use of the strategic management tool Strength-Weaknesses-Opportunities-Threats, or SWOT analysis [12]. The SWOT analysis guidelines are derived from contemporary strategic management theory, especially the resource-based view of the firm [13]. SWOT analysis may also have applications within appreciative inquiry, benchmarking, industry analysis, situation analysis, and scenario planning [14].

The protection of the planet has a crucial meaning nowadays. Society changes because technology moves forward. The economic environment makes up the cycle of life. The modern era needs “smart” and green solutions. For instance, cultural heritage includes buildings, routes, museums, and intangible and tangible cultural heritage. For example, the history of the places and the songs needs to be shared and preserved by the new generation.

In other words, Neoclassical buildings have the same goals: preservation, protection, and documentation because they offer income to their inhabitants. Also, the historical places are part of the history of Italy. Making decisions is always significant for successful management. Social-technology conditions depend on age, gender, education level, and business environment. Also, the economic and environmental situation has significant meaning nowadays, such as the European green transformation. Preservation, protection, and alternative energy are the main pillars nowadays. **Table 4** depicts the Cinque Terre region's strengths, weaknesses, opportunities, and threats. Demography is sometimes presented as maps, graphs, tables, and data modeling. Visualizing demography is excellent because it constructs attractive and innovative digital products. This year's digital transformation is a reality. The new technologies build intelligent products.

Table 4. SWOT analysis [15–17].

SWOT				
	Strong	**Weakness**	**Opportunities**	**Threats**
Tourism	Tourism philosophy	Protect flora and fauna	Need management planning in person, local, governance level	Overpopulation sometimes
Culture	UNESCO world cultural heritage	Continuous care	Sharing the history	Preservation of Buildings
Environment	Protected areas	Need more business persons	New technologies	Fires, flows
Geography	Strategic location	Huge slope in villages	International cooperations	

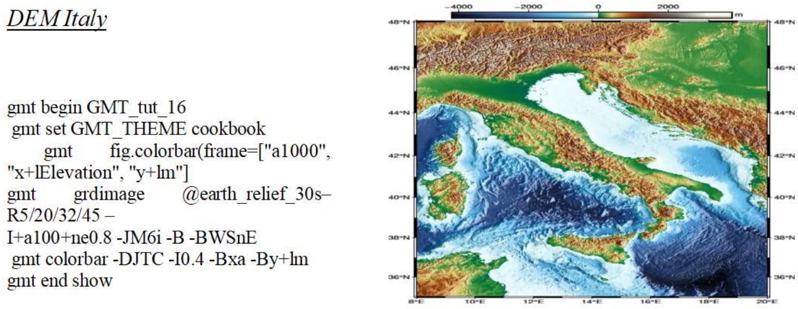
4. Digital products

4.1. Generic mapping tools

The construction digital elevation model, or DEM, in Italy has requirements for the following things: Firstly, the author creates the color bar relative to the topography theme of the earth. For instance, the low elevation is green because it represents the alleys. The sea is blue, the high mountains are maroon, and the high mountain peaks are white. GMT, or Generic Mapping Tools, is a tool that creates modern, “smart,” and innovative solutions. The commands can be searched on the website, generic-mapping-tools.org. [18]. It is free and open-source software. Since GMT classic mode has existed for 30 years, I participated in the InSar Processing and Theory with GMTSAR short course, which was organized by the Earth Scope Consortium [19]. The GMT toolbox includes various and varied core and supplemental program modules sharing a common set of command options, file structures, and documentation [20]. The Generic Mapping Tools progress based on three pillars:

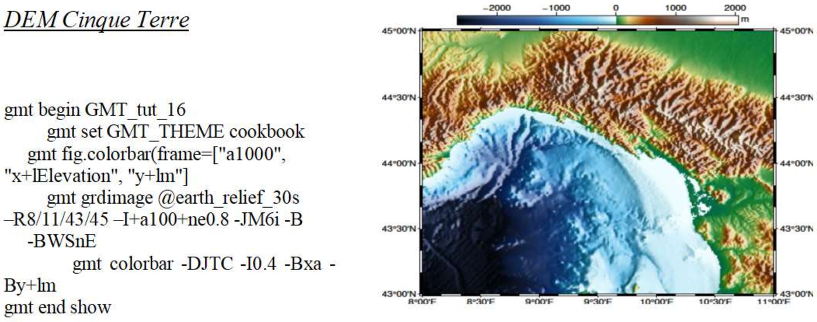
- Generic Mapping Tools installation.
- Import GMT Color Bar.
- Import GMT Earth Relief (Coordinates Latitude, Longitude).

Figures 1–3 show the region of Cinque Terre. The coordinates are from 8′00″ to 11′00″ East and from 43′00″ to 45′00″ North. The location is near the sea and mountains. Also, there are a few alleys paralleling the coastline.



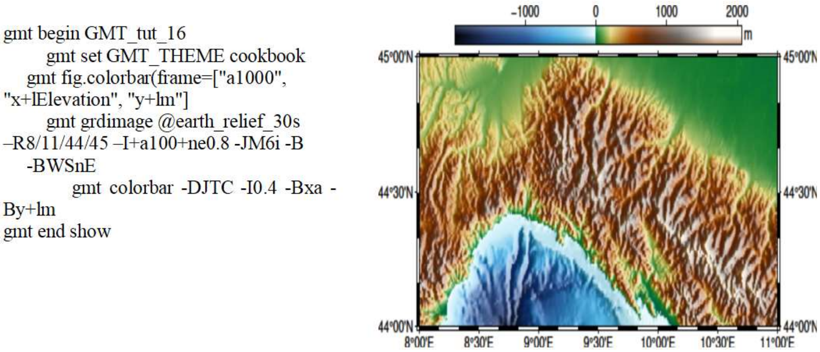
```
gmt begin GMT_tut_16
 gmt set GMT_THEME cookbook
 gmt fig.colorbar(frame=["a1000",
"x+lElevation", "y+lm"]
gmt grdimage @earth_relief_30s–
R5/20/32/45 –
I+a100+ne0.8 -JM6i -B -BWSnE
 gmt colorbar -DJTC -I0.4 -Bxa -By+lm
gmt end show
```

Figure 1. GTM Italy [18].



```
gmt begin GMT_tut_16
 gmt set GMT_THEME cookbook
 gmt fig.colorbar(frame=["a1000",
"x+lElevation", "y+lm"]
 gmt grdimage @earth_relief_30s
–R8/11/43/45 –I+a100+ne0.8 -JM6i -B
 -BWSnE
 gmt colorbar -DJTC -I0.4 -Bxa -
By+lm
gmt end show
```

Figure 2. DEM Cinque Terre [18].



```
gmt begin GMT_tut_16
 gmt set GMT_THEME cookbook
 gmt fig.colorbar(frame=["a1000",
"x+lElevation", "y+lm"]
 gmt grdimage @earth_relief_30s
–R8/11/44/45 –I+a100+ne0.8 -JM6i -B
 -BWSnE
 gmt colorbar -DJTC -I0.4 -Bxa -
By+lm
gmt end show
```

Figure 3. DEM Cinque [18].

The specialized flora of serpentine outcrops in Tuscany (Italy) is analyzed in terms of species richness and geographic variation to identify major centers of diversity and provide a basis for conservation programs [21]. Due to a centuries-old agricultural practice, the coastal landscape of the Cinque Terre (eastern Liguria, northwestern Italy) has been almost completely modified by terracing the slopes by reworking millions of cubic meters covered in rubble and the construction of thousands of kilometers of dry stone walls [22].

4.2. Maps

Figures 4 and **5** show the maps from Cinque Terre. In the region, there are five traditional villages with unique natural beauty. The map presents the location and the photos from Riomaggiore, Manarola, Corniglia, Vernazza, and Monterosso. Also, the map contains the scale bar and the symbol North. The map product is scaled at 1:50.000. The orange points show the location of each village. The coastline is the Ligurian Sea.

Figure 4. The location in Cinque Terre [23].

Figure 5. Location in Cinque Terre in Europe [23].

Cinque Terre—UNESCO world heritage site

Figure 5 shows the region of Cinque Terre in the orange cycle. The five most beautiful villages in Italy are in western and northern Italy. The map contains the symbol North, the scale bar, and the topographical basement. The coastline, the five villages, and the surrounding hillsides are all part of Cinque Terre National Park, a UNESCO World Heritage Site. Vernazza is a member of the I Borghi più belli d'Italia ("The most beautiful villages of Italy") association [24].

Figure 6. The train distance in Cinque Terre [25].

Figure 6 shows the train stations and the distance to each village. The total distance is 8.870 meters. The mean distance (total distance/four measurements) due to the shapefile (**Figure 6)** is ≈ 2217.5 m. There are five train stations in each village.

Figure 7 presents the elevation of every village. Vernazza (255 m) and Riomaggiore (250 m) have the highest elevations. Manarola has the lowest elevation of the five villages, at 161 m.

Figure 7. The elevation in Cinque Terre [25].

In the villages of Cinque Terre, the visitors meet the "green" and "blue." The train system between the villages is significant. Each village has something unique. The Monterosso al Mar has fantastic coastlines and mar, the Vernazza has romantic sunshine and quiet shops; the Corniglia is located at a high elevation; the Monterosso likes a cart postal; and Riomaggiore is a fish's village. The conditions in the villages of Cinque Terre are the environmental conditions, the fresh air, the sound of the waves, and the vision without cars. The name comes from the geography itself, because there are five traditional villages. **Figures 8–12** are screenshots from Google Earth [26]. It configures the angle, and the camera zooms in on every village. There are various and varied ways to export screenshots. Each photo presents the details of the area. Also, it is possible to configure each photo's contrast, brightness, and dpi.

Figure 8. The location from RioMaggiore [26].

Figure 9. The location from Manarola [26].

Figure 10. The location from Cornilia, from Manarola [26].

Figure 11. The location from Vernazza, from Manarola [26].

Figure 12. The location from Monterosso al Mar, from Manarola [26].

4.3. 3D Terrain

Figure 13 shows the steps of the project. It is significant to use Google Earth and Zephyr 3DF [27]. Google Earth has enough quality 3D aerial images. The author takes 20–25 screenshots for each village. The photos cover the spherical villages. The process is part of a photogrammetric function because of the purpose of the 3D Terrain Cutch with the software 3DF Zephyr.

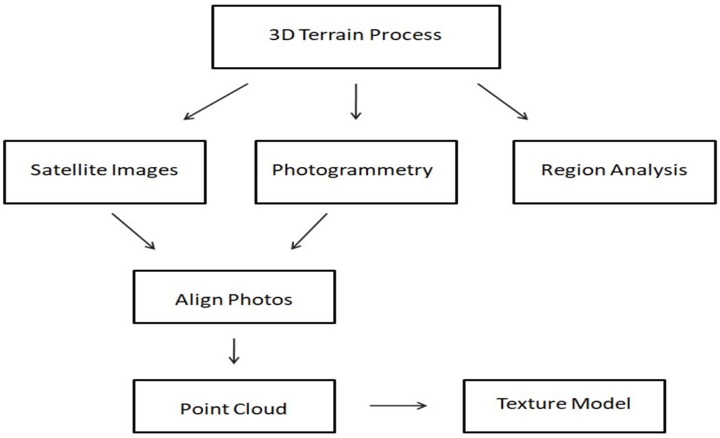


Figure 13. Data modeling the process.

The 3D aerial photos align with the 3DF Zephyr software. The steps are simple, understandable, and intelligent. There is an Italian tradition surrounding the design of products. Italian programmers and planners are famous because they have the philosophy to create new products. The final results **(Figure 14)** present the five beautiful villages. The texture model can rotate, cut areas, and zoom out/in. Also, the products are sometimes present on online platforms and stored in various formats.

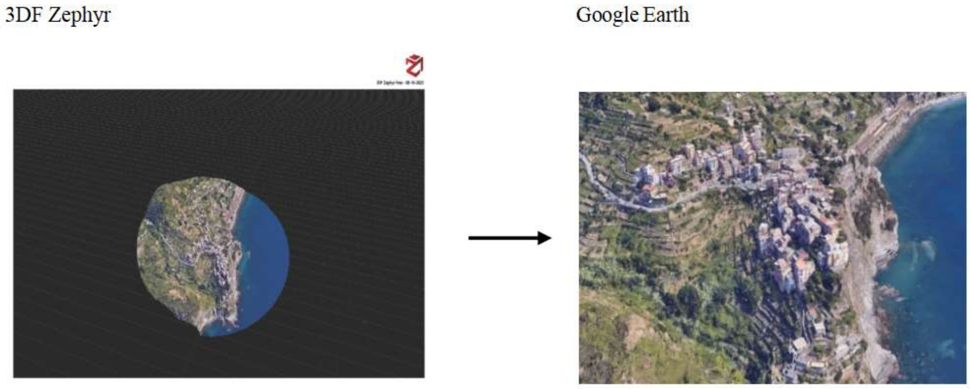


Figure 14. Photos and 3D model.

The 3D Model allows the terrain analysis and observations of the villages. Many times scientific results export with digital way, because the pedestrian observation in the field work hasn't effective. For instance, the slope of the ground is useful measurement, because it helps in the conditions of the walking roads and the buildings preservation. The following **Figures 15–19** show the view of the villages. The texture models present in the **Figures 15–19**. The platformplaycanvas [28]. The modern time needs modern solutions. Also, in the platform sketchfab.com [29] shows the 3D view of the five traditional villages in Cinque Terre.

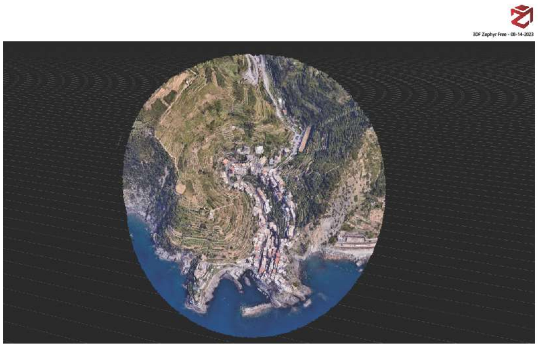


Figure 15. 3D Terrain from Manarola [30].

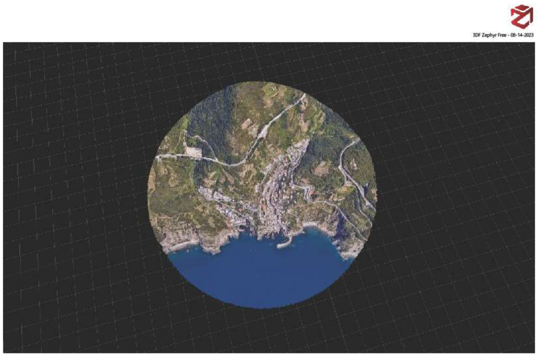


Figure 16. 3D Terrain from Riomaggiore [31].

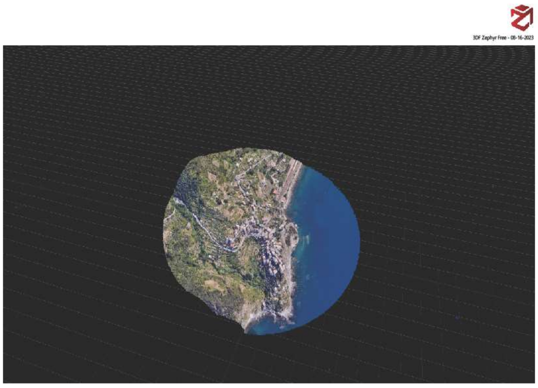


Figure 17. 3D Terrain from Corniglia [32].

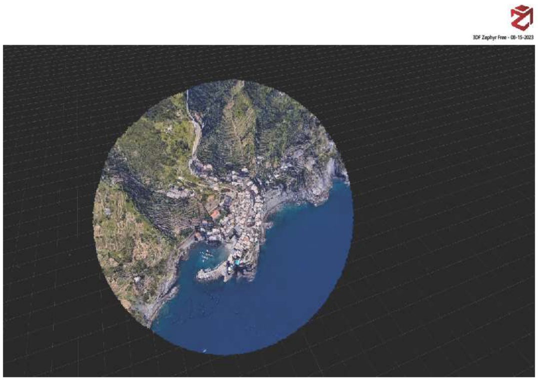


Figure 18. 3D Terrain from Vernazza [33].

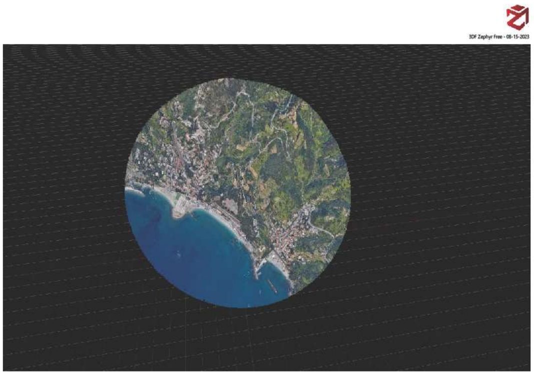


Figure 19. 3D Terrain from Monterosso al Mare [34].

5. Conclusion

The current paper is an individual effort. The work objectives are the visualization and spatial analysis of Cinque Terre. The manuscript describes the maps, statistics, graphs, DEM, and 3D Terrains. The new technologies offer modern solutions. In the final years, technological tools grow. This fact helps in a better study of the regions. For example, in the previous 20 years, visitors traveled to cities with analogical maps. Archeology works with maps and traditional measurements. Nowadays, digital products emphasize accuracy and authenticity in regions. Also, spatial, environmental, and cultural management are crucial for success.

Conflict of interest: The author declares no conflict of interest.

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Article

Science in the service of politics. The cartographic representation of a local territorial context of the Kingdom of Naples in the early nineteenth century

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Abstract: The erudite priest Marciano Di Leo (1751–1819), a prominent personality in the historical and geographical panorama of his time, not only in his home territory, authored a vast literary and poetic production but also tried his hand at producing some maps, referring to a province of the Kingdom of Naples. At a time when the principles of geodetic cartography had become increasingly known, even locally, hand in hand with improvements in technology and accuracy of measurements, the author reflected on the historical narratives of the progress of the European (and Neapolitan) Enlightenment and translated them into an unpublished manuscript of statistical, historical, and geographical nature, accompanied by numerous maps of various scales. The rediscovery of a largely unknown—and therefore not very thorough—minor cartographic production underscores the spread, even in more marginal contexts, of the most innovative ideas and increasingly precise scientific foundations in the cartographic-mathematical representation of the territory. It also illustrates the role of a number of intellectuals in the service of the political choices of their time, in an attempt—often unrealized—to bring about a decisive change of course in public administration, in accordance with Enlightenment ideals and in the spirit of reform that spread throughout Europe thanks to the French Revolution.

Keywords: Marciano Di Leo; historical cartography; Kingdom of Naples; Principato Ultra

1. Introduction

The research conducted here aimed to illustrate the cartographic production of the priest Marciano Di Leo (1751–1819), the author of a manuscript drawn up in 1816—the very difficult "year without summer" [1]—complete with numerous maps, drawn up to illustrate the historical-geographical-economic characteristics of the Principato Ultra. The administrative division of the Kingdom of the Two Sicilies was based on a 4-tier structure. There were 22 first-level divisions, called provinces (provincie in ancient Italian). The 22 provinces were divided into 76 districts (Distretti). The districts were divided into Circondari (present in a total number of 684). The districts were divided into municipalities (Comuni), one of the 22 provinces of the Kingdom of Naples, which encompassed the southern part of the Italian peninsula and has been the largest state entity since the Norman conquest in the 11th century (several times separated and then reunited with the Kingdom of Sicily), which was conquered in 1734 by the Spanish Bourbons, who reestablished the Kingdom of the Two Sicilies. After the Napoleonic interlude (1806–1815) and the return of the Bourbons to the throne, Naples and Sicily were included in the new Kingdom of Italy in 1860.

At the time, the basic principle of modern geography, that is, the application of social studies to the reading of the environment, in addition to only physical description until then prevailing, was becoming established among Italian and European intellectuals [2]. However, the Kingdom did not yet possess advanced maps, despite having had for centuries some fundamental references (Tabula Peutingeriana, Tabula Rogeriana, etc.) and the survey of Mario Cartaro (1540–1620?) and Nicola Antonio Stigliola (1546–1623), a true cartographic monument [3]. The Map of the Kingdom of Naples by these two authors had no circulation in print [4], with a similar fate to the magnificent Aragonese maps of the early Modern Age, perhaps derived from a Roman cartographic base, which were so innovative and precise as to constitute a historical and cartographic enigma [4]: these maps circulated "only for a very short time or among a very small group of people, maps that were forgotten or lost without a trace, and maps that were never completed or never printed" [5]. And, in addition to the multiplication of small- and large-scale maps from the 18th century onward, cartography gradually became not only a descriptive representation but a symbol of appropriation: a representation of a political space, also becoming enriched with this important meaning as a political instrument for boundary drawing and tax collection [6]. Insist also on a deeper knowledge of the territory, including through appropriate cartography, to improve agriculture and trade and thus the living conditions of peoples, their common welfare, and thus their happiness, one of the cardinal principles of Enlightenment thought. As one of the masters of Italian and Neapolitan economic thought of the time, Antonio Genovesi (1713–1769) had already wisely exhorted, "It is a turpish and shameful thing for a philosopher [...] not to know the land in which he lives" [7].

Marciano Di Leo responds to these changes throughout his vast cultural output, through poetry, theater, science, and even cartographic achievements, demonstrating how expertise in such complex topics was widespread even in more peripheral territorial areas [8]. The community of erudites also welcomed these scholars with encyclopedic interests into the Respublica litteraria, an utopian space in which intellectuals like our priest contributed to the circulation of ideas and innovations with a true constructive spirit. This one is part of his attempt to map the territory with finally modern criteria, in the wake of a geodetic-geometric consciousness derived from the French influence [9], also spread in the Neapolitan cultural milieu.

Di Leo, therefore, is an example of a local production rarely found elsewhere in southern Italy, and he indicates the ability of the periphery to stay abreast of the great directives of contemporary thought.

2. Materials and methods

The unpublished manuscript in question is preserved at the State Archives in Naples (Ministry of Internal Affairs, Inventory I, b. 2060, dated 1816). It is in a good state of preservation and consists of 465 pages, transcribed on the recto and verso on sheets of paper of excellent quality but of varied sizes. So, it was assembled at separate times, perhaps after the author's death.

The text has been transcribed in full, philologically, respecting the handwriting of the time without making the spelling corrections that today's Italian grammar would require (the diagram in **Figure 1** shows the entire transcription and commentary process). The manuscript fully reflects the role that intellectuals of the XIX century were assigning to themselves, urging politicians to equip for more up-to-date systems for administering finances, a deeper understanding of resources and their management, and improved agricultural and industrial practices in the wake of Enlightenment ideals and the rapid advances in applied sciences that were maturing in that era (Geology, Chemistry, Crystallography, Optics, and especially the ubiquitous electricity, the latter a real craze [7]). And, after the official "cartographic silence" that characterized southern Italy, noted, for example, economist and philosopher Domenico Grimaldi (1734–1805):

> "…abbiamo notizie assai più distinte delle produzioni e dell'Agricoltura della Cina, che del più bel Regno dell'Europa, qual'è il nostro". In fact, "quali notizie si hanno mai dell'Istoria naturale dell'Agricoltura, delle Arti, del Commercio, e delle Finanze delle nostre provincie? Niuna notizia certamente che fosse fedele, circostanziata ed esatta…" and so much would be helpful "…form a Topographical Map" ("…we have far more distinct news of the productions and Agriculture of China, than of the most beautiful Kingdom of Europe, which is our own", and "what news do we ever have of the Natural History of Agriculture, Arts, Commerce, and Finance of our provinces? No news certainly that was faithful, circumstantial and exact") [10].

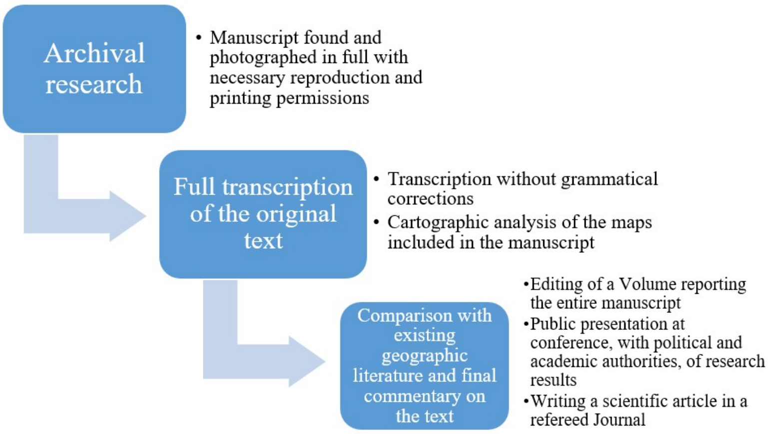


Figure 1. Path of manuscript analysis and subsequent publication.

So, Marciano Di Leo specifies in his introduction to the manuscript the need to equip his territory with a modern, rigorous cartography that would surpass previous productions, more like "paintings" than precise representations of reality. Therefore, he includes in the final part of the manuscript 63 maps, described later, justified by the need for a more precise description of the province and its administrative subdivisions and by the Kingdom's requirement to build a new, faster, and more convenient road, uniting the two seas, Tyrrhenian and Adriatic, through the Apennine chain, passing right through the Principato Ultra.

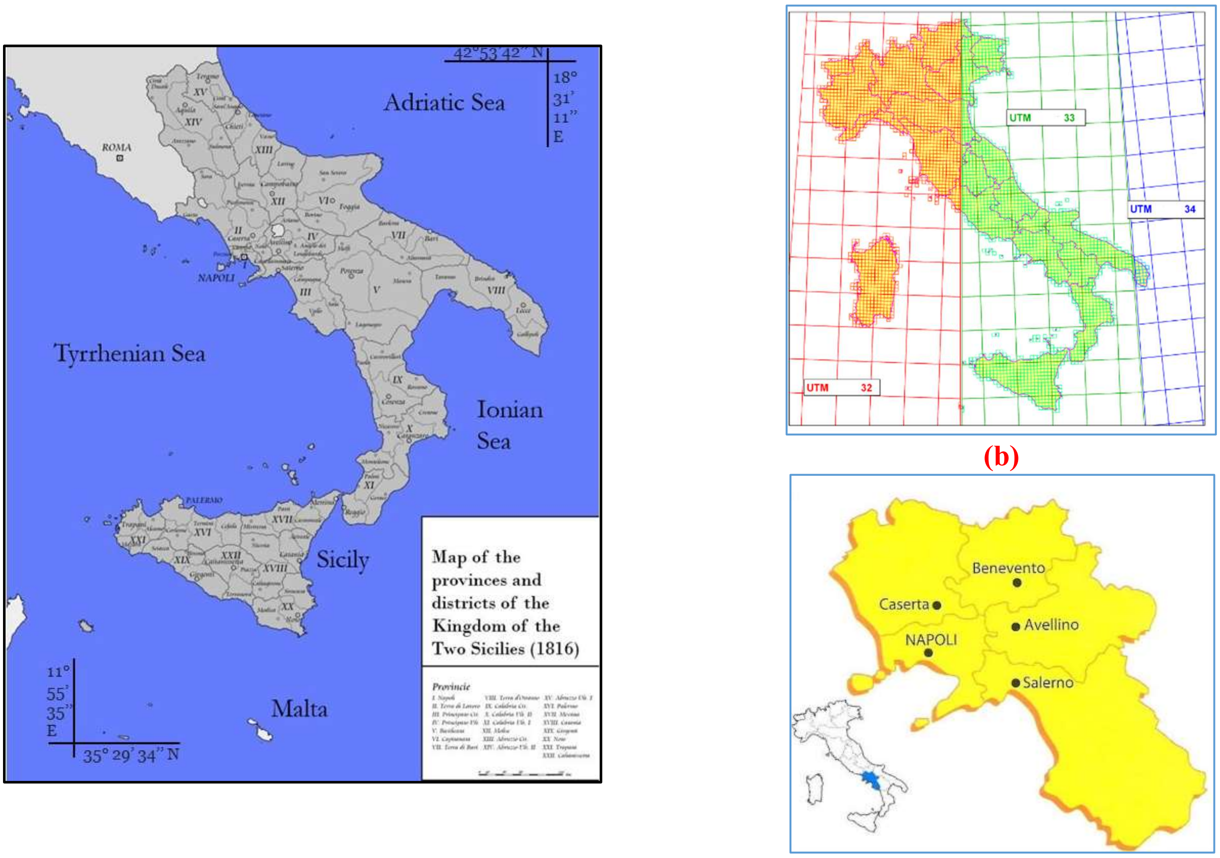
The maps drawn by the priest-geographer are also accompanied by a statistical report illustrating history, physical geography, human settlements, roads, natural and agricultural resources, and even the hydrogeological instability of the described territory. The manuscript begins with these auspices:

"Al benevolo Lettore

Tralle tante carte topografiche, nelle quali viene dinotata e descritta La Provincia

> del Principato Ulteriore del nostro Regno di Napoli, non mi è riuscito finora di osservarne una, che esattamente comprenda le terre, e fissi tutt'i Luoghi nella propria posizione, dirigga con accuratezza il corpo de' Fiumi, che la bagnano, ne determini con specificazione i Confini, e metta ne dovuti punti di prospettiva la vera configurazione, l'elevatezza, e la distanza delle Montagne, che la circondano, ed i tanti continuati colli, che per ogni parte la covrono. Per la deformazione di queste carte particolari è necessaria assolutamente l'oculare ispezione, per così notare, e specificare il Sito de Luoghi in quella parte, e posizione, che si conviene" (In the English translation of the early 19th century Italian, simplifications have been made that are useful for understanding the text: "To the benevolent Reader. Among the many topographical maps in which the Province of the Principality of Naples is described, I have not yet succeeded in observing one that exactly encompasses the lands, and fixes all the Places in their position, accurately directs the body of the Rivers that flow through it, determines its Boundaries with specification, and places in due perspective the true configuration, elevation and distance of the Mountains that surround it, and the many continuous hills that cover it on all sides. For the deformation of these particular maps it is absolutely necessary to make an ocular inspection, in order to note and specify the Site of Places in that part and position that is appropriate…") [2].

In fact, important historical factors (pandemics, demographic crises, and economic crises) had slowed down the Kingdom in the seventeenth century, and scientific production was also somewhat reduced [11] compared to the previous exceptional Aragonese period, while in Europe and the rest of Italy, the Scientific Revolution was inspiring a formidable evolution in every field. The encounter between cartography and astronomy, which will be used to fix the positions of the earth using the positions of the stars, will not take place in the Kingdom of Naples until the end of the 18th century (when it will take on the name Kingdom of the Two Sicilies, **Figure 2**), in a completely overturned cultural climate, so much so that the Capital of the Kingdom will become one of the driving centers of Italian and European culture, as it had already been in the aforementioned fifteenth century [5]. This thirst for knowledge, even under the impetus of the new sciences, was responsible for so many initiatives in the Kingdom, such as—among other things—the establishment of the Royal Mineralogical Museum, the Botanical Garden, or the Royal Agricultural Societies (later to become Economic Societies) in the provinces of the Kingdom to make Naples one of the European capitals for cartographic engravings [12].



(a) (c)

Figure 2. (a) The Kingdom of Two Sicilies in 1816 and its provinces, divided into districts. The Kingdom occupied the entire southern part of the Italian peninsula, including Sicily. The Principato Ultra is indicated by the number IV, not far from the capital city of Naples (from Wikipedia, free use); **(b)** the territory of the ancient kingdom is included almost entirely in UTM Zone 33; **(c)** the location of Principato Ultra is in the present Campania Region, Southern Italy (it roughly corresponds to the present united provinces of Avellino and Benevento).

3. Results and discussion

The maps attached to the manuscript, some in draft, some final, have a small size, and we ignore whether they were engraved or printed in larger formats (maximum width 50 cm, height about 25 cm).

The North is correctly placed always at the top, in all maps produced, at any scale (Septentrio in the maps of ancient Hirpinia); the South is shown at the bottom, with the inscription Mezzogiorno (Meridies in historical maps). Occasionally, the words West appear on the left of the cards and East on the right.

Contour lines are absent, as in Rizzi Zannoni's more famous Atlante geografico del Regno di Napoli (Geographical Atlas of the Kingdom of Naples), published by Giovanni Antonio Rizzi Zannoni (1736–1814), the great scientist from Padua who called to Naples to design a map of the entire Kingdom. First published in 1808, the atlas was not completed until 1812 to replace the old 1769 map of the Kingdom by the same author and the partial ones edited during the Napoleonic Wars in Italy (after all, they would appear in cartography in Italy decades later), and relief is still rendered by stylization, although the tops of the best-known mountains are correctly located with geographic coordinates.

The territory represented occupies thirty-six miles of latitude and forty-seven miles of longitude, which, in current measurements, can be calculated by the product 66.4 km × 86.7 km, for a value of about 5758 km^2.

Such maps reproduce:

1) the Antiquus Hirpinorum Ager, the ancient territory of the Hirpini, i.e., the Italic people who inhabited the territory called in the future Principato Ultra (**Figure 3**);
2) the map of the province of Principato Ultra (**Figure 4**);
3) an example of a district map is shown in **Figure 5**;
4) finally, an example of a map of a Circondario (**Figure 6**).

In order, Antiquus Hirpinorum Ager:

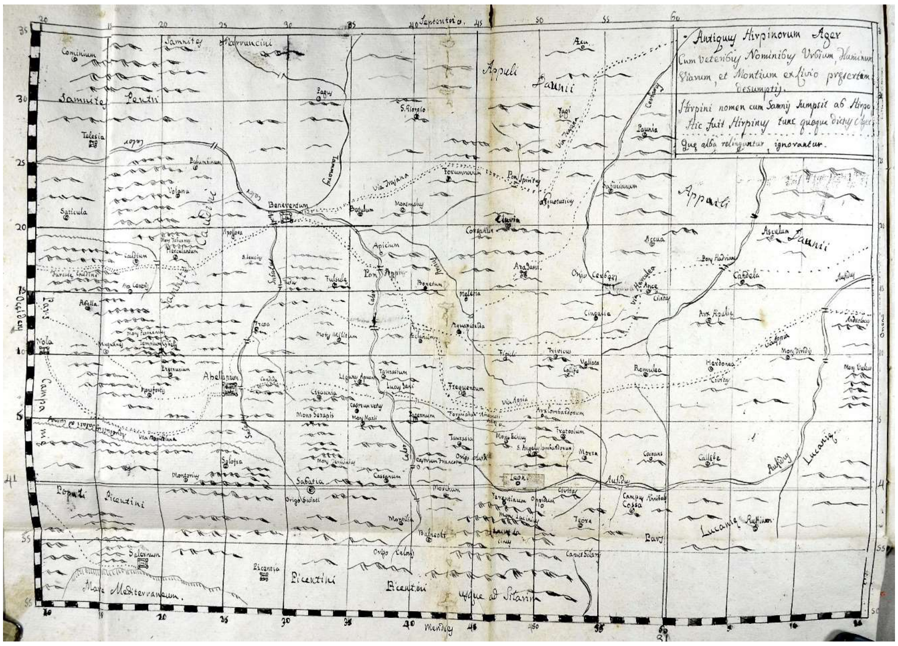


Figure 3. One of the maps drawn, relating to the same territory in pre-Roman times: Antiquus Hirpinorum Ager ("the ancient territory of the Hirpini", i.e., the Italic people who inhabited the territory called in the future Principato Ultra). The author claims to have reported the ancient names of cities, rivers, roads, and mountains as given by Titus Livy in his monumental work on the history of Rome (ASNa, State Archive of Naples, Ministry of Internal Affairs, Inventory I, bustage 2060).

The map of the province of Principato Ultra shows meridian 33, in which cities, major roads and bridges, rivers, mountain ranges, etc. are shown.

An example of a district map is shown in the next figure; the territory represented is that of the Ariano District, divided into 7 Circondari. The rivers are represented by thick black lines, while in brown are marked the boundaries between the Circondari (**Figure 5**).

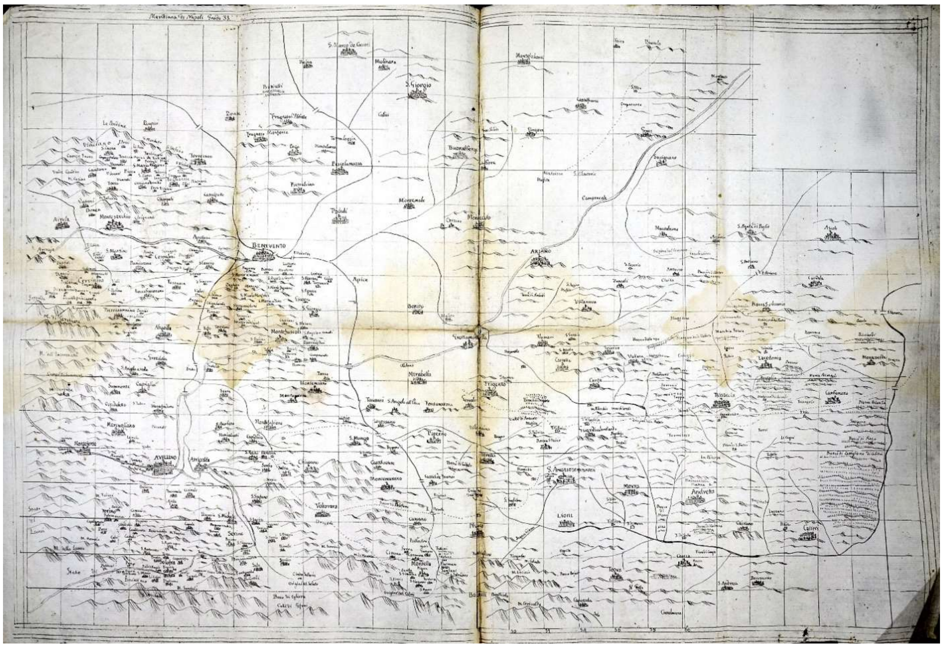


Figure 4. Map of the Province of Principato Ultra (ASNa, State Archive of Naples, Ministry of Internal Affairs, Inventory I, bustage 2060).

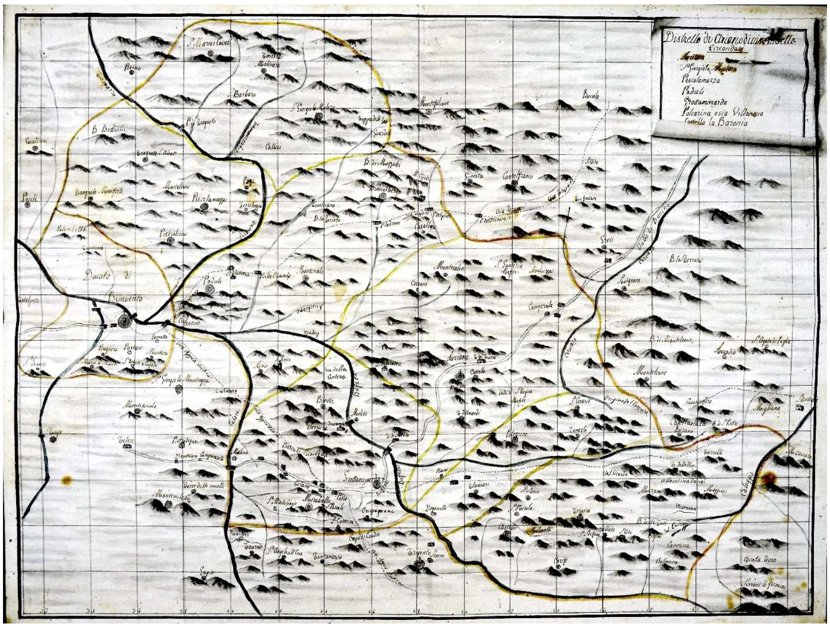


Figure 5. The district of Ariano (ASNa, State Archive of Naples, Ministry of Internal Affairs, Inventory I, bustage 2060).

An example of a map of Circondario (Circondario di Frigento), including six municipalities, with indications of non-routable roads, main and secondary waterways, forests, and with the reliefs just stylized:

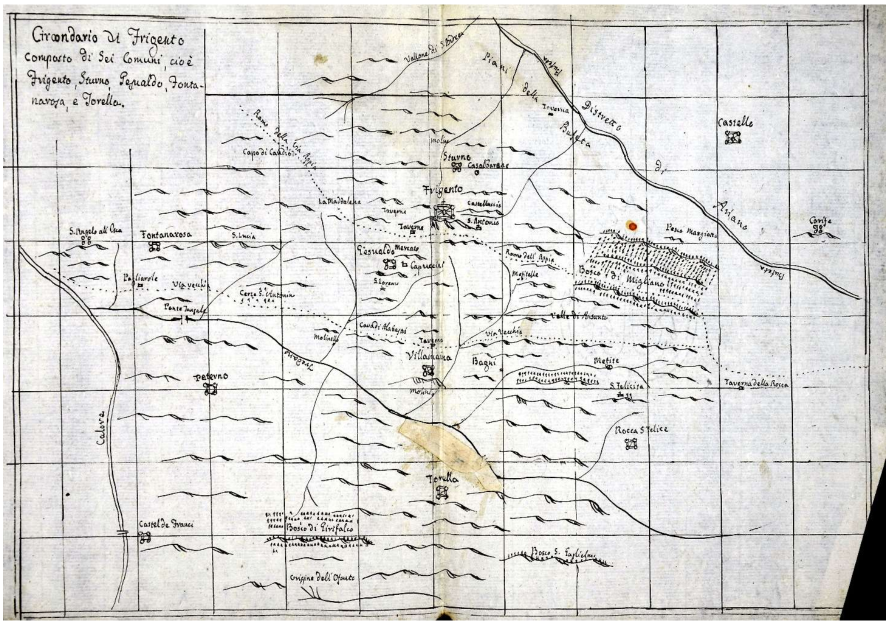
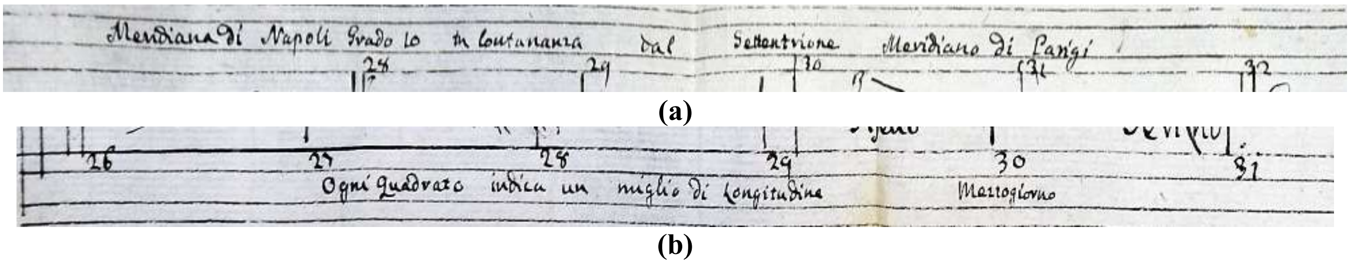


Figure 6. The Circondario of Frigento (ASNa, State Archive of Naples, Ministry of Internal Affairs, Inventory I, bustage 2060).

3.1. The problem of geographical coordinates

The maps elaborated by our scholar all present the geographical grid. The latitude obviously refers to the Equator; almost all of the mapped territory lies above the 41° N parallel, except for the southernmost part of the province.

Longitude, on the other hand, generally refers to the meridian of Paris (or meridian of France), which was commonly adopted at the time and remained as a universal reference until the 1884 Washington Conference, when it was decided—not without bitter controversy—to adopt the Greenwich meridian. A fortiori, the Paris meridian, is used by the scholar who drafts his papers in the decade when the Napoleonic dynasty ruled Naples (1806–1815). Naples is exactly 10 degrees from the meridian of Paris (**Figure 7**), as the author points out several times in the manuscript; this angular distance was later confirmed by the Capodimonte Astronomical Observatory in Naples, the first one established in Italy to fix exact time, astronomical surveys, and meteorological measurements.



(a)

(b)

Figure 7. Some details from the maps: **(a)** literally: the Meridian of Naples is 10 degrees of distance from the Meridian of Paris; **(b)** each square indicates one mile of longitude (amplitude). The terms Settentrione (North) and Mezzogiorno (South) appear in the two details.

In the manuscript text and in a few maps, longitudes of 32° E or 33° E sometimes appear, referring to the El Hierro Isle (the Meridian Island), in the Canary Islands, which, as we know, has been the reference since the 2nd century A.D., when Ptolemy considered the meridian passing there to be the zero meridian, the westernmost point of the Old Word.

The author clarifies that in the province and district topographic maps, each square indicates two miles of longitude and latitude, while in the district maps, each square has only one mile of side. This will enable the reader "at a glance" to find the distance between villages and to measure the longitude and latitude of mountains and their height. In fact, in the topography and descriptive geometry texts of Marciano Di Leo's historical period, there is a special emphasis on providing the reader with an "at a glance" perspective. Just as an artist does with the "picturesque," the topographer must show an immediate glimpse of nature, as if the reader were actually immersed in a field observation [9]. The mile that our author uses for his square grids measured seven thousand palmi, equal to one-sixtieth of a degree on the meridian; this mile was used in Naples as the "sixty-degree mile" for more than three centuries, and its final measurement would not be fixed until 1782 by the famous cartographer Giovanni Antonio Rizzi Zannoni [5] through direct surveys. During these surveys, Rizzi Zannoni met Marciano Di Leo, with whom he made numerous field "measurements with available scientific instrumentation".

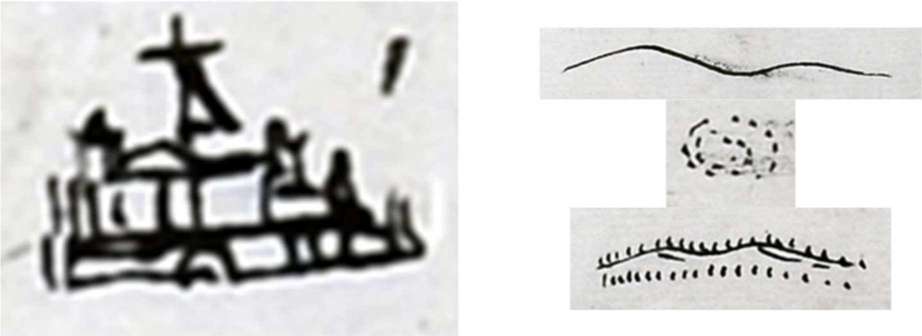
For surface measurements, our author used the measurements of square miles, corresponding to 200 Neapolitan palmi and 1 moggio. The moggio (from Lat. modius = measure) was an ancient unit of volume measurement, used particularly for grain, and counted among the more than 200 agrarian measures widespread in southern Italy. But as with other local units, it was also a unit of measurement of area, which in the Kingdom of the Two Sicilies—although highly variable—corresponded to about 3365 m^2. The moggio generally corresponds to 220 palmi, while the author uses the equation 1 moggio = 200 palmi. The entire Province of Principato Ultra, according to his calculations, from South to North measured 42 miles, while from West to East it was 54 miles wide, for a total of 2268 square miles; in this vast territory were more than 200 municipalities and villages, with a population of 324,000.

3.2. The map legend

The map legend is never given in the cartographies but is listed within the manuscript in a section named Avvertimento ("Warning," "Monition").

It specifies, through the size of the font used, the importance of the cities: the largest ones ("Capoluoghi" = Chief Towns) are presented in isometric capital letters; the medium-populated ones in capital letters with larger initials; those over 4000 inhabitants only in capital letters and italics; and, finally, the villages in capital letters and no italics.

The few other symbols on the maps concern man-made elements (bishop's seats, provincial governor's or sub-governor's seats, inns, carriageable and non-routable roads, bridges) and natural elements, like rivers, lakes, and forests (**Figure 8**).



(a) **(b)**

Figure 8. Examples from the map legend: **(a)** chief towns, including bishoprics, are indicated by this symbol; **(b)** other symbols are used in the maps: top, rivers; middle, lakes; bottom, forests.

4. Summary and conclusion

There is now an endless literature on European cartographic production, both for general and local studies; in many articles, the activity of the many professionals who worked between the second half of the eighteenth century and the beginning of the nineteenth century (geographers, engineers, mathematicians, astronomers, topographers, engravers, etc.) has been emphasized [13]. In the Age of Enlightenment, the refinement of topographical tools, the transition from lists of landed properties without cartography (Apprezzi in the technical language of the time) to geometric representations of these properties, the creation of geometric land registers, and the development of urban cartography with plans of large cities indeed led to unprecedented innovation. These detailed, high-quality cartographic productions, linked to the spread of cadastres, have the parcel geometric cadastre (in Italian, catasto geometrico particellare) in Tuscany, compiled between 1817 and 1834, and that of the papal dominions (1816–1835). It has also been argued that in these valuable cartographic representations, the real and the symbolic-ideological, the technical and the imaginary, were mixed [14].

The cadastre had no geometric character in the Kingdom of Naples, having been drawn up on an expert basis; more or less illustrious land surveyors (agrimensori) worked there [12]. The provisional or Murattian Cadastre of the Kingdom of Naples, started at the end of 1806, was almost completely rectified between 1813 and 1816 [15], using a bird's-eye view/perspective for the measurement and description of these tiny parts of the earth's surface, with figurative-type symbolism and details that were immediately comprehensible, thanks also to the reduction scale that inexorably conditions any cartographic representation. However, examples abound, especially in ecclesiastical archives, of representations of the properties of religious orders that demonstrate the intense professional activity of land surveyors, experts in measurement and estimation (an example of an Indian ink drawing, without scale or wind rose indication, is given in the following **Figure 9**).

Alongside this vast, mainly local, cartographic production, state-oriented cartography also advanced in the pre-unitary Italian States, and the influence of Napoleonic innovations was felt in every territorial sphere, as it was in so many other fields of state organization, economy, and culture. It is true that Southern Italy and, in general, the entire Peninsula were not without cartographic representations, known since antiquity, but the construction of such maps was not yet based on mathematical principles (there were no underlying geometric projections, no geographical grid of meridians and parallels, etc.). And the actual quantity and quality of the studies on historical cartography and the history of cartography published (at least in Italy [16]) testify to the great interest in the issues that these disciplines address, also in light of the possibilities offered by GIS [17], sensing the need to arrive at a "geographically integrated historiography" [18].

Figure 9. An example of very large-scale mapping of a church property (APME, Mirabella Eclano Parish Archives, Platea (the term Platea indicates a document, including a cartographic one, that inventories the complex of real estate and patrimonial rights, territorial pertinences with their annuities, of an ecclesiastical institution, of a municipality, of private individuals) of ecclesiastical property of the distinguished collegiate church of Santa Maria Maggiore, vol. I, 1731). In current measurements, the rustic property measures 59.2 m in width and 122 m in length.

An intellectual like Marciano Di Leo, with a non-scientific background, was able to learn some of the cartographic techniques that would enable him to produce maps that were innovative compared to the production that had preceded it. His maps were certainly used by royal engineers in designing new roads for the province, although their construction was never completed until much later. In any case, they also remain valuable as an intellectual product in the happy meeting of geography, history, and natural sciences. A precious attempt to restore an idea of territory in Roman antiquity and then in its time, an important step for a history of cartography and the statistical-geographical thought that permeated its reforming time, in the reconstruction of the landscape and the understanding of its functions.

Hence, not surprisingly, several times in the manuscript the author insists on the importance of knowledge of science subjects, but he especially urges on the need to—istruire i Fanciulli nella Geografia, e nella Storia, affinché avendo aperto avanti gli occhi questo gran Teatro ("…instruct the Children in Geography, and History, so that having opened before their eyes this great Theater". The great Italian geographer and writer Eugenio Turri (1927–2005) used the metaphor of theater to define landscape in one of his successful and significant volume)—can more consciously make the choices best suited to their happiness. As Marciano Di Leo states, l'abitazione degl'uomini è la Terra ("The habitation of men is the Earth").

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Article

Enhancing integrated resource management through remote sensing and GIS

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Abstract: Integrated Resource Management plays a crucial role in sustainable development by ensuring efficient allocation and utilization of natural resources. Remote Sensing (RS) and Geographic Information System (GIS) have emerged as powerful tools for collecting, analyzing, and managing spatial data, enabling comprehensive and integrated decision-making processes. This review article uniquely focuses on Integrated Resource Management (IRM) and its role in sustainable development. It specifically examines the application of RS and GIS in IRM across various resource management domains. The article stands out for its comprehensive coverage of the benefits, challenges, and future directions of this integrated approach.

Keywords: integrated resource management; remote sensing, geographic information system; light detection and ranging; synthetic aperture radar

1. Introduction

Integrated Resource Management (IRM) aims to harmonize multiple resources, such as land, water, forests, and minerals, to achieve sustainable development goals. Remote Sensing (RS) and Geographic Information Systems (GIS) have revolutionized IRM by providing valuable spatial information for planning, monitoring, and decision-making [1]. This section provides an overview of IRM and the role of RS and GIS in its implementation.

Remote Sensing involves the acquisition of data about the Earth's surface through sensors onboard satellites, aircraft, or drones, capturing information in various spectral bands and resolutions [2]. On the other hand, GIS provides a framework for organizing, analyzing, and visualizing spatial data within a geographic context [3]. The combination of RS and GIS offers a powerful synergy, enabling the integration of diverse data sources and facilitating a deeper understanding of resource dynamics.

This review article aims to explore the application of RS and GIS in IRM, shedding light on their contributions to various resource management domains. By utilizing remote sensing technologies, such as satellite imagery, LiDAR, and hyperspectral imaging, alongside GIS analysis techniques, such as spatial modeling and data integration, a range of resource management challenges can be addressed [4]. These challenges include monitoring land cover changes, assessing biodiversity and ecosystem health, managing water resources, optimizing agricultural practices, planning urban development, and evaluating the impacts of mining activities, among others.

The benefits of incorporating RS and GIS into IRM are manifold. These technologies provide a means to collect accurate and up-to-date spatial data over large areas, enabling informed decision-making processes based on real-time information. The ability to analyze and model spatial data allows for the identification of patterns, trends, and anomalies, facilitating the development of effective resource management strategies. Moreover, the integration of RS and GIS supports data-driven approaches to planning, conservation, and sustainable development [5].

However, the application of RS and GIS in IRM is not without challenges. These challenges include the need for robust data processing techniques to handle the vast amounts of remote sensing data, ensuring data interoperability and integration from different sources, addressing issues of data accessibility and sharing among stakeholders, and incorporating socio-economic factors into resource management strategies. Additionally, effective stakeholder engagement and supportive policy frameworks are essential for the successful implementation of integrated approaches [6].

Looking towards the future, this review article also discusses the potential future directions for RS and GIS in IRM. These directions encompass advancements in remote sensing technologies, integration of multi-source data, utilization of big data analytics and machine learning, enhanced data accessibility and sharing, incorporation of socio-economic factors, stakeholder engagement, and the development of supportive policy and governance frameworks [7].

In summary, the combination of RS and GIS presents a powerful and integrated approach to IRM, facilitating comprehensive decision-making processes for the sustainable management of natural resources [8]. By examining the applications, benefits, challenges, and future directions of this integrated approach, this review article aims to contribute to a deeper understanding of the role of RS and GIS in supporting IRM and promoting sustainable development practices (**Table 1**).

Table 1. Applications of remote sensing and GIS in natural resource management.

Resource Type	Remote SensingTechnique	GIS Analysis	Application
Forests	LiDAR	Land cover classification, tree height estimation	Monitoring forest health, mapping canopy structure
Water bodies	Multispectral imagery	Change detection, water quality assessment	Monitoring water pollution, mapping wetland changes
Agriculture	Hyperspectral imaging	Crop mapping, yield estimation	Precision farming, monitoring crop health
Urban areas	LiDAR, satellite imagery	Land use/land cover classification, urban growth analysis	Urban planning, infrastructure development
Rangelands	Satellite imagery	Vegetation index analysis, change detection	Assessing rangeland condition, monitoring grazing impact
Coastal zones	Synthetic Aperture Radar (SAR)	Shoreline mapping, erosion analysis	Monitoring coastal changes, assessing vulnerability

2. Applications of RS and GIS in IRM

2.1. Land resource management

Remote Sensing (RS) and Geographic Information Systems (GIS) have been widely employed in land resource management to support various activities such as land use planning, land cover mapping, and land degradation assessment [9]. These technologies provide valuable spatial information and tools for effective decision-making and sustainable land management practices (**Figure 1**).

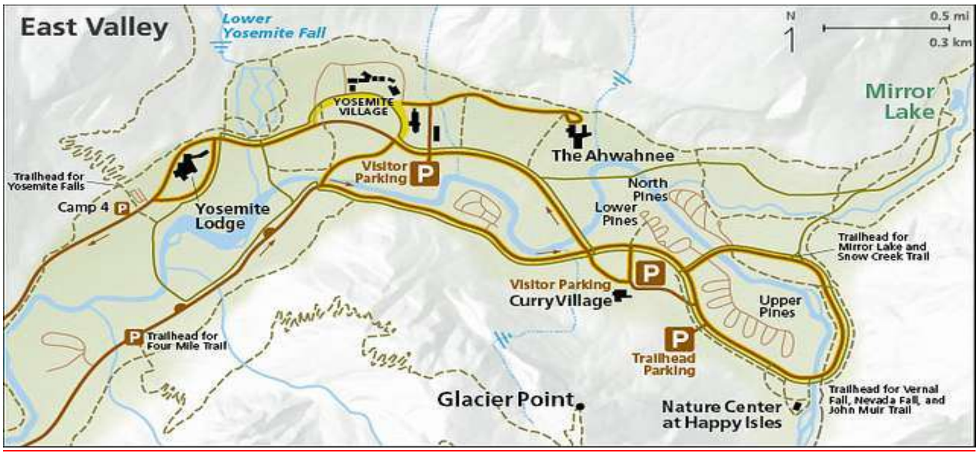


Figure 1. This figure shows land use management using land use and land cover in East valley, Arizona (under CC license).

Land use planning: RS and GIS play a vital role in land use planning by providing accurate and up-to-date information about land cover types, land suitability, and land-use change dynamics [10]. RS data, including satellite imagery and aerial photographs, can be used to map and monitor land cover and land use patterns over time. GIS facilitates the integration of multiple spatial datasets, enabling the identification of suitable areas for various land uses based on ecological, social, and economic factors [11].

Land cover mapping: RS data, with its ability to capture detailed spectral information, enables the creation of accurate land cover maps. Satellite images acquired at different wavelengths can be processed to classify land cover types such as forests, agriculture, urban areas, and water bodies. This information is essential for assessing land resources, identifying areas vulnerable to degradation, and monitoring land cover changes over time [12].

Land degradation assessment: RS and GIS techniques are valuable in assessing and monitoring land degradation processes, such as soil erosion, desertification, and deforestation [13]. RS data can be used to identify areas prone to erosion, monitor vegetation health and productivity, and detect changes in land cover associated with degradation. GIS provides a platform for spatial analysis, allowing the integration of multiple factors contributing to land degradation, such as soil type, slope, and land management practices.

Land resource inventory: RS and GIS are employed in land resource inventory to gather detailed information about land characteristics, including soil types, topography, and vegetation cover [14]. RS data, combined with field measurements and ground truthing, can provide accurate and up-to-date information on land attributes at various scales. This information aids in land suitability analysis, optimal resource allocation, and informed decision-making in land resource management.

Land-use monitoring and enforcement: RS and GIS enable regular monitoring and enforcement of land-use regulations and policies [15]. By comparing current land cover with established land-use plans, RS data can identify unauthorized land-use changes, encroachments, and illegal activities. GIS tools can assist in spatially analyzing land-use violations, prioritizing enforcement actions, and supporting land management agencies in enforcing land-use regulations.

2.2. Water resource management

Water resource management is a critical aspect of Integrated Resource Management (IRM), and Remote Sensing (RS) and Geographic Information Systems (GIS) have proven to be valuable tools in this domain [16]. RS and GIS technologies provide essential data and analytical capabilities for monitoring, assessing, and managing water resources effectively.

Water availability assessment: RS data, including satellite imagery and aerial photographs, can be utilized to assess water availability by monitoring surface water bodies, such as lakes, rivers, and reservoirs. GIS platforms facilitate the integration of spatial data, enabling the calculation of water storage capacity, estimating water levels, and tracking changes in water bodies over time [17]. This information helps in evaluating water availability for various purposes like irrigation, domestic supply, and industrial use (**Figure 2**).

Figure 2. This figure has been utilized in the California Department of Water Resources for irrigation, domestic supply, and industrial use (under CC License).

Water quality monitoring: RS techniques can provide valuable information on water quality parameters, such as water turbidity, chlorophyll-a concentration, and dissolved oxygen levels. RS sensors can capture the spectral signatures of water bodies, allowing the identification and monitoring of water quality variations [18]. GIS tools assist in spatially analyzing water quality data, identifying areas with poor water quality, and supporting decision-making for water treatment and pollution control measures [19].

Water demand and allocation: RS and GIS technologies support the estimation of water demand and the allocation of water resources based on spatial information [20]. RS data can be utilized to determine land use patterns, crop types, and evapotranspiration rates, which aid in estimating agricultural water demand. GIS platforms enable the integration of data from multiple sources, allowing the identification of water demand hotspots and facilitating optimal water allocation strategies.

Flood mapping and risk assessment: RS and GIS play a crucial role in flood mapping and risk assessment by providing accurate and up-to-date information about flood-prone areas [21]. RS data, including radar and optical imagery, can be used to detect flood extent and changes in water levels during flood events. GIS tools facilitate the analysis of terrain characteristics, land use, and hydrological data to assess flood risks, identify vulnerable areas, and support flood management planning.

Water infrastructure management: RS and GIS technologies support the management of water infrastructure systems, such as dams, canals, and pipelines [22]. RS data can be used to monitor the condition of water infrastructure, detect leakages, and assess the efficiency of water distribution systems. GIS platforms aid in spatially managing infrastructure data, optimizing maintenance schedules, and supporting decision-making for infrastructure expansion or rehabilitation.

2.3. Forest resource management

Forest resource management involves the sustainable utilization and conservation of forest ecosystems. RS and GIS technologies have revolutionized the way forest resources are managed, offering valuable tools for forest monitoring, inventory, planning, and conservation [23].

Forest monitoring and change detection: RS data, particularly satellite imagery, enables continuous monitoring of forest cover, deforestation, and forest degradation. Through time-series analysis, RS can detect changes in forest cover, identify areas of deforestation, and monitor forest regrowth [24]. GIS platforms facilitate spatial analysis and mapping of forest cover changes, contributing to effective forest monitoring and management.

Forest inventory and mapping: RS and GIS play a crucial role in forest inventory, providing accurate and up-to-date information on forest characteristics such as tree species, canopy height, and biomass [25]. RS data, including LiDAR and radar imagery, can capture detailed information about forest structure and composition. GIS tools enable the integration of RS data with other geospatial datasets, allowing for comprehensive forest mapping and inventory assessments (**Figure 3**).

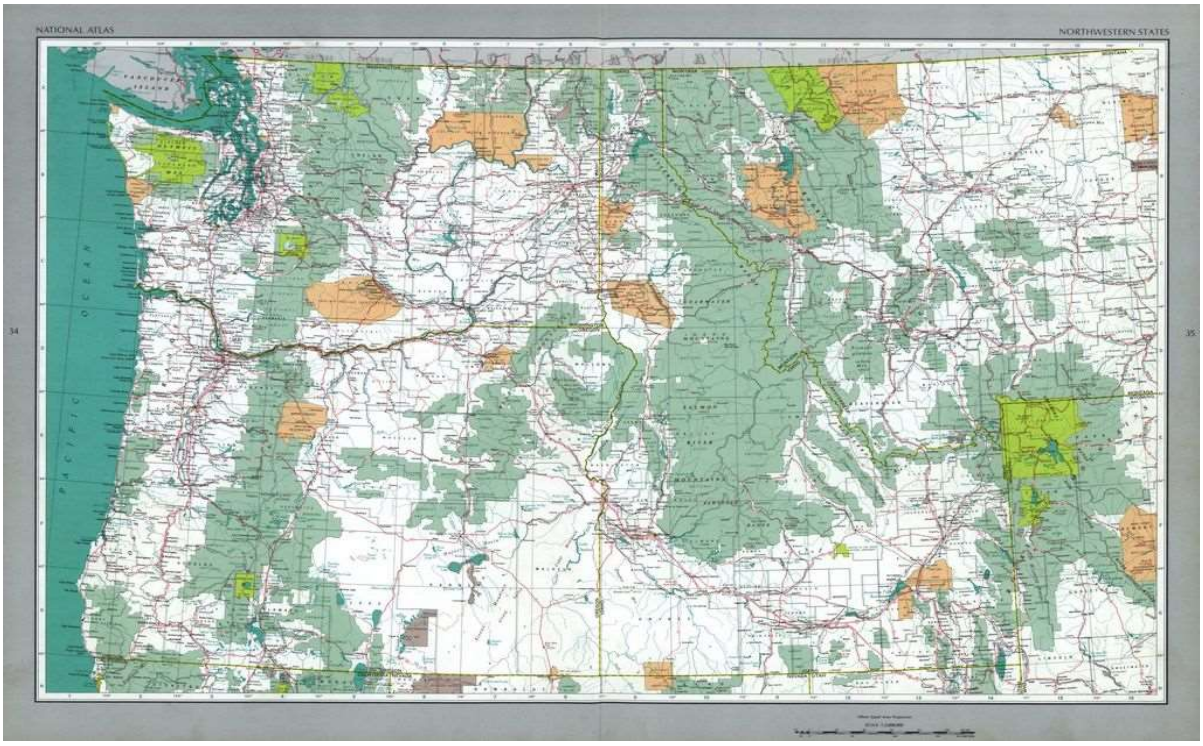


Figure 3. This figure has been utilized for forest inventory, mapping, planning, and conservation in the Northwestern States of the United States of America (Under CC License).

For forest fire management, RS and GIS technologies provide real-time fire detection, monitor fire spread, and assess fire damage [26]. This real-time data allows decision-makers to plan fire responses effectively, allocate firefighting resources where they are most needed, and carry out post-fire assessments. This can lead to more efficient and effective management of forest fires, potentially reducing their impact and aiding in quicker recovery. RS sensors can detect thermal anomalies and smoke plumes associated with wildfires. GIS platforms enable the visualization and analysis of fire data, supporting fire response planning, the allocation of firefighting resources, and post-fire assessment.

In the context of biodiversity conservation, RS and GIS techniques provide spatial information on habitat types, species distribution, and ecosystem dynamics [27]. This information can be used to map and monitor biodiversity-rich areas, identify habitat fragmentation, and assess the impact of land use changes on ecosystems. By integrating this data with other environmental layers on GIS platforms, decision-makers can support conservation planning and make informed decisions about resource allocation, protection measures, and policy development.

2.4. Mineral resource management

In the context of mineral resource management, which involves the exploration, extraction, and sustainable use of mineral resources [28], RS and GIS technologies play a crucial role. They provide valuable data for mineral exploration, resource assessment, and environmental impact assessment.

For mineral exploration, RS data, including hyperspectral and multispectral imagery, can assist in identifying mineral signatures and anomalies. RS sensors can detect specific wavelengths associated with minerals of interest, aiding in target selection for further exploration activities. GIS platforms enable the integration of geological, geochemical, and geophysical data, supporting spatial analysis and target prioritization [29].

The applications of mineral resource management through remote sensing and GIS are extensive. Some of these applications are presented in **Table 2**.

In decision-making, the references provided can be used to guide the exploration and extraction processes, assess the availability and impact of resource extraction, and plan for sustainable use. The data from RS and GIS technologies can help decision-makers understand the distribution and availability of mineral resources, identify potential exploration targets, assess the environmental impact of extraction activities, and plan for sustainable resource management. This can lead to more informed and effective decisions, contributing to the sustainable development of mineral resources.

Table 2. Applications of remote sensing and GIS in mineral resource management.

Resource Type	**Remote Sensing Technique**	**GIS Analysis**	**Application**
Mineral Prospecting	Hyperspectral imaging	Spectral unmixing Anomaly detection	Identification of mineral deposits, mapping mineral potential
Exploration	Gravity, Magnetic, and Electromagnetic surveys	Spatial analysis Data integration	Targeting exploration areas, identifying geological structures
Mining	LiDAR, Satellite Imagery	Terrain modeling Change detection	Monitoring land disturbances, assessing mine operations
Environmental Monitoring	Hyperspectral imaging, LiDAR	Land cover classification Terrain analysis	Monitoring mine reclamation, assessing environmental impacts
Site Rehabilitation	Satellite Imagery, UAVs	Vegetation analysis topographic modeling	Assessing vegetation regrowth, monitoring rehabilitation progress
Land Management	Satellite Imagery, GIS data	Land use/land cover mapping Spatial planning	Allocating mining concessions, managing land conflicts

Resource assessment: RS and GIS technologies are used for resource assessment to estimate the quantity and quality of mineral deposits. RS data can provide information on mineral composition, alteration zones, and structural features that help in assessing the potential of mineral resources [30]. GIS tools enable the spatial analysis and visualization of resource data, supporting resource estimation and reserve calculations.

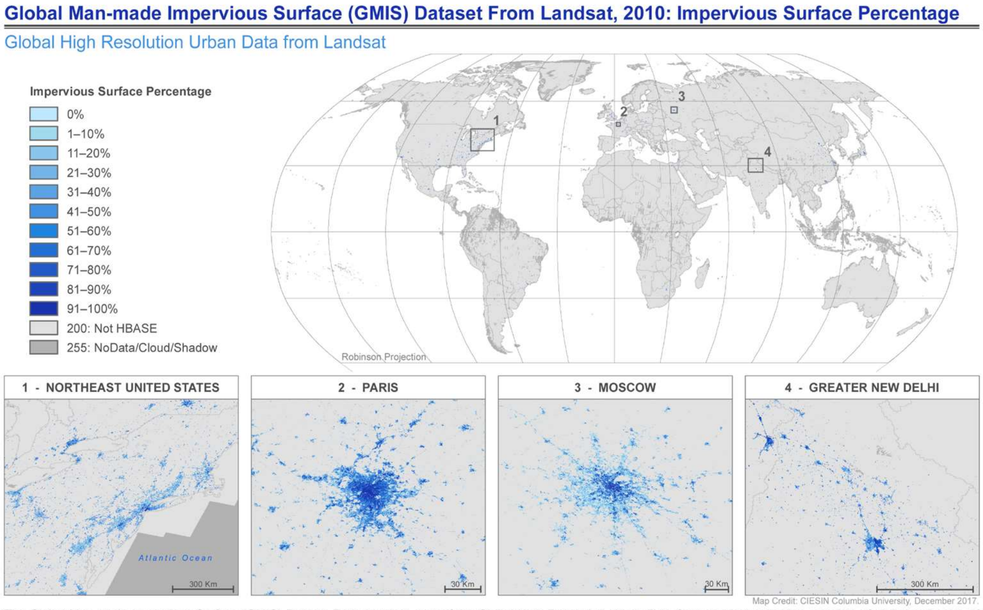
Environmental impact assessment: RS and GIS techniques contribute to environmental impact assessment in mineral resource management. RS data can be utilized to monitor the environmental impact of mining activities, such as land degradation, water pollution, and deforestation [31]. GIS platforms aid in spatially analyzing environmental data, identifying sensitive areas, and supporting decision-making for mitigating the environmental impact of mining operations.

Land reclamation and rehabilitation: RS and GIS technologies support land reclamation and rehabilitation efforts in mining areas [32]. RS data can be used to monitor vegetation recovery, assess soil erosion, and detect land cover changes following mining activities. GIS platforms facilitate the integration of rehabilitation plans with spatial data, enabling effective monitoring and evaluation of reclamation efforts.

2.5. Urban resource management

Urban resource management focuses on the efficient use of resources in urban areas, including energy, water, infrastructure, and land. RS and GIS technologies offer valuable tools for urban resource management, aiding in urban planning, infrastructure management, and environmental sustainability [33].

Urban planning and land use management: RS and GIS play a crucial role in urban planning by providing spatial information on land use, land cover, and population distribution. RS data can be used to generate accurate land use/land cover maps, identify areas for urban expansion or redevelopment (**Figure 4**), and assess population density and growth patterns. GIS platforms enable the integration of various spatial datasets, facilitating land use management, zoning regulations, and infrastructure planning [34].



Map Credit: CIESIN Columbia University, December 2017.

The Global Man-made Impervious Surface (GMIS) Dataset From Landsat, part of the Global High Resolution Urban Data from Landsat collection, consists of global estimates of fractional impervious cover derived from the Global Land Survey (GLS) Landsat dataset for the target year 2010. The GMIS dataset consists of two components: 1) global percent of impervious cover; and 2) per-pixel associated uncertainty for the global impervious cover. These layers are co-registered to the same spatial extent at a common 30m spatial resolution. The spatial extent covers the entire globe except Antarctica and some small islands. This dataset is one of the first global, 30m datasets of man-made impervious cover to be derived from the GLS data for 2010 and is a companion dataset to the Global Human Built-up And Settlement Extent (HBASE) dataset.

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Data Source: Brown de Colstoun, E. C., C. Huang, P. Wang, J. C. Tilton, B. Tan, J. Phillips, S. Niemczura, P.-Y. Ling, and R. E. Wolfe. 2017. Global Man-made Impervious Surface (GMIS) Dataset From Landsat. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H4P55KKF.

Figure 4. This figure shows the methodology adopted using Landsat data to process and visualize the Global Impervious Area (Under CC License).

3. Benefits of integrated RS and GIS in IRM

3.1. Enhanced data acquisition and analysis

Integrated RS and GIS in IRM enhance data acquisition by utilizing satellite imagery, aerial photographs, and other remote sensing data sources. These technologies provide a comprehensive and up-to-date view of the Earth’s surface, enabling the collection of spatial data across large areas. Moreover, GIS tools facilitate the integration and analysis of multiple data sources, allowing for a holistic understanding of resource dynamics and patterns.

3.2. Improved resource monitoring and assessment

RS and GIS enable improved monitoring and assessment of resources in IRM. By regularly capturing and analyzing RS data, such as land cover changes, water quality variations, or forest dynamics, managers can gain valuable insights into resource conditions and trends. This allows for proactive and timely decision-making in resource management, including early detection of degradation, effective conservation measures, and targeted interventions.

3.3. Effective planning and decision-making

Integrated RS and GIS provide powerful tools for effective planning and decision-making in IRM. By integrating spatial data with relevant attribute data, GIS enables comprehensive analyses and simulations, supporting informed decisions on resource allocation, land use planning, and infrastructure development. RS data assists in identifying resource potentials and limitations, optimizing resource use, and evaluating the impacts of different management scenarios, contributing to more efficient and sustainable resource planning.

3.4. Increased stakeholder engagement

The integration of RS and GIS in IRM enhances stakeholder engagement by facilitating data visualization and communication. GIS platforms offer interactive maps and visualizations that can be easily understood by diverse stakeholders, fostering better communication and engagement in the decision-making process. This promotes collaboration between resource managers, policymakers, local communities, and other stakeholders, leading to more inclusive and participatory resource management approaches.

In summary, the benefits of integrated RS and GIS in IRM include enhanced data acquisition and analysis, improved resource monitoring and assessment, effective planning and decision-making, and increased stakeholder engagement. These benefits contribute to more efficient, informed, and sustainable resource management practices, ensuring the optimal utilization and conservation of natural resources.

4. Challenges and limitations

4.1. Data availability and accessibility

One of the primary challenges in using integrated RS and GIS in IRM is the availability and accessibility of data. High-quality and up-to-date RS data may not always be readily available, especially in remote or inaccessible areas. Additionally, accessing and acquiring proprietary datasets or data from different sources can be complex and time-consuming. Limited data availability can hinder comprehensive analysis and decision-making in resource management.

4.2. Technical expertise and training

The effective utilization of integrated RS and GIS in IRM requires technical expertise and training. Skilled professionals who can process and analyze RS data, interpret GIS outputs, and integrate data from various sources are essential. However, there is a shortage of experts with the necessary knowledge and skills, particularly in developing regions. Insufficient training opportunities and a lack of awareness about the potential of these technologies can pose limitations to their widespread adoption.

4.3. Integration of multiple data sources

Integrating data from diverse sources, such as satellite imagery, ground-based observations, and socioeconomic data, can be challenging. Each data source may have different formats, resolutions, and spatial reference systems, requiring careful preprocessing and harmonization. Furthermore, effectively integrating data from different disciplines, such as ecology, hydrology, and land use planning, necessitates interdisciplinary collaboration and data sharing, which can be hindered by institutional and technical barriers.

4.4. Cost and infrastructure constraints

The cost of acquiring RS data, maintaining GIS infrastructure, and implementing integrated RS and GIS systems can be prohibitive for resource management agencies, particularly those with limited budgets. Furthermore, the processing and storage requirements for large-scale RS datasets can strain existing infrastructure capacities. Insufficient computing resources and internet connectivity in remote areas can further limit the application of integrated RS and GIS in IRM.

5. Future directions

Advancements in remote sensing technologies, including improved sensors and data processing techniques, will enhance the capabilities of integrated resource management (IRM). Integrating data from multiple sources, such as remote sensing, GIS, and ground-based monitoring systems, can provide a comprehensive understanding of resource dynamics and support adaptive management approaches. The application of big data analytics and machine learning algorithms will enable the extraction of valuable insights from complex datasets for more efficient resource management. Efforts should be made to enhance data accessibility and sharing among stakeholders to promote collaboration, transparency, and collective decision-making processes. Integrating remote sensing and GIS with socio-economic factors will provide a holistic understanding of resource management challenges and support the development of sustainable solutions. Stakeholder engagement should be prioritized through participatory approaches, incorporating local knowledge and perspectives in decision-making processes. Supportive policies and governance frameworks are necessary to fully utilize RS and GIS in IRM, including legal and regulatory frameworks, capacity-building initiatives, and international collaboration.

6. Conclusion

In conclusion, the integration of Remote Sensing (RS) and Geographic Information Systems (GIS) in Integrated Resource Management (IRM) offers significant contributions to sustainable development by facilitating efficient allocation and utilization of natural resources. This review article has explored the applications of RS and GIS in IRM, emphasizing their role in various resource management domains. The utilization of RS and GIS technologies enables the collection, analysis, and management of spatial data, providing comprehensive insights into resource dynamics. By leveraging these tools, decision-makers can make informed choices regarding resource allocation, conservation, and monitoring. The ability to monitor and analyze resource changes over time supports adaptive management strategies and facilitates the implementation of sustainable practices.

While the benefits of employing RS and GIS in IRM are substantial, there are challenges to overcome. These challenges include the need for advanced data processing techniques, data integration from multiple sources, and ensuring data accessibility and sharing among stakeholders. Additionally, the integration of socio-economic factors and stakeholder engagement is crucial for holistic resource management. Looking ahead, future directions for RS and GIS in IRM include advancements in technology, such as improved sensors and data processing algorithms, integration of multi-source data, utilization of big data analytics and machine learning, enhanced data accessibility and sharing, integration with socio-economic factors, stakeholder engagement, and supportive policy and governance frameworks.

By embracing these future directions, RS and GIS can continue to play a pivotal role in IRM, contributing to sustainable development and ensuring the efficient and equitable management of natural resources for present and future generations. The integration of these powerful tools enables comprehensive and integrated decision-making processes that pave the way toward a more sustainable and resilient future.

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Article

Integrative geography—Current issues in theory and practice (on the example of the Georgian geographical school)

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Abstract: The article discusses the essence of integrative geography and its importance for the theory and practice of geographical science. Such areas of integrative geography are characterized, the development of which will further increase the importance of applied geographical science. They include teaching about cultural landscape and historical landscape (part of landscape studies), geoecological expertise and environmental impact assessment (part of geographic ecology), geographic archeology and ecological culture (part of historical geography), landscape management and landscape services (part of landscape planning), and tourism—Assessment and planning of recreational resources (part of recreational geography).

Keywords: integrative geography; cultural landscape; historical landscape; geo archeology; ecological culture

1. Introduction

Integrative Geography [1,2]. It is the third main branch of geography, the history of which is one century long. It is also known in different geographical schools of the world as social-natural geography, synthetic geography [3,4], unified geography, regional geography [5,6], physical anthropogeography, environmental geography, or human geography, although its content is essentially represented by the term integrative geography. Thus, integrative geography studies the spatial-temporal features and regularities of the interdependence of society and nature. In integrative geography, public and related natural processes in the geographical environment (or vice versa) are considered equally important. Integrative geography is the most important arena of modern geography, which is related to its relevance, greatest application, and development prospects. The main areas of integrative geography include country studies (regional geography), landscape geography (landscape studies), geographic cartography, military geography, geographic ecology, medical geography, natural resource geography, human ocean geography, landscape planning [7], environmental impact assessment, geoecological expertise, geographic forecasting, etc. [8,9]. A clear example of integrative geography is landscape science and geographic cartography. Both of them require a complex approach and a synthetic vision. However, landscape science in Georgia still remains under the influence of the Russian geographical school and is considered a part of physical geography. Such an approach harms the importance of landscape geography and prevents the development of such “Western” directions as landscape planning, landscape services and landscape management, landscape perception, cultural and historical landscape research [10,11], landscape recreation, etc.

The current geopolitical, ecological, and socio-economic processes in Georgia require a new understanding of the development prospects of the Georgian school of geography. Along with theoretical research, which is a necessary prerequisite for the development of science, it is desirable to rapidly develop and popularize applied geographical directions, to grasp the European experience of geographical research, to expand cooperation with international organizations, and to show the importance of integrative geography (the focus of different directions of geography on the complex study and solution of interconnected topics). The agenda includes the research of issues that demonstrate the greatest importance of geographic education and science in solving the problems of sustainable development.

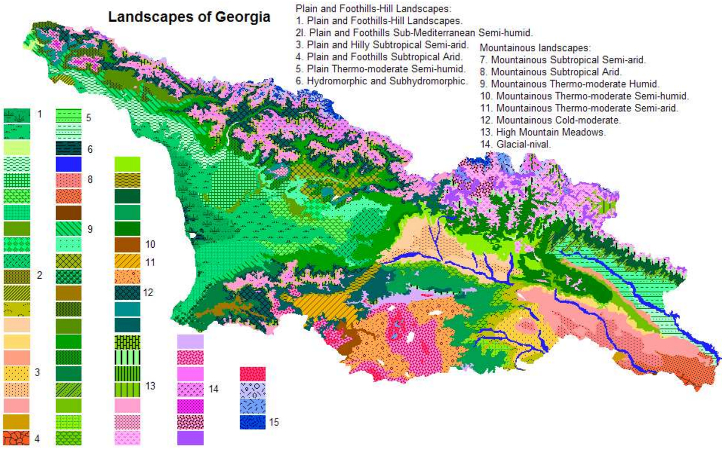

Figure 1. Natural landscape diversity of Georgia [12].

The Georgian school of geography, more than ever, needs to focus on the problems of sustainable development of mountainous areas [13] and the need to involve various scientific or practical organizations interested in similar topics.

Modern geography is concerned with both the assessment of the geographical environment and the modeling and forecasting of the development of the environment. Global modeling, which is very popular in the world's leading scientific circles, and has been widely spread since the 1980s of the 20th century, has undergone gradual "geographicization" and regionalization. Such a situation leads to the fact that any global or regional problem (political, economic, social, ecological, demographic, etc.). It is possible to analyze geographical, regional, or local events through analysis and reconciliation. Because of this, many types of global problems cannot be modeled and predicted without an integrative approach, complex geographic analysis, and synthesis. In addition, the aspiration towards unified geography, and the integration of geographical disciplines is due to the "non-geographical" trends in the development of sectoral geographical directions, the need to assess the extent of anthropogenic transformation of the natural environment (**Figure 1**), and the consequences of environmental impact. As noted by the prominent Georgian geographer, Professor Niko Beruchashvili (1947–2006), complex physical- and economic-geographic research appears as the main task of geography, a social order [14]. It is a fact that the effectiveness and applied value of geography are greater the more integrated and complex the space-time research is, the more geographical events and processes are considered in a cause-and-effect relationship, and the more complete their forecasting.

Any nature-beneficial project requires the analysis of natural factors and socio-economic processes, as well as a unified geographic assessment and expertise. Two scientific directions can claim to create the conceptual foundations of rational nature use: ecology and integrative geography. The majority of proponents of integrative geography consider the research task to be the study of the spatio-temporal characteristics of the interdependence of man and nature both in the geographical framework (global, regional, and local points of view) and in the territory of different ranks (river basins, administrative units, settlements, and landscapes). In many Western countries (USA, Great Britain, France, the Netherlands, Belgium, etc.), geography is considered a unified science, although here the main emphasis is on the analysis and forecasting of socio-economic processes.

2. Research methodology

A relatively small amount of scientific literature on integrative geography (environmental geography, human-environment geography) can be found. However, most scientists recognize the effectiveness of complex, systematic geographical research for the theory and practice of geography, and its importance in analyzing the spatio-temporal features of sustainable development problems [15–26].

The research methodology is based on both the analysis of scientific literature and the results of physical-geographical and public-geographical field research conducted in Georgia and the Caucasus. They are mainly related to the assessment of the geographical environment and territorial (spatial) planning. The results of the field research were reflected in the landscape planning methodology of several protected areas (national parks), urban agglomerations (Tbilisi-Rustavi), and historical cities (Mtskheta). All of them are based on the well-known landscape planning methodology [9,27,28], which has a long history in the geographical schools of many European countries.

During the last two decades, directions of integrative geography such as landscape geography, landscape planning, military geography, medical geography, environmental impact assessment, recreational geography, etc., have rapidly developed in Georgia. Their research methodology is in the process of formation and is based on the theory and practice of geographical and related sciences (history, culture, military affairs, medicine, ethnography, geography of tourism, etc.).

3. Results

Some current issues in integrative geography

A number of directions of integrative geography (**Figure 2**) require special attention. Among them are medical geography, recreational geography, military geography, etc. In addition, several new directions are emerging, the development of which will further increase the importance of geographical science. They include teaching about the cultural landscape, landscape management, and landscape services (part of landscape studies), geoecological expertise, socio-ecological systems, environmental impact assessment (part of geographic ecology), geographic archeology, and ecological culture (part of historical geography), tourism-recreational resource assessment and planning (part of recreational geography). Separate directions are discussed in various publications published by us [11,13,29,30]. This time we will touch on those new and interesting directions, in the research in which the students and graduates of the Georgian (Integrative) Geography and Landscape Planning Department of Tbilisi State University are actively and successfully involved.

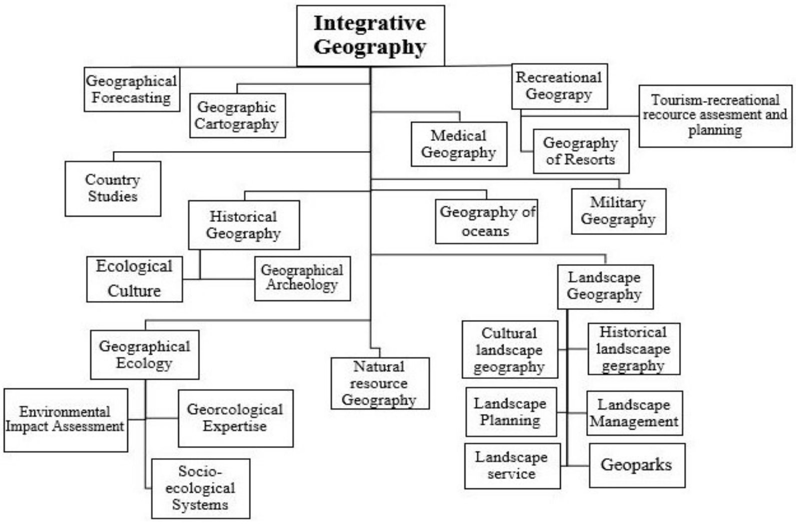

Figure 2. Integrative geography—thematic scheme.

(1) Teaching about the cultural landscape. The cultural landscape is the result of a long (historical) and harmonious relationship between man and nature. It is rightly considered an essential part of national heritage as it reflects local culture and identity. It can be related to an important historical event, as well as traditional economic or various social activities.

Through the cultural landscape, it is possible to have an idea of the trends of development of the territory and the utilization of the environment, the potential and ecological features of the landscape, and economic and social values.

Teaching about the cultural landscape (the so-called landscape science) began to take shape at the beginning of the 20th century, which is attributed to the German geographer Otto Schluter. He considered the geographical environment in two forms: natural or original (without human intervention) and as a collection of cultural landscapes. According to him, the main task of geography was the study of the process of transformation of the natural landscape into a cultural landscape.

The vast majority of researchers in this direction agree that:

1) The cultural landscape is developed on its natural foundation,
2) Preserves the main geographical elements (relief, geological structure, climate, waters, soil, accommodation, communications, etc.),
3) Basically (essentially) “submits” to the processes taking place in the natural environment [11].

Thus, the cultural landscape is part of the natural and cultural heritage. It clearly shows the peculiarities of the origin and development of this or that country (territory), the interdependence of man (the local community), and nature. Among the values of the cultural landscape, the areas related to forms of religion, traditional agriculture, historical places, landscape architecture, and traditional use of natural resources stand out in terms of importance and quantity.

Teaching about the cultural landscape is an essential part of integrative geography. Its development in geography is connected with the synthesis of research methods of natural science and public geography, integration of history and culture, agriculture and architecture, ecology and ethnoculture with geography.

In Georgia, despite several thousand years of statehood and farming history, no territory has the status of a cultural landscape. However, such a status would clearly show the country's public importance. There are dozens of places in Georgia that can be assigned the status of different types of cultural landscapes, the assessment of which is one of the important scientific tasks of the Georgian School of Geography.

(2) Teaching about the historical landscape. The historical landscape consists mostly of historical settlements created in a homogeneous geographical environment. It can be a city or a part of a city, a village or its part, a separate architectural monument, a defensive structure, etc. A historical landscape can be made up of individual buildings, as well as agricultural and recreational infrastructure. A historical landscape can be inhabited or uninhabited, but its architectural and archaeological monuments must clearly reflect the values of the past. Historic landscapes must have national or world value. They represent a clear example of historical development or process, as well as the result of the harmonious coexistence of man and nature. In scientific literature, the historical landscape is also considered a part of the cultural landscape. Historical landscapes can be classified according to different signs (characteristics). Its characteristics are considered: category (landscape of a populated point or its part), age (historical period), importance and identity (national, global), uniqueness (distinctiveness, style), architecture, a form of development, geographical compactness, harmony (in connection with the environment), according to function, degree of protection, scale of natural landscape transformation, and tourist attraction. Part of the listed characteristics is the object of geographical research. Because of this, teaching about the historical landscape should be considered as one of the tasks of integrative geography. Davit Bakuradze, a student at Tbilisi State University, is currently working on his master's thesis: Historical Landscape: Geographical Foundations of Identification Methodology. Identifying a historic landscape, especially within its natural environment, requires the integration of a number of scientific disciplines. Among them are the scientific directions of architecture, urban planning, history, archeology, culture, geography, and ecology. Several dozen historical landscapes are represented in Georgia. Their identification and planning should be carried out on the basis of clearly defined principles and methodology. Currently, in Georgia, only the historical capital—Mtskheta—has a UNESCO nomination. It was identified in 2013–2014.

(3) Geographical archeology (geoarchaeology) is an interesting and rapidly developing scientific direction of historical geography. It is a contiguous science of geography and archeology and combines humanitarian (social) and natural science disciplines. In 2021, a master's thesis was prepared for the first time in geographical archeology at Tbilisi State University, which deals with the place and importance of integrative geography in geographical archaeology. Now we can talk about

geographical archaeology, as well as the prospects of establishing an integrative (interdisciplinary) geographical science and its inclusion in the educational process. From a practical point of view, geographic archeology provides a new opportunity to study in more depth the peculiarities of the development and transformation of the geographical environment, the historical economic activity of society and its connection with the natural environment, and the peculiarities of the formation of cultural landscapes. Hopefully, geographic archeology will firmly take its place in the system of geographic sciences and contribute to the development of both integrative geography and archaeology.

(4) Ecological culture is a new scientific direction in geographic ecology, which is one of the main parts of integrative geography. A master's thesis was prepared for the first time on this topic in 2021, which deals with the place and importance of integrative geography in the field of ecological culture research. The task of the research was to study the ecological culture of the mountain population, to determine the different forms of human adaptation to the environment in mountainous regions, the influence of geographical features on the life and economic activities of the mountain population, to reveal the geographical and ecological features of preserving their ethnocultural identity. In this direction, it is important to study and compare the factors affecting the formation of the eco-culture of different peoples and different regions of the world. The topicality of the topic is determined by the trends of climate change, which are manifested in the change in the geographical distribution of many natural zones and landscapes, and in the ability of the population to adapt to new ecological challenges.

4. Conclusion and discussion—Perspectives on integrative geography

The importance of integrative geography is related to the effectiveness of systematic and synthesis research of geographic objects, geographic events, and geographic processes. Through it, it is possible to analyze and integrative the interconnected characteristics of the geographical environment. They can be imagined as a geographical chain. The main "links" of such a chain are geographical location → components of the natural environment → natural resources → population → economic situation → social situation → ecological situation. Integrative geography is most effective for research and analysis of spatial issues of sustainable development and socio-ecological systems.

The study of socio-ecological systems [31–38] is an interesting and promising scientific-practical task that can be considered an object of integrative geography research. This is especially true for Georgia, where such studies were practically not carried out. Many publications of ethno-cultural content are published in Georgia, although the interdependence of nature and society, the ecological culture of the local population, the history and ethics of environmental protection, ecological economics, etc. are rarely reflected in them. Preliminary studies show that the ecological ethics and traditional ecological knowledge of the mountain population of Georgia deserve a lot of attention. This becomes especially relevant in the background of climate change, when aridization of plain and lowland landscapes, degradation of medium-mountain forest landscapes, and the tendency to replace alpine grassland ecosystems with forest ecosystems are observed. In mountainous regions, the use of water and forest resources is already problematic, which requires the analysis and application of traditional knowledge and ecological culture. We should consider landscape services and landscape management as perspectives in integrative geography. Both of them are new and very interesting directions in modern landscape geography and landscape planning.

Landscape management is a rapidly developing scientific-practical direction, in which geographers, territorial planning and management specialists, sociologists, urbanists, landscape architects, economists, etc. are engaged. Its essence, first of all, is related to maintaining and ensuring the ecological sustainability of the environment. This refers to the development and management of spatial policies that arise at the local, regional, country, or global level (there are other forms of spatial relations: rural space → urban space → national space).

The ultimate goal of landscape management is the harmonious coexistence of the natural and public environment. It is impossible to achieve such a goal without knowing the natural mechanisms that determine the geographical features of the structure and functioning of the natural environment. On the other hand, public processes and awareness essentially determine the ecological state of the natural environment, which is why the study of the socio-economic situation and community behavior characteristic of this or that place is a necessary prerequisite for landscape management. Thus, landscape management is a multifaceted activity involving scientific, practical (economic), and administrative circles.

A universally accepted methodology for landscape management does not yet exist because it does not have a long history. The foundations of such a methodology are gradually being created, for which specialists from many countries around the world (Sweden, Germany, Switzerland, Norway, Austria, Finland, Australia, Japan, etc.) are especially active. Traditional forms of landscape use and management have a much longer history, especially in Southeast Asia and Europe.

Landscape service refers to the set of actions that the local population takes to maintain its aesthetic and national significance. The appearance of the landscape clearly speaks of the household and ecological culture of the population. Polluted and uncared for, the degraded, and depressing landscape is considered to be an obstacle to the development not only of local residents but also of society.

Only the local population can make the landscape attractive and interesting, healthy and safe, and clean, which also affects their psychological mood and socio-economic activity. For this purpose, great attention is paid to the beautification and purposeful regulation of building facades, gardens, yards, and parks in the settlements of European countries. The local population takes responsibility for landscape services, which is an integral part of European ecological culture.

Many directions of integrative geography are of great importance for the further development of the Georgian school of geography. This is related to the study of the landscape diversity of Georgia, the problems of spatial planning in the country, the tasks of preserving natural and historical-cultural heritage, the formation of new protected areas, the restoration of resort farming, the need to analyze the trends of climate and agro-climatic resource changes, environmental impact assessment, etc.

Thus, many directions of integrative geography can become an essential tool for the analysis of problems related to the sustainable development of contemporary Georgia.

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Article

Integrating remote sensing and field investigation for lithological mapping of Per-Eonile to Neonile sequences west of Sohag city, Egypt: Impact on urban development

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Abstract: In the domains of geological study, natural resource exploitation, geological hazards, sustainable development, and environmental management, lithological mapping holds significant importance. Conventional approaches to lithological mapping sometimes entail considerable effort and difficulties, especially in geographically isolated or inaccessible regions. Incorporating geological surveys and satellite data is a powerful approach that can be effectively employed for lithological mapping. During this process, contemporary RS-enhancing methodologies demonstrate a remarkable proficiency in identifying complex patterns and attributes within the data, hence facilitating the classification of diverse lithological entities. The primary objective of this study is to ascertain the lithological units present in the western section of the Sohag region. This objective will be achieved by integrating Landsat ETM$^+$ satellite imagery and field observations. To achieve our objectives, we employed many methodologies, including the true and false color composition (FCC&TCC), the minimal noise fraction (MNF), principal component analysis (PCA), decoration stretch (DS), and independent component analysis (ICA). Our findings from the field investigation and the data presented offer compelling evidence that the distinct lithological units can be effectively distinguished. A recently introduced geology map has been incorporated within the research area. The sequence of formations depicted in this map is as follows: Thebes, Drunka, Katkut, Abu Retag, Issawia, Armant, Qena, Abbassia, and Dandara. Implementing this integrated technique enhances our comprehension of geological units and their impacts on urban development in the area. Based on the new geologic map of the study area, geologists can improve urban development in the regions by detecting building materials "aggregates". This underscores the significance and potential of our research in the context of urban development.

Keywords: RS; lithological mapping; Landsat ETM$^+$; Nile evolution; sustainable development

1. Introduction

Geological mapping is crucial in most geological studies, mineral exploration, geological hazard assessment, and environmental management [1]. It provides vital insights into the Earth's crust's distribution, composition, and geological history [2]. Accurate lithological maps offer a detailed understanding of different rock types' distribution, properties, and characteristics within a study area. However, traditional methods of lithological mapping involve intensive fieldwork, which is time-consuming and challenging in inaccessible areas [3,4]. This is where remote sensing data proves valuable, as it can furnish detailed information across vast regions, particularly in semi-arid and arid areas [5]. Lithological mapping can be achieved rapidly, cost-effectively, and accurately by amalgamating remote sensing and fieldwork [6]. This approach offers several advantages compared to other techniques, including integrating multiple data sources, which enhances the accuracy and comprehensiveness of lithological maps. Additionally, it enables the provision of up-to-date information on areas undergoing rapid changes due to anthropogenic factors while being capable of handling large amounts of data.

Various image-processing techniques have been developed in recent decades to improve, delineate, and classify geological characteristics, including alteration zones and tectonic lineaments [7]. Multiple studies have been conducted on the classification of lithologic units [8], and recent advancements in image-processing techniques in remote sensing have opened new possibilities for lithological mapping [9]. Advanced remote sensing enhancing processes can be used to recognize patterns and features in data and classify them into different lithological units. Integrating remote sensing and field investigation processes is faster, more efficient, and more accurate than the traditional "field survey" [10]. On the other hand, remote sensing techniques can process large amounts of data from various sources, such as multispectral and hyperspectral satellite imagery, field data, and geological and topographical maps [11]. This facilitates the integration of multiple data sources, thereby enhancing the precision of lithological maps.

Sustainable development of human society is closely related to geosciences by scientifically reviewing contributions made by geosciences to promote the geosciences to address the challenge faced [12]. It emphasizes the crucial role of geology in future urban planning, which significantly contributes to limiting conflicts, reducing risks, and lowering the costs of subsurface challenges [13]. Urban areas may tackle challenges by managing the subsurface based on geological knowledge and data. Geological maps play a significant role in urban development by providing the extensive data archives and cutting-edge expertise necessary for sustainable urban development [14].

The area under consideration represents a part of the Nile Valley. The lithostratigraphy of the sediments exposed in the study area has been studied by many authors [15–18]. Recently, Said [19] reviewed the earlier classifications of the Nile sediments and proposed new lithostratigraphic classifications in which the Nile sequence is classified from bottom to top into Madamud, Armant, Issawia, Qena, Abbassia, and Dandara formations. The various rock units at Sohag are composed of a sedimentary succession ranging in age from the Lower Eocene to the Quaternary [20].

The present work considers the nomenclature Said [21] gave for the Nile sediments. The detailed field study, the constructed geological maps and cross sections using satellite images (Landsate7 (ETM$^+$)), and new remote sensing processing techniques have shown that these sediments exhibit significant lateral and vertical lithological variations. These characteristic features have yet to be illustrated among the different formations proposed by the earlier literature, enabling the authors to redefine the boundaries of some rock units proposed by Said [19] and to recognize new rock units not mentioned before in the stratigraphy of the Nile sediments. In addition to understanding the role of geology maps in urban sustainable development in the area.

2. Study area

The study area is located west of Sohag City. It includes the old floodplain and part of the western limestone plateau (**Figure 1a**). It is situated between the longitudes of 31°25′ and 32°00′ East and the latitudes of 26°00′ and 26°35′ North (**Figure 1b**), and it has an area of approximately 2164 km^2. To the east, it is surrounded by the recent Nile Valley floodplain. The highway that connects Cairo and Aswan passes through the middle of the study area. The area may be reached by many asphalt highways linking it to the cities. Several wadis also dissect the area. The area's elevation ranges from 63 m in the east to 393 m in the west.

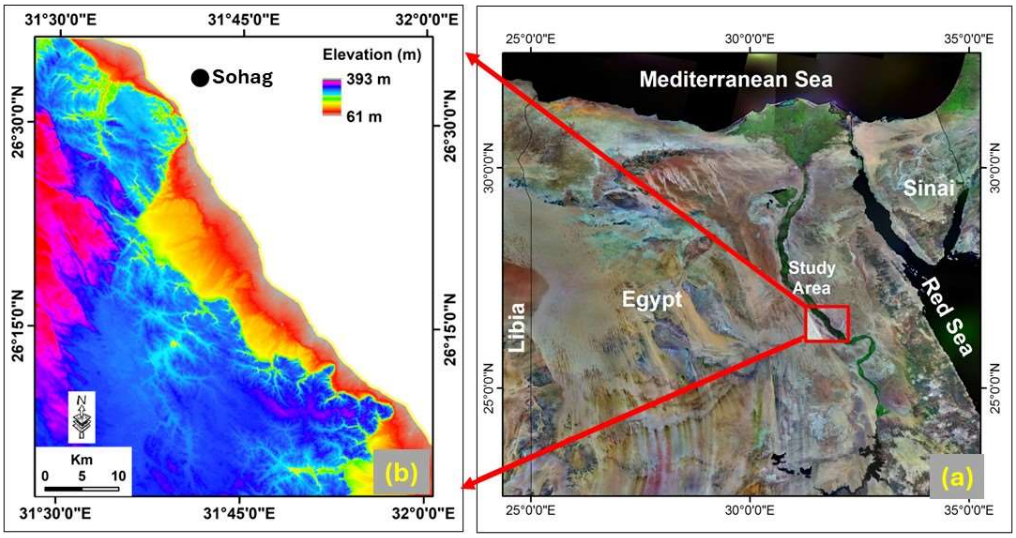

Figure 1. (a) Location map of the study area; **(b)** elevation map of the study area.

3. Data used and method

Remote sensing enables identifying, measuring, and analyzing various characteristics of target objects located on, above, or even below the earth's surface without direct contact between the sensors and the observed targets or events [2]. It allows for the extraction of information regarding the characteristics of objects by detecting and capturing the reflected or emitted energy, followed by the processing, analysis, and application of that acquired information [22]. Remote sensing data primarily consists of the reflected or emitted electromagnetic radiation from the targets. These data can be detected by a sensor usually mounted on airborne or spaceborne platforms. The application of remote sensing technology for lithological mapping has gained widespread application due to its ability to detect and differentiate surface characteristics that are not visible to the naked eye. Various remote sensing techniques are employed for lithological mapping, including hyperspectral imaging [1] and multispectral imaging [10,23]. Multispectral imaging involves collecting data in a few broad spectral bands with moderate spectral resolution and rapid coverage of large areas [24]. Its application in lithological mapping involves distinguishing between different lithological units by analyzing their spectral signatures. The limitation of remote sensing data can be overcome by integrating it with field investigation to improve the accuracy and efficiency of multispectral imaging.

In recent decades, Landsat satellites have provided valuable multispectral remote sensing datasets for various applications, including mapping rock types and mineral deposits [9]. The Landsat series includes several types, such as Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM$^+$), and Landsat Operational Land Imager (OLI). In the current study, Landsat-7 launched on 15 April 1999, carries the Enhanced Thematic Mapper Plus (ETM$^+$) sensor, which was used. ETM$^+$ offers seven spectral bands: Visible (B1, B2, B3), Near-Infrared (B4), and Short-Wave Infrared (B5, B7) with 30 m spatial resolution and a panchromatic band (B8) with 15 m spatial resolution. The sixth band (B6) is Thermal Infrared (with 60 m spatial resolution). The flowchart in **Figure 2** illustrates the method used in the current study. Various techniques were applied in the current research, including true and false color composites (TCC & FCC), principle component analysis (PCA), minimum noise fraction (MNF), decoration stretching (DS), and Independent Component Analysis (ICA). In addition, a field investigation was conducted to study the lithological framework. Various lithological sections were measured and acquired to verify the remote sensing results. Finally, evaluate the role of the geological mapping of the study area on urban development in the area.

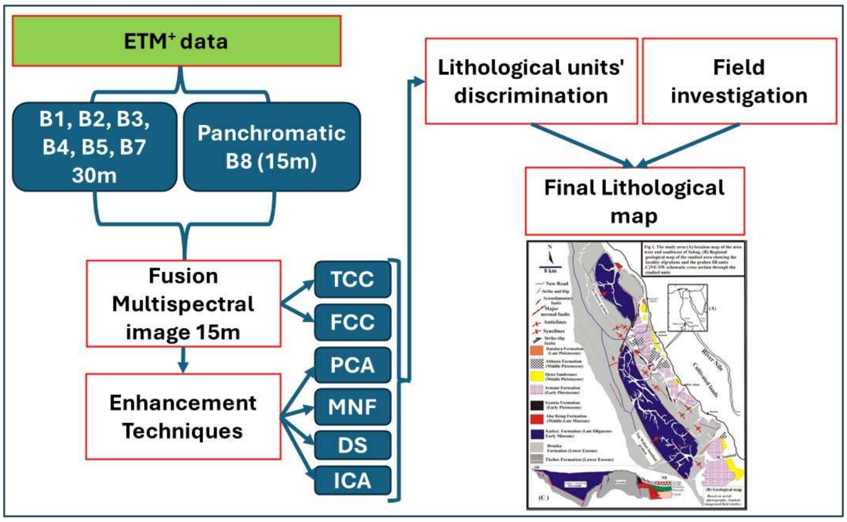

Figure 2. Flowchart showing the methodology of lithological unit mapping of the study area.

4. Results and discussion

4.1. Remote sensing analysis

This study applied a true-color composite (bands 321 in RGB) (**Figure 3a**). The results indicated that it was not helpful for lithological analysis. The image only offers a little information, except for discriminating between the bedrock units (limestone) and the fan deposits (sediments) under the scarp. In addition, a false-color composite (bands 742) has been produced (**Figure 3b**). It was found that the false color is somehow helpful for lithological analysis. In this image, aggregate deposits appear with a dark to light brown color, vegetation in green, and other materials in a light color. However, this composite did not clearly distinguish between different types of aggregate materials and the surrounding deposits.

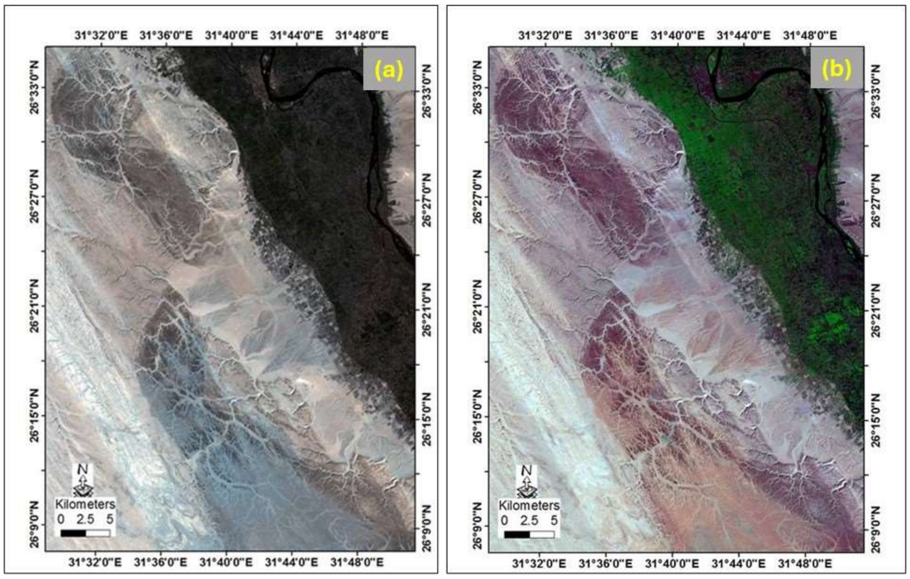

Figure 3. (a) a true color composite of Landsat ETM$^+$ bands 321 in (RGB); **(b)** a false color composite bands 742 in (RGB).

Note: The Katkut Formation appears to be distributed in brick and brown colors.

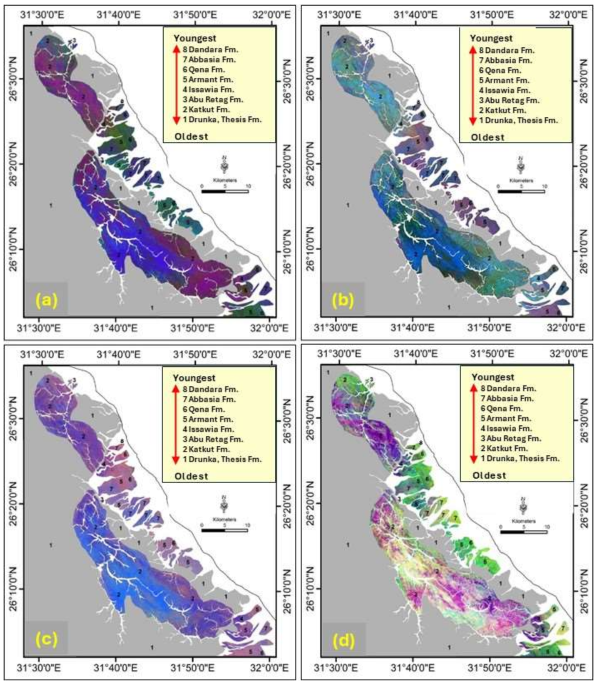

Figure 4. (a) PC image bands 124 in RGB; **(b)** MNF image 531 in RGB; **(c)** DS image 321 in RGB; **(d)** ICA image 561 in RGB. Drunka, Katkut, Abu Retag, Issawia, Armant, Qena, and Abbassia formations take numbers 1 to 7 in the image, respectively.

Several enhancing remote sensing processes were applied to bands 1, 2, 3, 4, 5, and 7 of the ETM$^+$ image. 1) Principal component analysis (PCA) was applied, as shown in **Figure 4a**. The best PC combination was band 124 in RGB, respectively. 2) The minimum noise fraction (MNF) technique was applied, as shown in **Figure 4b**. Results show that the MNF band 531 in RGB provides the best discrimination between various rock units. 3) The decorrelation stretch (DS) was applied to the selected band triplet (321 in RGB) (**Figure 4c**). Results show that this DS combination succeeded in differentiating the different rock units from each other and the surrounding materials. 4) The independent component analysis (ICA) was applied to the study area's image data to enhance the image's spectral variability. **Figure 4d** shows the ICA band 156 in RGB. This combination from ICA differentiated the different rock units in the study area. These four advanced techniques (PCA, MNF, DS, and ICA) successfully distinguished the different sedimentary rock units from each other and the surrounding materials. These units include Drunka (1), Katkut (2), Abu Retag (3), Issawia (4), Armant (5), Qena (6), and Abbassia (7) formations (**Figure 4a–d**). Based on the analysis of these methods, they are instrumental in discriminating between different exposed rock units.

4.2. Field investigation and lithological formations

Generally, these sediments are grouped into three primary lithostratigraphic sequences: the Lower Eocene limestone sequence, the Late Oligocene-Late Miocene sequence (Pre-Eonile–Eonile), and the Pliocene-Quaternary sequence (Paleonile-Neonile). Each sequence is distinct in lithology and stratigraphic relationships and is limited by apparent structural discordance. **Figure 5** summarizes the proposed lithostratigraphy of the rock units of the study area.

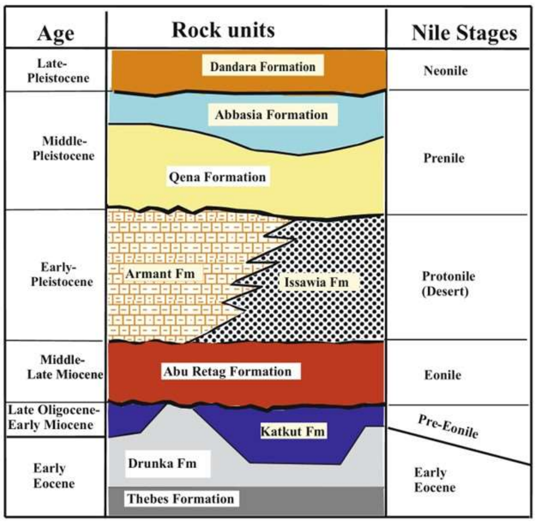

Figure 5. Chorostratigraphic summary chart of late Oligocene-Pleistocene, sequences of the Pre-Eonile—Neonile stages of the Nile evolution at the west Sohag area.

4.2.1. The lower Eocene limestone sequence

Lower Eocene limestone plateaus border the study area's Nile Valley. Due to lithology and faunal content variations, this sequence is divided into two rock units: the Thebes Formation at the base and the Drunka Formation at the top.

The Thebes Formation: This formation represents the Lower Eocene limestone of the Nile Valley. Thebes Formation has a local distribution in the area west of Sohag. Lithologically, the Thebes Formation is characterized by 30 meters of laminated limestone with flint bands west of El-Kawamil village, where it conformably underlies the Drunka Formation (**Figure 6a**).

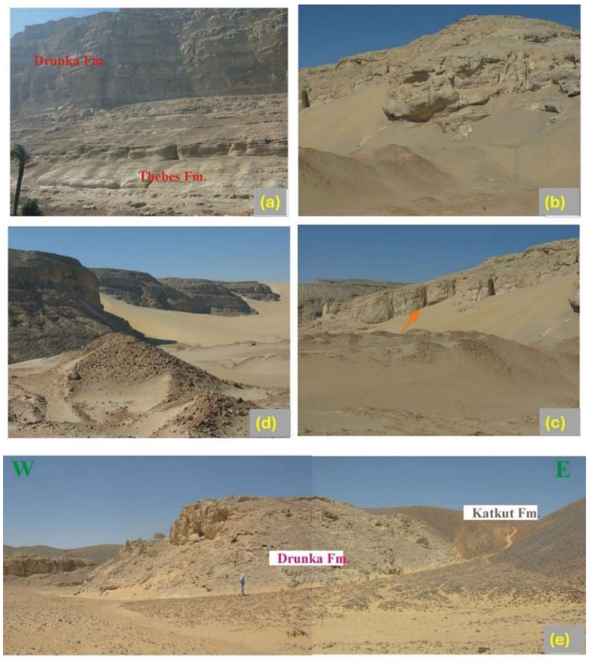

Figure 6. Field photographs showing: **(a)** the Drunka Fm. overlies the Thebes Fm.; **(b)** the massive and thick-bedded nature of the Drunka Fm.; **(c)** a tilted block of the Drunka Fm. The arrow points to fractures affected by the west-dipping fault block; **(d)** reentrant features due to the intersections of NW and ENE fault segments; **(e)** E-W oriented panoramas showing conglomerates of Katkut Fm.

The Drunka Formation: The Drunka Formation covers more than 90% of the area around Sohag. It overlies the Thebes Formation and is easily differentiated from it by its snow-white color and massive bedding (**Figure 6b**). The lower part of the Drunka Formation (~30 m) is composed of laminated limestone with chert bands interbedded with bioturbated hard massive limestone, including large, silicified limestone concretions (up to 1.2 m in diameter). The upper part (up to 100 m) comprises greyish-white, massive, bedded bioturbated limestone enriched with echinoderms, mollusks, large foraminifera, and calcareous algae. The field view shows the Drunka Formation affected by faults and reentrants due to the intersections of NW and ENE fault segments (**Figure 6c,d**). In addition, conglomerate deposits of the Katkut Formation are resting unconformably upon the E-dipping Eocene fault block, where the conglomerates are trapped west of blocks in some places (**Figure 6e**).

4.2.2. The Late Oligocene—Late Miocene sequence

4.2.2.1. The Katkut formation

Many authors first introduced the name Katkut Formation to the post-Eocene stratigraphy west of the Nile Valley [25,26]. It comprises all the coarse clastic sequences that unconformably overlie the Early Eocene sequence. In the current work, we use the name Katkut Formation to describe all coarse clastic sediments, which are entirely restricted to the filling of the NW grabens formed in the Early Eocene sequence along the Nile Valley western margin (**Figure 7a**). The type section for the Katkut Formation is located on the southern flank of Wadi El Yatim, where it measures more than 60 m thick. The base of this formation is not exposed to the surface. Considering the analysis of the sedimentary record, we have divided the Katkut

Formation into three unconformably bounded units; their boundaries correspond to changes in depositional and erosional processes (**Figure 7b,c**). Unit (1) comprises more than 15 m of conglomerates and conglomeratic sandstones. Some channel-like bodies are observed, and most sequences are fining upwards. The western margin of this unit is truncated by an angular unconformity against which coarse slope deposits have accumulated. Unit (2) is formed by 5 to 40 m thick cross-bedded sandstones. The remaining section is composed of mottled, reddish-brown siltstone and claystone. The top part of this unit includes terrigenous paleosol and calcrete nodules. The base of unit (3) is 20 m thick of tabular cross-bedded conglomeratic sandstones. The overlying section (5 to 20 m thick) comprises conglomerates and conglomeratic sandstones of varying proportions of extrabasinal material (mainly chert). In most cases, the beds display an upward-coarsening.

4.2.2.2. The Abu Retag formation

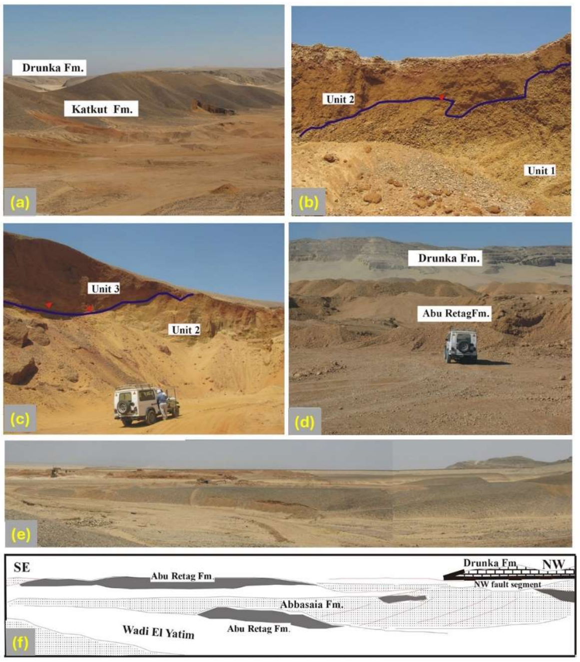

Figure 7. Field photographs showing **(a)** the Katkut Fm. filling NW-trending Graben; **(b)** Unit (2) unconformably overlying Unit (1) of Katkut Fm.; **(c)** Unit (3) unconformably overlying Unit (2); **(d)** the Eonile coarse clastics (Abu Retag Fm.) occurring in "Wadi Abu Retag"; **(e)** NW-SE panorama view; **(f)** line drawing of Abu Retag Fm. (gray color) unconformably overlying by Prenile Abbassia Fm.

The formal name Abu Retag Formation has been newly introduced to the local stratigraphy of the Nile sediments by Mahran et al. [27] to describe the mottled reddish brown coarse clastic sediments that predominantly crop out along the lower slopes of the western Eocene limestone scarps (**Figure 7d**). It is well developed in the hanging wall of the NW, N, and NE fault segments, where the Eocene plateau is intensely faulted (**Figure 7e**). The Abu Retag Formation forms the first stage of fluvial sedimentation within the Nile basin fill. The line drawing of the view south of Wadi El Yatim shows the Abu Retag Formation (gray color) extending east of the Drunka Formation and unconformably overlying the Prenile Abbassia Formation. Foreset dips of Abbassia conglomerates indicate an eastward progradation direction (**Figure 7f**). Some of the Abbassia Formation is trapped within depressions west of the Abu Retag deposits. Locally, the Abu Retag deposits unconformably overlie the tilted carbonate blocks of the Drunka Formation. The thickest section of the Abu Retag Formation was measured at the northern flank of Wadi Abu Retag, where exposures occur in three closely spaced sections in boreholes. The most complete of these totals is about 50 m in thickness. These sediments comprise a wide range of clast sizes and extrabasinals (silicified and biogenic limestones, cherts, and sandstones). Basement clasts are also present and localized in the upper part of the conglomerate section. Bedding varies from massive to crudely stratified to trough cross-bedding. Most of the sequence exhibits a coarsening-upward depositional trend. Individual beds are commonly lenticular in shape and have irregular bases. Paleosol horizons and desiccation cracks are common in these sediments.

4.2.3. The Pliocene—Quaternary sequence

The Pliocene-Quaternary sequence in the study area (west of Sohag city), belonging to the Paleonile-Prenile stages, forms the Nile terraces between the cultivated flood plains and western Eocene limestone cliffs. This sequence is classified into five lithostratigraphic units: Armant, Issawia, Qena, Abbassia, and Dandara formations.

4.2.3.1. The Issawia formation

Said [28] used “Issawia Formation” to describe a succession of massive rubble breccias topped by characteristic hard red breccias. Careful examination of aerial photographs, Landsat-7 ETM$^+$ images, and facies analysis indicate that both Issawia and Armant formations are laterally interfingering; hence, the sediments of the two units were contemporaneously deposited. Sediments of the Issawia Formation crop out along the margins of the Eocene escarpment. The type section is measured south of Wadi El-Kiman, where it attains its maximum thickness of up to 30 m. It is subdivided into three units, separated by paleosol horizons. The lower unit comprises breccia clasts ranging from 0.3 to 3 m in diameter. The middle unit is dominated by crudely bedded breccias of different sizes. The clasts tend to decrease in size westward. The upper unit has a wedge-like geometry and is composed of thick-bedded conglomerates. Laterally, the conglomerates intercalate with calcrete and palustrine beds. Generally, the sequence of the Issawia Formation is terminated by hard red breccias reaching about 10 m in thickness. At Wadi El Yatim, west of Sohag, the Issawia Formation crops out, plastering the foot of the western scarp. It is represented by inclined beds of hard red breccias (up to 15 m thick, **Figure 8a,b**).

This facies association consists of aggradational stacked crudely bedded breccias displaying aggradation upper contact and is often interbedded with calcrete and palustrine limestone. The beds are mostly disorganized and occasionally inversely graded. Clasts of this breccia are monomictic in origin and are mostly derived from the Drunka Formation. Clasts are mostly angular or subangular. Boulder-size clasts are common (maximum 1.5 m on the long axis). Matrix consists mainly of fine-grained silt and sand, often argillaceous, and angular carbonate clasts. The top part is hard and cemented by ferruginous lamellar calcrete crusts. The predominance of crudely bedded breccia in steeply inclined contact with Eocene limestone indicates a localized origin of sediment and a short transport distance. This local provenance, together with the angularity and monomictic composition, suggests sediment deposited as colluvial debris generated from the fractured bedrock on a steep-gradient slope. The extremely poor sorting and the local inverse grade of some breccia beds, as well as the disorganized fabric of clasts, are indicative of debris flow deposition.

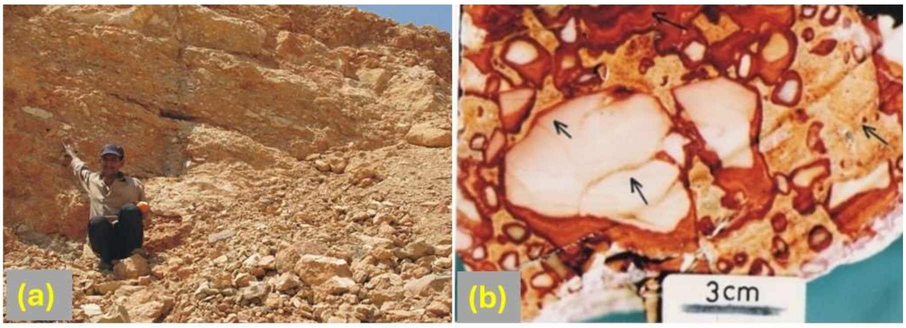

Figure 8. Field view showing the Issawia Formation. (Occurs at the footslope of the Eocene escarpment). **(a)** Red breccia cemented by ferrigenous calcrete crusts; **(b)** close-up view of inclined crudely bedded breccias of different sizes.

4.2.3.2. The Armant formation

The name Armant Formation was first introduced into the stratigraphy of the Nile sediments by Said [15,28] to describe the fine-grained clastic beds alternating with bedded travertine carbonates. In the study area, the Armant Formation attains lateral lithological variations. West of Sohag, the Armant Formation is predominantly carbonates and tufas (averaging 10 to 20 m thick). Locally at Wadi El-Yatim, this formation unconformably overlies the Abu Retag Formation and underlies the Abbassia Formation (**Figure 9**). The temporal and spatial distribution of the sediments of the Armant Formation led to the recognition of two major lithofacies associations, as follows:

1) The peripheral facies associations occupying the lake’s eastern margin. Siliciclastics, tufa, and associated carbonates dominate them. It is subdivided into three main facies: a) Fluvial channel facies, which consist of tabular cross-bedded medium- to coarse-grained sandstones indicating a northwesterly trending paleocurrent direction. This grades upward into laminated fine sandstone intercalated with siltstone and claystone. This sequence is terminated by massive conglomerates (up to 4 m thick) that interfingered laterally with tufas and palustrine limestone; b) Oncolytic facies, which consist of oncolites of variable size and shape. Three groups of oncolites are distinguished based on the lengths of the long axis: small (about 10 cm), large (10–25 cm), and giant oncolites (30 cm up to 1 m long). The small and large oncolites occur as lenticular bodies up to 50 cm thick, interfingering and directly overlying the conglomerate beds. Their nuclei consist of carbonate fragments. The thickness of the coatings ranges from a few millimeters up to 2 cm, and they are symmetrical or asymmetrical. The giant oncolites occur as ovoid shapes, from 40 cm to at least 1 m long, and in some cases, they have cylindrical shapes, resulting from nicrobialite-coated tree trunks and large stems. Giant oncolites are flat-laminate and undulatory, and the laminae tend to be continuous. Occasionally, the oncolites include

irregular pores and cavities filled with spar calcite; and c) Tufa facies, which are localized in the eastern margin of the lake. It is composed of boundstones, rudstones of calcite-coated phytoclasts, and in situ stems. Phytoclasts and intraclasts mainly constitute lenticular layers up to 3 m thick, interbedded near the base with ochre mudstones.

2) The second facies is the central lacustrine—palustrine facies associations. The strata that comprise the central lake basin can be characterized as two distinct lithofacies: the lacustrine and the palustrine carbonate facies. a) The lacustrine facies predominate in the southern outcrops of the entrance of Wadi Tag Waber and Wadi El Dukhan, and are represented by three distinct surfaces: a1) Micritic limestone, which is represented by tabular beds (1–1.5 m thick). Most beds have a mottled appearance, varying from gray to reddish yellow. In some places, the beds contain curved to straight veins filled with sparry calcite and siltstones. Subvertical root traces commonly extend from the upper contact of the beds and taper downward; a2) Ostracodal limestone overlies the micritic limestones. It is 2 m thick. The ostracods are mainly hosted by micritic wack stones and packstones, in which calcite spars fill some ostracod shells. Clastic grains are represented by quartz and carbonates and have an iron oxide coating. Locally, cracks, pores, and cavities are encountered, and they are filled with coarse calcite. a3) Intraclastic limestone, which contains grey angular to subangular clasts up to 5 cm in diameter that are mixed and not related to the underlying substrate. The limestone comprises clasts of varied composition: nodular micrites, carbonates, laminar, and brecciated limestones. The clasts are dispersed within a gray-yellow marly matrix. These intraclasts decrease down to silt size. b) The palustrine facies occupy the most abundant facies in the central lake basin. Two surfaces may be broadly recognized: limestone with irregular desiccation and root bioturbation; and nodular and brecciated limestones: b1) Limestone with irregular desiccation and root bioturbation is clastic free, and alternates with nodular and brecciated limestones. The interbeds have sharp lower and upper boundaries. This surface consists of micritic and microsparite with poorly preserved gastropod shells. Their thickness varies from 50 cm to 1 m. The desiccation cracks are well-pronounced at the tops of the beds and are recognized in thin sections as large and elongate cavities filled by intraclasts, quartz, and later sparry calcite cement; b2) Nodular and brecciated limestone is crudely bedded brownish yellow limestone and averages 1.5–3 m in thickness. The limestone clasts are micritic to microsparitic calcite and display a distinctive nodular structure and in-situ brecciation associated with red mottling. The nodular limestone beds display extensive vertical root traces up to 20 cm long.

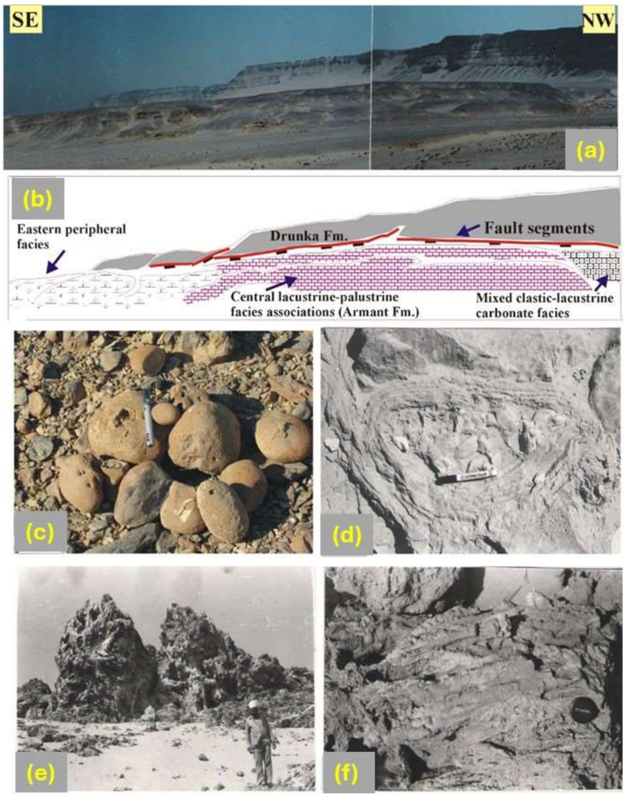

Figure 9. (a,b) Panorama and line drawing of view looking southeast along Wadi Tag Wabar showing the lateral facies association of ArmantFormation; **(c,d)** close-up view of small and large oncolites, peripheral facies associations; **(e)** field view of tufa mounds, boundstones, and rudstones, tufa deposits facies; **(f)** a photograph of columnar tufa and large stems.

4.2.3.3. The Qena formation

Said [28] used the name Qena Formation to describe a thick succession of gravel-sand associations near the Qena area. The Qena Formation exhibits low-topographic hills with rounded surfaces and low scarps extending in the NW-SE direction near the cultivated land in the study area. West of Sohag City, many quarries are used to exploit the Qena Formation for construction purposes. A measured section at one of these quarries showed that the exposed section of the Qena Formation started at the base with cycles of cross-bedded coarse-grained sandstones, followed upwards by laminated and cross-laminated fine sandstones and siltstones.

The exposed 10 to 24 m thick Qena Formation west of Sohag is conglomeritic sandstone and sandstones. Three main surfaces are associated with the Qena Formation, mainly related to the fluvial in-channel process. They include 1) Facies (A) consisting of medium- to coarse-grained planar cross-bedded sandstones. This facies represents 50% of the total succession and consists of medium- to coarse-grained, poorly sorted quartz to feldspathic sandstones arranged into tabular sets, which are characterized internally by planar-cross bedding displaying a fining-upward trend. They show a unidirectional paleocurrent direction to the N and NW. Both high-angle (25°) and low-angle (10°–15°) planar cross-bedding occur in these facies. Facies A is interpreted to form by the migration of straight-crested channel bars [29] deposited under conditions of a lower flow regime. The deposition of low-angle cross-bedding within large-scale cross-bedding sets of these facies indicates that these large sets are a product of bar migration [30]. 2) Facies (B) are represented by ripple cross-laminated sandstones. This facies represents 20% of the total succession, overlies the planar cross-bedded sandstones, and consists of fine-to coarse-grained sandstones that are generally well sorted. It has a wedge-like geometry that pinches out laterally and contains asymmetrical ripple marks and small-scale sets of the trough and planar cross-stratification, load casts, and convolute beddings. Facies B represents slow sedimentation within largely inactive channels as fill deposits. The presence of asymmetrical current ripples and cross laminations indicates deposition by alternating subaqueous fractions and suspension processes in areas between bars or in overbank areas [31]. 3) Facies (C) are represented by flat-bedded sandstone and siltstone. This facies represents 10% of the total succession and consists of fine-to-medium-grained horizontally laminated sandstone. Weathered surfaces are a light-dark brown. Texturally, the sandstone is mostly subangular to subrounded, poorly sorted, and has intercalations of mica. Exposure evidence in these facies includes desiccation, calcrete nodules, and bioturbations. Facies (C) accumulate as planar beds under either an upper or low flow regime [32]. The thin, sheet-like geometry and fine-grained nature of the lithology suggest deposition as sand sheets or in-channel deposits during flood events' waning stages [33].

4.2.3.4. The Abbassia formation

The Abbassia Formation was first proposed by Said [15,28] to describe the gravel sequence overlying the Qena Sands. In the studied area, the Abbassia Formation occurs on the western bank of the River Nile. It can be easily distinguished in the field by its yellowish-grey to greyish-white coarse terrigenous clasts, which reach their maximum thickness in areas facing the major wadis draining the Eocene plateaus. West of Sohag, the Abbassia Formation is represented by a 10 m thick, unconformably overlying Armant Formation (e.g., Wadi El-Yatim, Wadi Dukhan, **Figure 5e**). Locally, these sediments are trapped in low-topographic areas west of the Armant and Abu Retag formations and are dominated by progradational conglomerates that laterally interfinger with sandstones and siltstones.

These sediments construct an alluvial fan of radiating distributary channels that nearly spread eastward and southeastward towards the Nile axis. Two main surfaces are recognized, the proximal alluvial fan and the alluvial plain: 1) The proximal alluvial fan crops out close to the Eocene escarpment and unconformably overlies the Abu Retag Formation. It is 3 m thick and consists of red, ochre, and grain-supported conglomerates. The gravels are arranged in progradational coarsening upwards. They are poorly sorted and immature. The gravels consist of Eocene carbonates (70%), cherts, and quartz (25%). These sediments were deposited by debris flow-dominated alluvial fans during high-energy episodic flows of flash floods. Paleocurrents measured on conglomerates and their textural changes indicate an eastward-down valley spreading. The clast composition suggests the local derivation of the source rocks. 2) The Alluvial plain is represented by vertical stacking fining-upward fluvial channel cycles. The bottom surface is erosive and irregular, cutting into the underlying one. Paleocurrent measurements from imbricated clasts and axis channel deposits indicate easterly and northeasterly trending transport. This sequence is terminated by medium-to-fine-grained reddish-brown sandstones displaying a sheet-like geometry. These surfaces represent deposition in the middle to distal zones of the fluvial fan, where fluvial channels developed. The vertical stacking channel fills are interpreted as low-sinuosity fluvial channel deposits. Sheet floods in fluvial fans' more distal terminal areas formed sheet-like sandstone beds.

4.2.3.5. The Dandara formation

The name Dandara Formation was first proposed by Said [28] to describe the silt and fine sand section west of Dandara. In the study area, the Dandara Formation is generally closer to the cultivated land and is represented by sand and silt intercalations along the eastern bank of the Nile. West of Sohag, the Dandara Formation forms small hills composed of 5 m thick sand and silt intercalations with lenses of hard sandstones. The facies association can be divided into two main vertical surfaces: (i) 1 to 4 m thick packages composed entirely of massive to flat laminated mudstone with calcrete nodules. (ii) 2 m thick, coarsening-upward beds, composed of massive mudstones at their base, locally displaying mud cracks, overlain by fine sandstones with cross laminations. Massive and laminated mudstone is interpreted to represent overbank deposits accumulated through the setting of the suspended load within flooded areas [31]. The presence of mudcracks indicates ephemeral and subarid exposures. The coarsening-upward cycles are interpreted to represent shallow-lake marginal deposits formed due to the deceleration of streams as they enter water bodies.

5. Discussion

5.1. Age relations of the Late Oligocene—Late Miocene sequence

Due to the absence of marine fauna in such continental sediments, the authors assigned the strata of the Katkut Formation to the late Oligocene—early Miocene age based on the following: i) The NW-trending faults forming grabens, in which the sediments of the Katkut formation were deposited, clearly deform the Eocene limestone; hence, these grabens-fill sediments must be younger than the Eocene age. ii) The conglomerates of the Katkut Formation have a very close resemblance in composition with that of the known Late Oligocene conglomerates of Egypt through the correlation with other and similar lithologic units in nearby areas. These gravels are analogous to the Late Oligocene Nakheil Formation on the eastern side of the Red Sea Mountains, as described by Akkad and Dardir [34] and Mahran [35]. The later sediments are also composed of limestones and cherts and devoid of Precambrian basement pebbles. These deposits' rare granitic and volcanic rocks prove that the Precambrian Red Sea Mountains were not exposed during the early rift phase, which started during the Late Eocene–Early Oligocene.

The presence of basement pebbles in the Abu Retag Formation indicates that the basement in the Western Red Sea Mountains was exposed later in the Late Miocene than in the Eastern Red Sea Mountains (lower Miocene) and probably extended back to the Middle Miocene, especially since it is known that the valley of the Nile is considered as old as the Miocene [28]. Furthermore, the establishment of the Eonile stage of Said [28] during the Late Miocene time, as well as the stratigraphic position of the Abu Retag Formation by the interfingering with the upper parts of the Eonile fine siliciclastic of the Nile Canyon of Said [28] during the Late Miocene, all give indications that the age of the Abu Retag Formation ranges from Middle to Late Miocene time.

5.2. Age relations of the Pliocene—Quaternary sequence

Said [28] gave the Pliocene age for the fine siliciclastics of the Madamud Formation. The Issawia and Armant formations unconformably overly channelized the Qena and Abbassia formations and are underlain by the Pliocene Madamud Formation. Hence, a post-Pliocene age is more likely. Thus, the authors propose that the age of the Issawia and Armant formations is early Pleistocene and is equivalent to the pluvial sediments of the Early Quaternary of Said [21].

The Locus of the Prenile system (Qena and Abbassia formations) as a separate terrace extending to the west of Early Pleistocene Protonile sediments (Issawia and Armant formations) indicates the Prenile system excavated its channel to the west of the Protonile after the later had ceased to flow. These formations are probably younger and could be considered Middle Pleistocene. Furthermore, most of the conglomerate clasts are either granites or gneisses, and their source is suggested to be the Precambrian basement rocks. Hence, it is most likely that the supply of these sediments began before its connection with sources outside of Egypt, which was established in the Late Pleistocene [21,36,37]. This indicates that the sediments of the Qena and Abbassia formations were deposited in the Middle Pleistocene. The interfingering Dandara and El Gir formations are dated to late Pleistocene age, based on the appearance of the Ethiopian mineral suite that was extracted from the Ethiopian highlands during the Late Pleistocene [17,21,28].

5.3. New geologic map of the west Sohag area

In the current research, Landsat ETM$^+$, 15 m resolution, covers the study area and was used to map various lithological units. Environment for Visualizing Images (ENVI 5.5) software was used for data analysis and interpretation. Several image enhancement techniques have been applied to enhance the spectral differences between rock units. These techniques begin with True and False Color Composites (TCC&FCC), Principal Component Analysis (PCA), Minimum Noise Fraction (MNF), Decorrelation Stretching (DS), and Independent Component Analysis (ICA). The data was validated with extensive field investigation to identify these rock units, their contacts, and facies. Finally, the authors compiled the results, and a new lithologic map was prepared (**Figure 10**). The sediments belonging to the area west of Sohag are exhibited by two primary lithostratigraphic sequences (**Figure 11**). The older sequence belongs to the Late Oligocene-Late Miocene. It comprises dominantly coarse siliciclastic sequences deposited in low-topographic grabens and hangingwall fault segments (e.g., Katkut and Abu Retag formations). The younger sequence is of Plio-Pleistocene age and consists of mixed siliciclastics—carbonates and sandstones deposited in reentrants on the western side of the Nile basin (e.g., Issawia, Armant, Qena, Abbassia, and Dandara formations, **Figure 11**).

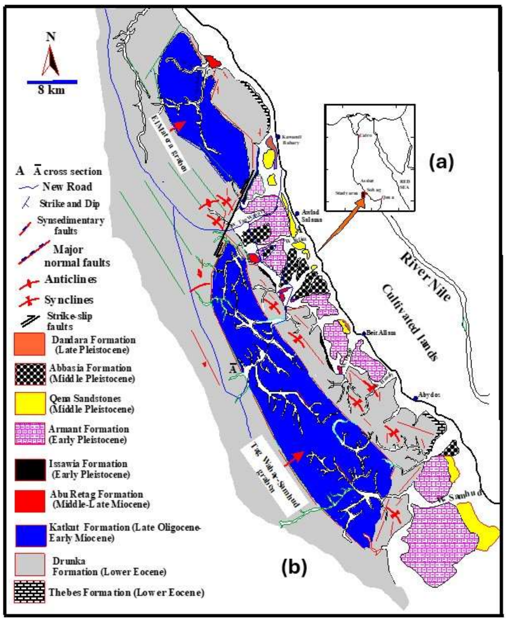

Figure 10. The study area. **(a)** A location map of the area west and southwest of Sohag; **(b)** a regional geological map of the study area showing the locality of grabens and the graben fill units.

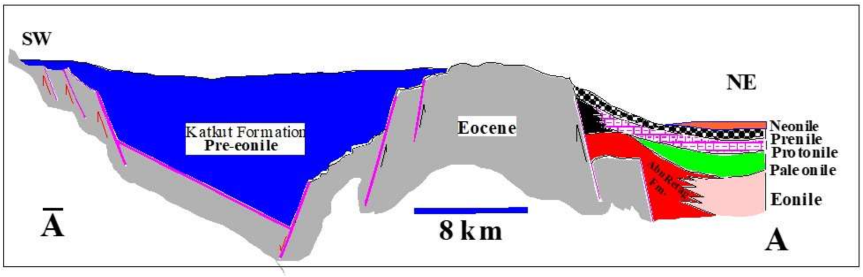

Figure 11. SW-NE cross section (A-A) showing the two main lithostratigraphic units of Pre-Eonile-Neonile sediments west of the Sohag area.

5.4. Geological mapping and urban development in the area

With time, there has been an increase in urban development operations being carried out in low desert zones (west Sohag desert areas). These operations have encompassed regions that have been an essential supply of natural resources, particularly aggregates. As a consequence, there is a diminished availability of these materials in the low desert zone [38]. Numerous projects have been underway throughout Egypt's regions, including substantial transportation initiatives, industrial zones, land reclamation, and urban activities since the 1980s. As a result of these recent construction operations, the vast majority of the quarries have been set aside and have yet to be utilized. This leads to the exploitation of aggregates produced in places that are entirely unsuitable for various purposes, particularly urban development.

The geologic map strives to understand the geological unit distributions, their composition, and their structures. Within the past few decades, geographic information systems (GIS) have begun to change aspects of geologic mapping by providing software tools that permit the geometry and characteristics of rock bodies and other geologic features to be digitally stored, displayed, queried, and analyzed in conjunction with a seemingly infinite variety of different data types. Accordingly, GIS dramatically facilitates the analysis and, as a result, offers geologists the opportunity to provide information in map form that is easily interpreted and used by nongeologists (e.g., land use planners and decision-makers). Geologic mapping is a highly interpretive, scientific process that can also be used for assessing environmental issues (e.g., location of landfills), predicting various geologic hazards (problematic soils), industrial activities (aggregate accumulations), and, finally, education activities. These maps will have good benefit-cost analyses to reduce uncertainty for future projects. In the current study, and for urban development, the geologic map offers an essential location for new aggregate resources that could be used as construction materials (e.g., Katkut and Abu Retag formations). These materials are very close to urban areas, so the transportation cost is minimal.

6. Conclusion

Remote sensing is a commonly used tool in earth science, particularly for studying geological issues, such as lithological mapping. Remote sensing has garnered significant interest owing to its capacity to mitigate the expenses associated with field mapping, surmount challenges related to accessing specific locations, and identify regions exhibiting elevated levels of mineralization and alteration. The data acquired using the conventional methodology were derived from field surveys. The collected data exhibit notable limitations that impact the goals of the present investigation. The combination of Remote Sensing (RS) and Field Survey offers significant potential for cost reduction in field mapping and overcoming constraints related to field access. The lithological units and facies of the research region were accurately delineated through satellite image processing and field data collection. The PCA, MNF, DS, and ICA techniques have shown significant efficacy in distinguishing geological characteristics. The field study conducted as part of this work facilitated the comparison and evaluation of the effectiveness of remote sensing data in the cartographic representation of sedimentary units. Precise outcomes are obtained using RS methodologies, such as color compositions, MNF, PCA, ICA, and DS. The combination of these bands holds significant importance in identifying lithological formations. Using PC1, PC2, and PC3, a more optimal combination of the color composite was achieved, leading to enhanced results in the cartographic representation of the geological units encompassed within the designated research area. Moreover, the most notable maps were meticulously crafted with meticulous attention to detail. The current geological map of the region is scaled at a ratio of 1/250,000, resulting in poor spatial resolution. However, applying satellite imagery for lithology mapping provides higher precision, characterized by a high spatial resolution. In summary, satellite imagery for lithology mapping provides a notable level of spatial resolution. Despite the advantages above, it is imperative to remember that RS methodologies cannot detect minuscule entities, necessitating their enhancement. These approaches are highly efficient and accurate for comprehending the geological features of a particular site. Using remote sensing technology enables the acquisition of a wide range of data over extensive geographical regions. The current step of the procedure involves the introduction of two new lithological units, namely the Katkut and Abu Retag formations. These approaches are highly efficient and accurate for comprehending the geological features of a particular site. Using remote sensing technology enables acquiring a wide range of data over extensive geographical regions.

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Article

The French discourse on the delineations of the Spanish colonies in the early 19th century: The memoirs of Rigobert Bonne and Eustache Hérisson

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Abstract: The 19th century proved to be one of the most complicated periods in Spanish history for the Spanish Crown, as it faced both internal conflicts—the French War of Independence—and external conflict—the independence of what were its territories in most of America. France did not remain indifferent to this and always had a clear idea of where to draw the boundaries of what "belonged" to it. Thus, amid the wave of independence movements in the Spanish colonies, the French continued to produce rich cartography to establish these boundaries and settle their power over the new nations that were arising after the period of revolutions. The cartography of Rigobert Bonne, the last cartographer of the French king and the Revolution Era, and one of its disciples, Eustache Hérisson, represent the perfect witness to the changes over the borders of the Spanish colonies during the change of the century. This study aims to analyze such cartography, examine the rich toponyms it offers, and examine the changes in the boundaries created over time between both empires. The main cartography we will rely on will be that of Bonne, one of the most important cartographers of the 18th century, and his disciple Hérisson, a geographer engineer, who lived through the onset of the conflicts and always prioritized the French perspective and the interests of their nation.

Keywords: limits; historical cartography; French cartography; geographers; independencies

1. Introduction

The 19th century posed one of the most complicated periods in the history of the Spanish Crown, as it faced both a conflict within its own country, the French War of Independence, and an external conflict, the independence of what were its territories—or colonies—in most of South America. The territorial disputes that followed this era of independence for various territories are a complex and multifaceted aspect of the geopolitical landscape of South America. In the establishment of new border boundaries, historical legacies, colonial-era treaties, and conflicting territorial claims were involved, some of which persist to this day.

France, like other countries, did not remain unaffected by this and always had a very clear idea of where to draw the boundaries of what "belonged to it". Some countries, like Portugal, decided not to wait and see how events unfolded. The so-called Luso-Brazilian Invasion (1816–1820) resulted in the annexation of what is now Uruguay, the southern region of Brazil, and the Argentine Mesopotamia to the United Kingdom of Portugal, Brazil, and the Algarves, and upon its independence in 1824, to the Kingdom of Brazil. This area was the origin of the subsequent conflict, the War of Brazil (1825–1828), in which Brazil lost the Eastern Bank, or Cisplatina, which would become a new country: Uruguay). Thus, amidst the wave of independence movements in the Spanish colonies, the French nation continued to produce rich cartography to establish the disputed boundaries. This cartography, from the late 18th and early 19th centuries, bears witness to the settling of borders and even to the names attributed to those regions, some of which differ from one map to another and, moreover, differ from those coined by the Spanish Crown.

This study aims to analyze this cartography, explore the rich toponyms it offers, as well as the delineations created over time between both empires. The primary cartography we will rely on will be that of Bonne and Hérisson, masters and disciples of the Enlightenment era. The former was the official geographer of the king before the Spanish conflict in the American colonies and was so renowned for his work that his ideas were widely utilized. The latter was a geographer and engineer who lived through both conflicts and whose cartography continued to be reproduced posthumously. Most notably, they always prioritized the French perspective, which sometimes gave a different sense of the cartographic reality seen in the atlases.

In this research, we aim to showcase the toponyms and borders of the new nations created from the conflict, such as Uruguay, from this perspective. The cartography we will utilize is available in libraries such as the National Library of France but has not been studied or valorized until now. The ultimate goal is to shed light on the French view of the political situation in Latin America during its most tumultuous period.

2. The cartographic challenges of the new political spaces

The establishment of borders in South America, that is, the creation of geopolitical, cultural, and often natural delineations that shape the current political landscape of the region, was not an easy task when revolutions began across the various territories. These borders are not mere lines on a map, but rather they represent complex historical, economic, and social factors that subsequently influenced relationships between countries and the development of regional identities. On a canvas that had become blurred, the cartographic configuration depended on factors such as:

- Colonial legacy: Much of the current borders in South America ultimately followed patterns established earlier. These boundaries were set during the colonial period, when European powers, primarily Spain and Portugal, divided the continent between themselves through treaties such as the Treaty of Tordesillas (1494). Other countries, like the Netherlands and France, also joined in. These colonial borders often did not consider the ethnic or cultural composition of the indigenous peoples of the region, leading to conflicts and tensions that persist to this day.
- Geographic characteristics: The diverse geography of South America, which includes mountain ranges like the Andes, vast river systems like the Amazon, and extensive plains like the Pampas, influenced the establishment of borders. Natural barriers have both facilitated and hindered interactions between countries, shaping trade routes, migratory patterns, and political alliances.
- Territorial disputes: Some of the established borders in South America are still

subject to ongoing territorial disputes. For example, the long-standing border dispute between Chile and Bolivia over access to the Pacific Ocean has deep historical roots and remains unresolved, affecting diplomatic relations in the region.

- Cultural and linguistic diversity: South America is characterized by a rich cultural and linguistic diversity, with indigenous communities, Afro-descendants, and immigrant populations contributing to the vibrant tapestry of identities in the region. The established borders often intersect with cultural and linguistic boundaries, influencing social dynamics and political loyalties.

In this context, the key factor was territorial sentiment, which would later evolve into a national one. The concept of nation, in this case newly born, is intrinsic to the possession of established boundaries that allow coexistence. Up to that point, the only established boundaries were those set by the Spanish nation itself, but when these are broken, the process of territorial formation and the construction of different national identities goes through the new, yet fragile, governments. The differences shown in the maps of Bonne and Hérisson regarding territorial identity reflect the framework of problems that the acquisition of a proper political map, as well as a name and identity, posed for these new nations [1].

The issue of identity and cartography was not something that emerged as a result of the dismantling of the Spanish empire, but rather a topic that has been extensively discussed in different eras [2–8].

The examination of political cartography from a historical and cultural perspective allows for addressing these political-territorial tensions, issues of identity, agreements, and disagreements before and after the revolutionary outbreak, and the practices of demarcation commissions. Political cartography, which inherently establishes boundaries and creates the concept of a nation, reveals in its preliminary stage and just at its inception the instability or non-existence of a common identity that gathers that territory rebelling against the predecessor government and leaves the imagined community contained in the map without an identity to cling to [9].

Unlike other countries, which were dismantled and included in new empires during the 19th century, the dismembered territories of South America did not have their own identity per se as a country but had only been conceived as territories of different empires (Mayan, Aztec, or later Spanish, Portuguese, French, or Dutch). In this context, each territory carried out a claim of belonging [10,11].

The liberators at that time faced the sentiment of belonging to a people, culture, or territory and the establishment of boundaries [12–14].

All of that was supported and registered by different countries, but especially France. The political ideas introduced during the Revolutions were fed over decades by French literature and cartographic representations. Some of the most important writers of the 19th and 20th centuries constantly cited and justified the American Revolutions and the establishment of new nations following the revolutionary French ideas that allowed the creation of a bond between France and the new countries. Just a glimpse,

> “Spain would be represented as a rosary to represent its fanaticism, a chain to express its servility, and a bag to demonstrate the greed of a tax collector.”—

José María Samper [15].

> “Spain lost on all fronts the rich countries where it had until recently ruled tirelessly; that shameful defeat was the just expression of its conduct towards the peoples it cruelly tyrannized.”—Alfred Deberle [16].
>
> “It was necessary to offer the enlightenment of the great Latin people.”—Manuel María Buenaventura [17].

In this context, geographic atlases came into play as disseminators of the factors that influenced the establishment of boundaries. For example, the maps—part of atlases—that we will see below display territorial disputes. The different territories claimed, such as Argentina [18,19]—territory that was not even reflected before the dismantling of the empire, Brazil, Uruguay, or Paraguay and their boundaries appear in different atlases of the time in various ways. For this reason, it was not until the development of local cartography that the new names and boundaries could be fully established. French cartography, following the discourse of the literature of that time, offers and confirms a different perspective from the promoted atlases.

2.1. The French perspective on the conflict: The master and the disciple

Rigobert Bonne was born in Raucourt, in the Ardennes, on 6 October 1727, and is considered the most important cartographer of the late 18th century. He learned mathematics without a teacher and became an engineer at the age of eighteen. He served in this capacity in the War of Flanders, where he participated in the siege of Bergen-op-Zoom in 1747. He dedicated himself to physics, mathematics, and geography, with such success that for fifteen years he was one of the most sought-after professors in Paris, during which time he met Hérisson. Among his roles within society, his membership in the lodge of the Neuf Soeurs, or Nine Sisters, stands out. This Masonic lodge was founded in 1776 by the astronomer Jérôme de Lalande and is known for its influence in organizing French support for the American Revolution. Among its ranks were other reputable men, such as Voltaire or Benjamin Franklin, who was elected Worshipful Master. Due to his membership, during the French Revolution, Rigobert Bonne served in the Jacobin ranks as a political advisor.

On a scientific level, all his experience led him to succeed Giovanni Rizzi-Zannoni in 1775 as the cartographer of the King of France in the Hydrographic Service of the Navy—the Navy’s map and plan depository was created by order of King Louis XV in 1720, making him the second generation to lead such an institution. However, that same year, he suffered a stroke that left him ill for the rest of his life. Nonetheless, he remained active as a cartographer, and five years later, he precisely defined the projection that would later bear his name: the Bonne projection. This projection became famous because it was used by César-François and Jean-Dominique Cassini in the surveying of the National Map of France, the first topographic and geometric map of the French kingdom.

Among his works, in addition to the official state cartography, he produced maps for the works of Abbé Raynal and for Nicolas Desmarest’s Encyclopedia Méthodique. In mid-1795, he suffered from dropsy, from which he passed away on November 2 of that year. His son Charles-Marie Rigobert, known as Chevalier Bonne (25 June 1771 to 23 November 1839), continued his work along with other disciples.

Among them, Eustache Hérisson (Paris 1759 to Paris 1832) stood out at the beginning of the century. He was one of the most prolific cartographers of his time, particularly during the 1810s and 1820s, that is, in the post-Napoleonic era and amidst the instability of European countries, including Spain. In contrast, France was experiencing a period of resurgence and economic improvement. This fostered the cultural development of centers such as the University of the Sorbonne, where Hérisson was known. His works have been repeatedly reissued for their quality, especially posthumously, by Jean at the Rue Jean de Beauvais publishing house in Paris, near the Sorbonne, or by the Basset family, founders of the publishing house of the same name [20].

2.2. Cartographic production in France during the era of revolutions

During the decline of the consulate, the geographer engineers, such as Eustache Hérisson, under the authority of the War Depot, amounted to only 100 engineers. Thanks to them, gradually, they carried out the rules established by the 1802 commission, leading to the standardization of maps during the territories conquered by the French armies. Ultimately, under the empire, map production, especially during the Napoleonic era, flourished thanks to topographic offices, but overall cartographic production relied on old maps due to limited available capital, albeit with a reputation for reliability.

The production of new maps allowed their use and knowledge of the situation in each country during the wars fought by Napoleon and other European powers. The reliability of this cartographic production was never in doubt, as during the French Revolution, maps were considered a national treasure and essential for territorial defense. For this reason, geographical knowledge became exhaustive. This resulted in both the first consul and later Emperor Napoleon I demonstrating their taste and knowledge of geography during the consulate and empire periods. The maps of this era were extensively studied with the assistance of the chief of the topographic cabinet of the first consul and the emperor, Bacler d’Albe.

Spain, a neighboring country of France and one of the main powers that made the geographical expansion of the Napoleonic Empire difficult, was of great interest in cartographic terms. The arrival of the French and their knowledge led to the development of the first maps of Spanish territory, both national and colonial, until their last days.

Napoleon I’s invasion and the establishment of his brother Joseph as king of Spain profoundly affected the overseas territories. They were able to create a French discourse in the Spanish colonies, and that discourse was translated into maps. The power vacuum resulting from the French invasion of the Peninsula was a key cause of the beginning of the independence process in Spanish America.

The French discourse in the Latin American independence war had several significant aspects. France, as a European power, was interested in the events unfolding in Latin America due to its rivalry with Spain and Portugal. For this reason, and for years prior, France took it upon itself to ideologically inspire what would become new nations. The French Revolution and its ideals of liberty, equality, and fraternity had a significant impact on the Latin American independence leaders. Many of them were inspired by the principles of the French Revolution and sought to replicate them in their struggle for independence.

Likewise, France provided logistical and military support to some of the independence movements in Latin America. For example, Simón Bolívar received financial and military support from France in his struggle for the independence of Venezuela, Colombia, Ecuador, Peru, and Bolivia. This support allowed for alliances that benefited him, as France also had economic interests in Latin America, especially in the Spanish colonies rich in natural resources. French trade was hindered by the commercial monopoly imposed by Spain, and the independence of the Spanish colonies represented an opportunity to expand French trade in the region.

Therefore, France was one of the first countries to recognize the independence of the newly formed Latin American nations. This contributed to legitimizing the independence movements and establishing diplomatic relations between France and the new Latin American states.

One of the achievements of French authors in the 19th century was to institutionalize and formalize the name “Latin America” for the former Ibero-Portuguese and French colonies—including Brazil, Haiti, and other territories. This triumph brought France into the cultural formation of the peoples, countries, nations, and states known as Latin America.

However, despite the fact that the Napoleonic army was expelled from Spain, the situation overseas never returned to the previous situation, and the “Juntas” that had been created in the different viceroyalties over the years decided not to continue being part of Spanish territory and fight for independence.

2.3. Characteristics of French cartography in maps of South America

The French cartography of the 18th and early 19th centuries was characterized by a combination of scientific rigor, artistic sophistication, and exploratory spirit, as evident in the atlases we see in this article. Maps produced during this period not only served practical purposes but also reflected the intellectual and cultural achievements of the French Enlightenment, as demonstrated by the works of Bonne and Hérisson [21]. During this period, French cartographers made substantial contributions to the field, both in terms of mapping France itself and exploring and mapping other regions of the world.

As seen in the presented maps, French cartographers of the 18th century placed a strong emphasis on accuracy and precision. They incorporated the latest advancements in mathematics, trigonometry, and topographic techniques to ensure the precision of their drawings. This scientific rigor contributed to France’s reputation as a leading center of cartographic excellence during this period, which was extrapolated to other powers.

Likewise, many of the atlases produced during this time were sponsored by the state, as is the case with Bonne’s cartographic production. The French government recognized the strategic importance of accurate maps for military, administrative, and economic purposes. As a result, large-scale cartographic projects were initiated to study and map various regions of France, such as the topographic survey of France conducted by the Cassini family, to which Bonne partly contributed, and other areas of the world.

These maps often included features such as terrain contours, rivers, forests, roads, and settlements, as well as nomenclature, providing valuable information for military planning, territorial management, and navigation. However, cartographers were not only concerned with scientific accuracy but also with aesthetic presentation. Many maps from this period were elaborately decorated with ornate title cartouches, wind roses, and illustrations of prominent landmarks or historical events. These artistic embellishments increased the attractiveness of the maps and reflected the cultural and artistic sensibility of the time [22].

All these cartographic achievements of Enlightenment France had a profound influence on European cartography as a whole. French cartographic techniques, standards, and conventions were widely adopted and emulated throughout Europe, contributing to the development of modern cartography.

A clear example of this precision in mapmaking, as well as all the knowledge of the terrain to be displayed, is **Figure 1**, which shows a map by Hérisson representing the Iberian Peninsula and the Balearic Islands, with an emphasis on depicting roads, paths, routes, etc., as they were arranged during the first third of the 19th century. It is printed in black and white with color demarcations, following the techniques of the time.

Figure 1. Map of Kingdom of Spain and Portugal (Source: Bibliothèque National de France).

3. The borders of the Spanish colonies in French cartography

The situation before and after the Napoleonic Empire was portrayed by Bonne and Hérisson. Both authors depicted the world map with its borders, and thanks to them, we can distinguish the French perception of the conflict that the neighboring country was going through with its colonies in South America. There are very remarkable elements such as Bonne's maps, which do not make a distinction of borders and place Paraguay and Uruguay together, while Hérisson closely follows the changes and discoveries, but simply names this part of the globe Southern America and establishes the limits of some cities, such as Buenos Aires, or a region like "Desert" without going into details.

The approach of both cartographers is framed in the general dynamics carried out in Europe to reflect a situation in various territories that was not clear since the rupture with the homeland—as happened previously with the United States after its separation from the United Kingdom. Since the beginning of the century, and after the passage of the French empire through Spain and the subsequent loss of the territories of South America, cartography has reflected doubts about the new configuration of the borders. The old administrative boundaries ceased to exist in cartography to give way to different situations: either continue using the borders given until then—the Viceroyalties—until the new political situation became clear, or draw new state administrative boundaries, or give way to new political units that wanted their own identity, or follow the case of Africa, and opt for geometric state boundaries.

In this case, the focus is not on evaluating how the identity of each new state was formed or how administrative or political boundaries were established, but on how French cartography reflected this moment. Both Bonne and Hérisson gave rise to two of these cartographic models: the use of old administrative boundaries, that is, from the colonial period, and the reflection of political units with their own identity that wanted to distance themselves from the boundaries in which they are currently included [23].

Territorial disputes in South America during the period of independence (early 19th century) were frequent and complex, arising from a combination of colonial legacies, power struggles between emerging nations, and ambiguous borders inherited from the colonial era. These disputes often led to armed conflicts, diplomatic tensions, and shifting alliances among the recently independent states. The main notable territorial disputes during the era of South American independence involved years of conflict, and this issue was well reflected [24].

For example, the region known as Upper Peru, which encompasses present-day Bolivia, was a focal point of territorial disputes during South America's struggle for independence. Bolivian nationalists, led by figures such as Simón Bolívar and Antonio José de Sucre, fought against Spanish forces to assert control over this strategically important territory. However, internal divisions and conflicting visions about the region's future sparked tensions and power struggles even after achieving independence.

Regarding the La Plata Basin, which includes what is now Argentina, Uruguay, Paraguay, and parts of Brazil and Bolivia, it witnessed several territorial disputes during the independence era. Conflicting territorial claims among the emerging nations, along with the strategic importance of access to rivers and control of trade routes, fueled tensions and occasional armed conflicts. Establishing clear borders and resolving these disputes required diplomatic negotiations and, in some cases, the intervention of external powers.

The case of the project known as Gran Colombia was different. Gran Colombia, a short-lived federation comprising present-day Colombia, Venezuela, Ecuador, and Panama, was partly driven by territorial disputes and regional rivalries. Disputed borders between the constituent republics, particularly the border between Venezuela and Ecuador, contributed to internal tensions and the eventual fragmentation of the federation into separate nation-states. Additionally, it faced challenges with Peru over sovereignty in areas in the Amazon and on the Pacific coast (in the Andes, Tumbes, and Guayaquil).

The northern borders of Brazil, particularly along the Amazon Basin, were subject to disputes with neighboring countries like Colombia and Venezuela. These disputes revolved around conflicting claims over territories rich in natural resources, including rubber and minerals. Diplomatic negotiations and occasional military conflicts characterized Brazil’s efforts to assert control over its northern border and secure its territorial integrity.

The southernmost regions of South America, including Patagonia and Tierra del Fuego, witnessed territorial disputes involving Argentina, Chile, and the indigenous peoples inhabiting these territories. Conflicting claims over lands, resources, and access to strategic waterways such as the Strait of Magellan led to border disputes and occasional military confrontations between Argentina and Chile, which persisted well into the 20th century.

Most of these disputes were resolved through treaties [25] or through the Uti possidetis iuris (Public International Law extensively used in America). It is based on the principle that “what was possessed continues to be possessed,” therefore recognizing a right of possession based on the succession of legal titles existing prior to the independence of the State. According to Garay Vera [24], “What was possessed on behalf of the King of Spain is now possessed in the name of each American State.” The border between Paraguay and Argentina was delineated through the “Boundary Treaty” of 3 February 1876 (Machain-Yrigoyen), and the “Complementary Treaty” of 5 July 1939 (Arbo-Cantilo). It extends 1345 km along the river and 345 km of dry border, totaling 1690 km in its entirety.

In both cases, the “y” means “water” in Guarani (the name of the Iguazú or Iguaçu River, at the tri-border area between Argentina, Paraguay, and Brazil, means “big water”). In the case of Uruguay, the Guarani etymology might seem unusual since the Guarani people were not in that area, but the name of the country comes from that of the river, which does pass through the Guaranitic region (northeast Argentina, southern Brazil, and all of Paraguay).

Similarly, Chile and Argentina disputed the precise location of their border in several areas for a long time, particularly in the Southern Cone region. The most notable disagreement concerns the border between the Southern Patagonian Ice Field and the Beagle Channel. The Beagle Channel dispute was resolved thanks to Vatican mediation in 1984, but tensions occasionally resurface between the two countries.

Chile was also involved in a territorial dispute with Peru, which was largely resolved with the signing of the Lima Treaty in 1929. However, tensions occasionally arise over maritime boundaries in the Pacific Ocean. For example, in

2014, the International Court of Justice ruled on a maritime dispute between the two countries, granting Peru a larger maritime territory, but the issue still remains delicate.

The long-standing territorial dispute between Guyana and Venezuela focuses on the Essequibo region, which covers approximately two-thirds of Guyana’s territory. Venezuela questions the validity of the 1899 Arbitral Award—almost a century after independence—that delineated the border, leading to periodic diplomatic tensions. The discovery of offshore oil reserves in the disputed territory has further intensified the dispute in recent years.

Guyana is also involved in a dispute with Suriname and Brazil. Brazil has occasionally faced territorial disputes with its northern neighbors, Suriname and Guyana, over areas along the border in the Amazon rainforest. These disputes mainly concern the demarcation of borders in remote and sparsely populated regions, where both countries engage in diplomatic dialogue and sporadic efforts at demarcation.

This highlights the difficulty these territories faced throughout the 19th century in conceptualizing their space and defining themselves. As new states in South America were established and configured their own territories, the very idea of territorial boundaries was being reconceptualized, both in international jurisprudence and political theory. While boundaries had long been zones or strips of diffuse borders, modern territorial formation processes required boundaries that could be delineated as lines on maps. In practice, old and new boundaries were drawn and redesigned throughout the 20th century during complex negotiations, unstable alliances, and military conflicts, and some of them remain unresolved.

Around maps of various origins, such as French maps, which had a particular interest in knowing the fate of the Spanish colonies as they had territories on that continent, narratives of territorial formation and arguments to support their territorial claims were developed. This literally made it impossible for the assembly of maps of the new Latin American nation-states elaborated by each country to result in a coherent political map of Latin America (on the contrary, each Latin American country produced maps of South America, demarcating borders in different ways).

On the other hand, French national maps, with Guiana present in that territory, or the Caribbean islands, were exposed, along with the Netherlands, to a climate of uncertainty during the central years of the revolution, an idea captured by both Bonne—who lived through the final years of the Spanish Empire—and Hérisson, who witnessed the beginning of destabilization of borders.

French cartographers played an important role in the exploration and mapping of overseas territories during the Age of Exploration. Expeditions led by French explorers, such as Samuel de Champlain, Louis-Antoine de Bougainville, and Jean-François de Galaup, Count of La Pérouse, resulted in the mapping of new lands and coasts, including parts of North America, South America, the Pacific Islands, and Africa.

4. The situation of territorial disputes before Bonne and Hérisson

In Bonnet’s time, in the late 18th century, concerns about the future of the colonies and their identity were already beginning to be felt. Bonne was the first cartographer to move away from decorative elements, giving more importance to detail and practicality. The map of South America belongs to the "Atlas moderne ou collection de cartes sur toutes les parties du globe terrestre par plusieurs auteurs. Avec approbation & privilege du Roy" was first published in 1761. This atlas contained maps drawn by Bonne, Janvier, and Rizzi Zannoni. The chart contains information on relief, hydrography, political division traced in color, and scale expressed in leagues. In it, the distinction of cultural and identity entities was evident in the maps. For example, in the case of Brazil in **Figure 2**, it did not include the Amazon, which was presented as its own country. Popayán, now part of Colombia and neighboring Peru, was not within the territory of New Granada, also now part of Colombia.

Figure 2. Map of North and South America (Source: Bibliothèque National de France).

Amidst such concerns, late-century cartography focused first on establishing the borders of territories adjacent to French colonies. In this case, the direct implication, as shown in **Figure 3**, was French Guiana, bordering Dutch and Portuguese territories.

Figure 3. French Guiana with part of Dutch Guiana, according to the operations and recent maps of French geographical engineers 1777 (Source: Municipal Archive of L´Havre).

Indeed, due to all the challenges they faced in claiming the territories they deemed necessary to form a new country, Colombia, later under the “Gran Colombia” project (1819–1833), called upon French engineers and cartographers to work on the creation of its new identity. The problems reflected in the maps of Bonne and Hérisson were passed on to these workers, as this project claimed not only the territory of present-day Colombia but also Venezuela, Ecuador, Panama, northern Peru, western Guyana, and northwest Brazil. Scholars recall this ephemeral republic.

As can be seen in **Figure 4**, the same occurred for what is now Venezuela, simply dubbed “Terre Ferme,” along with other territories such as Caracas, during the colonial era, which both cartographers—including what is now Ecuador—depicted as a subdivision of Venezuela, Caracas, and Cumaná.

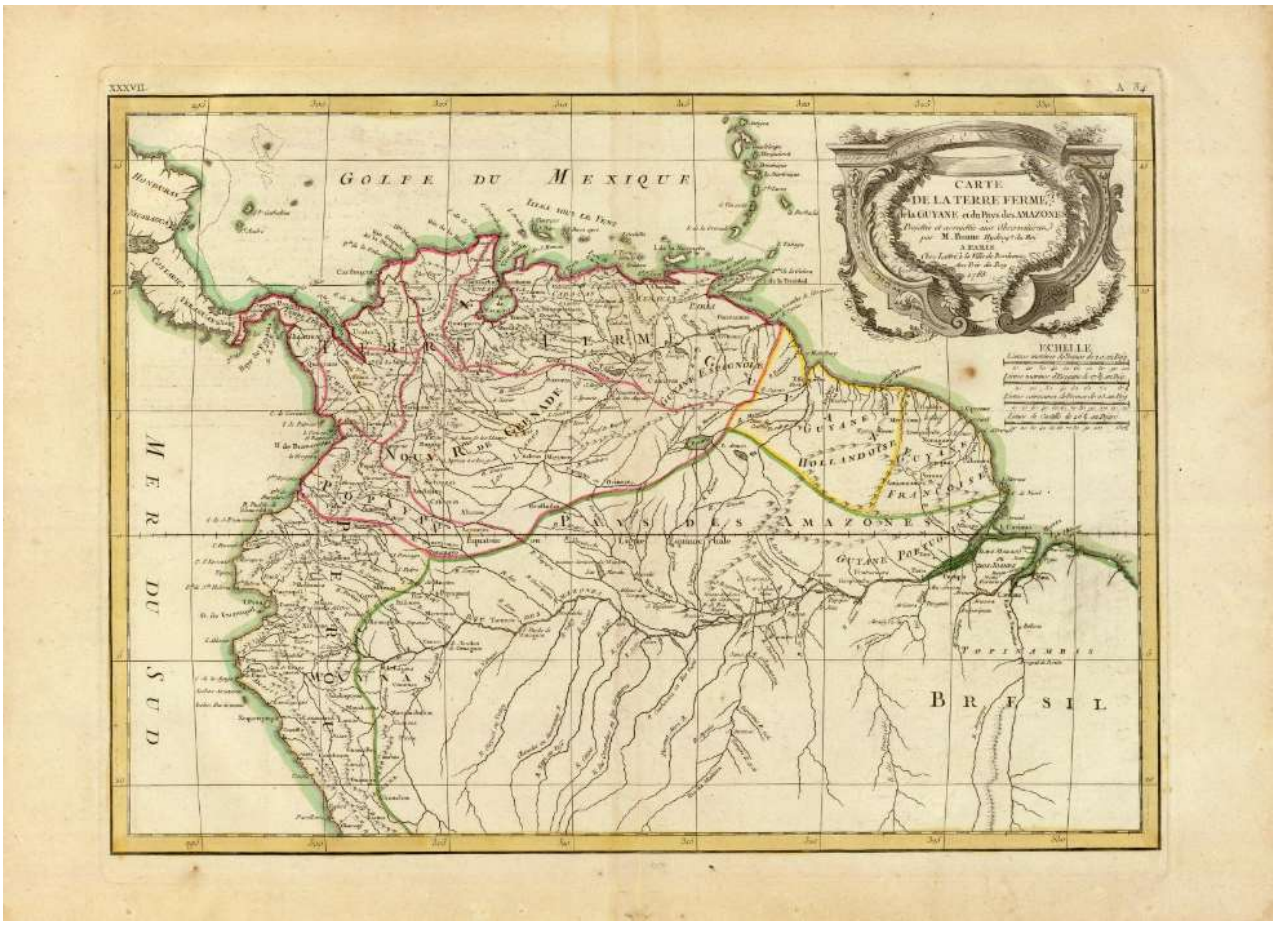

Figure 4. The Map of the Spanish Main, Guiana, and the Land of the Amazons 1785 (Source: David Rumsay Library).

The only territories that seemed to respect their given nomenclature during the Iberian regime were Uruguay, Paraguay, and Chile, leaving the rest of the nations that would make up the new political map after independence in limbo. However, as noted, all these territories endured years of territorial disputes before becoming the nations they are today. Conflicting territorial claims between emerging nations, along with the strategic importance of access to rivers and control of trade routes, fueled tensions and occasional armed conflicts. **Figure 5** particularly highlights Argentina, whose territory is now larger than that of its neighbors and which, at the end of the 18th century, did not have a defined entity.

The nomenclature seemed to evolve as the century drew to a close, and by 1795, the entire region was referred to as South America, a name that would continue to be used throughout the 19th century until the official creation of the new nations. It is noteworthy how even between master and disciple, differences in this nomenclature appear, with Hérisson omitting the name of Uruguay, a name that clearly appears in all the earlier maps of his master Bonne and in the later ones, produced both by him and by other cartographers (**Figure 6**).

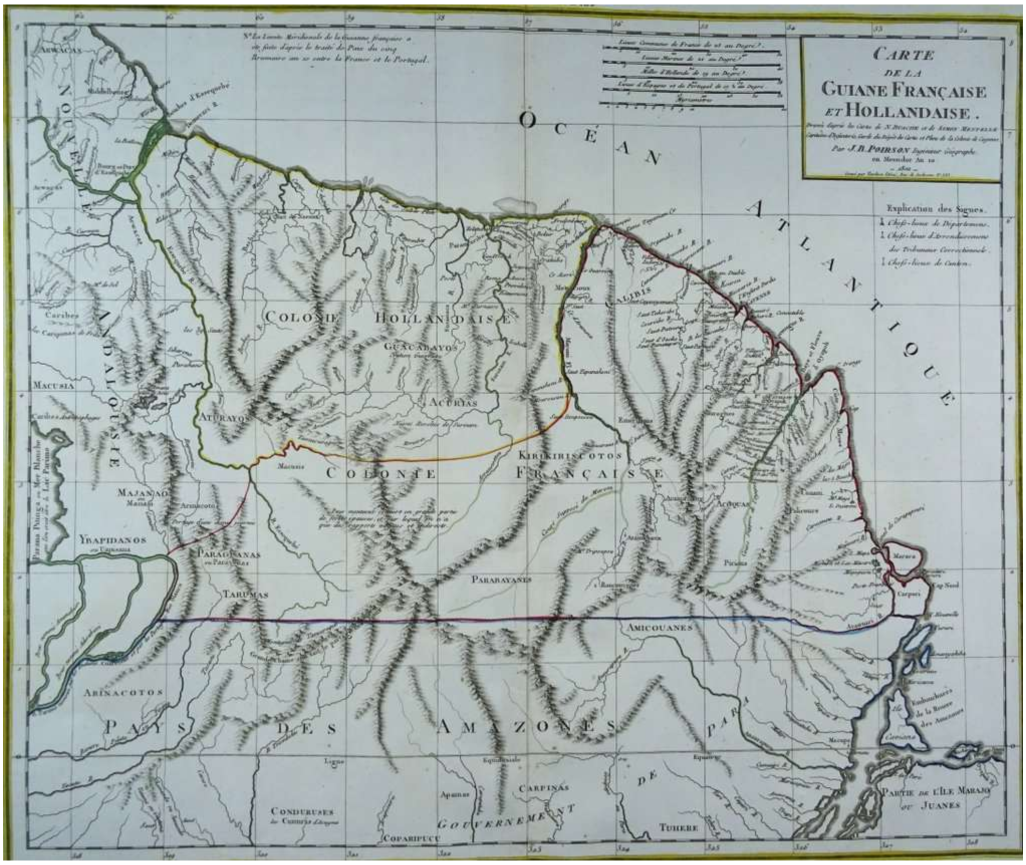

Figure 5. Map of Paraguay and Part of the Adjacent Countries 1782 (Source: Bibliothèque National de France).

Figure 6. Detail of the Map of North and South America 1795 (Source: Bibliothèque National de France).

However, as we have emphasized, the turn of the century and the advancement of conflicts among the different territories to form their own identity were in full swing. The confusion in the formation of each new country's own identity is evident in **Figure 7**, from 1817—that is, once the conflicts that would unfold over decades had already begun—a map where emerging countries like Brazil or Chile already appeared, but not in the case of others. Uruguay appears as the United Provinces, Banda Oriental, or Cisplatina still; Argentina as Buenos Aires and Patagonia. Likewise, there continue to be appearances of non-existent places based on popular lore, such as Lake Parima, a mythical site of El Dorado in the 15th century, which is linked to Lake Amuku in Guyana, and Lake Xareyes, another speculated point for the beloved legend, which was supposed to be the mouth of the Paraguay River. What always remained clear were the boundaries of French Guiana, which maintained its borders to the present day.

Figure 7. Geographical, Historical, and Political Map of South America (Source: Bibliothèque National de France).

5. Conclusions

The cartography from two of the most important cartographers of the change of the century, this is, before and during the era of South American independence, reflected the complexities of nation-building, identity formation, and geopolitical rivalries after colonial rule. Resolving these disputes often required diplomatic negotiations, compromises, and, in some cases, the intervention of external mediators or guarantors.

In that case, France tried to introduce its ideas through politics, through a discourse where new concepts and boundaries appeared and changed over the years. Cartography, and specifically the French cartography offered by Rigobert Bonne and Eustache Hérisson, is a witness to this problem. Despite the challenges, the establishment of clear and stable borders laid the groundwork for the consolidation of independent nation-states in South America thanks to French collaborators.

The configuration of borders in South America reflects a complex interaction of historical, geographical, and socioeconomic factors that shape the political landscape of the region. Understanding these borders is essential for grasping the dynamics of interstate relations, efforts at regional integration, and the challenges facing South American societies in the 21st century.

The myriad challenges in South America since the late 1700s highlight the intricate dynamics of sovereignty, past grievances, and resource competition. Although certain conflicts have seen progress through diplomacy or global arbitration, many persist, casting shadows over regional stability and inter-country ties. Tackling these issues necessitates diplomatic discourse, respect for international laws, and a steadfast dedication to peaceful conflict resolution methods.

In summary, Rigobert Bonne and Eustache Hérisson provided insight into the complexities of boundary delineation and their efforts to maintain control over French settlements, such as Guayane. Initially straightforward, as evidenced by the clear, color-coded boundaries depicted in various maps, the process grew increasingly intricate. In some instances, it took nearly a century for countries to solidify their territories as they stand today.

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Article

Global mining in the 21st century: An overview

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Abstract: At present, states and entire regions that possess significant reserves of sought-after minerals have great potential to maintain and even improve their socio-economic position in the foreseeable future. Since the beginning of 2000, the increase in mining volumes of minerals has been more than 50%; however, more than half of all extracted raw materials fall to only five leading countries: China, the USA, the Russian Federation, Australia, and India. This article presents the results of the analysis of the global structure of mineral production by type and geographic region. The article provides an in-depth analysis of the world's leading mining companies, identifying the key players in the industry. A comprehensive overview of each company's performance, including key financial indicators and production statistics, is presented. The main environmental risks as a result of the continued increase in the global scale of mining have been identified. The prospects for the development of the mining sector are shown. The results of the study can be used by the scientific community as an information source.

Keywords: mining sector; mining volumes; mineral resources; scale of mining; mining companies; environmental issues

1. Introduction

The insatiable thirst for technological advancement and societal progress has propelled the global mining industry to unprecedented levels of activity. Since the early 2000s, mineral extraction has skyrocketed by over 50%, driven by the ever-growing demand for raw materials [1,2]. This surge has been fueled by the rapid expansion of emerging technologies such as electric vehicles, renewable energy systems, and advanced electronics, all of which require a steady supply of minerals like lithium, cobalt, and rare earth elements. However, this surge in production masks a significant geographical disparity, with a handful of dominant players like China, the USA, and Australia extracting a disproportionate share of global resources [3].

China, for instance, not only leads in the extraction of rare earth elements, essential for various high-tech applications but also dominates the processing and refining stages, controlling nearly 80% of the global supply chain. In contrast, countries in Africa and South America, despite being rich in mineral resources, often face challenges such as political instability, a lack of infrastructure, and investment, which hinder their ability to fully capitalize on these assets. Furthermore, the environmental and social impacts of mining have become increasingly prominent, with local communities and ecosystems bearing the brunt of the industry's expansion. This has led to a growing emphasis on sustainable mining practices and stricter regulations, aimed at mitigating the adverse effects while ensuring that the industry can continue to meet global demand. As the world moves towards a greener future, the mining industry is at a crossroads, balancing the need for increased production with the imperative of sustainability.

While the general scale of extraction is known, a thorough understanding of the current mining landscape is crucial. This study delves deeper, providing a short overview across four key areas:

- Global extraction scale—A detailed analysis of the current worldwide extraction volumes and trends in mineral production;
- Leading mining companies—An in-depth exploration of the world's largest mining companies, highlighting their key roles and performance metrics;
- Environmental Impact—A critical examination of the main environmental risks associated with the expanding scale of mining operations.

Significance of the study

The global mining industry plays a crucial role in shaping the following:

- Understanding the economic impact—This research sheds light on the distribution of mineral wealth and its impact on global economic development. By identifying the leading producers and analyzing production trends, the study allows resource-rich countries to formulate informed strategies for maximizing the economic benefits of their mineral reserves. Additionally, it helps assess the contribution of mining to global supply chains and infrastructure development;
- Navigating environmental challenges—The significant rise in mining activity necessitates a focus on environmental responsibility. This study serves as a platform to identify and analyze the environmental risks associated with large-scale mining operations. By highlighting these challenges, it encourages the development and implementation of sustainable mining practices that minimize environmental impact;
- Informing future strategies—This study offers valuable insights for stakeholders like policymakers, investors, and industry leaders. By analyzing the performance of leading mining companies and future industry prospects, the research helps inform strategic decision-making. This includes policy development for sustainable resource management, investment opportunities in the mining sector, and strategies for technological advancements in mining techniques;
- Bridging the knowledge gap—The comprehensive analysis of the global mining industry provided by this study contributes to a deeper understanding of this complex sector. It serves as a valuable resource for the scientific community, researchers, and anyone interested in gaining insights into the present and future of the global mining landscape.

Thus, the purpose of this research is to conduct a retrospective evaluation of global volumes of mineral extraction, identify leading countries and major mining companies, and analyze the potential environmental consequences of the annual increase in extraction volumes.

2. Materials and methods

In order to conduct a comprehensive overview of the current state of the global mining industry, various sources of information were utilized, including industry reports, academic articles, government statistics, and online databases. The following methods were used to gather and analyze the data:

- Literature Review: A thorough review of academic literature was conducted to gather information on the current trends and developments in the mining industry. Keywords such as “global mining industry”, “mining trends”, and “mining production statistics” were used to search for relevant articles in academic databases such as Elsevier, Scopus, and Google Scholar.
- Industry Reports: Industry reports from organizations such as the World Mining Congress, the International Council on Mining and Metals, and the United States Geological Survey were consulted to obtain data on the production, consumption, and trade of minerals and other raw materials.
- Government Statistics: National and international government statistics were collected from sources such as the World Bank, the United Nations, and the US Bureau of Labor Statistics to obtain information on the economic impact of the mining industry and to track the growth of the industry over time.
- Online Databases: Online databases such as Companiesmarketcap, Investing.com, Mining Intelligence, Mining Technology, and Mining Journal were consulted to gather data on the top mining companies, production capacities, and exploration activities.

The data was analyzed and presented in the form of tables, charts, and graphs to provide a comprehensive overview of the current state of the global mining industry. The information was then synthesized and summarized to provide a clear and concise overview of the key trends and developments in the industry.

This research provides a comprehensive overview of the current state of the global mining industry and offers insights into the key trends and developments shaping the industry. The findings of this study will be useful for policymakers, industry stakeholders, and researchers in understanding the current state of the mining industry and in making informed decisions about the future of the industry.

3. Results and discussions

3.1. General information on a global scale of extraction of minerals

The consumption of minerals and other raw materials has been an integral part of human civilization, driving technological advancements and economic growth. Over the past 100 years, the rate of consumption of minerals has increased significantly, reflecting the growing demand for mineral resources from a rapidly expanding global population and increased industrialization.

During the 20th century, the global population grew from approximately 1.6 billion people in 1900 to 8 billion people in 2022. This significant increase in population has driven the demand for minerals and other raw materials, as well as the need for increased production capacities to meet this demand. Additionally, the rise of industrialization and technological advancements has also led to an increase in the demand for minerals and other raw materials, as these materials are used in the production of a wide range of goods and services.

One of the most notable trends in the consumption of minerals over the past 100 years has been the increasing demand for metals such as iron, aluminum, and copper. These metals are used in a wide range of applications, including construction, transportation, and electronics. The increasing demand for these metals has driven the expansion of mining operations, leading to increased production and consumption of these minerals.

Another notable trend has been the increasing consumption of minerals such as rare earth elements, which are used in a wide range of high-tech applications, including electronics, renewable energy systems, and military equipment. The increasing demand for these minerals has driven the expansion of mining operations, particularly in countries with significant deposits of these minerals.

Thus, according to the data from the annual analytical report World Mining Data [4], a total of 17.2 billion tons of minerals were extracted in 2020, which is 5.89 billion tons more than at the beginning of the 21st century. The production volume dynamics for these 20 years can be traced by the types of minerals in **Table 1**.

Table 1. Global structure of mineral production and dynamics of its change in the period from 2000 to 2020 [4].

Type of minerals	**Volume of mineral extraction, million tons**					**Change in production dynamics from 2000 to 2020, %**
	2000	**2005**	**2010**	**2015**	**2020**	
Iron and ferroalloys	627.28	858.62	1224.03	1494.89	1567.41	149.8
Non-ferrous metals	50.00	60.53	74.87	96.19	104.56	109.1
Precious metals	0.021	0.023	0.026	0.031	0.029	38.09
Non-metallic minerals	539.43	656.65	712.67	790.28	781.51	44.8
Mineral fuels	10,105.16	12,229.18	13,827.77	14,833.65	14,774.45	46.2
Total	11,321.89	13,805.00	15,839.37	17,215.04	17,227.96	52.1

The annual increase in the growth rate of mining is linked to both the development of technologies and equipment in general [5,6], and to the increase in demand for certain types of raw materials for the transition to new environmentally friendly energy sources [7–11].

The steady growth of the global mining industry has been continuing for more than a decade, however, it has not been uniform in all regions. As of 2020, more than half of the minerals were extracted in the Asian region –59.8%, followed by North America –15.4%, Oceania –7.3%, Europe –6.8%, South America –5.5%, and the African region –5.2% (**Table 2**) [4,12,13].

Table 2. Structure of mineral production by region and dynamics of its change in the period from 2000 to 2020 [4].

Region	**Volume of mineral extraction, million tons**					**Change in production dynamics from 2000 to 2020, %**
	2000	**2005**	**2010**	**2015**	**2020**	
Africa	765.73	944.54	1009.67	940.17	891.82	16.4
Asia	5051.12	7069.40	8921.79	9820.60	10303.43	103.9
Europe	1755.97	1749.87	1621.73	1487.18	1174.17	–33.1
South America	908.63	1068.29	1128.72	1196.13	956.91	5.3
North America	2324.94	2343.74	2355.46	2632.65	2652.40	14.1
Oceania	515.49	629.11	801.95	1138.20	1249.27	142.3
Total	11,321.88	13,804.95	15,839.32	17,214.93	17,228.00	52.1

3.2. Regional distribution and influence in the global mining sector

When analyzing the scale of global mining, it is important to note that the huge statistical weight of the Asian region is provided by China, which is the world leader in the extraction of 32 different types of mineral raw materials, and also provides 43.0% of the total extraction of all minerals in the region [14].

Similarly, Australia, the United States, Russia, India, Canada, Brazil, Chile, South Africa, etc. have an impact on their regions. The presence of a large mineral resource potential and, as a result, the location of world-class research institutions in these countries in the field of profile studies, allow the mining industry to develop at a fast pace. The government policy in the field of natural resources is favorable to the investment of foreign assets, and advanced achievements in science and technology are used in the development of deposits [15–19].

The African region has enormous potential in terms of mineral exploration and extraction. The continent is home to many of the world's mineral reserves: diamonds, vanadium, manganese, copper, phosphates, platinum, uranium, cobalt, gold, etc. Investors are eager to enter new markets, especially in developing countries, which offer new investment opportunities for leading mining companies. In this context, the African mining industry offers unprecedented opportunities for both local and international investors.

The European mining industry has long traditions and is today one of the most modern and innovative industrial sectors on the continent. Europe is rich in natural resources, however, the supply of minerals on the territory of its states from other regions continues to play a decisive role in the European economy and society, as it has been for centuries.

South America continues to remain an important jurisdiction for investments in the mining industry. The region boasts rich strategic natural resources and has been the target of a large number of direct foreign investments in the geology exploration sector in recent years.

Figure 1 shows the leading countries in mineral production for the 2020 calendar year and information about the largest mining companies in the world.

Thus, it has been demonstrated that the mining industry plays an important economic role in the structure of many countries. The produced products, both in the form of raw materials and finished products, can be competitive in the external markets and bring a significant portion of export revenue.

However, in addition to the economic benefits to nations and the development of world science and technology in general (creation of new electronic devices, instruments, machines, etc.), the global expansion of mining is also characterized by obvious environmental problems. For example, the construction and operation of mining facilities can lead to such long-term consequences as the loss of flora and fauna habitat, changes in the shape of the relief, changes in the soil profile, or changes in surface and subsurface drainage [20–22]. All this makes it necessary to regulate the mining industry in each individual region.

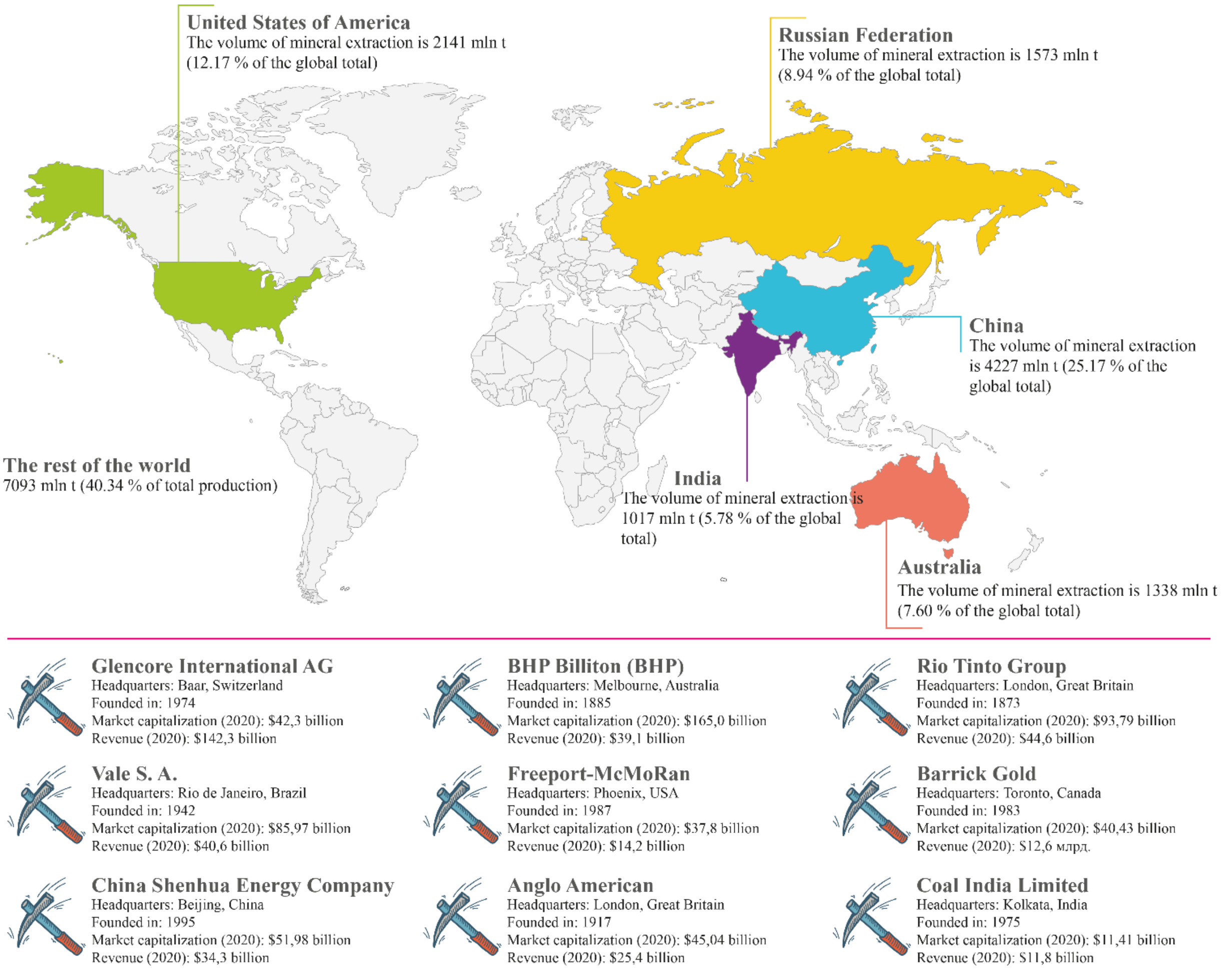

Figure 1. World leaders in the extraction of minerals (for 2020) and the largest mining companies.

3.3. Key facts about largest mining companies in the world

Large mining companies play a crucial role in the mining sector, accounting for a significant portion of global mineral and resource extraction. With their extensive experience, expertise, and financial resources, these companies are capable of executing large-scale mining operations that would be challenging for smaller firms to undertake.

The mining sector is capital-intensive, and large mining companies are typically better equipped to manage the high costs associated with exploration, development, and production. They also have access to advanced technology and equipment, which enhances efficiency and productivity.

Furthermore, large mining companies are often involved in multiple stages of the mining process, from exploration to production and refining. This comprehensive involvement allows them to maintain greater control over the entire value chain, thereby reducing the risk of supply chain disruptions.

Many large mining companies also have a strong global presence, enabling them to respond more effectively to market demands and fluctuations. Their financial strength allows them to invest in research and development, leading to new and improved mining methods and technologies.

Additionally, large mining companies can have a significant impact on local communities and the environment. While some companies have made efforts to minimize their environmental footprint and improve their social and environmental responsibility, concerns remain about the potential negative consequences of large-scale mining, such as environmental degradation and social displacement. It is crucial for these companies to be held accountable for their actions to ensure sustainable and responsible mining practices.

Given the above, key information on the world’s largest mining companies will be presented below.

Glencore International AG, now known as Glencore, is a multinational mining company that is headquartered in Baar, Switzerland. Here are some key facts about the company:

1) Origin and Evolution: Glencore was originally founded as Marc Rich & Co. AG in 1974, named after its founder, Marc Rich. In 1993, the company rebranded as Glencore International AG.
2) Diversified Business: Glencore operates in several areas, including mining, refining, smelting, and trading of metals and minerals. The company also has significant business interests in oil and agricultural products.
3) Global Reach: With operations in over 50 countries, Glencore is one of the world’s largest diversified natural resource companies. It has a significant presence in regions such as Europe, North America, South America, Africa, and Australia.
4) Major Miner: Glencore is one of the largest producers of copper, cobalt, and nickel, and has significant reserves of zinc, lead, and tin. The company is also one of the largest coal producers in the world.
5) Environmental Concerns: Glencore’s mining operations have faced criticism over environmental and human rights concerns. The company has taken steps to address these issues and has committed to reducing its carbon footprint and reducing its impact on local communities and ecosystems.
6) Philanthropic Efforts: Glencore is involved in various philanthropic efforts and initiatives, including supporting education and health programs in the communities where it operates. The company also supports the development of renewable energy and sustainability initiatives.
7) Financial Performance: Despite the challenges faced by the global mining industry, Glencore has consistently delivered strong financial results. The company has a solid balance sheet and a track record of profitability, making it a key player in the global mining sector.

Vale S.A. is one of the largest mining companies in the world. It was founded in 1942 in Brazil and is now headquartered in Rio de Janeiro, Brazil. The company specializes in the production of iron ore, nickel, and other metals. Some interesting key facts about Vale S.A. include:

1) Vale S.A. is the largest iron ore producer in the world, producing over 300 million metric tons of iron ore annually.
2) The company operates in over 30 countries worldwide and has a diverse range of mining activities, including open-pit mining, underground mining, and processing operations.

3) Vale S.A. has a significant presence in the Asia-Pacific region, with operations and offices in countries such as China, India, South Korea, and Australia.
4) The company has made significant investments in technology and innovation, with a focus on sustainability and environmental responsibility. This includes initiatives such as reducing greenhouse gas emissions, increasing the use of renewable energy sources, and improving water management practices.
5) Vale S.A. has faced significant challenges and controversies, including a tailings dam collapse in Brazil in 2019 that caused widespread environmental damage and loss of life. The company has since taken steps to improve its dam safety and emergency response measures and has faced significant fines and legal action as a result of the disaster.

Overall, Vale S.A. is a major player in the global mining industry, with a strong focus on sustainability and innovation, and a commitment to responsible resource development.

BHP Billiton is a global mining company with headquarters in Melbourne, Australia, and London, UK. Here are some key facts:

1) Origin and History: BHP Billiton was formed in 2001 through a merger of two mining giants: BHP (Broken Hill Proprietary Company) and Billiton. BHP was established in 1885 in Broken Hill, Australia, and Billiton was founded in 1860 in the Netherlands.
2) Size and Reach: BHP Billiton is one of the largest mining companies in the world, with operations in over 25 countries across five continents. It is a dual-listed company, with shares traded on both the Australian and London Stock Exchanges.
3) Product Range: BHP Billiton’s primary focus is on the production of commodities such as iron ore, coal, copper, nickel, and oil and gas. The company also produces other minerals and metals such as bauxite, silver, lead, and zinc.
4) Environmental Responsibility: BHP Billiton takes environmental sustainability seriously and has implemented various initiatives to reduce its carbon footprint, such as investing in renewable energy sources and reducing its water usage.
5) Community Involvement: BHP Billiton is committed to supporting local communities where it operates, and has established various programs to promote education, health, and community development.
6) Health and Safety: BHP Billiton places great emphasis on the health and safety of its employees and has implemented various programs to prevent workplace accidents and injuries.
7) Financial Performance: BHP Billiton has consistently delivered strong financial performance over the years, reporting high levels of revenue and profits. The company has a robust balance sheet, with low levels of debt and a strong credit rating.

In conclusion, BHP Billiton is a large, global mining company with a strong history, a diverse product range, and a commitment to environmental sustainability and community involvement. Its financial performance has been strong, making it a significant player in the mining industry.

Freeport-McMoRan is one of the world’s largest mining companies, primarily focused on the exploration, extraction, production, and sale of copper, gold, and molybdenum. The company was formed in 1987 through the merger of Freeport Minerals and McMoRan Oil & Gas. Here are some interesting facts about Freeport-McMoRan:

1) Diversified operations: Freeport-McMoRan operates mines in North and South America, including the Grasberg mine in Indonesia, which is one of the largest gold and copper mines in the world.
2) Size and scale: Freeport-McMoRan is a major player in the global mining industry, with a market capitalization of over $30 billion and over 40,000 employees worldwide.
3) Sustainability efforts: Freeport-McMoRan is committed to sustainable mining practices and has implemented several initiatives aimed at reducing its environmental impact, including water conservation and energy efficiency measures.
4) Community involvement: The company has a strong focus on community engagement and works closely with local communities to support economic development and improve living standards.
5) Financial performance: Freeport-McMoRan has consistently delivered strong financial results, with robust revenue and earnings growth in recent years.

Overall, Freeport-McMoRan's commitment to sustainability, its diverse operations, and its financial performance make it a significant player in the global mining industry.

Barrick Gold is a Canadian mining company that is one of the largest gold mining companies in the world. The company was founded in 1983 and is headquartered in Toronto, Canada. Some interesting facts about Barrick Gold include:

1) Size and scale: Barrick Gold is one of the largest gold producers in the world, with a market capitalization of over $30 billion and operations in North America, South America, Africa, and Australia.
2) Significant production: Barrick Gold has produced more than 160 million ounces of gold and is one of the largest gold producers in the world.
3) Strategic acquisitions: Over the years, Barrick Gold has made several strategic acquisitions, including the acquisition of Homestake Mining Company in 2001, which helped the company become one of the largest gold producers in the world.
4) Focus on sustainability: Barrick Gold is committed to sustainable mining practices, and has a number of initiatives in place to minimize its impact on the environment, including a water management program and a tailings management program.
5) Community engagement: Barrick Gold places a strong emphasis on community engagement, and has a number of programs in place to support the communities in which it operates, including education initiatives, health programs, and economic development initiatives.
6) Responsible gold production: Barrick Gold is committed to responsible gold production, and is a signatory to the United Nations Global Compact, which is a voluntary initiative aimed at promoting responsible corporate citizenship.
7) Innovative technology: Barrick Gold is known for its innovative use of technology in the mining industry, including the use of autonomous trucks and drills, and the implementation of advanced analytics to optimize its operations.

China Shenhua Energy Company is one of the largest coal-mining companies in the world and is headquartered in Beijing, China. The company was established in 1995 and is a subsidiary of the state-owned China National United Fuel Company. Here are some interesting facts about China Shenhua Energy Company:

1) Coal production: China Shenhua Energy Company is the largest coal producer in China and one of the largest coal producers in the world. The company produces both thermal and coking coal.
2) Size and scale: The company operates several large-scale coal mines across China, and also has significant operations in Australia and Mongolia.
3) Diversification: In addition to its core coal-mining operations, China Shenhua Energy Company has diversified into several other business segments, including electricity generation, railway transportation, port operations, and coal-to-chemicals.
4) Environmental initiatives: China Shenhua Energy Company has made a commitment to sustainable development, and has implemented several initiatives aimed at reducing its environmental impact. For example, the company has invested in renewable energy and has also undertaken a number of reforestation projects.
5) Financial performance: Despite a challenging economic environment, China Shenhua Energy Company has consistently performed well financially, making it one of the largest and most successful mining companies in the world.

Overall, China Shenhua Energy Company is a major player in the global mining industry, and its continued success is a testament to its commitment to sustainable development and responsible business practices.

Anglo-American is a global mining company that was established in 1917. The company is headquartered in London, Great Britain, and is listed on the London and Johannesburg stock exchanges. Here are some key facts about Anglo American:

1) Diversified Portfolio: Anglo American is a diversified mining company that operates across a wide range of commodities, including platinum, copper, diamonds, nickel, iron ore, and metallurgical coal.
2) Global Presence: The company operates in over 20 countries around the world, including South Africa, Chile, Brazil, Peru, and Australia.
3) Sustainable Mining Practices: Anglo American is committed to sustainable mining practices and has implemented a number of initiatives to reduce its environmental impact, including the use of renewable energy sources and reducing greenhouse gas emissions.
4) Community Investment: The company has a strong focus on community investment and works with local communities to support development and improve living standards.
5) Innovation: Anglo American invests heavily in innovation and research and development, in areas such as automation, artificial intelligence, and digital technologies, to improve its operations and reduce costs.
6) Leading Company in the Mining Industry: Anglo American is widely considered one of the leading companies in the mining industry, known for its strong financial performance, commitment to sustainability, and focus on innovation.

7) Significant Production: In 2020, Anglo-American produced over 5.5 million ounces of platinum, 1.3 million tons of copper, and more than 20 million carats of diamonds.

Coal India Limited (CIL) is a state-owned coal mining company based in India and is the largest coal producer in the world.

1) Founded in 1975, CIL is the largest coal-producing company in India and the largest employer in the Indian coal industry, with over 300,000 employees.
2) CIL produces over 82% of the coal in India and holds a monopoly in the Indian coal sector.
3) The company operates through 81 mining areas spread across eight states in India, including West Bengal, Jharkhand, Odisha, Madhya Pradesh, Chhattisgarh, Telangana, Maharashtra, and Andhra Pradesh.
4) In addition to coal mining, CIL also provides various other services, including consultancy and engineering services for coal and lignite mines, and operates washeries to process coal and produce clean coal.
5) CIL is committed to sustainability and has implemented various measures to minimize its environmental impact, including reforestation and afforestation programs, and measures to reduce greenhouse gas emissions.
6) Despite being a state-owned company, CIL has been listed on the Bombay Stock Exchange and the National Stock Exchange of India since 2010 and is subject to regulation by the Securities and Exchange Board of India.
7) CIL is also involved in various social initiatives, including programs to improve the living conditions of local communities, support for education and health initiatives, and the promotion of local sports and cultural activities.

Having explored the profiles and contributions of major global mining companies, it is evident that these industry giants play a pivotal role in meeting global demand for minerals and resources. However, the expansion of their operations brings with it significant environmental considerations. In the next section, we will delve into the main environmental risks associated with increasing the scale of production, examining the challenges and implications for sustainable mining practices.

3.4. The main environmental risks of increasing the scale of production

The growth of global mining can result in various environmental risks that can have negative impacts on the ecosystem and human health. Some of these risks include [23–29]:

1) Water pollution: The release of toxic chemicals from mining operations into nearby water sources can cause water pollution, which can harm aquatic life and negatively affect the health of local communities that rely on these sources for drinking water.
2) Land degradation: The removal of large amounts of earth and rock during the mining process can result in land degradation, causing soil erosion and decreased biodiversity in the area.
3) Air pollution: Dust and emissions from mining operations can contribute to air pollution, leading to respiratory health problems for local communities and damaging delicate ecosystems.

4) Climate change: The extraction and transportation of minerals and other resources used in the mining process can contribute to greenhouse gas emissions, driving climate change and its associated impacts such as sea level rise and the increased frequency of extreme weather events.
5) Loss of biodiversity: The clearing of large areas of land for mining operations can result in the loss of biodiversity, as well as the displacement of local communities and wildlife.
6) Health risks: Mining operations can expose workers and nearby communities to hazardous chemicals and dust, leading to health problems such as lung diseases and other respiratory issues.

In conclusion, the expansion of mining operations globally brings with it significant environmental risks that cannot be overlooked. It is important for the mining industry to take these environmental risks into account and implement practices to minimize their impacts, such as using cleaner technologies, restoring degraded land, and protecting water sources.

4. Conclusion

As consumption increases, humanity demonstrates a culture of consumption, resulting in the mining industry becoming hostage to growing consumer demands. At the same time, mineral deposits are being depleted. Despite this, the mining industry remains one of the few sectors of the economy that maintains positive growth dynamics, despite the COVID-19 pandemic-related quarantine restrictions.

The mining industry should not be limited to just the extraction sector. Creating favorable economic conditions within each individual region or country can attract new investors, who in turn will develop existing or create new technological chains. The involvement of leading global companies in the processing of metallurgical raw materials will have an even more positive impact on the economic development of the region. However, it is important not to forget about the accompanying risks and problems.

The present study was aimed at demonstrating the overall situation in the global mining industry. At the same time, the analysis conducted provides the opportunity to outline future directions for research in the areas considered.

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